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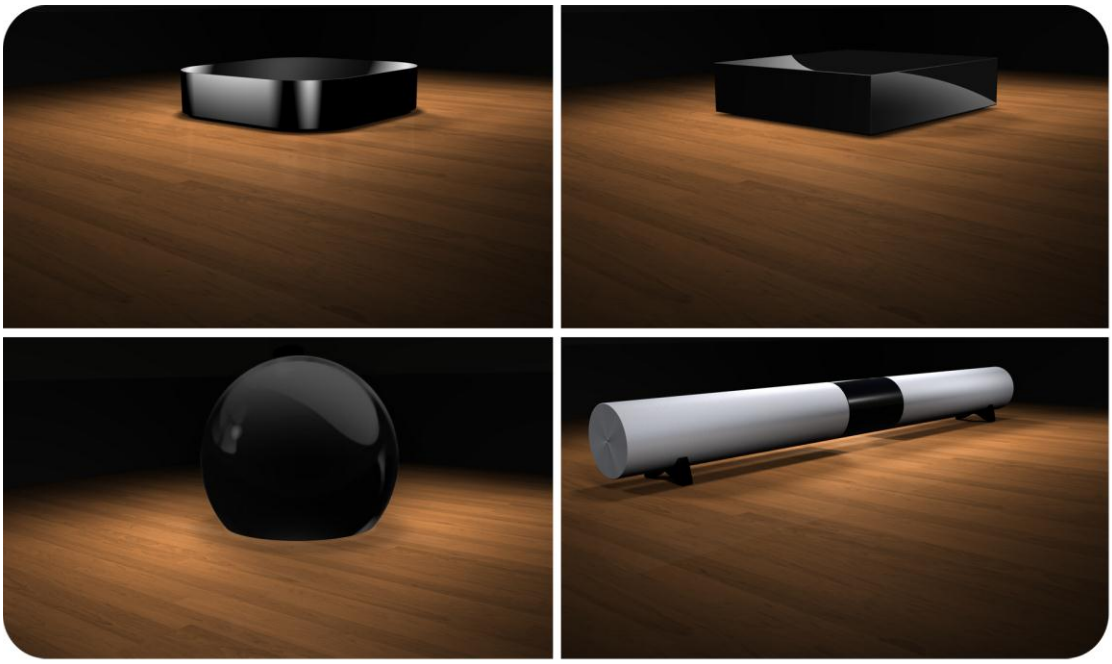

Universal Remote Control for Smartphones

Development of a communication station

Master of Science Thesis in the Master Degree Program, Product Development

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Göteborg, Sweden, 2011

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Cover:
The images on the cover show the four promising design concepts for the intended product. More information about the concepts can be found in section 5.2.1.
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ABSTRACT

This master thesis report describes the concept of a universal remote control for smartphones, with a focus on the development of a communication station with hardware needed in order for such a product to function as intended. The development starts with a "blank canvas", and the resulting product functionality and design is based on an extensive market analysis conducted at the start of the project, including an analysis of current trends and competitors, as well as the thoughts and ideas of approximately 300 potential customers. The development process is based on the methods taught during the two years of the master program *Product Development* at *Chalmers University of Technology*. The project ends with the construction of a prototype able to demonstrate the product's functionality. In addition to this, a set of design concepts are developed in order to come up with a product that people would want to place visibly in their living room. The product is developed in close collaboration with another master thesis group, focusing on the development of an end user interface in the form of an Iphone application.

Keywords: product development, smartphone, universal remote control, embedded system

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1 INTRODUCTION

The first wireless remote control for a television was introduced back in 1955 (Bellis, 2011). From then on a lot of other devices in the home started using remotes and today we see a large trend of increasing interest for home entertainment systems that include a lot of electronic devises using remote controls (Logitech, 2010). The problem with this situation is that all these remotes together will occupy a large part of the coffee table and none other than the buyer of the products knows how to tell them apart.

Another largely increasing trend today is the use of advanced cell phones, called smartphones (MobilTeleBranschen, 2011). A smartphone differ mostly from a regular phone by offering more advanced computing abilities. Smartphones have a good ability of implementing tailor made programs for various purposes and they also have a good communication ability, which makes them a suitable candidate for controlling external electronic devices.

This master thesis describes the development of the hardware needed for controlling a basic set of home entertainment equipment, as well as the lighting of an ordinary home, using a smartphone.

The thesis is written for the master program *Product Development* under the *Department of Product and Production Development* at *Chalmers University of Technology*. The project is supervised by *Andreas Dagman*, assistant professor at the Department of Product and Production development.

The project is done in collaboration with another master thesis group, which is focusing on developing the needed smartphone software for the same purpose.

1.1 Purpose

The purpose of the project is to link communication with all electronic devices in a home to a smartphone, replacing the traditional remotes used for every device and thus enabling control of a house from a central unit.

1.2 Goal

This project aims at developing a *communication station*, able to receive signals from a smartphone, translate them and forward them as recognizable signals for various electronics equipment. A physical prototype will be designed to be able to demonstrate the functionality of the product.

In order to assure a low price, the product should use existing technology that the general public already has access to, to as large an extent as possible. This is why the product is developed towards smartphones, which otherwise would be an expensive technology to include in the product.

1.3 Delimitations

The equipment initially supported by the product is narrowed down to a standard home entertainment set, which usually consists of a TV, a DVD player and a receiver, as well as remote controlled power switches for wall sockets.

1.3.1 Project time interval

The project started *2011-01-17* and was completed in *2011-06-01*, which means that the time spent on the project spanned over *20* weeks.

1.3.2 Resources

The project funding consisted of *5000* SEK, which was used for educational purposes, experimenting and manufacturing of a prototype. The project used about *1,400* man-hours split between two participants, with assistance from the two participants of the collaborating master thesis project as well as the supervisor.

1.4 Layout of the report

The report starts out strictly theoretical. The first chapter explains the technology behind remote controls as well as how it is used. The next chapter presents the theory of product development methodology, covering the full development process; from coming up with ideas for the product, using a market analysis for setting requirements on the product and building up a collection of concepts, to narrowing the concepts down to a few and breaking them down to work on the details.

The general project approach will then be briefly described, through a presentation of the time plan as well as a description of how the project in itself was organized and what tools were used.

After these theory chapters, the larger part of the report follows, which deals with the practical details of execution and project results.

The execution and results chapter is divided in six parts, based on *the generic product development process* as described by Karl Ulrich and Steven Eppinger. Their steps have been modified by adding a market analysis chapter and replacing their last step of *production ramp up* with *verification of final concept*. The resulting steps are as follows: (Ulrich & Eppinger, 2008).

- *Planning* describes how the project is organized, how the work is divided and in what order everything is supposed to be done.
- *Market analysis* present how the market was scanned and what demands there are from customers. The result from the market analysis is illustrated in this chapter as a requirement specification for the product.
- *Concept development* describes the generation of a number of solution concepts and the selection of the best suited concept based on the requirement specification.
- *Detail design* walk through choosing the specific parts that are needed for each sub system. The geometry of the product is designed and the functionality of the electronics is programmed.
- *Testing and refinement* consist of the construction of a prototype that is used for testing the chosen concept. The results from the testing are used for refinement of the detail design.
- *Verification of final concept* emphasizes on how well the final concept satisfies the requirements and desires and what could be changed in the design to achieve a better performance.

Following these six phases are a few words on the sustainability aspect of the product, a discussion that sums up and discusses the result drawn from the development phases and the project as a whole. A conclusion chapter then reflects on the project goals and their fulfilment.

The report ends with an overlook on remaining development work that would need to be done before releasing the product on the market.

2 TECHNOLOGY WITHIN REMOTE CONTROLLING

In order to produce a working remote control, a basic understanding of the technology behind such devices must first be ensured. More specifically, this understanding concerns communication between remote controls and their respective equipment, as well as the electronic components that make it all work.

This chapter describes how remote controls utilize microcontrollers, coupled with infrared light emitting diodes and radio frequency transmitters, for sending out commands to their surrounding equipment. Since the topical product is intended to communicate with a smartphone, wireless network communication will also be described.

2.1 Infrared light

Infrared light (IR) has a longer wavelength than visible light, which can be seen in Figure 2.1. The longer wavelength makes the infrared light invisible for the human eye. There are however sensors that can detect it.

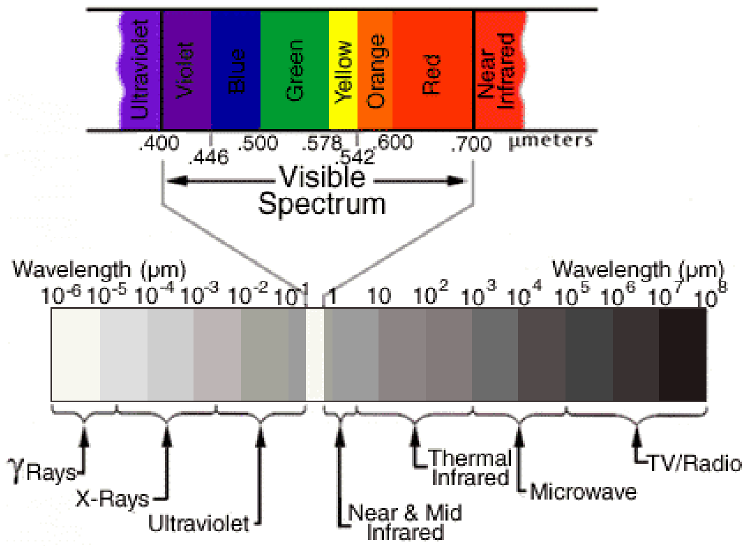


Figure 2.1. Light spectrum showing the wavelengths of different light (Short, 2010).

Most standard home media devices (such as TVs, receivers, Blu-ray-players, etc.) are controlled by infrared light signals emitted from a Light Emitting Diode (LED) in a remote control. The signals sent from the remote represents a binary code, which the receiving device interprets and compares to a stored list of accepted commands.

2.1.1 Using IR for communication

Infrared light is not only emitted from remote controls. Other light sources in the home emit IR light as well, and a large part of the light we receive from the sun also falls within the IR spectra. This means that the receiving equipment somehow needs to separate the remote control command from all the ambient light. For this reason, IR command signals are modulated at around 40 kHz, which means that when the IR LED is turned *on*, it is actually rather flashing at a rate of around 40 000 times per second. The IR detector can thus filter out all slowly changing IR radiation and only the remote control command will be left to interpret. Depending on type of equipment and manufacturer the actual modulation frequency varies between 36 and 40 kHz, but most products use the 38 kHz frequency (Johnson, 2011).

The protocol determining how the binary IR command sequences are made up varies slightly between manufacturers, but they generally start with a long *lead in* bit, telling the receiver to "*start listening, because here comes a command*". The actual command code then follows, and to denote the end of the sequence is yet another long *lead out* bit. An example of an IR command sent from a remote control can be seen in Figure 2.2.

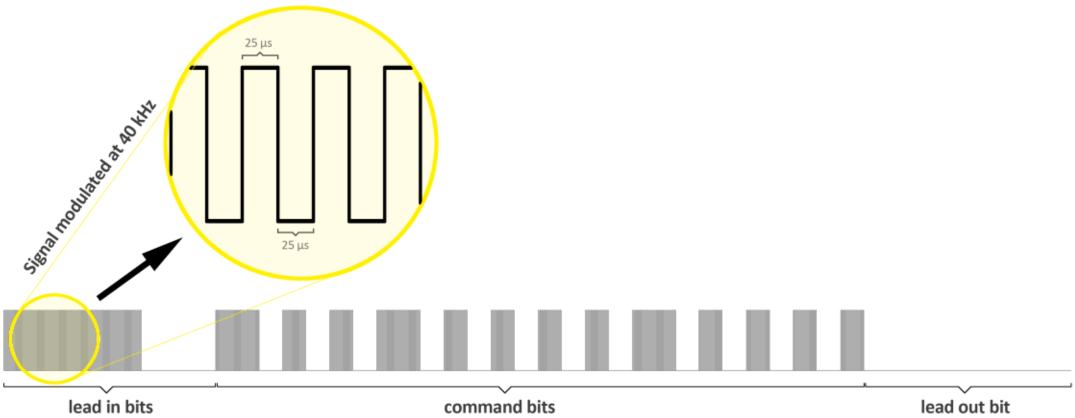


Figure 2.2. A graphical example of an IR signal sent from a remote control.

2.1.2 The Philips Pronto protocol

The *Philips Pronto* line of universal remote controls has the ability to copy and mimic other remote controls' signals. The copied signals are stored as hex code in the Pronto memory, and can be read and edited by the user via a web interface. The hex code generated by the Pronto has more or less become the standard way that remote control IR codes are expressed, and home cinema enthusiasts has created websites dedicated to sharing hex codes from different manufacturers (Tonks, 1998). It would therefore be wise to use the Pronto protocol for storing IR codes in this product as well, to make old enthusiasts feel at home with the product, and to simplify for all users who want to find tables of codes for their remotes manually.

A command in the pronto protocol consists of a number of hexadecimal codes, which are basically made up of three parts: (Gordon, 1998)

1. Description of the signal. The first few codes describe the modulation frequency as well as the lengths of both the main sequence and the repeat sequence.
2. The main sequence. The second part represents the specific code for the button that the user has pushed. This sequence is sent once.
3. The repeat sequence. The third part is the repeat sequence, which is sent directly after the main sequence and repeated for as long as the user holds the button down.

2.2 Communication using simple radio frequency signals

All oscillating signals within 3 kHz to 300 GHz are called *radio frequency (RF) signals* and oscillations of electromagnetic pulses within this range are widely used for communication. In contrast to IR signals, RF signals can travel through walls and they are not sensitive to which direction the transmitter is pointed, which makes them suitable for applications demanding a longer range and for use in areas with an obstructed view.

Home electronic devices often use the license free *ISM*-band (Industrial, Scientific and Medical), which is specified in Figure 2.3, for communication (Radiocommunication Advisory Group, 2007).

Figure 2.3. The complete radio frequency range from 3 kHz to 300 GHz, with green segments representing the license free frequency ranges of the ISM-Band. Numbers from Radiocommunication Advisory Group (2007)

Within this band, different types of devices work on different frequencies in order to not disturb each other. Most simple electronics, for example a remote switch, utilize the frequency 433.92 MHz.

Similar to IR communication, the electronic devices communicate by sending and receiving pulses of binary code in certain protocols depending on the manufacturer. The modulation to achieve the binary code can be done by three different methods; (1) varying the amplitude of the signal, (2) varying the frequency and (3) turning the sine wave on and off, creating pulses of the wave.

2.3 Communication over wireless networks (Wi-Fi)

Wi-Fi is a trademark for the Wi-Fi alliance to indicate a certified use of the wireless communication standard IEEE 802.11 (Wi-Fi Alliance, 2011). Communication through these standards is a way to connect several computers and computer like electronics wirelessly by use of radiofrequencies in the ISM-band around 2.4 GHz. The first network constructed by wireless communication was in Hawaii in 1971 to connect the Hawaiian Islands without the use of cables over the sea (Johns Hopkins School of Public Health, 2007).

Today the use of wireless networks has been established in most homes, which can be seen in section 5.1, and many companies and governments has started to provide networks in public areas to make the internet available for mobile users (Mottl, 2008).

2.4 Electronic components needed

To be able to utilize the aforementioned technologies a number of electrical components need to be embedded in the system. The components used for this project will now be briefly described.

2.4.1 Microcontroller

A microcontroller is a small chip with a number of embedded components, including a microprocessor. The basic embedded components include, but are not limited to, memory for storing data and instructions, a CPU for moving around the data and performing calculations with it, and a number of input/output ports in order to communicate with peripheral devices.

The microcontroller can be considered the brains of the embedded system, since it is connected to all of the other components and handles all of the communication amongst them. The microcontroller needs to be manually programmed to make the system function in the desired way.

2.4.2 IR diode and receiver

As mentioned in section 2.1.1, infrared light is used to control most home entertainment systems. The light is sent from remote controls via one or several *Light Emitting Diodes*. These diodes are small component which need nothing other than an electric current to work and be lit up. The microcontroller can be used as a power source for the IR LED in order to make it send out binary signals. In this way the microcontroller can send out bit codes though an output pin directly to the IR LED power input, making the IR LED light up when it receives a *1* and be turned off when receiving a *0*.

To be able to copy and mimic other remote controls' signals, an IR receiver is needed as well. The receiver works in a similar way to the LED, only the functionality is reversed. It listens for modulated IR signals, and when it registers one it can send the bit code to the microcontroller. The microcontroller also needs to be programmed with a function able to recognize and receive the signal.

2.4.3 Radio transmitter and receiver

In order to communicate using RF, a receiver and transmitter is needed. A transmitter basically consists of an oscillator, an antenna and a modulating source which is powered by an external power source. The oscillator is creating a sine wave of the desired frequency to make it recognizable by a transmitter of the same frequency. By letting the sine wave go through an antenna, electromagnetic pulses are sent out. The modulator is used to modulate the signal to make it transfer data. The modulation can be done in three different ways as described in section 2.2. However, the important thing is that the receiver is using the same protocol to translate the modulation.

A receiver basically consists of an antenna, a tuner, a detector, an amplifier and a power source. The antenna is used to catch the generated sine waves from the air. The problem is that there are a lot of different waves of electromagnetic pulses in the air, which is why a tuner is needed. The tuner is used to single out the wanted frequency and filter out the others. The detector is then used to translate the signal into something understandable depending on the modulation. The amplifier is used to amplify the signal into the desired amplitude for its purpose (Brain, 2000).

Since RF signals are made up by bit code similarly to IR signals, the microcontroller can also handle the radio transmitter and receiver in a similar way as the IR LED and receiver.

2.4.4 Wi-Fi transceiver

In order for the microcontroller to be able to communicate with the smartphone, a stand-alone Wi-Fi module is needed. The Wi-Fi module usually connects to the microcontroller via *SPI* (Serial Peripheral Interface), and is signalled by the microcontroller through an interrupt line when data is available. When the Wi-Fi module has forwarded the data wirelessly, it resets the state of the interrupt line to signal to the microcontroller that it is ready for more data.

Wi-Fi modules often comes with a ready-to-use code stack adapted to *the Internet Protocol Suite* (a set of protocols used for network communication). However, this stack still needs to be implemented and adapted to the main program code and the network in which it will operate.

2.5 Programming languages

When it comes to programming microcontrollers, the most common programming languages to choose from are *Assembler* and *C*.

2.5.1 Assembler

Assembler is a low level programming language used to express machine code for a computer processor in a way that is more easily understandable for humans. Assembler code does not look the same for all processors, since the list of usable instructions vary considerably between different processors, which makes the assembler code difficult to copy and paste when changing the hardware. To be able to do this, a high level language (such as *C*) is better suited (Bilting & Skansholm, 2000).

2.5.2 C

The programming language simply called *C*, which is based on the language Algol from 1958, is one of the most influential high level languages. C has been a basis for many other popular languages, for instance *C++*, *C#* and *Java*. The language has got compilers for almost all computer architectures, which has caused it to almost dominate among development of embedded systems. (Bilting & Skansholm, 2000)

3 PRODUCT DEVELOPMENT METHODOLOGY IN THEORY

This chapter describes methods that are commonly used in the product development process. All of these methods will not be exercised in this project but the methods are described to give the reader an understanding of alternative approaches.

3.1 Product development processes

There are a lot of different processes for product development like *PROPS*, developed by *Ericsson* (Semcon Project Management AB, 2006), and *Wenell* (Wenell Management AB, 2009). These processes are however very similar to each other and because of that, only one process will be described. The process which is described in the following section has been used before by the project group and it is important that the utilizer feels confident with the methods for a project to run smoothly (Kaulio, Karlsson, Rydebrink, & Klemets, 1996).

3.1.1 The generic product development process

Ulrich and Eppinger have produced a process of developing products, which is called the generic product development process. The process consists of five phases together with a starting planning phase, called phase 0 (Ulrich & Eppinger, 2008). The phases are organized as Figure 3.1 is showing.

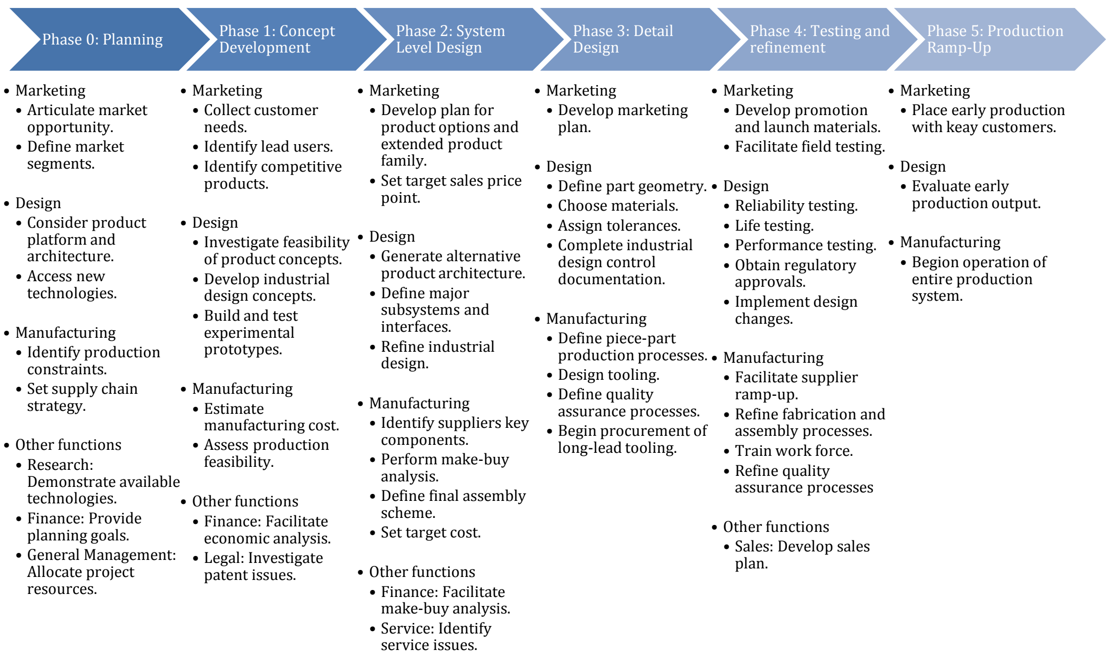


Figure 3.1. The six phases of the generic product development process (Ulrich & Eppinger, 2008).

Planning

The planning phase is actually not a part of the product development process since it is something that is supposes to be done even before deciding to start with a project or not. In this phase the company should consider their product strategy and assess the available technology to decide the feasibility and to determine the target market and the business goals with such a project.

Concept development

As a first step of the concept development phase, the market needs to be scanned in order to specify what the customers want and how the competition looks like. A number of concepts should be developed and based on the needs of the customers; a few concepts should be selected for further development.

System level design

In the system level design phase the product's structural design should be determined and it should be divided into subsystems with clarified specifications. The assembly process should be mapped out and a target cost of the production should be established.

Detail design

In the detail design the product should be completely designed down to each single part, with materials, tolerances and in some cases the suppliers of the parts. After the parts have been specified on a detail level, the tooling should be designed and the production process determined together with a better estimation of the cost.

Testing and refinement

The phase testing and refinement consist of developing prototypes based on the specified detail design. The prototypes are then tested to make sure that the product will meet the customer needs. The output from the tests is used to enhance the detail design to make a product ready for production. The production process should be changed to meet the new specifications.

Production ramp-up

The production ramp-up should start by producing the product in low quantities to be able to train the production staff, calibrate the process and to give an early product that could be evaluated and refined if any misses are found. When the errors has been detected and solved the full scale production can start.

3.2 Methods for planning

Before a product development project has begun, the planning of the product should already be done. The process can include both high level planning – as in what products a company should pursue – and low level planning – as when a specific part of a product should be developed. The high level planning may focus on which, and how much, resources that should be allocated for different products, which products that should be prioritized and even how the company's product portfolio should be balanced.

The release of a product should also be planned in matters of when the market is mature enough and when the needed technology is invented in order to ensure feasibility of the product. The low level may concern how to divide a project into parts and how the time interval and resources should be distributed between the parts of the project (Ulrich & Eppinger, 2008).

3.2.1 Gantt chart

A simple and effective method for planning on a low level is to use Gantt charts (Johannesson, Persson, & Pettersson, 2004). The method will end up giving a good overview of the time for each activity. The chart should consist of a list of activities in chronological order and an axle representing the time. The start and stop for each activity should be marked out by a bar on the chart according to the time axle (Johannesson, Persson, & Pettersson, 2004). As it is seen in Figure 3.2, *Activity 1* is planned to have ended before *Activity 2* is started, while *Activity 3* and *Activity 4* runs parallel to each other in May and June.

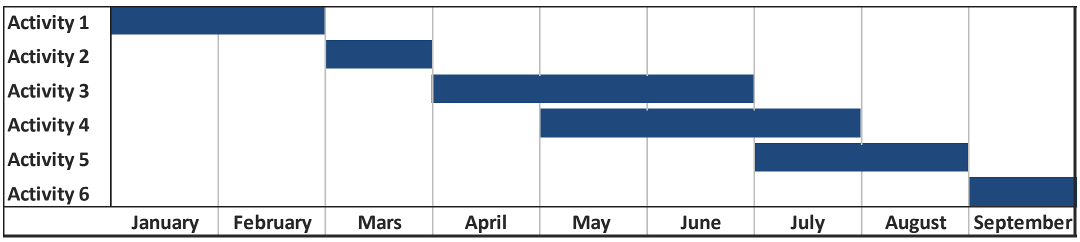


Figure 3.2. A simple example of a Gantt chart. The project starts with Activity 1 in January and ends with Activity 6 in September.

3.3 Methods for performing a market analysis

In order to produce a successful product it is critical to have a good view of the market. A need for the product might not yet exist on the market. Or the market might already be saturated by the competitors' similar products. If the market is not ready for the product, or if the product is not adapted to what the market requires, it will not be successful. An extensive analysis on the current market must therefore be performed before the actual development work is started.

There are numerous ways of analysing the market in order to get a good view of its current situation. A trend analysis can be performed in order to get an overview of the present trends from a political, economic, social and technological aspect, which can be used to predict changes in the market and plan how to use them to your advantage by adapting the product for sustainability. Further, another analysis can be done in order to get a look on the environment of the idea, in order to compare it with competing products already in the market.

In addition to researching the current market situation, a systematic analysis of the actual need for the proposed product must also be performed. The data elicited through this analysis should provide a clear view on what to expect from the market as the product is released, which should be detailed in terms of *customer categories*/*market segments*, *market potential*, *market penetration* and *market shares*. (Johannesson, Persson, & Pettersson, 2004)

3.3.1 Describing the environment using a SWOT-analysis

SWOT-analysis is a method used to elicit *strengths* and *weaknesses* of the organization or team as well as *opportunities* and *threats* within the market. The technique was developed by academics at the American business schools in the sixties and has since then become a popular method for measuring the compatibility between external conditions and internal qualities (Hill & Westbrook, 1997).

- ***Strengths*** describe the advantages the organization or team have in relation to the competitors. It can also describe how the team stands out in relation to the competitors.
- ***Weaknesses*** describe the disadvantages of the organization or team in relation to the competitors.
- ***Opportunities*** describe favourable circumstances in the market of your product. Examples of opportunities are new technology, change in regulations etcetera.
- ***Threats*** describe unfavourable circumstances in the market of your product.

The result of the analysis gives an understanding of how to differentiate the products and how to make the development team aware of possible threats.

3.3.2 Researching user needs

To get a good view of the needs that users have on a given product, direct communication with users is needed. This can be achieved in a number of different structured ways, a couple of which is presented in this section. Although, it should be noted that since the suggested processes are generic in nature, they are highly adaptable, and most experienced companies have with time developed their own process for managing customer needs. It is however good to use a generic process as a ground to build your own specific model on (Kaulio, Karlsson, Rydebrink, & Klemets, 1996).

Methods for collecting data from customers

Interviews and focus groups are used primarily for *qualitative* data collection, whereas surveys more often give *quantitative* data. This basically means that interviews give answers to *how*- and *why*-questions, whereas surveys answer the *how much*-, *how many*- and *how often*-questions (Karlsson, Data Collection, 2010).

Interviews

To gather data about the interest of a product and discover exactly what the end-user requires in a product it is very helpful to conduct interviews with people that could potentially be interested in the end-result. There are very specific guidelines that need to be followed in order to elicit good data from the interviewees, e.g. "the goal is to elicit an honest expression of needs, not to convince a customer of what he or she needs" (Ulrich & Eppinger, 2008).

The interviews are often held with one or more development team members and one interviewee. The interview is best conducted in the interviewee's environment and lasts about one to two hours (Ulrich & Eppinger, 2008).

Interviews are most often used as the primary means for data collection (Ulrich & Eppinger, 2008). They are effective since they allow for a direct discussion with the user, where probing can be used for getting further explanations when interesting opinions arise, resulting in a good information depth. Good interviews results are however dependent on having an open and flexible interviewer able to resist showing signs of bias, which otherwise could sway the interviewee's answers in one direction or the other (Karlsson, Data Collection, 2010).

Focus groups

Focus groups are conducted by a moderator, who can be either a member of the project group or a hired market research professional. The group consists of eight to twelve potential customers and the proceedings are often observed by the rest of the project members remotely, through video or a two-way mirror if such a room is available. Focus groups inherit the same positive aspects as those of interviews, in terms of depth, with the addition that discussions can arise within the group from points that an interviewer might not have considered in a one-to-one interview. Focus groups are however usually more expensive to conduct than interviews since they often involve more people and professionals are often hired as moderators. (Ulrich & Eppinger, 2008)

Surveys

Surveys can be performed using questionnaires through a wide selection of mediums such as webpages, emails, mails and paper hand-outs. Since questionnaires have no need for supervision, they can be sent out to a large amount of people. For this reason they are a good means to gather statistical data. (Karlsson, Data Collection, 2010)

Observation

In addition to using discussions or questions, data collection can also be done through observation. When a person performs a certain task often enough, the process of doing it often becomes habit. Exactly how such tasks are performed might then be difficult to describe in detail during an interview. In some cases the user might not even be sure about which details are relevant to the interviewer. Users might also be hesitant to describing needs in problematic situations because they blame themselves for the problems instead of the product design. In these cases it might be more fruitful to observe the user performing the task instead of (or in addition to) asking questions about it (Ulrich & Eppinger, 2008).

Eliciting user needs with Ulrich and Eppinger's process

Ulrich and Eppinger have proposed a process for gathering and interpreting data as well as translating it into specific user requirements and desires (Ulrich & Eppinger, 2008). Their process consists of the following five steps.

1. **Gather raw data from customers**
   Raw data is collected using questions and/or observations as previously described. The result is a long list of customer statements regarding all aspects of the product.
2. **Interpret the raw data in terms of customer needs**
   The customer statements are analysed and interpreted in order to compose a list of user needs. The user needs should be expressed in terms of *what* the product has to do, not in terms of *how* it should do it.
3. **Organize the needs into a hierarchy of primary, secondary and (if necessary) tertiary needs**
   The user needs are divided into groups according to similarities in what they express. Redundant statements are eliminated and a *primary* need is set for each group. The rest are considered *secondary* needs, which describes the primary needs further.
4. **Establish the relative importance of the needs**
   All needs cannot be considered to be of equal importance. Thus, they will all need to be compared against each other in order to be assigned a weight value.

5. **Reflect on the results and the process**
   The results are verified for consistency with what the development team has learnt through interacting with customers. A reflection is done on whether there are any areas in need of follow-up interviews/surveys and other ways the process could be improved.

Eliciting user needs with the Product Requirement Engineering process

Another way for eliciting user requirements and desires is by adopting the *PRE* process (*Product Requirement Engineering)* (Kaulio, Karlsson, Rydebrink, & Klemets, 1996). PRE is a full framework of descriptions on how to manage customer demands, including a general six step process with suggestions on methods to use for each step. The steps suggested by PRE will now be described. Short descriptions of the suggested methods will then follow.

1. **User selection**
   The process is started by selecting a proper target group for the intended product, through for example a *stakeholder analysis* or a *customer segment matrix*.
2. **Data collection**
   Data is then collected from the target group through methods such as *interviews*, *surveys*, *focus groups* or *observations*, as described previously.
3. **Data analysis**
   The results of the data collection are then analysed and interpreted. A *KJ analysis* can be used to sort the collected information into categories which can be used as topics in the requirements specification. Requirements and desires can then be formulated based on the collection of customer statements in each category. Other analysis methods can be useful at this stage as well, such as histograms for describing statistics from a questionnaire.
4. **Visualization**
   The user requirements and desires produced from the previous steps now need to be communicated internally to the personnel that are supposed to work towards them. There are numerous methods for visualizing user needs, and which way to go about it depends on if the need's focus is on the product appearance or on a usage situation. Product appearance is often visualized using *mock-ups*, *CAD-models* or *prototypes*, while usage situations can be visualized with, for instance, *scenarios* or *personas*.
5. **Verification and value assessment**
   Before proceeding any further, the user should be contacted once again, in order to verify that the gathered user needs have been correctly appreciated. In this step the needs can also be compared

against each other in order to determine their value to the customer. This could be done using telephone interview with a few users. A survey could also be sent out to get a look on the priorities of a wider segment of users.

6. **Concept generation**
   For this step some methods for generating concepts are suggested. This will however not be covered here, since this section only deals with eliciting user requirements. For more information on methods for concept generation, see section 3.5.1.

Stakeholder analysis

Stakeholders are all people who in some way are affected before, during and after the product development. The idea of this method is to produce a mind map showing all these stakeholders and how they are connected to the product or project, in order to facilitate for the user selection (Kaulio, Karlsson, Rydebrink, & Klemets, 1996).

There are several ways to perform a stakeholder analysis. One way is to use post-it notes when "brainstorming" stakeholders. Each stakeholder gets their own post-it and the notes can then be moved around during the session, to form a mind map describing relationships in terms of dependencies (one-/two-way, weak/strong), transactions (information, goods, money) and means for distribution.

Customer segment matrix

The stakeholder analysis can be used to list all people affected by the product, but it does not fully describe what separates them from each other. This is where the customer segment matrix comes in (Kaulio, Karlsson, Rydebrink, & Klemets, 1996). Using the list of stakeholders, a list of characteristics can be generated, which describe the stakeholders and how they differ from each other. Suggestions on what characteristics to use can be *level of influence on product design*, *frequency of use* and *experience of the product or similar products.*

The completed customer segment matrix can then be used in the process of selecting relevant people to talk to during the user needs elicitation.

KJ analysis

Data collected from a large number of people will result in a vast list of customer statements. All these statements will need to be organized and sorted somehow, in order to facilitate for the formulating of specific user needs.

A KJ analysis, also known as an Affinity Diagram, is used to create groups of similar statements or statements concerning the same subject (Kaulio, Karlsson, Rydebrink, & Klemets, 1996). This can be done by writing down each statement on a post-it note and then place these notes on a wall one at a time. If the note in your hand has a relation with some of the others on the wall, it is placed in connection to these; otherwise it gets its own spot. When all the notes have been placed, each group gets its own name based on its subject. Examples of group names are *Design*, *Function* or *Usability*.

If a large number of groups are generated, a second iteration can be performed where the groups are sorted into a smaller number of groups. This could for example result in the *Function* group getting sub-groups with statements specific for each of the product's functions.

The result of the KJ analysis is a graphical overview of the customer statements and their connections to each other. The categories can later be used as topics in the requirements specification. The statements in each category can then be used to generate specific requirements and desires in the affiliated topic.

Product appearance visualization

How to visualize product appearance mostly depends on how far the product has come in the development process.

Early on in the process, concepts are mostly loose ideas and often large in numbers. Making accurate 3D models in this stage would be very time consuming and not very wise, since the ideas will keep changing a lot along the way. For this reason the visualization in early stages should most often be based on sketches.

Over time, the number of concepts will decrease but the level of detail and complexity in the remaining ones will get higher, and an increased level of detail will also require increased accuracy in the visualization. This leads to the using additional methods, such as *mock-ups*, *CAD-models* and *prototypes*.

A mock-up is a physical or virtual representation of the product, which can be constructed physically, either in scale or full size, or virtually using CAD (Computer-Aided Design). This method is used mostly for demonstration and evaluation purposes. (Kaulio, Karlsson, Rydebrink, & Klemets, 1996)

Prototypes differ from mock-ups only through the adding of functionality. While mock-ups are mostly used for visualizing designs, prototypes can also be used for demonstrating and verifying that the product works as intended. Thanks to advanced engineering analysis programs, CAD models can also be used as virtual prototypes for testing and verification (Ulrich & Eppinger, 2008).

Usage situation visualization

Usage situations can be described using *scenarios*, which is basically a constructed typical situation in which the product is to be used (Kaulio, Karlsson, Rydebrink, & Klemets, 1996). Scenarios can be used internally for communicating the product purpose to other disciplines or externally when speaking with potential customers or other stakeholders, to give a clear view on product goals, such as what the product will be able to do, how it will do it and who will be using it.

In addition to usage scenarios, a clearer view on the typical product user can also be used at this stage. This is done through constructing *personas* (Kaulio, Karlsson, Rydebrink, & Klemets, 1996). Personas are made up people, given names and background stories, used to facilitating for the developers in putting themselves in the users' shoes. The developers can use this method in internal discussions for questions such as "*what would this or that person want the product to do*" and "*what would he/she think about this solution?*"

3.3.3 Defining requirements and needs according to the KANO model

The Kano model describes how to achieve customer satisfaction by including functions that fulfils different customer needs and requirements. The functions can be divided into three main dimensions which are the basics, performance and exciters/delighters; these can be represented by three curves on a satisfaction scale as seen in Figure 3.3.

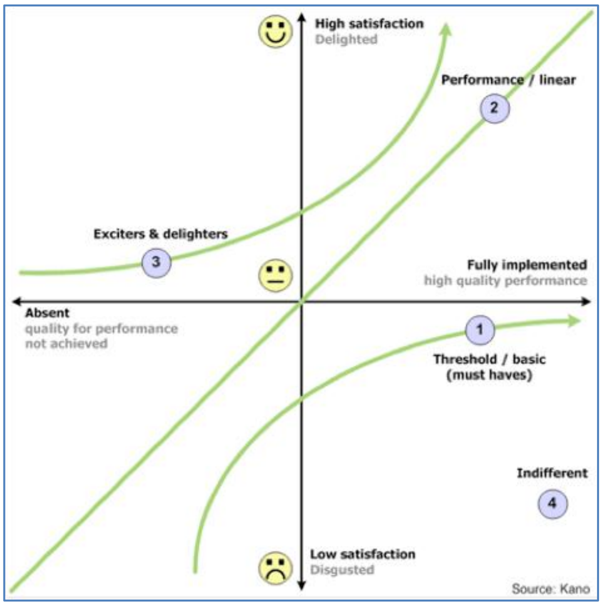


Figure 3.3. A graphical view of the KANO model

The basics curve describes how satisfaction is affected by whether the essential functions are present; these functions are so called "must haves". The second dimension is performance, which describes how well it performs its functions. And the third dimension is exciters; these are unexpected functions that fulfil needs the customer did not know they had. The model shows that basic functions can cause dissatisfactions, but cannot satisfy a customer on its own. The performance increases the satisfaction linearly, and the exciters always add to the satisfaction, even if they do not fully work.

3.4 Using a requirement specification

A requirement specification should be created early in the process, but with an open mind to changes. This specification is not a static document; changes during the product development process are common. It is supposed to work as a foundation during concept generation and selection phase and it also makes it possible for the developers to verify the result of the development process. (Almefelt, 2009)

When formulating the requirements there are many guidelines to be followed. Hull et al. presents the following statements that each requirement should meet (Hull, Jackson, & Dick, 2004):

- **Atomic**: Each statement carries a single traceable element
- **Unique**: Each statement can be uniquely identified
- **Feasible**: Technically possible within cost and schedule
- **Legal**: Legally possible
- **Clear**: Each statement is clearly understandable
- **Precise**: Each statement is precise and concise
- **Verifiable**: Does not impose a solution of design specific to the layer below

The full set of requirements should also meet:

- **Complete**: All requirements are present
- **Consistent**: No two requirements are in conflict
- **Non-redundant**: Each requirement is expressed once
- **Modular**: Requirements statements that belong together are close to one another
- **Structured**: There is a clear structure to the requirements document
- **Satisfied**: The appropriate degree of traceability coverage has been achieved
- **Qualified**: There are acceptance criteria appropriate to demonstrate that the requirements are acceptably met.

In addition to these points, the requirement specification should validate the requirements and present evaluation/verification methods as shown in Table 3.1. The validation should present why the requirements are stated, for example to meet standards or a technical demand. The verification method should present how to control if the product fulfils the requirement (Almefelt, 2009).

Table 3.1. Example of a structured requirements list.

Requirement	Validation	Evaluation/Verification
Requirement group 1		
R1: Requirement 1.1	Validation 1.1	Verification 1.1
R2: Requirement 1.2	Validation 1.2	Verification 1.2
D1: Desire 1.1	Validation 1.3	Verification 1.3
Requirement group 2		
R3: Requirement 2.1	Validation 2.1	Verification 2.1
D2: Desire 2.1	Validation 2.2	Verification 2.2

3.5 Product concept development

The concept development process is generally divided in two phases: (1) generating ideas and (2) narrowing them down to a select few. The process of retrieving a concept to pursue could be described as a funnel, which is illustrated in Figure 3.4. The thought is to have a wide opening to catch as many ideas as possible and to later narrow them down by screenings to end up with only one or a few concept in the end that will be developed into a final solution (Wheelwright & Clark, 1992).

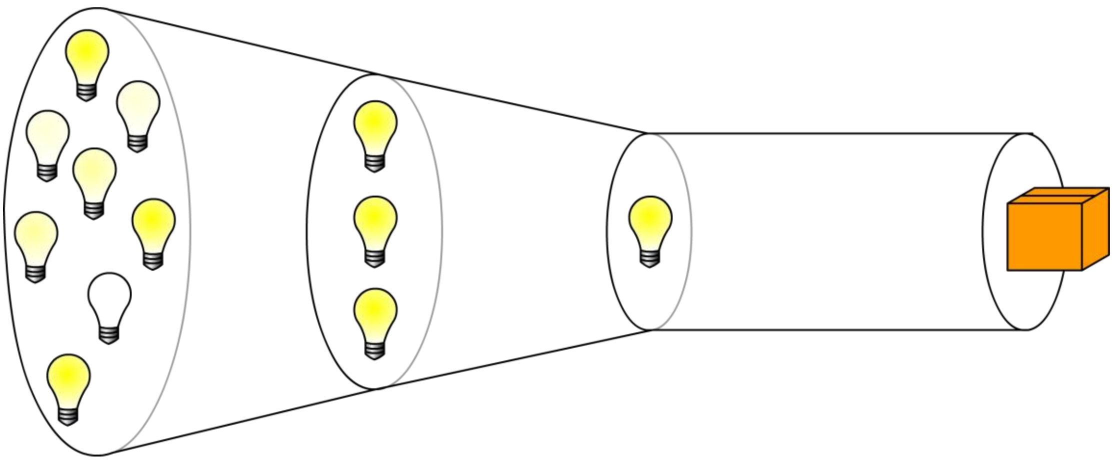


Figure 3.4. A representation of a development funnel, where many ideas are screened out to end up with the best suited which will be developed into a final product.

3.5.1 How to generate concepts

A concept could have different definitions depending on the context. A concept could in some occasions refer to a first working prototype of a product (Johannesson, Persson, & Pettersson, 2004). In this report a concept is defined as a solution on a system level, based on an elementary level of study and assumptions.

Generating concepts is to formulate ideas for solutions based on a given problem. Channelling knowledge from the mind to formulate a realizable solution ad-hoc could be troublesome; luckily there are defined ways for performing concept generation in a structured manner. A few of these methods will be described in the following sections.

The five-step method

The five-step method is a process outlined by Ulrich and Eppinger as a means to break down a complex problem into a defined smaller set of sub-problems (Ulrich & Eppinger, 2008).

A step by step approach such as this is suitable for groups with limited experience, since it lays out a well-defined path for the group to follow. The method consists of the following five steps:

1. ***Clarify the problem***
   Describe the problem in order to make it easy to grasp. A good requirement specification can be used as a way of clarification. If the problem includes a complex task, it can be divided into subtasks, making it easier to approach.
2. ***Search externally***
   An external search is a way to gather knowledge outside of the group. A search for patents can be performed and already existing solutions for tasks, or subtasks, can be researched.
3. ***Search internally***
   An internal search utilizes the group members' own knowledge and creativity in order to generate ideas for concepts. This can be done with methods such as *brainstorming* or *method 365*. *Mood boards* can also be helpful as inspiration in this stage.
4. ***Explore systematically***
   The divided tasks and the generated ideas can be merged in *concept classification trees* or *concept combination tables* as a way to organize the knowledge that has been gathered. The classification trees and combination tables can be used to create concepts by combining sub solutions. This should help to organize the thinking of the designer into smaller problems.

5. ***Reflect on the solution and the process***
   It is important to always try to identify ways to improve the process of concept generation. A reflection should be done after the use of each method, and also when the project has been completed, to assist the work of future projects.

Brainstorming

Brainstorming is a method for generating a large quantity of ideas that may or may not lead to feasible concepts (Pahl & Beitz, 1995). The intention is that a group of open-minded people, with different backgrounds and not necessary any expertise in the subject, should mention their every thought in order to trigger more ideas within the group.

The group should consist of at least five participants, to be able to have a variety of minds and background, but no more than 15 participants, to make sure that everyone gets to speak their mind. Everyone should be encouraged to speak freely and mention absolutely everything that comes to mind. It is important that no criticism is allowed in order to keep the ideas flowing.

There should be a leader, but the leader should only seek to minimize organizational problems and to keep the brainstorming session going by making sure no one is criticising any ideas. To minimize repetitive ideas the session should be no longer than 45 minutes; a better way to gather more ideas would instead be to start over with new participants. When the session has ended, the results should be reviewed by experts to find potentially feasible concepts, but the group should help the experts to keep free of any misunderstandings (Pahl & Beitz, 1995).

Method 635

The *Method 635* is an alternative to brainstorming with the same goal, to bring out a large variety of solutions by combining the minds of a number of participants (Pahl & Beitz, 1995). The method generates ideas more systematically, providing a path for how every solution was developed, showing who the initiator of a successful solution was. The method is conducted by six people writing down three rough solutions each in the form of keywords on a paper. The papers will be rotated five times and each time the participants either develop the existing solutions or write down three new ones. By having everyone silently writing on the paper there will never by any chance of conflicts or criticism, as compared to *Brainstorming,* within the group but on the other hand the creativity will be reduced due to isolation (Pahl & Beitz, 1995).

Mood board

Mood boards are collages of pictures used to mediate a feeling. It is often used by graphical designers to clarify for themselves and to show others in what direction the design is supposed to go. The mood board should not show exactly what design that is pursued, it is only supposed to show the desired feeling from the product design. A mood board could be done with physical objects but it is often done as a poster with pictures, mainly because it is faster and it could show images of things that are not available in physical form (Karlsson, Mediating tools, 2010).

3.5.2 How to select a superior concept

After a satisfying amount of concepts has been generated, they all need to be thoroughly reviewed to be able to bring out the most promising ones. This could be done through a defined set of methods, presented in the following sections.

Elimination matrix

To begin the selection process, a fast way to eliminate the most unsuitable proposals is to use an *elimination matrix* or as it is sometimes called, *selection chart* (Pahl & Beitz, 1995). The concepts are screened against six criterions; the proposed concepts' solution or sub-solutions should:

- be compatible with the overall task and with one another
- fulfil the demands of the requirements list
- be realizable in respect of performance, layout etcetera
- be expected to be within permissible costs
- incorporate direct safety measures or introduce favourable ergonomic conditions
- be preferred by the designer's company, that is, can be readily developed with the available know-how, materials and procedures and under favourable patent conditions

To make the selection as fast as possible the first two of these criterions should be addressed first for every concept before the other criterions are evaluated and as soon as a concept fails to incorporate these two criterions there is no need to evaluate the other criterions. It could be argued that the other criterions do not need to eliminate the concept since they may not be as important for every project (Pahl & Beitz, 1995). The method could easily be practiced by establishing a table where all the concepts are compared against every criterion as is illustrated in Table 3.2.

Table 3.2. Example of an Elimination matrix, showing three concepts evaluated against the criterions stated above. Since Concept 2 cannot satisfy the second criteria, it will be eliminated, and thus there is no need to evaluate the other criterions.

Criteria	**Concept 1**	**Concept 2**	**Concept 3**
Compability assured	✔	✔	✔
Fulfills demands of the requirements list	✔	✗	✔
Realisable in principle	✔	-	✔
Within permissible costs	✔	-	✔
Incorporates direct safety measures	✔	-	✔
Preferred by designer's company	✔	-	✔
Continue development?	**YES**	**NO**	**YES**

Weighing desires

When a satisfying amount of promising concepts are left, they could be evaluated against each other with a Kesselring matrix, which is a way to compare their ability to satisfy user desires. However, to do this, the relative importance of all desires must first be determined.

Using a *weighting matrix* is a good way to measure the importance of the desires coherently. The matrix uses pairwise comparison to individually relate each desire with all the others. A pair comparison can in total get 1 point. The most important desire receives the whole 1 point while the other gets 0 points. Desires that are of equal importance will share the point, meaning that the pair will get 0.5 points each. When all desires have been compared to each other, the sum of points is summed up for every desire. The importance of a desire is determined by the individual score divided by the sum of all points, giving it a weight from 0 to 1 or from 0% to 100%. (Johannesson, Persson, & Pettersson, 2004)

In practice a table could easily be established where all desires are listed both horizontally and vertically as seen in Table 3.3. Desires are then compared to each other, one at a time, and if the *column desire* is considered more important than the *row desire*, it received a value of *1*. Similarly, if less important, it received a *0*. When there is no difference in importance the value *0.5* will be given instead.

When all desires are compared, the values for each column are summed, resulting in individual weights for all the desires which can then be used in a Kesselring matrix. In order for no desire to receive a weight of *0* (and thus be rendered useless), the counting is starting at *1*.

Table 3.3. Example of a Weighing matrix where six desires are compared to each other. Desire 2 has been received the highest weight and is therefore appointed the most important desire.

		D01	D02	D03	D04	D05	D06
Desire 1	D01	-					
Desire 2	D02	0	-				
Desire 3	D03	0	1	-			
Desire 4	D04	0,5	1	1	-		
Desire 5	D05	0,5	1	1	0	-	
Desire 6	D06	0,5	1	1	1	1	-
Sum weight + 1		2,5	5	4	2	2	1
Percent of total		15%	30%	24%	12%	12%	6%

Kesselring matrix

The *Kesselring matrix*, as seen in Table 3.4, is a useful method for scoring and subsequently ranking potential concepts, with the goal of narrowing them down to one or two winning concepts. Since inherently unsuitable concepts should have been eliminated prior to the Kesselring, the remaining concepts will now be measured against the product desires. In order to reflect the importance of one desire over another, they are each given weights as described previously.

The concepts are given a value of *1-5* for their ability to satisfy each desire. The values are then multiplied by the weights to produce a total score value. Summing up the total scores for each concept gives an overall score for the concept, which can then be calculated as a percentage of the ideal score. Once this process has been completed for each concept, they can be ranked and subsequently brought forward for further development or be eliminated (Johannesson, Persson, & Pettersson, 2004).

Table 3.4. Example of a Kesselring matrix, showing that Concept 1 is most suited for further development.

Evaluation Criteria			**Ideal**		**Concept 1**		**Concept 2**		**Concept 3**	
No.		**Weight**	**Value**	**Total**	**Value**	**Total**	**Value**	**Total**	**Value**	**Total**
1	Desire 1	1	5	5	5	5	4	4	1	1
2	Desire 2	7	5	35	4	28	3	21	2	14
3	Desire 3	6	5	30	3	18	3	18	2	12
4	Desire 4	3	5	15	2	6	2	6	5	15
			100,0%		67,1%		57,6%		49,4%	

3.6 Methods for detail design

Detail design is where the product should be defined down to every part. To avoid spending too much time on the details it is often good to do this in a structured way. The following sections present some methods that can help to create the detail design in a structural and rational way.

3.6.1 Flowcharts for programming

When programming, it is useful to first sketch how the structure of the program is supposed to work. A useful method for doing this is by using *flowcharts* (MindTools, 2011). The use of flowcharts could be done to help design a process, to present and to document it. The method is supposed to show how a process or program is structured in a step by step approach and to show the relation between each step as simple as possible to make it easier to understand and improve. Dividing a program into steps also gives the advantage of being able to divide the work and programming it a little at a time. A flowchart is basically built up by three types of symbols as well as arrows in between them; elongated circles indicates the start and finish, rectangles represent an action or instruction and diamonds represent a decision that must be made (MindTools, 2011). Figure 3.5 show how a simple flowchart could be sketched for the process of drinking milk.

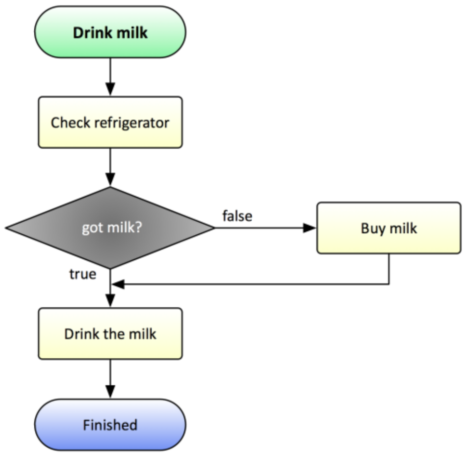


Figure 3.5. A simple flowchart for drinking milk. If there is no milk in the refrigerator it needs to be bought before it could be ingested.

3.6.2 CES – Cambridge Engineering Selector

The *Cambridge Engineering Selector* is a computer software tool used to select the best suited material and production process for a product design. The program can be used to plot a large variety of materials and production processes on charts depending of a huge number of properties such as price, energy consumption, E-modulus, service temperature and many more.

The program consists of a large database which can be screened systematically to suit the needs of a product by defining criterions. With some criterions decided the materials left to be chosen can be arranged in a trade-off curve more easily. The Cambridge Engineering Selector is not only used for screening, the database also provides a huge library of information that can be browsed and read to widen the knowledge of materials and production processes (Granta Design Limited, 2010).

3.6.3 CAD models

Making designs manually can be a time consuming process. The introduction of *Computer Aided Design* (CAD) tools in the 1970's made it possible to edit drawings easily and copy designs to be able to reuse them in other projects.

CAD systems are not only able to create drawings, but also three dimensional geometries. Parameterising the dimensions of a model also provides the ability to perform changes on its design instantly. Platform designs can be constructed, able to describe a variety of products with only one design combined with a parameter sheet. (Johannesson, Persson, & Pettersson, 2004).

Creating CAD models gives the opportunity to realise and evaluate a design with no material or production cost. The models can be rendered and displayed in large formats with cross-sections to be able to see views that are impossible in real life and with computer models it is also possible to visualize physically impossible designs.

However, CAD models are not only used for geometry visualization; the volumes and weights of parts can easily be calculated and parts can be combined in assemblies as well, where manoeuvrability of full product concepts can be tested. More extensive tests are also possible with CAD models through the use of finite element tools. With these tools a design can be tested in accordance to limits in mechanical strength without having to destroy an expensive prototype (Lindkvist & Ćatić, 2009).

3.7 Methods for testing and refining

An important aspect about the development process is to keep it going in iterations. When a solution has been developed it needs to be tested to make sure it will manage all parts of the target problem. To be able to make tests a prototype will be needed. After the testing, the solution should be changed in order to account for the found faults. A new prototype should then be made to be able to do the tests again.

3.7.1 Prototypes

There are different types of prototypes that could be made for testing. The reason for not making a complete prototype at first is because it will take more time to produce and the cost will be much higher. At first a prototype would probably be made out of parts that only may fulfil the basic functionality; a prototype that will be used when developing certain aspects of the product. Later, a prototype should be made out of the parts that are intended for the production and are delivered from the intended supplier, to make sure that all the parts are compatible with each other and that they will solve the problem. When the refinements has been made at this stage a prototype should be made with the proposed production processes to make sure that the product will be reliable and perform as it is supposed to do. This is the most costly prototype and should only be done when the product is nearly finished (Ulrich & Eppinger, 2008).

3.7.2 Testing

When a prototype has been made it should be tested to be able to find areas of improvements. The testing could be made with different intentions; usual tests are reliability testing, life testing and performance testing. The reliability and life testing should focus on the use of the product, to make sure that the product will function for the specified time without being unstable or break down. These tests could be performed by internally by simulating the use over a time but could also be tested externally by selected users. The performance tests are used to make sure that the product work as it is supposed to do and that every need is fulfilled (Ulrich & Eppinger, 2008). Testing could also be used to evaluate the aesthetic design of the product. With a prototype in hand it is easier to grasp the appearance of the product. However the looks of the product should not always be determined internally, since it is the users that should find it appealing.

Life Cycle Assessment

Another type of testing is to make a *Life Cycle Assessment* (LCA). Life Cycle Assessment is a method of mapping the entire production, use, transport, dismantling and disposal of the product in matters of ecological impact. The results from the LCA can then be used to alter the design in order to minimize the products negative effect on the environment. The LCA should not be seen as a process to be done as a last stage to get the inputs of how to make the product better, instead it should be something to consider throughout the whole design process. When the life cycle of a product has been mapped, the same input could easily be used to make a *Life Cycle Cost* (LCC), which is a method of calculating the total cost for the user of a product (Johannesson, Persson, & Pettersson, 2004).

4 PROJECT APPROACH

In this chapter the approach of the project will be explained. What processes that was used and how they were planned along with how the work was divided and managed throughout the project.

4.1 Adopted processes and methods

The tasks of the project were divided into steps as a modified version of the generic product development process, which is described in section 3.1.1. These phases are describing work on a marketing, design and manufacturing level. Since this thesis is focusing on the design aspects of the product development process there will only be a market analysis in the beginning and from there on, few considerations are made on the marketing the product. Manufacturing of the product will not be considered either, since this project primarily focuses on developing a functional prototype and the design will stay on a conceptual level. The phase 2, system level design, is in this case more or less implemented in the phase 1, concept development, because it gives a more structured way of generating concepts by first defining the major subsystems. Phase 5, production ramp-up, was not performed for the same reason as for the manufacturing not being considered at this stage. Instead of production ramp up as phase 5, a step of verification was performed to make sure the requirements of the product was met and to find what is left to be done in order to complete the product. The flow of the steps is described in Figure 4.1 and the adopted methods are shown below each respective step.

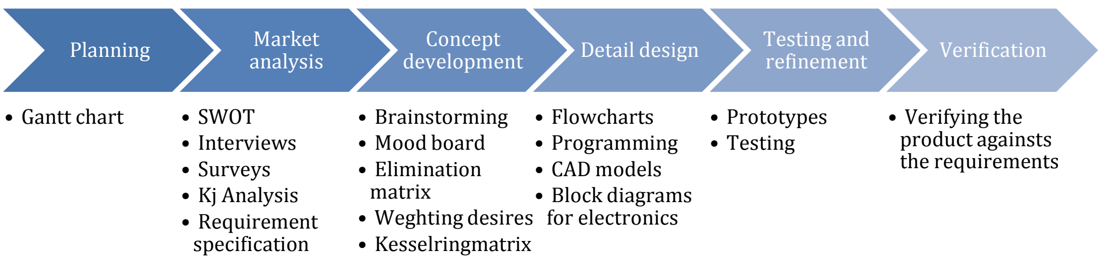


Figure 4.1. A representation of the project's processes with underlying methods

4.2 Physical arrangements

The development of this product was conducted in an office with a capacity of four people. The office housed whiteboards which is good for communicating ideas, sketching concepts and keeping a good overview. The office was located in the product and production laboratory at Chalmers University of Technology, which provided access to a near supply of basic electronic components. In the office there were power tools and a soldering iron, which was useful for assembling the components. Each member of the thesis group had a computer with an internet connection. Each computer had access to a microcontroller programmer PICkit 3 and a development board. The programming was conducted in the program development environment MPLAB IDE. With the PICkit 3 followed tutorials that was used for learning how to write programmes for a microcontroller. To monitor the signal processing, an oscilloscope was available.

4.3 Roles and responsibilities in the project

The project consisted of two members that divided the workload equally. The members worked individually with their tasks and consulted each other in some decisions. No leader was decided; instead all the major decisions was discussed and agreed upon. The collaborating thesis group assisted in some work and was useful for bouncing ideas against. The Market analysis was done in total collaboration with the other thesis group and while doing that, the work was conducted in the same way by individual work with no leader.

4.4 Project plan

The project has a time limit of 20 weeks, which needed to be planned in order to get the most out of the time and to never end up idle. The time for each step was assumed and graphically represented by a Gantt chart, which can be seen in Figure 4.2. Testing and refinement was planned to be the most time consuming step, where all parts developed in detail design were supposed to be tested and refined until they worked as planned.

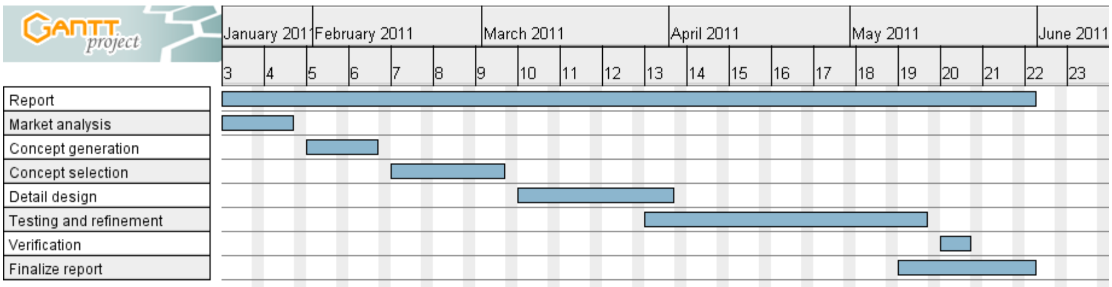


Figure 4.2. The Gantt chart, showing the planned time table for each task.

As it is seen in Figure 4.2, there are two tasks for the report. The first is to make sure that everything is documented along with the development and the step *Finalize report* is a step to make sure that the report is correct and finished in the end.

Throughout the project emphasis has been on completing each step before continuing the next. However the steps *Detail design* and *Testing and* *refinement* has been done in iterations, where the results of the testing could have been of such big importance that the detail design has to be repeated.

A quick calculation of the funding was performed in the beginning of the project. The result from this calculation showed that there was an excess of resources for the purpose, which meant that purchases could be done without having to consult a financial plan. Instead the needed equipment and parts could be obtained quickly in the early stage and later an optimization could be done for the final product to keep the costs down.

5 EXECUTION AND RESULTS

In this chapter the execution of the product development process is presented. The methods used in every section are motivated and the respective result from the methods follows. All execution is based on the theory described in chapter 3

5.1 Market analysis

The project revolves around a product produced side-by-side with a software team, and for the groups to begin developing their respective parts, they both will need to perform a market analysis and search for requirements. The requirements are largely based on end-user needs, concerning the product as a whole, which are interesting for both groups. Both groups doing a full market analysis was therefore considered a waste of both time and resources, and instead a joint market analysis was performed. To start, a joint focus was put on the overall product and its intended market as well as overall end-user needs; to later digress into more individual work on setting specific requirements for hardware and software respectively.

The requirements for the product are primarily elicited using interviews and surveys, but they also need to be adapted to a specific product target group as well as the current market situation, which has been described through a trend analysis.

A SWOT-analysis has been performed as well, to analyse the environment of the idea and compare it with other solutions available on the market.

5.1.1 Trend analysis

Recent trends have been analysed from a *social*, *economic* and *technological* perspective, in order to see what is happening on the market at the moment, and to verify that the proposed product is in fact a good fit on the market.

Social and economic trends

Early adopters are always looking for new innovative products to be released. Since the current alternatives for universal remote applications requires additional hardware to be attached to the smartphone, this idea can be viewed as innovative since it requires nothing else than starting the application on your phone. If the user interface is constructed in such a way that it is intuitive and easy to use, yet still powerful and functional, the product will sit well with the early adopters and through them the word will spread out that it is a cool and hip product, generating a craving for it on the market.

When flat screen TV:s first arrived they were considered expensive luxury equipment, but over time the technology has become more and more affordable and today the flat screen is practically standard appliance in the average home. Other appliances such as surround sound systems, DVD/Blu-ray players and external media boxes have also become cheaper. The use of a high definition projector and projector screen in the living room can still be considered a luxury item, but their price is steadily decreasing as well. These economic trends have led to an increased number of users, which means that more and more people are getting their coffee tables filled up with remote controls. A survey conducted by Logitech concludes that the average living room has four or more devices with remote controls (Logitech, 2010). Swedish people are now also watching more TV than ever, with about three hours a day per person (Oscarsson, 2010). The more time people spend in their couch watching TV and the more extra equipment they buy, the more use they will find for a simple universal remote.

Technological trends

A low price tag on the equipment is not the only thing that attracts people, but also the technology inside it is getting better. Every time a new technology is released older hardware will seem more and more out-dated, and these last few years we have seen a lot of new releases on the technology market. Examples of these are improvements on the TV screen with the introduction of LED and 3D technology, but also functional advances such as interaction with Internet applications through a broadband connection as well as home theatre media boxes for viewing downloaded or recorded movies and TV shows. With an increased number of functions, the remote controls also needs to be able to control them, which often leads to more buttons, making the remotes increasingly complex. It should also be noted that even though the number of functions in the equipment increases, people do not necessarily use all of them, which leads to a large number of buttons on the remote controls that are rarely or never ever used.

Since 2007, when Apple released their smartphone Iphone, the market for smartphones has increased rapidly. In 2010 the sales of smartphones reached 1.75 million in Sweden, which constitutes 45 per cent of the country's total mobile phone sales, to be compared with the sales for 2009 which only reached 0.78 million or 25 per cent of sales (MobilTeleBranschen, 2011).

Today's smartphones holds a large touch screen display, which can be fully utilized by third party applications. With this display, the user interface for a remote control application can be tailor made to fit any individual by only showing the functions that he or she wants to use. And because of the rapid growth of the smartphone market, the same growth is implied for the market of applications for them, which is why now is a good time to combine the areas of smartphone applications and home cinema control equipment.

5.1.2 SWOT-analysis

In order to analyse the environment of the idea and to compare it with the solutions on the market, a SWOT-analysis was made. The result of the method is the possible strength, weaknesses, opportunities and threats for the realization of the idea. The result can be seen in Table 5.1.

Table 5.1. SWOT analysis for the product

	Helpful	Harmful
Internal	**Strengths** • Utilises the power of the iPhone • Big high definition display • Touch screen • Internet access • Modes of communication • The users have experience with the smartphone user interface • Less important size and shape restrictions • Experience with the iPhone (developer) • PD background (developer)	**Weaknesses** • Limited experience of market • Limited resources • No name on the market
External	**Opportunities** • Expensive products on the market • Growing smartphone market • Growing amount of remote controls • Growing amount of functions • The market trends • Physical user interface on products of today • Limited modes of Communication on the products of today • No direct competition found	**Threats** • Tough competition • Smartphone solutions already on the market • Bounded by the limited iPhone market • Decreasing iPhone market share • Limitations of the iPhone

Strengths

By using a smartphone to act as user interface, advanced technology can be utilized whilst the price is kept to a minimum. The smartphones can provide the product with computing power, a big high definition touch screen and Internet access. The smartphones also has the ability to communicate through different types of mediums, including Bluetooth and Wi-Fi. The user will in most cases have some level of experience with the smartphones' user interface, giving the product an advantage within human-machine interaction. As the products hardware is stationary and will not demand any direct interaction with the user, the size and shape of it will be less important. The developers also have high level of experience with the iPhone and product development processes.

Weaknesses

The developers have limited experience of the market and therefore have less understanding about trends and pit falls. The resources are also limited, which can act as a constraint for the product. The limited resources are time (20 weeks), personnel (Two engineers on software resp. hardware) and money (10 000 SEK). A newly launched company will also have no name on the market, which sets higher demands on the product introduction to reach success.

Opportunities

Aforementioned, a variety of universal remote controls can be found on the market today, with a price range from 50 SEK up to 30000 SEK (Prisjakt, 2011). But to get a product with similar or better user interface as the one possible on a smartphone, the price would range higher than 1000 SEK (Prisjakt, 2011). The smartphone market grows every year (MobilTeleBranschen, 2011), which makes the potential market of the product grow as well. A growth can also be seen in the amount of electronic equipment used in the homes, leading to more remote controls in the living room. The growing amount of equipment also leads to more functions and settings, making the process more complex (Logitech, 2010). As the products of today often have a physical interface, and have no ability to adapt to different situations, it could make the complex task even harder. Investigating today products, within the same price range, shows a lack of communication modes. The remote controls can generally only communicate through IR signals. As the idea for the intended product is to have the ability to communicate through multiple mediums, with no need for attaching additional hardware to your phone, no direct competitor has been found.

Threats

The market for universal remote controls is well established with tough competition. The competitors are global electronic companies as Philips and Logitech, specialised companies such as RTI or small newcomers like L5 remote and RedEye developed for the Iphone. The L5 remote (Figure 5.1) and RedEye (Figure 5.2) are solutions developed to take advantage of the smartphone technology (L5 Technology LLC, 2011) (Thinkflood, 2011). Another threat is the limitations of the Iphone and its market. The Iphone has restrictions on how apps can utilise the hardware (Apple, 2011), the performance of the Iphone hardware can also be seen as a limitation of the product. The smartphone market is still growing, which could be seen as an opportunity, but the Iphone is still only the third biggest product on that market and with a shrinking market share, therein lies a threat if the product is made dependent on the Iphone (Gartner, 2010).

Figure 5.1. The competitor L5 Remote (L5 Technology LLC, 2011)

Figure 5.2. The competitor RedEye's attachable solution and docking solution (Thinkflood, 2011)

5.1.3 Eliciting requirements and desires

The process of eliciting requirements and desires is inspired by the *Eliciting user requirements process* and the *Product requirement engineering process*. The two processes present a given way to elicit requirements, but highlights that the process should be tailored to fit the specific project. The applied process has six steps; the first three steps are taken from the Product requirement process and the corresponding steps in the Eliciting user requirement process are disregarded. The fourth step of the Product requirement engineering process, *visualisation,* is disregarded as it is only used to communicate in larger projects. The fourth, fifth and sixth steps of the applied process are as following *Establish the relative importance of the needs, Verification and Value assessment* and *Reflect on the results and the process.* A visualisation of the process can be seen in Figure 5.4 and in Figure 5.3 the handpicked steps are displayed.

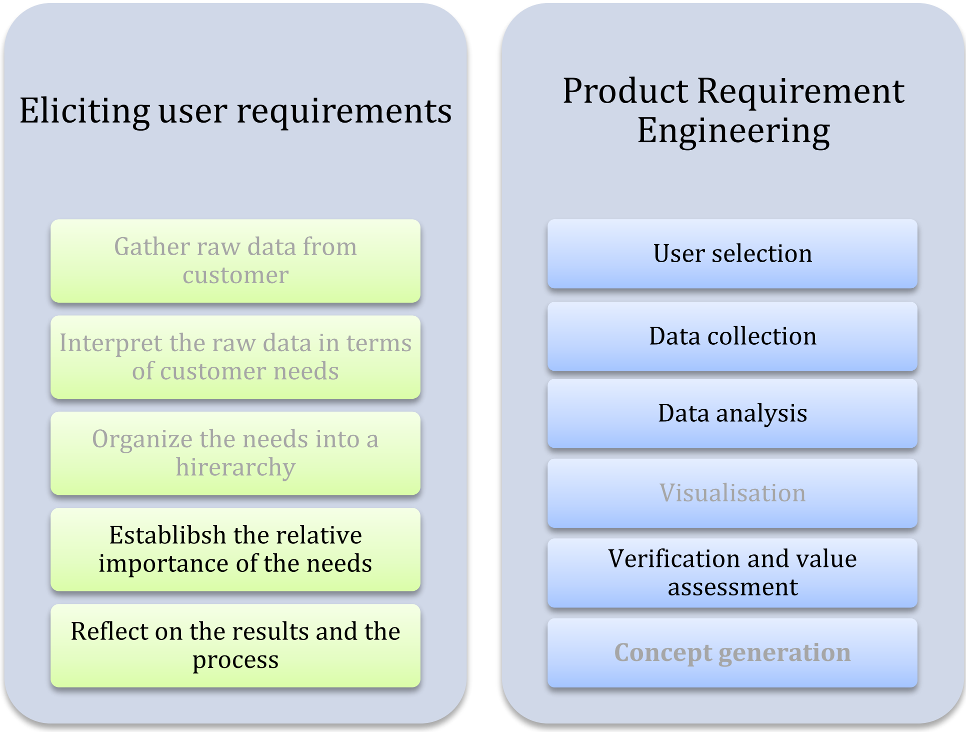


Figure 5.3. Handpicked steps of the eliciting requirement and desires process

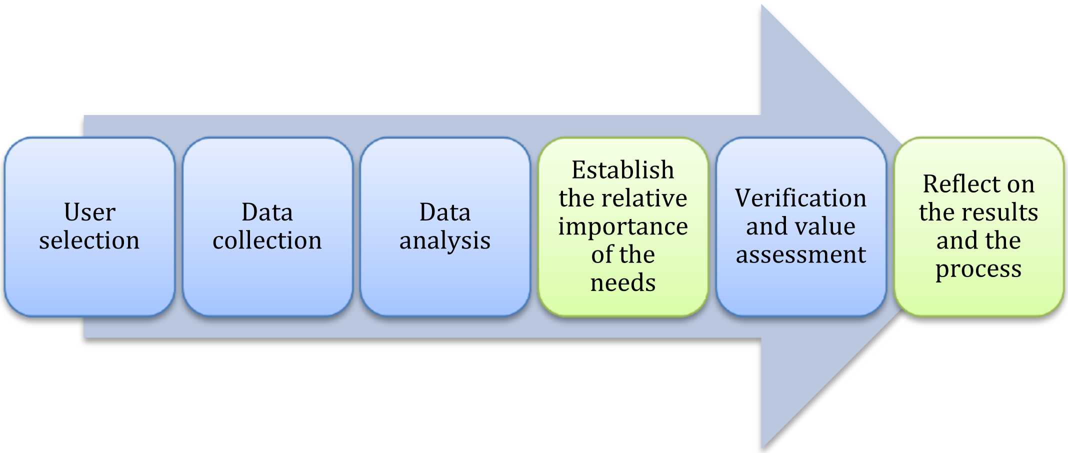


Figure 5.4. The tailored eliciting requirement and desires process

User selection

The studies were carried out with possible future customers/users. This is basically every smartphone user or anyone with appliance that can be controlled using a remote control. It was of extra interest to ask users of other types of universal remotes what they like about them, what they would like to see changed and also if they would prefer to use a smartphone instead of their current solution.

Because the user group of smartphones has grown and diversified so much, it is important to cover many different user demographics. The demographic groups of smartphones range from very young teenagers to retirees, as seen in Table 5.2. A gender demographic breakdown of Iphone subscribers also shows a majority of men in the group, as seen in Table 5.3.

Table 5.2. Age demographic breakdown of Iphone subscribers (comScore MobiLens, 2010)

Age (year)	Percentage of mobile market (%)
13 – 17	7
18 – 24	17
25 – 34	28
35 – 44	23
45 – 54	15
55 – 64	7
65+	4

Table 5.3. Gender demographic breakdown of Iphone subscribers (Nielsen, 2010)

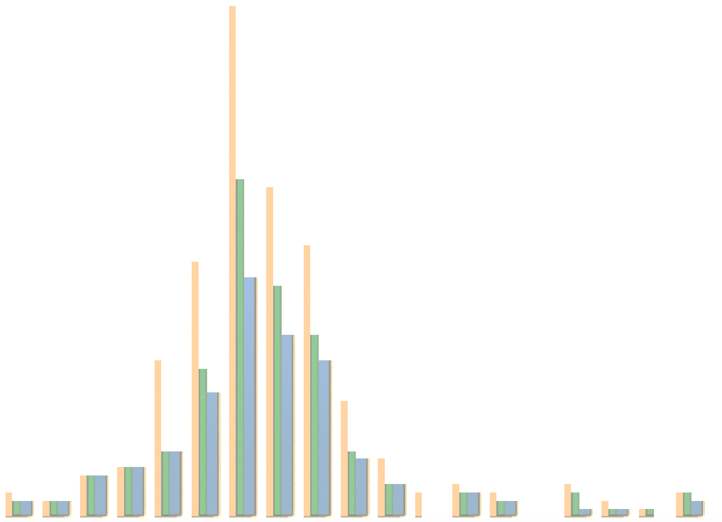
Women (%)	Men (%)
45	55

Requirement specification

The requirements for the product were determined using Ulrich and Eppinger's five step method, which is described in the methodology theory chapter, section 3.5.1.

Data collection

In order to gather statistics about regular home equipment, a survey was performed using a web questionnaire. The questionnaire focused on determining how many and what types of remote controls are present in peoples' homes today, the full questionnaire can be found in Appendix A. The selection group was assembled using Facebook and consisted of approximately 550 people. The gender distribution was approximately 60 per cent men and 40 per cent women. The age distribution had the majority in the span of 18-24 and 25-34. To get more participants in the span of 35-44, the questionnaire was uploaded to the home cinema forum '*Min Hembio.com'.* The questionnaires posted in the internet forum generated quite poor results. However, the ones sent out through Facebook generated huge response. More than 50 per cent of the people that were sent the questionnaire via Facebook submitted answers. The results were rendered from a total of 260 submitted answers, from users with an age distribution as shown in Figure 5.5.



Age:	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Submissions:	3	2	5	6	19	31	62	40	33	14	7	3	4	3		4	2	1	3
S-phones:	2	2	5	6	8	18	41	28	22	8	4	0	3	2	0	3	1	1	3
[%]:	*67*	*100*	*100*	*100*	*42*	*58*	*66*	*70*	*67*	*57*	*57*	*0*	*75*	*67*		*75*	*50*	*100*	*100*
S-phones:	2	2	5	6	8	15	29	22	19	7	4		3	2		1	1		2
[%]:	*67*	*100*	*100*	*100*	*42*	*48*	*47*	*55*	*58*	*50*	*57*	*0*	*75*	*67*		*25*	*50*	*0*	*67*
Remotes:	4	3	3	4	3	3	3	3	3	3	4	4	4	4		5	4	5	3

Figure 5.5. A histogram showing age distribution and smartphone ownership. Orange represents all people who answered the questionnaire. Blue represents people that own a smartphone. Green is the same as blue but also includes people who plan on getting a smartphone.

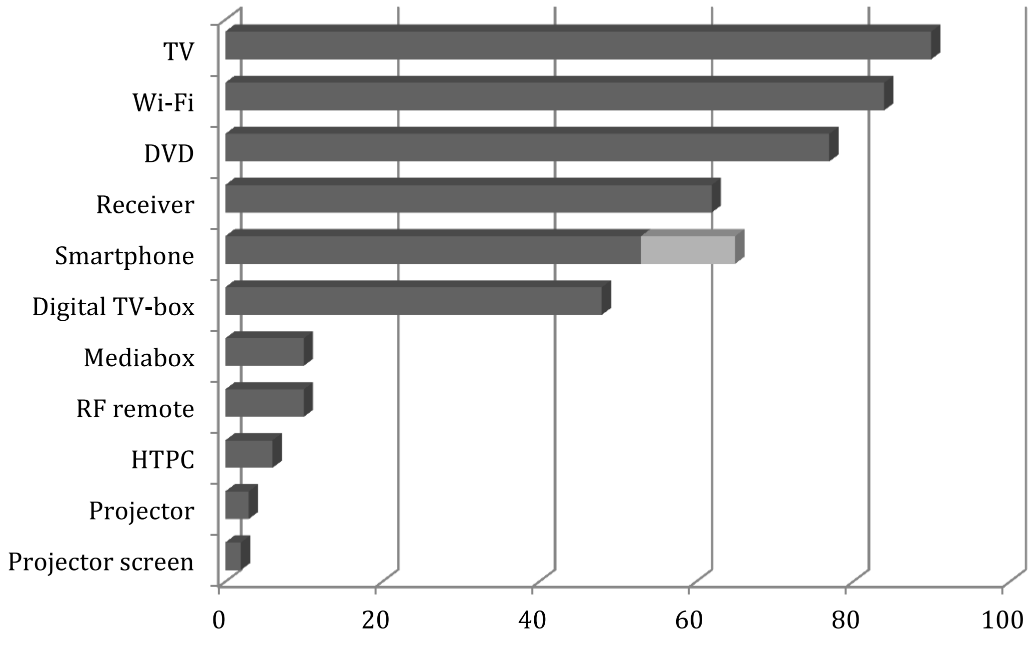


Figure 5.6. The diagram shows the percentage of the participants who owns the listed types of equipment. The grey area of the Smartphone represents people who are planning to buy a smartphone in the near future.

The results seen in Figure 5.6 show that most people have a TV (90 %), DVD/Blu-Ray (77 %) and a receiver (62 %), and almost half of the people have a digital TV box (48 %). Most of them have a Wi-Fi connection at home (84 %). Smartphone owners represent 53 %, while an additional 12 % is planning to get a smartphone.

The statistics gathered resulted in a good collection of quantitative market data, but the questionnaire also served as a means to generate qualitative data in the form of customer need statements. The survey included some voluntary questions to answer in text form, hoping that some people would be kind enough to write a few words about their opinions of current universal remote controls. The people currently owning a universal remote control were asked to give their opinions of it in terms of what they like about it, what they dislike, which functionality they often and rarely use respectively, what their remote lacks and how it could generally be made better. The ones who did not own a universal remote control were asked about what could make them buy one. Around 50 per cent of the replies also contained elaborate answers to the voluntary text questions.

Aside from the questionnaire, semi structured interviews were also carried out with people within the chosen product target group. These were used to get a more detailed description of user needs and desires, by having a more laid back conversation with the ability to ask follow-up questions when interesting opinions came up.

Data analysis

At this time, a large set of customer statements have been collected and categorized. These statements should now be analysed and interpreted, in order to compose a list of customer needs. Each customer statement may be used to set up one or more user needs. However, one person's interpretation of a user statement may differ from another's, and for this reason it is wise to do this step in collaboration with at least one other team member (Ulrich & Eppinger, 2008). This step was therefore done through a discussion session together with the thesis writers of the collaborating software group.

In the data collection step the needs of the users were elicited. In this step the underlying requirements and desires are found and presented. The focus is now only on the product hardware and functionality, to read more about how requirements were elicited for software see the collaborating software group's report.

To sort the requirements and desires, five different categories were expressed. The categories were defined as the most commonly occurring topics that the statements concerned, namely:

- Product price
- Compatibility
- Usability
- Quality
- Design

The complete requirement specification can be found in Appendix B.

Establish the relative importance of the Needs

In order to get a good comparison between desires and later be able to do a Kesselring matrix, a weighing matrix was performed. The weighing matrix is used to do pairwise comparisons between all of the desires and results in individual scores for all of them. The process of performing the weighing matrix is further described in section 5.2.2.

Verification and value assessment

The desires given the highest weight values were prioritized from the start, and when concepts were generated, effort was put on producing solutions without compromising the fulfilment of these desires. Verification of the desires was then done along the way in the development process, through surveys and focus groups for the ones concerning design and through engineering assessments for those concerning technological functionality. Desires were then ticked off in the list when their fulfilment had been verified. This list can be seen in Table 5.4, where verified desires are marked with bold text and a blue background. For further details of the verification for each desire, see section 0

An unmarked desire does not constitute a desire impossible to fulfil at this point. It rather only means that additional development work is requires in order for it to be verified.

Table 5.4. The collected desires in order of importance.
The ones written in bold text a have been verified during the development.

Using the remote should not interfere with other communication from the phone	12%
The remote control should be started up and connected as fast as possible	10%
The IR diode should have as wide a sight as possible	10%
The remote should have as long range as possible	9%
The price should be as low as possible	8%
The device design should blend in with a living room environment	7%
The product should give a good quality impression	7%
The device should be aesthetically appealing	6%
The system should be cordless	6%
The remote should be usable even when not in the same room as the equipment	6%
The product should be placeable on any vertical or horizontal surface	5%
The communication station should connect to the smartphone via Internet	4%
The product should be stable where it stands	4%
The communication station should run preprogramed instructions without a phone connected	3%
The system should consume as little power as possible	3%
The system should be able to send Bluetooth signals	2%
The communication station should provide feedback when receiving commands	2%
The product should be as environmentally friendly as possible	1%

Reflection on the results and the process

By the use of pre-defined standard methods, the project member own ideas for the product has been expanded with thoughts and opinions from hundreds of potential customers, which has resulted in a broad comprehension of what users expect from these types of products. By asking people about aspects around the intended product, such as what equipment they have at home and what is useful, as well as unnecessary, in other home entertainment products that they use, even some latent needs has been identified. An example of these is the ability to control your home equipment from wherever you are, via internet connection, which can be useful for turning on and off lights to make it appear as if someone is home, or to start recording a TV show that you are missing because you are stuck in traffic on your way home.

The user need elicitation has laid down the grounds for the product requirements specification. This specification is however a “living” document and will be updated along the way when additional aspects and ideas emerge.

5.2 The concept development process

This chapter describes the process that led to finding a final concept for further development. The process starts with generating a large variety of concepts, which are then narrowed down to one final concept through a collection of methods, as described in the theory chapter, section 3.5. The remaining concept will be that which best meets the requirements and desires specified by the market analysis.

5.2.1 Concept generation

The concept generation for hardware solutions was organized as a two-phase-process in which sub-concepts were generated. The first phase focused on concepts for the functionality of the communication station - the technology that makes it work - whereas the second phase focused on the exterior case design. Sub-concepts from the two phases were then merged in different ways and evaluated in order to find a superior final concept.

The implementation of the Five-step method, described in section 3.5.1, is detailed in the following sections. However, the last step (reflect on the solution and the process) is not presented here, but rather in the discussion chapter in the end of the report, where the development process in its whole is also discussed in the same manner.

Clarifying the problem

The problem was to find a solution for a device that could receive information from a smartphone, translate it to commands that could be recognized by the target device and transmit the translated information in the right format that the target device could receive. The process flow is: receive information, translate the information, change format of the information and transmit the information. Subtasks in this problem were divided into development of the technical aspects and development of the casing.

Searching externally

To find different solutions from where to draw inspiration and where to set the level of the product, a search was conducted externally to gain knowledge that was not within the project group. The search was done in three different stages.

Screening of the market

As a first step, the market was screened by searching the Internet for already existing solution. The products found were then examined by visiting the producers' homepage, watching demonstrational videos and reading reviews. The conclusion was drawn that no direct competitors exists visibly at the moment, but there are similar products that only focuses on IR signals, such as the RedEye.

Let the users create a solution

To gain knowledge of the market demands, interviews and questionnaires were used. During these, the users were told to create their solution to the problem. Some questions with more depth, for example what is wrong with today's universal remote controls and what would make them buy a new one, were also asked to get more information that could be useful once the overall solution has been decided. As the interviewees came from a different background and had their own view of the problem, this provided useful opinions and statistics for the requirement specification.

Focus group for further development

A focus group was assembled with people that were all technically aware and in some way experienced in the problem. At this stage some solutions to the technical issue had already been created and the focus group provided a discussion on how to further develop and evaluate the concepts. As a mediating tool sketches of the concepts were provided to help the focus group level with the situation and easier describe their thoughts. This brought up interesting discussions on things such as placement of the product in the living room, providing opinions which later could be used to justify decisions for concept selection at a later stage.

Search internally

To gather the knowledge from within the project group different approaches was pursued depending on the different task. For the technical issue a search was conducted internally through a *brainstorming* sessions.

The choice fell on brainstorming to be used as concept generation method, because it gives a large input of different solutions to choose from which allows for a larger chance of finding a good solution. Brainstorming was also familiar to all the participants, which allowed for a smooth and fast implementation of the method.

The session was focusing on the system level design of the product and was conducted together with the collaborating thesis group and three additional participants making the session consist of a group of seven. The search is, because of this, not only internally but the three other participants can be seen as triggers of ideas for the group. The session lasted for 40 minutes and ideas were formed around how to perform the given task. A white board was used, where every possible and impossible concept imagined was sketched up. No judgment on feasibility of the concepts was allowed in order to not repress the creativity. The ideas was later interpreted and sorted out by the thesis group using their previous experience with some influence from the results of the market analysis to form different concepts that seemed realizable.

Before ideas for the casing was sought, the solution for the communication had already been determined, which led to the prerequisite that the casing is supposed to be a box containing the electronics with an opening for the IR light to travel through. For this purpose, a mood board was created, as is seen in Figure 5.7, to be able to focus on a certain direction with the design and to grasp what feeling that is supposed to be obtained from the product. With this mood board as an inspirational source some concepts were sketched up on paper to easier demonstrate and evaluate the different designs. All sketches of the concepts were done with the requirements list in mind to make sure no concept would conflict with what is essential for the product. However, the requirements list has no demands that are sensitive to the casing design, which means that there was no additional effort to design with considerations to the requirements.

Figure 5.7. The mood board used as a source for inspiration when designing the casing

Explore systematically

To explore the problem systematically another session similar to *brainstorming* was performed, with a focus on variables, to define what settings and properties could be changed in every aspect of the task. The session only consisted of the two collaborating thesis groups to give relevant ideas of changeable variables. The variables were divided into two groups: Technology and Casing. Subgroups were drawn from these two groups to represent different parts and aspects, in order to get a clear view of what needs to be thought about when designing the product. These variables, which are seen in Figure 5.8, could then be used to compile new concept.

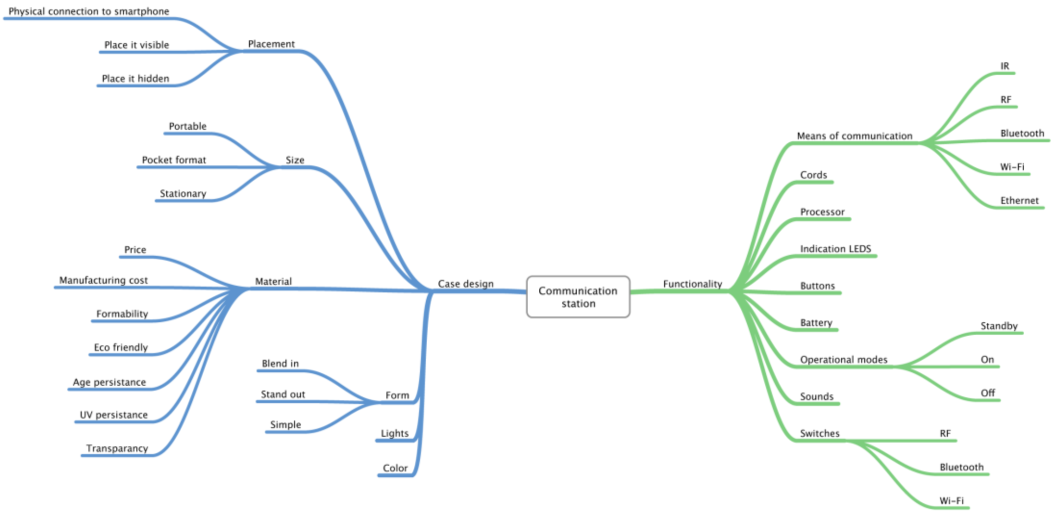


Figure 5.8. The different changeable variables for the product

The resulting concepts of communication solutions

This section provides a presentation of the concepts generated based on the results of the five-step-method described above. These concepts concern the *Technology* part of the product, which describes the communication between the smartphone, the communication station and the target device.

BlueBox

The smartphone connects directly to the box via the Bluetooth protocol. The box contains transmitters for infrared, radiofrequency and Bluetooth as well as a power source either as a battery or as a chord with an adapter. An illustration of the concept is seen in Figure 5.9. This concept does not require anything to be added to the phone. Bluetooth needs to be turned on and active on the phone, which is battery consuming.

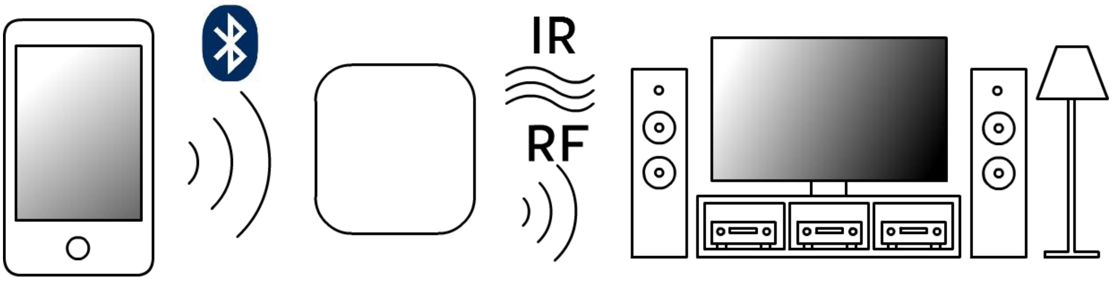


Figure 5.9. A graphical representation of the concept BlueBox

WiBox

The smartphone communicates with a box through a home wireless router. The box contains a Wi-Fi card, transmitters for both infrared and radiofrequency and a power source either as a battery or as a chord with an adapter. An illustration of the concept is seen in Figure 5.10. No attachment is needed on the phone but the user needs to have a Wi-Fi router in excess of the box. Wi-Fi needs to be turned on and active on the phone, which is battery consuming.

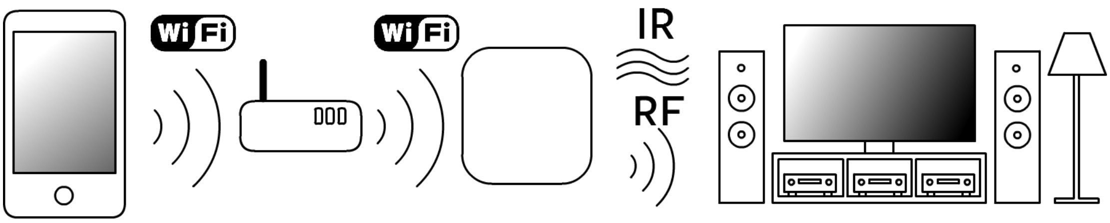


Figure 5.10. A graphical representation of the concept WiBox

HalfWi

Similar to the WiBox concept, except the box is connected to the router with an Ethernet cable. An illustration of the concept is seen in Figure 5.11. No attachment is needed on the phone but the user needs to have a Wi-Fi router in excess of the box. As compared to WiBox the HalfWi an Ethernet card is needed but no Wi-Fi card and one less wireless signal is needed for the system, which consumes less energy. Requires Wi-Fi to be turned on and active on the phone, which is battery consuming.

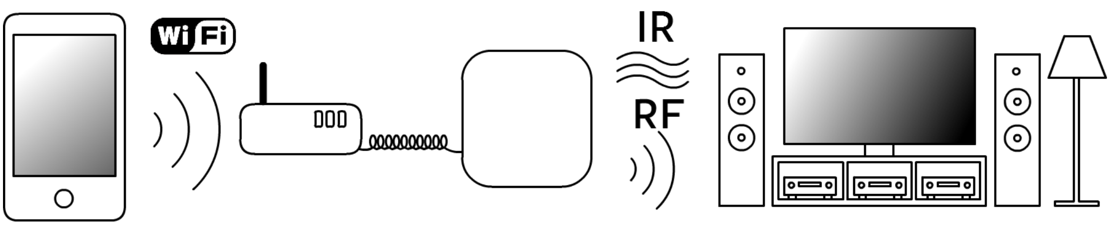


Figure 5.11. A graphical representation of the concept HalfWi

WiDirect

The smartphone is connected directly to a box, which acts as a wireless access point. The box contains a Wi-Fi card, transmitters for both infrared and radiofrequency and a power source either as a battery or as a chord with an adapter. An illustration of the concept is seen in Figure 5.12. No attachment is needed on the phone and no wireless router is needed, since the box acts as one. A smartphone cannot connect to the Internet via 3G when a Wi-Fi connection has been established with the box. Requires Wi-Fi to be turned on and active on the phone, which is battery consuming.

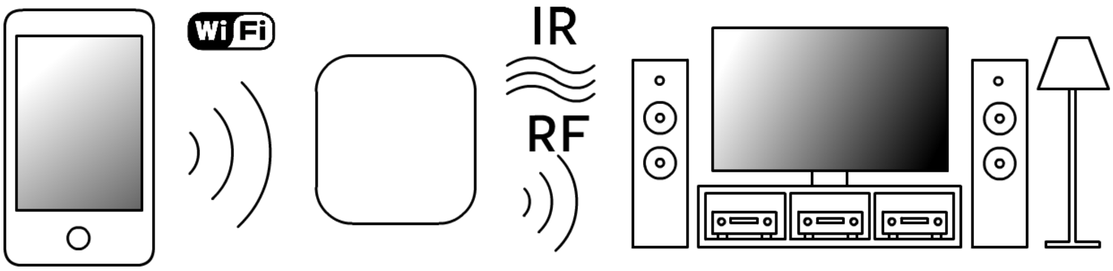


Figure 5.12. A graphical representation of the concept WiDirect

Antenna

A device is plugged on to the smartphone via the 3.5 mm audio input. The device is small and contains transmitters for both infrared and radiofrequency. An illustration of the concept is seen in Figure 5.13. The device may be hard to find when it is small and it could break or harm the audio input if stored in a pocket, since it is standing out from the audio input. The device is powered via the audio input, which consumes battery from the smartphone. While transmitting infrared, the smartphone needs to be pointed at the device the user wants to control.

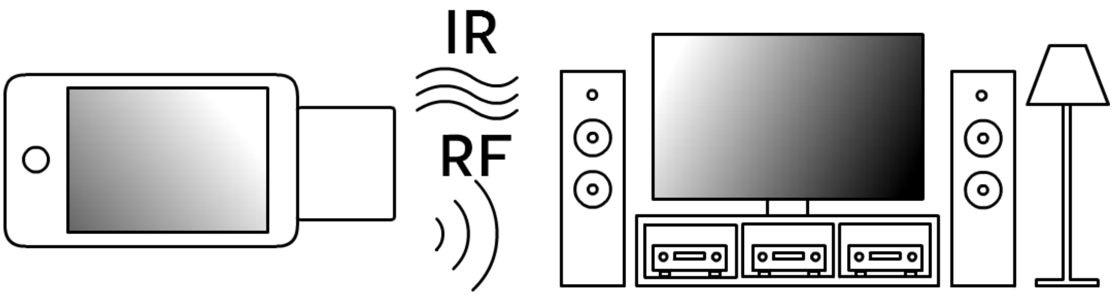


Figure 5.13. A graphical representation of the concept Antenna

USB Plug

A device is plugged on to the smartphone via the USB input. The device is small and contains transmitters for both infrared and radiofrequency. An illustration of the concept is seen in Figure 5.14. The device may be hard to find when it is small and it could break or harm the USB input if stored in a pocket, since it is standing out from the USB input. The device is be powered via the USB input, which consumes battery from the smartphone and unable the phone from being charged at the same time. While transmitting infrared, the smartphone needs to be pointed at the device the user wants to control.

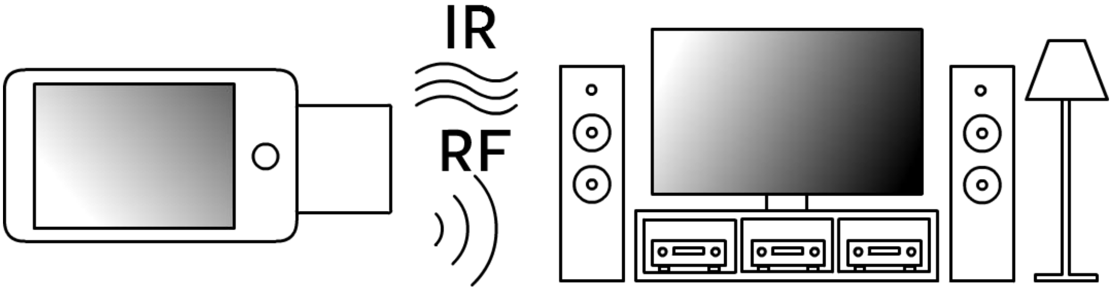


Figure 5.14. A graphical representation of the concept USB Plug

USB Shell

The smartphone has a shell connected to it via the USB input. The shell contains transmitters for both infrared and radiofrequency. The shell provides protection to the smartphone and it is not exposed for any harm while it is stored in a pocket. An illustration of the concept is seen in Figure 5.15. The device is powered via the USB input, which consumes battery from the smartphone and unable the phone from being charged at the same time. While transmitting infrared, the smartphone needs to be pointed at the device the user wants to control. The shell needs to be altered for different phone models.

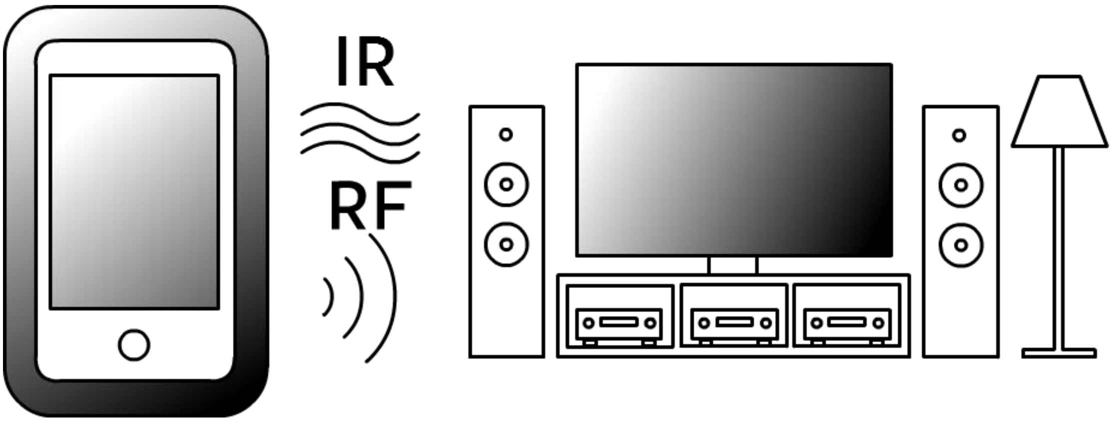


Figure 5.15. A graphical representation of the concept USB Shell

CordBox

A box is connected via a chord from the smartphone. The box contains transmitters for both infrared and radiofrequency. An illustration of the concept is seen in Figure 5.16. The box could be placed in a position that is optimal for the transmission of infrared, thus the smartphone would not need to be pointed at the controlled device. The box would not be suitable to keep on the phone at all times, since the cord is inconvenient to drag around.

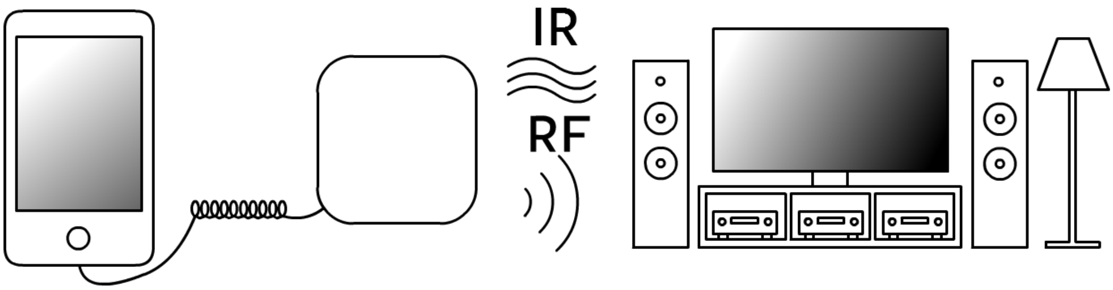


Figure 5.16. A graphical representation of the concept CordBox

Butler

The concept Butler consists of sending an SMS to a person that changes the settings as they are described in the SMS. This requires a dedicated person and probably food to keep the person going. The cost of an SMS per action sums up to an expensive upkeep.

The resulting concepts of casing solutions

This section illustrates and explains the sketches of the casing concepts generated with inspiration from the mood board.

The Amp

As seen in Figure 5.17, The Amp is looking like an amplifier with a window made of a dark transparent plastic which allows IR light to pass. The front is made out of brushed metal. The Amp is supposed to blend in with other home entertainment electronics.

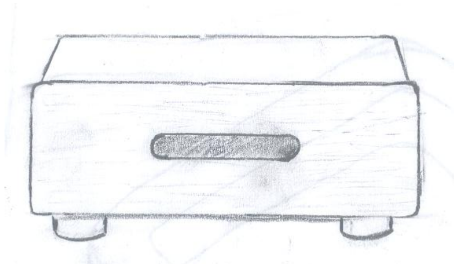


Figure 5.17. A sketch of the concept The Amp

The Projector

Figure 5.18 shows the sketch of The Projector which is built with black glossy plastics with a convex lens I front that is spreading the light from the IR led.

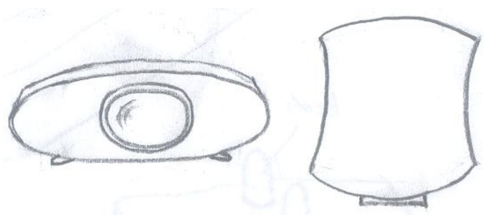


Figure 5.18. A sketch of the concept The Projector

The Flute

The Flute, which is seen in Figure 5.19, is a concept consisting of a metal tube with a layer of dark transparent plastics in the middle. The electronics are located in both ends of the tube. The Flute would fit in like a decoration and could be placed on a wall in both horizontal and vertical position.

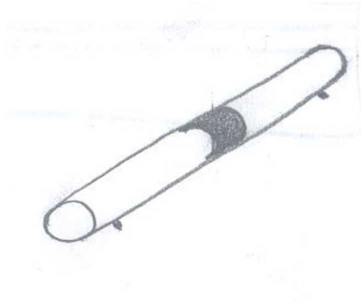


Figure 5.19. A sketch of the concept The Flute

The Book

The Book, illustrated in Figure 5.19, is supposed to blend in with books in a bookshelf. It has an outer layer of leather and on the back there is a window of dark transparent plastics, which allows IR light to travel through. In a bookshelf, possible cords could easily be hidden.

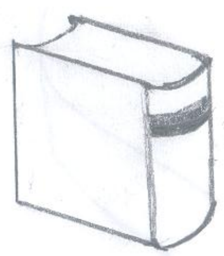


Figure 5.20. A sketch of the concept The Book

The Lighthouse

The Lighthouse, which is seen in Figure 5.21, is supposed to look like a decoration to blend in with a living room environment. It is made out of plastics, the IR led is placed in the top and are looking out from the lighthouse windows, which gives a good field of view.

Figure 5.21. A sketch of the concept The Lighthouse

The Beacon

The Beacon, shown in Figure 5.22, is similar to The Lighthouse as it is standing upright and has IR led in the top, which is covered by a dark transparent plastic. It would not blend in like a decoration but it has a simple design, which makes it discrete. The body is made out of brushed metal.

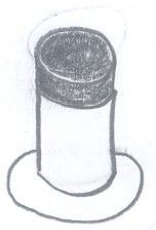


Figure 5.22. A sketch of the concept The Beacon

The Valve Amp

The Valve Amp, which is illustrated in Figure 5.23, is supposed to look like a miniature of a classic valve amplifier. The body, which is made out of wood, contains the electronics and the IR LEDs are located on top of the body and are representing the vacuum tubes on a valve amplifier.

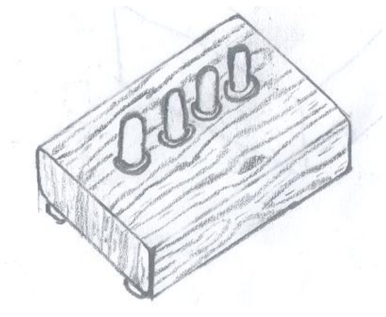


Figure 5.23. A sketch of the concept The Valve Amp

The Punsch Roll

The Punsch Roll, as seen in Figure 5.24, consist of a bended sheet of dark transparent plastics in the middle and covered in the ends plates made out of wood. The electronics are located inside the bended plastics together with the IR LEDs.

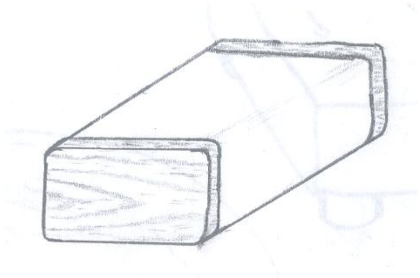


Figure 5.24. A sketch of the concept The Punsch Roll

The Sphere

The Sphere, which is shown in Figure 5.25, is a hollow ball made out of dark transparent plastics with a cut-out in the bottom to make it able to stand still. Inside the ball the electronics is positioned and near the walls there are IR LEDs that shoot out the light. By the spherical geometry the light could pass through in any direction.

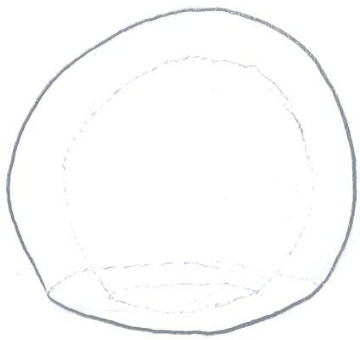


Figure 5.25. A sketch of the concept The Sphere

The Chest

The Chest, which is illustrated in Figure 5.26, is made out of dark transparent plastics and has a lot of curvature to give it a clean and simple look.

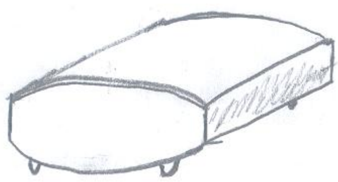


Figure 5.26. A sketch of the concept The Chest

The Sandwich

The Sandwich, as seen in Figure 5.27, is a square tube of dark transparent plastic, covered by two plates in the bottom and the top. The plates are made out of brushed metal. The Electronics is placed inside and the IR LEDs are pointing out of the walls.

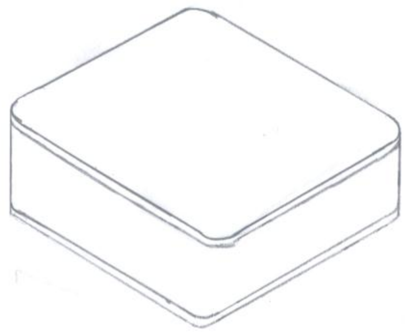


Figure 5.27. A sketch of the concept The Sandwich

The Puck

The Puck, shown in Figure 5.28, is similar to The Sandwich but differ by being round instead of square. By being round there would be less dead angles as could be possible in the corners of The Sandwich.

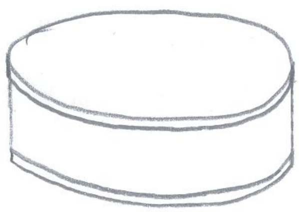


Figure 5.28. A sketch of the concept The Puck

The Brick

The Brick is made with a square base where all electronics is placed and covered by a rectangular parallelepiped of dark transparent plastics which is seen in Figure 5.29. The IR LEDs will be able to send light in all the directions of the sides as well as upwards.

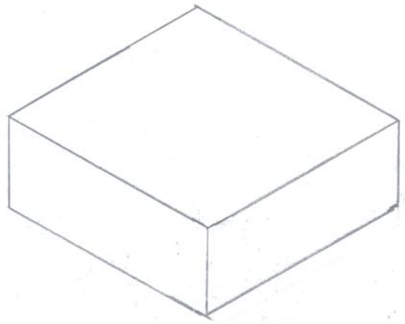


Figure 5.29. A sketch of the concept The Brick

The Toast

The Toast is made similar to The Brick but it has rounded edges instead to give it a smoother look, as is seen in Figure 5.30.

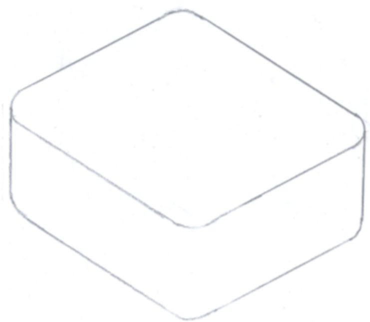


Figure 5.30. A sketch of the concept The Toast

The Robocop

The Robocop, which is illustrated in Figure 5.31, is made out of metal shaped as a rectangular parallelepiped with a square base. It has been split horizontally with a layer of dark transparent plastics to allow the IR LEDs to send out light.

Figure 5.31. A sketch of the concept The Robocop

The Burger

The Burger is similar to The Robocop but the plates on top and bottom has the same height as the transparent plastics in the middle, which is shown in Figure 5.32.

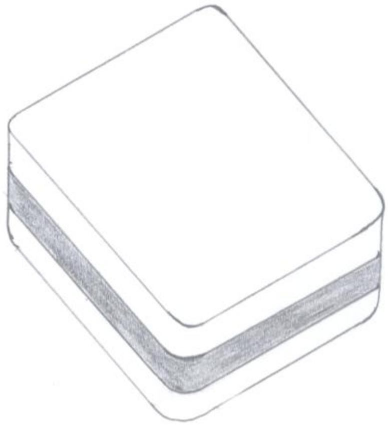


Figure 5.32. A sketch of the concept The Burger

Material selection

All the proposed concepts are based on three different materials: black glossy plastic, black semi-transparent plastic and a bright metal with a matt rough surface.

Metal

The look for the metal parts of the product is inspired old receivers such as the examples in Figure 5.33.

Figure 5.33. A collection of old receivers as examples for the look of the metal material.

This kind of look may be achieved with a number of different materials. Which one of these materials to choose depends on their respective *technical*, *aesthetic* and *ecological sustainability* attributes as well as their prices.

Technical attributes includes parameters such as *E-modulus*, *strengths* and *heat resistance,* etc. Since all types of metals are strong enough to be suitable for the intended type of product (i.e. a small stationary unit placed in a living room under no type of stress), the technical attributes will be overlooked when choosing material for the metal parts. Focus will thus be on aesthetics, cost and ecological sustainability where the relative importance of each of these aspects is decided through a weighing matrix later on.

In order to get the right look and feel of the material, as expressed with the pictures in Figure 5.33, the most interesting materials to look at, based on aesthetics, is aluminium alloys, stainless steels, low alloy steels, titanium alloys, magnesium alloys and zinc alloys. Relevant attributes for these materials have been gathered in Table 5.5. All these materials have a similarly high recyclability potential, thus the sustainability aspect in the table is represented only with a value for *energy content* in the material. This number tells us the amount of energy that needs to be consumed in order to manufacture one usable square meter of the material in question.

Table 5.5. The considered metal materials with relevant attributes (Ashby & Johnson, 2010).

	Aluminum alloys	Stainless steels	Low alloy steels	Titanium alloys	Magnesium alloys	Zinc alloys	Nickel alloys
Energy content *(TJ/m³)*	587 - 988	614 - 931	468 - 656	3270 - 6050	519 - 975	275 - 1044	306 - 6417
Price *[kUSD/m³]*	3.25 - 16.8	8.9 - 69	3.1 - 7.1	91.6 - 135	4.5 - 22.2	4.95 - 20.9	32.9 - 266
Reflectivity [%]	80 - 92	60 - 80	40 - 60	44 - 53	68	74 - 85	50 - 65
Features	*Lightweight, Corrosion resistant, Easy to recycle*	*Durability, Handles extreme temperatures, Stiff and strong*	*Exceptionally strong, Stiff and strong, Relatively cheap*	*Exceptionally strong, Exceptionally corrosion resistant*	*Exceptionally light-weight, Easy to die-cast, Adequate strength*	*Easy to die-cast, Corrosion resistant, Easily machined*	*Exceptionally corrosion resistant, High temperatures, Stiff, strong and tough*

As can be seen in Table 5.5, *Low alloy steels* are both cheaper and more energy efficient to produce at the lower end of the spectra. However, even products used indoors need to be corrosive resistant to be able to handle a large variety of environments with different humidity. And since low alloy steels are not corrosion resistant, a coating layer would be required for protection. This would add an extra step in the manufacturing process, which would also increase the cost.

Aluminium and *Zinc* alloys are not much more expensive than the average low alloy steel and they are not necessarily more energy consuming to produce either. Aluminium is also less than half as dense as both low alloy steel and zinc, which makes it both cheaper and less energy consuming to transport, and since it is also the third most abundant metal on our planet (after iron and silicon) it is not a frail resource to consume (Ashby &

Johnson, 2010). This makes aluminium alloys seem superior at this stage, but zinc alloys should probably also be considered when making a final decision in the detail design phase, since they are known for their manufacturability, which could make a difference when deciding on a manufacture process.

Plastic material

The look for the dark plastic parts of the concepts is inspired by modern plastic products such as the Sony PlayStation 3™ and storage devices by LaCie. These products can be seen in Figure 5.34.

Figure 5.34. Inspiration for the dark plastic parts of the concepts. A storage device by LaCie (left), Sony PlayStation 3™ (right).

Since the IR LED is not supposed to be visible in most concepts, it will need to be hidden behind a dark plastic surface, transparent enough to let the IR light out but not enough for seeing the LED through it. This will require a material with good optical properties, such as *PS*, *PMMA* or *PC*.

Other black surfaces have no need for transparency and can thus be made of a common opaque plastic such as *ABS*, *PE*, *PP*, *PVC* or *POM*. The desired high gloss black surface is then achieved by adding a layer of coating.

Table 5.6 presents the mentioned plastic materials together with their respective relevant attributes. Based on this data, the most suitable materials would be *PP*, *PVC* or *ABS* for the opaque plastics. For the half transparent material a trade-off will need to be made between energy content and recycle potential. However, it could be argued that recyclability is more important in the long run since a new product could be produced by recycling a new one, which would drastically reduce the energy content for the new product since it required no extraction of new material. This argument would lead to choosing *PC* for the half transparent material. PC is more expensive, but considering how little of this material will be used for each unit, the price for this plastic can be considered negligible when looking at the cost for the entire product anyway.

Table 5.6. The considered plastic materials with relevant attributes (Ashby & Johnson, 2010).

	Acrylonitrile-butadiene-styrene (ABS)	Polyethylene (PE)	Polypropylene (PP)	Polyvinylchloride (PVC)	Polyoxymethylene (POM)	Polystyrene (PS)	Polymethyl-methacrylate (PMMA), Acrylic	Polycarbonate (PC)
Energy content *(TJ/m^3)*	96 - 126	96 - 160	68 - 77	100 - 131	160 - 173	105 - 115	113 - 128	137 - 157
Price *[kUSD/m^3]*	1.51 - 3.39	1.01 - 5.60	0.80 - 0.92	1.30 - 1.90	3.75 - 5.72	1.35 - 1.68	1.97 - 2.93	4.33 - 5.20
Recycle potential	Medium	High	Medium	High	High	Low	Low	High
Features	*Durable and tough, Readily colored, Easily molded*	*Easily molded, Durable, Low cost*	*Easily molded, Durable and tough, Low cost*	*Corrosion resistant, Low cost, Resilient*	*Low friction, Wear resistant, Water resistant*	*Optically clear, Easily foamed, Low cost*	*Optically clear, Easily colored, UV resistant*	*Optically clear, Strong, Tough*

5.2.2 Concept selection

To decide which one of the generated concepts to pursue in further development, a selection process consisting of three methods were used for the technology concepts. As for the casing concepts the effort was only to choose the best suited one since all of them would work. The aim is to keep the effort steady, and by eliminating concepts in iterations, the more promising concepts will ultimately receive a more thorough evaluation.

Elimination matrix

A first iteration of narrowing down the communication concepts was performed using a modified version of the *elimination matrix* described in the theory chapter, section 3.5.2. All needed criteria in the explained method are instead covered as a requirement in the requirements specification and thus the concepts only needs to be evaluated against the one list of demands instead of two. The change is not significant but it will more easily be represented by using one table. Since the casing concepts was developed with the requirements list in mind there is no need for an elimination matrix in that case.

The results from the performed elimination matrix can be seen in Figure 5.35. The *Butler* concept failed to satisfy the size requirement *R04*, since it would need to house all the remote controls that the product should replace, which would require much more space than *R04* permits (15x15x15 cm). Further, *R08* says that the remote should not need to be pointed in a specific direction. The *Antenna*, *USB Plug* and *USB Shell* concepts failed at this point, since they are all attached to the phone and their performance therefore depends on how the phone is held. Consequently, these concepts were eliminated, leaving only the "box"-concepts for further evaluation.

ID	Requirement	Antenna	USB Plug	BlueBox	WiBox	HalfWi	WiDirect	CordBox	Butler	USB Shell
R01	The system must be able to send infra red signals	✔	✔	✔	✔	✔	✔	✔	✔	✔
R02	The system must be able to send radio frequency signals	✔	✔	✔	✔	✔	✔	✔	✔	✔
R03	The remote control signal range should be sufficient	✔	✔	✔	✔	✔	✔	✔	✔	✔
R04	The volume of the external unit should not be to large	✔	✔	✔	✔	✔	✔	✔	✗	✔
R05	The price should not put the remote in the luxury segment	✔	✔	✔	✔	✔	✔	✔	-	✔
R06	The system must be able to receive, translate and pass on commands	✔	✔	✔	✔	✔	✔	✔	-	✔
R07	The external unit must be able to connect to Iphones	✔	✔	✔	✔	✔	✔	✔	-	✔
R08	The remote should not need to be pointed in a specific direction	✗	✗	✔	✔	✔	✔	✔	-	✗
R09	The system must be able to send radio frequency signals	-	-	✔	✔	✔	✔	✔	-	-
R10	Laws and regulations must not be broken	-	-	✔	✔	✔	✔	✔	-	-
R11	Copyright and patent infringement must be avoided	-	-	✔	✔	✔	✔	✔	-	-
R12	The communication station should not require service more often than every six months	-	-	✔	✔	✔	✔	✔	-	-
R13	The product should be UV resistant	-	-	✔	✔	✔	✔	✔	-	-
R14	The product should work in normal room temperature	-	-	✔	✔	✔	✔	✔	-	-
R15	The product should not be considered noisy	-	-	✔	✔	✔	✔	✔	-	-
	Continue development?	NO	NO	YES	YES	YES	YES	YES	NO	NO

Figure 5.35. An elimination matrix was used to compare the concepts to the list of requirements. This resulted in four eliminated concepts and five concepts to evaluate further.

Weighing matrix

The concepts remaining after the elimination matrix all satisfy the requirements. To be able to tell which one of these that is best suited the next step is to evaluate them by considering the desires. However, all the desires are not equally important. To get a satisfying comparison between the desires, a *weighing matrix* was performed with some modifications to the method. It was originally suggested that a desire can get 0, 0.5 or 1 point, which states that two desires can be equally important. Changing the points system to range from -2 to +2 prevents this by using a resolution of four instead of three, making a desire either more or less important than the compared desire, as shown in Table 5.7. The higher resolution also causes the most important desires to stand out even more. The result of the weighing matrix is later used in a *Kesselring matrix*, which is described in the following section.

Table 5.7. Point system for the weighing matrix

Score	Definition
+2	Much more important
+1	More important
-1	Less important
-2	Much less important

The comparison of desires was done internally by the two master thesis groups involved in the product. A more comprehensive way to do it would be to use interviews with potential customers. A trade-off with speed versus accuracy has to be done at this stage, and since the amount of comparisons to make increases exponentially with the number of desires, the resulting amount of questions to ask every customer will be in the hundreds. For a project group with only two members, this would take up great deal of the available time resources. Furthermore, since the two groups has worked with developing the needs for a long time, it can be argued that together they have a good enough understanding of the needs themselves, both through experience with customers and through being in the product target group themselves, which means their own preferences are valuable as well.

As seen in the results of the weighing matrix, illustrated by Figure 5.36, the most important desire is that the use of the product does not interfere with other communication functionality of the phone. The second most important desire is the start-up speed and the wide spread angle of the IR diode. Further, a long range and a low product price are also considered highly important. These desires will therefore also have the most influence in the *Kesselring matrix*.

		D01	D02	D03	D04	D05	D06	D07	D08	D09	D10	D11	D12	D13	D14	D15	D16	D17	D18
The system should be able to send Bluetooth signals	D01	0																	
The device should be aesthetically appealing	D02	-2	0																
The price should be as low as possible	D03	-2	1	0															
The communication station should run preprogramed instructions without a phone connected	D04	-1	1	1	0														
The system should be cordless	D05	-1	1	1	-1	0													
The communication station should connect to the Iphone via Internet	D06	-1	1	1	1	1	0												
Using the remote should not interfere with other communication from the phone	D07	-2	-1	-1	-2	-1	-1	0											
The remote control should be started up and connected as fast as possible	D08	-1	-1	-1	-2	-1	-1	1	0										
The remote should have as long range as possible	D09	-1	-1	-1	-2	-1	-1	1	1	0									
The remote should be usable even when not in the same room as the equipment	D10	-1	-1	1	-1	1	1	1	1	1	0								
The system should consume as little power as possible	D11	-1	1	1	-1	1	1	2	2	1	1	0							
The IR diode should have as wide a sight as possible	D12	-2	-1	-1	-2	-1	-1	1	-1	-1	-1	-1	0						
The device design should blend in with a living room environment	D13	-1	-1	1	-2	-1	-1	1	1	1	1	-1	-1	0					
The communication station should provide feedback when receiving commands	D14	1	1	2	1	1	1	2	2	1	1	-1	2	2	0				
The product should give a good quality impression	D15	-1	-1	1	-1	1	-1	1	1	1	1	-1	1	-1	-2	0			
The product should be stable where it stands	D16	-1	-1	1	-1	1	1	1	1	1	1	1	1	1	-1	1	0		
The product should be as environmentally friendly as possible	D17	1	2	2	1	1	1	2	2	2	2	1	2	1	1	2	1	0	
The product should be placeable on any vertical or horizontal surface	D18	-1	1	1	-1	1	-1	1	-1	1	1	-1	-1	1	-1	1	1	-2	0
Sum weight + 1		3	12	16	5	11	7	23	19	17	12	5	19	14	3	13	7	1	10
Percentage of total weight		2%	6%	8%	3%	6%	4%	12%	10%	9%	6%	3%	10%	7%	2%	7%	4%	1%	5%

Figure 5.36. A weighing matrix was used to determine the relative importance of each user desire. The desires expressed in bold are connected to the functionality of the product while the rest has to do with the exterior casing.

Kesselring matrix

To compare the different concepts with considerations to the desires, a *Kesselring matrix* is well suited, because it will systematically compare the concepts to each desire and end up with a score that will determine the winning concept. The matrix does not only provide an indication of the best suited concept, it will also show where the other concepts are better than the winning one, which could be used as input to where improvements could be done.

The Kesselring matrix used here is based on the method described in the theory chapter, section 3.5.2. The only difference to the described method is that here a concept could obtain a 0 as a value of not satisfying a desire at all. The first Kesselring matrix was performed on the concepts describing the communication and because of that the evaluation are only done against the desires that concern these concepts. As is seen in Table 5.8 the most promising concept is the WiBox, which is described in section 5.2.1. The basic difference between the winning concept and the second concept, the BlueBox is that the BlueBox can send Bluetooth, while the WiBox has the ability to connect via internet. Since the connection via internet requirement was more important than the Bluetooth signals the WiBox concept is considered the winning concept.

Table 5.8. Performed Kesselring matrix on the communication concepts.

	Evaluation Criteria		IDEAL		BlueBox		CordBox		HalfWi		WiBox		WiDirect	
No.		Weight	Value	Total	Value	Total	Value	Total	Value	Total	Value	Total	Value	Total
D01	The system should be able to send Bluetooth signals	3	5	15	5	15	0	0	0	0	0	0	0	0
D02	The device should be aesthetically appealing	12	5	60	4	48	3	36	3	36	4	48	4	48
D03	The price should be as low as possible	16	5	80	3	48	4	64	4	64	3	48	3	48
D04	The communication station should run preprogramed instructions without a phone connected	5	5	25	0	0	0	0	0	0	0	0	0	0
D05	The system should be cordless	11	5	55	5	55	0	0	0	0	5	55	5	55
D06	The communication station should connect to the smartphone via Internet	7	5	35	0	0	0	0	4	28	5	35	0	0
D07	Using the remote should not interfere with other communication from the phone	23	5	115	5	115	4	92	5	115	5	115	0	0
D08	The remote control should be started up and connected as fast as possible	19	5	95	4	76	2	38	4	76	4	76	4	76
D09	The remote should have as long range as possible	17	5	85	3	51	2	34	3	51	3	51	3	51
D10	The remote should be usable even when not in the same room as the equipment	12	5	60	4	48	1	12	4	48	4	48	4	48
D11	The system should consume as little power as possible	5	5	25	3	15	4	20	4	20	3	15	3	15
D13	The device design should blend in with a living room environment	14	5	70	4	56	3	42	3	42	4	56	4	56
D17	The product should be as environmentally friendly as possible	1	5	5	3	3	4	4	4	4	3	3	3	3
			100,0%		73,1%		47,2%		66,8%		75,9%		55,2%	

The second Kesselring matrix was performed in the same way as the first but with the casing concepts instead. As in the previous case, the evaluation is only done against the relevant desires and in this case, only against desires concerning the casing concepts.

Three of the desires that are to be used in the Kesselring matrix are that the design should be aesthetically appealing, give a quality impression and to blend in with a living room environment. The evaluation against these desires is something that could not be done within the group since these criterions are individual for the user of this product. To get a good value to use in the Kesselring matrix for these three desires, a questionnaire was conducted where all the casing concepts was presented and the participants rated each concept individually against how well the concept fulfil the three desires. The questionnaire can be found in Appendix C. A mean value of all the results was then used in the Kesselring matrix. All other rating was done internally by estimations. The result of the matrix can be seen in Table 5.9. Because a large share of the scoring was based on the questionnaire, which consisted of early sketches, there will be four concepts to be considered for additional development. These four are later given a better representation to be able to make another evaluation that lead to a winning concept. The reason for choosing four concepts is because the score is quite even in the top and the four top concepts differ much from each other. The four winning concepts from the Kesselring matrix are *The Toast*, *The Brick*, *The Sphere* and *The Flute*.

Table 5.9. Performed Kesselring matrix on the casing concepts.

Evaluation Criteria		IDEAL		The Amp		The Projector		The Flute		The Book		The Lighthouse		The Beacon	
	Weight	Value	Total	Value	Total	Value	Total	Value	Total	Value	Total	Value	Total	Value	Total
The device should be aesthetically appealing	12	5	60	4	45	2	29	4	43	3	38	2	28	2	27
The price should be as low as possible	16	5	80	4	64	4	64	4	64	3	48	3	48	4	64
The IR diode should have as wide a sight as possible	19	5	95	1	19	3	57	3	57	2	38	3	57	4	76
The device design should blend in with a living room environment	14	5	70	4	50	3	35	3	45	3	41	2	26	2	31
The communication station should provide feedback	3	5	15	4	12	4	12	4	12	4	12	4	12	4	12
The product should give a good quality impression	13	5	65	4	54	3	41	3	44	3	34	2	31	3	37
The product should be stable where it stands	7	5	35	4	28	4	28	5	35	3	21	2	14	2	14
The product should be as environmentally friendly as possible	1	5	5	3	3	4	4	3	3	3	3	3	3	3	3
The product should be placeable on any vertical or horizontal surface	10	5	50	3	30	3	30	5	50	2	20	3	30	3	30
		100,0%		64,4%		63,1%		74,5%		53,8%		52,3%		62,0%	

Evaluation Criteria		IDEAL		The Burger		The Valve Amp		The Punsch Roll		The Sphere		The Sandwich	
	Weight	Value	Total	Value	Total	Value	Total	Value	Total	Value	Total	Value	Total
The device should be aesthetically appealing	12	5	60	3	38	2	30	3	30	3	40	3	38
The price should be as low as possible	16	5	80	4	64	5	80	4	64	5	80	4	64
The IR diode should have as wide a sight as possible	19	5	95	3	57	3	57	3	57	4	76	3	57
The device design should blend in with a living room environment	14	5	70	3	44	2	26	2	34	3	43	3	43
The communication station should provide feedback	3	5	15	4	12	4	12	4	12	4	12	4	12
The product should give a good quality impression	13	5	65	4	47	3	33	3	37	3	40	3	44
The product should be stable where it stands	7	5	35	4	28	4	28	4	28	3	21	4	28
The product should be as environmentally friendly as possible	1	5	5	3	3	5	5	4	4	4	4	3	3
The product should be placeable on any vertical or horizontal surface	10	5	50	4	40	3	30	4	40	5	50	4	40
		100,0%		70,1%		63,2%		64,4%		76,9%		69,3%	

Evaluation Criteria		IDEAL		The Puck		The Chest		The Brick		The Toast		The Robocop	
	Weight	Value	Total	Value	Total	Value	Total	Value	Total	Value	Total	Value	Total
The device should be aesthetically appealing	12	5	60	2	29	3	36	3	40	3	42	4	43
The price should be as low as possible	16	5	80	4	64	5	80	5	80	5	80	4	64
The IR diode should have as wide a sight as possible	19	5	95	3	57	2	38	4	76	4	76	3	57
The device design should blend in with a living room environment	14	5	70	2	35	3	40	3	48	3	49	3	47
The communication station should provide feedback	3	5	15	4	12	4	12	4	12	4	12	4	12
The product should give a good quality impression	13	5	65	3	41	3	41	4	53	4	52	4	50
The product should be stable where it stands	7	5	35	4	28	4	28	4	28	4	28	4	28
The product should be as environmentally friendly as possible	1	5	5	3	3	4	4	4	4	4	4	3	3
The product should be placeable on any vertical or horizontal surface	10	5	50	4	40	3	30	5	50	5	50	4	40
		100,0%		64,9%		64,9%		82,3%		82,6%		72,5%	

5.3 Detail design

The grounds for the concept have now been laid down, and to develop it further the details for the design will now be taken into account. This includes defining the geometry and specific parts for each subsystem of the final product, as well as producing a block diagram for the hardware and programming the software for the electronics.

5.3.1 Component selection

The embedded system is developed by researching components for each part of the setup, in order to combine an optimized set of cooperating components, as well as building software that links them together.

The product should be able to communicate with home entertainment systems using *IR*, power outlets and projector screens using *RF* and smartphones using *Wi-Fi*. These are three protocols that require their own separate electronic modules in the communication station, and in order for these modules to talk to each other they will all need to be connected to a *microcontroller* as well.

Microcontroller

There is a wide selection of microcontrollers available on the market, when looking on this variety of microcontrollers; six general parameters are found that can be decided in order to narrow down the choice towards the most suiting one for a given project. These six parameters are further described and set for this project in the following paragraphs.

1. The needs in terms of programmability and reprogrammability in order to select the appropriate memory size

The microcontroller will be used throughout the entire development, which is a process that will contain a lot of testing. This requires the microcontroller to be highly reprogrammable. The amount of memory needed depends on how much programming it needs to store, which is a difficult variable to determine at the start of the project. However, it can be assumed that since the product will consist of 3-4 peripheral devices, which each will require some coding, it is better to be safe than sorry and use a controller with some excess in memory for the development process, and then decide on a more compact model later on when all code has been written and optimized.

2. The amount and what types of peripherals to connect to the microcontroller

A Wi-Fi module will be required in order to communicate with the smartphone via local network or 3G. Wi-Fi modules for direct communication with microcontrollers are not yet a very common component, and the only one found that fits the needs of the product was the *MRF24WB0MB* module from *Microchip Technology Inc*. This module requires a Microchip *PIC* microcontroller of the families *PIC18*, *PIC24*, *dsPIC33* or *PIC32*, which narrows the choice down somewhat (Microchip Technology Inc., 2010).

A 433 MHz AM radio transmitter will be needed in order to send RF signals for controlling electricity outlets, projector screens and other radio controlled equipment. In order to control TVs, DVDs, receivers, etc. an infrared LED is required. An infrared receiver, as well as an RF receiver, will also be needed in order to receive and save commands from other remote controls, if imitating signals from standard remotes is supposed to be a functionality of the product. Further, one or a couple of LEDs will be used to show the status of the device.

The Wi-Fi module will take up six of the microcontroller's I/O-pins, the RF module needs two pins, and the IR-LED, as well as the other LEDs, requires one pin each. Thus, depending on how many LEDs are used in the product; the microcontroller will need to house at least 13-17 I/O-pins. Since the components are ordered quite early on in the development process, it is still possible that additional equipment will be added later on. Therefore, a microcontroller with some additional pins should be considered for safety.

3. The physical packaging and the limitations that can be associated with it

The packaging for the final product is not significantly affected by the size of the microcontroller, since all available models are small enough to fit the size requirement. However, if a physical prototype should be produced without using development boards for the modules, the microcontroller should preferably be of *DIP* (Dual In-line Package) type rather than *SOIC* (Small-Outline Integrated Circuit), to ease in the assembly of the product, since assembling SOICs requires advanced skills in soldering tiny components.

4. The type of chip architecture that suits the system best

The chip architecture is defined by the choice of *instruction set* and *data path* in the microcontroller. The instruction sets to choose from are *RISC* (Reduced Instruction Set Computer) and *CISC* (Complex Instruction Set Computer), whereas the data path concept is usually a choice between *von Neumann* and *Harvard* (Schmidt, 2010).

The goal of *CISC* is to be able to perform tasks with as few lines of assembly code as possible. This is achieved by using a large set of instructions, where a single instruction can represent what two or three instructions in a RISC-environment would produce together (Jamil, 1995). An advantage with this is that the assembly code is more compact and thereby takes up less space, which means larger programs can fit in a given memory. However, since a large amount of instructions needs to be stored in the transistors, *CISC* has less space to house general-purpose registers than *RISC* (Jamil, 1995).

RISC on the other hand, is based on a set of simple instructions designed to be of the same length (a defined number of steps to complete each instruction). Having the same length for each instruction insures a predictable timing, which can be used to increase speed by preparing the start of the next instruction while the previous instruction is nearing its end. This technique is called pipelining, and insures that the microcontroller utilizes its fullest capacity at all times (Chen, Novick, & Shimano, 2000).

The difference between the *von Neumann* and the *Harvard* data path architecture is in the way that instructions and data are passed to and from the processor. *Von Neumann* uses a single data bus for all transfers, whereas *Harvard* uses separated pathways and memories for instructions and data. This means that a microcontroller using *Harvard* architecture can fetch and store data from memory while simultaneously executing and loading new instructions, while a *von Neumann* architecture requires all operations to queue up for the shared single bus (Schmidt, 2010). The advantages of the Von Neumann architecture is increased simplicity and minimized size, since less hardware is required, due to only using one memory and bus for both data and instructions.

Since the microcontroller will need to provide accurate timing in order to send correct signals, it should not be in the lower clock speed segment. However, a high end microcontroller should not be needed either, since no real-time control or other demanding tasks will be performed by the hardware. A model in the midrange segment is therefore probably the best suited choice. Further, since the desire to consume as little power as possible has been stated in the requirement specification, it could be wise to choose *Harvard* architecture since it offers more processing power per clock cycle due to its parallel data paths, and a lower clock speed also results in less power consumption (Schmidt, 2010).

It could also be favourable to choose the *RISC* architecture for the same reason, since its method of pipelining offers full utilization of the microcontroller's capacity, making sure that no power is wasted on inefficient use. Further, since the main focus for the communication station's microcontroller is translating and forwarding commands, most of the instructions used will be load and store based, which is what RISC is optimized for. Since very few complex instructions will be performed, the large instruction set of a CISC would not be employable in this product (Jamil, 1995).

5. The hardware and software tools that are manufactured for the microcontrollers, compared to what is needed for the project

A development board will be needed in order to program the microcontroller. The development board must also be able to house all the peripheral devices, to enable experimenting on all components throughout the development process. Computer software for programming as well as connectors between the computer and the development board will also be needed.

In order to write code for the chosen Wi-Fi module, a TCP/IP stack developed by Microchip must be implemented in the programming. This limits the choice of microcontroller further, since developing your own software based on this TCP/IP stack requires choosing between a small number of specific hardware setups, including development boards and thereby also microcontrollers.

6. The costs for different microcontrollers compared to the project budget and projected product cost

Most microcontrollers of the size required for this project are quite affordable. The most expensive parts are the development board and the programmer (the link between the computer and the development board). All the components needed for the project do however fit quite easily within the limitations of the budget. Since the expensive development boards will not be included in the actual product later on, the only part that affects the projected product cost is the actual microcontroller itself, and whichever of the reasonable microcontrollers is chosen, the price variation only goes up to around 30 SEK.

Conclusion and decision

The Wi-Fi module required the chosen microcontroller to be of the families *PIC18*, *PIC24*, *dsPIC33* or *PIC3* developed by *Microchip Technology Inc.*, and the amount of peripherals and their pin requirements eliminated all the PIC-models with less than 20 I/O-pins. This meant that the chosen microcontroller needed to be at least a 28-pin model, since some of the pins must be used for other purposes than I/O. Since there is a risk of additional peripherals being added later on in the development, a large pin number microcontroller was chosen for the development process.

A microcontroller from the *PIC18* family - *PIC18F8722* - was ultimately chosen. This model uses *RISC* and *Harvard* architecture, and is equipped with a flash memory of 128 kilobytes (Microchip Technology Inc., 2010). This chip is also built in on the *PIC 18 Explorer* development board, which should be an advanced enough board to be suited for all testing purposes during the project.

IR-transmitter and receiver

The IR-LED is required in order to send commands to the standard home entertainment equipment, such as TVs, DVDs, receivers, etcetera. The selected IR-LED should satisfy requirement *R03*, saying it should be powerful enough to reach all the devices in a large room (10 meter range).

A standard 5 millimetre IR diode designed for 5 V was selected for the development phase. A number of these diodes can later be coupled in parallel in order to get a stronger signal as well as a wider spread.

In order to be able to copy and mimic other remote controls' commands, the hardware will need to include an IR-receiver as well. The receiver should be able to pick up all standard remote control signals modulated at 36-40 kHz. The most commonly used modulation frequency is 38 kHz, and since this frequency is right in the middle of the range, it was chosen as the preferred carrier frequency for the IR receiver. Since IR receivers usually allow for an error margin at around ten per cent (near 2 kHz in this case), an IR-receiver with a carrier frequency of 38 kHz should likely be able to pick up 36 kHz and 40 kHz signals as well. This was later tested and confirmed with chosen components.

RF-transmitter and receiver

As with IR signals, RF signals also needs to be both transmitted and received by the product. Since all RF commands used for the intended application utilize the 433.92 MHz frequency, any RF transmitter/receiver with this frequency is eligible for the product, providing they have a fitting signal strength/sensitivity.

The transmitter and receiver for the development process were chosen through recommendations from enthusiast at a big Swedish electronics forum, where similar projects has been discussed. These components were then tested and verified for a satisfying range according to the requirements specification.

LED

Ordinary coloured LEDs can be used to show the status of the device. Which colours to use will depend on which concept that is chosen for the final design. A large collection of LEDs in different colours is however supplied by the product development department, so there is no need to search externally for this item.

Darlington transistor

The Darlington transistor (Hodges, 1999) is basically two resistors coupled together on a chip with a shared output. This transistor can be used to transform a weak signal, such as the 3.3 V signal from a microcontroller, into a stronger one, with the use of an external power source. The Darlington can be used for amplifying the 3.3 V microcontroller signal feeding the IR LED, in order to provide it with a more stable and strong drive signal.

5.3.2 Block diagram for the electronics

After all components had been chosen, their respective data sheets were studied in order to gather data on the components electrical properties and requirements. This data was then used to produce a block diagram specifying exactly how to connect them to each other. The resulting block diagram can be seen in Figure 5.37.

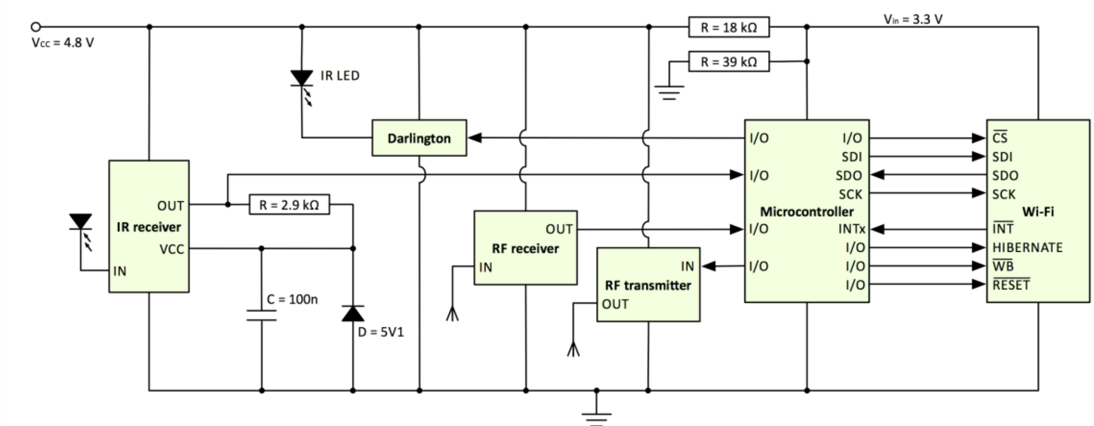


Figure 5.37. A block diagram for the electronics of the product, showing how all the components are connected to each other.

5.3.3 Programming the functionality

In order to obtain the desired functionality of the product, a number of subroutines will need to be written and programmed into the microcontroller. The layouts of these subroutines are presented below with a short description accompanied by flowcharts. Complete source code for all subroutines are available in Appendix D.

Learning IR codes

In order to copy IR commands from other remotes, the subroutine *learnIRCommand()* was written. For a graphical representation of the subroutine, see the flowchart in Figure 5.38.

IR commands from remote controls are represented by a stream of bits (ones and zeros) of different lengths. When *learnIRCommand()* is called, it waits for the IR receiver to start detecting such a bit stream. When the first bit is recognized a timer starts in order to calculate its length. The timer stops when the signal changes (from 1 to 0, or from 0 to 1), and the length of the bit is stored in an array called *command[]*. The timer then resets and starts counting the next bit length in the same way. This continues until the timer finally reaches the length of the *lead out* bit, which denotes the end of the command.

Many remote controls use a specific *repeat command* to be able to tell when a button is held down for a long time (for example when holding down the *volume up* button to keep increasing the volume). This repeat command is sent directly after the standard function command, and repeated for as long as the user holds the button down. To account for this, the subroutine *learnIRCommand()* iterates twice. The first iteration fills *command[]* with the standard command code, while the second iteration works in the same way, but fills the *repeat[]* array with the repeat command that follows. If no repeat command is detected, the subroutine ends.

When the *learnIRCommand()* subroutine has ended, the *command[]* and *repeat[]* arrays are sent to the smartphone application via Wi-Fi.

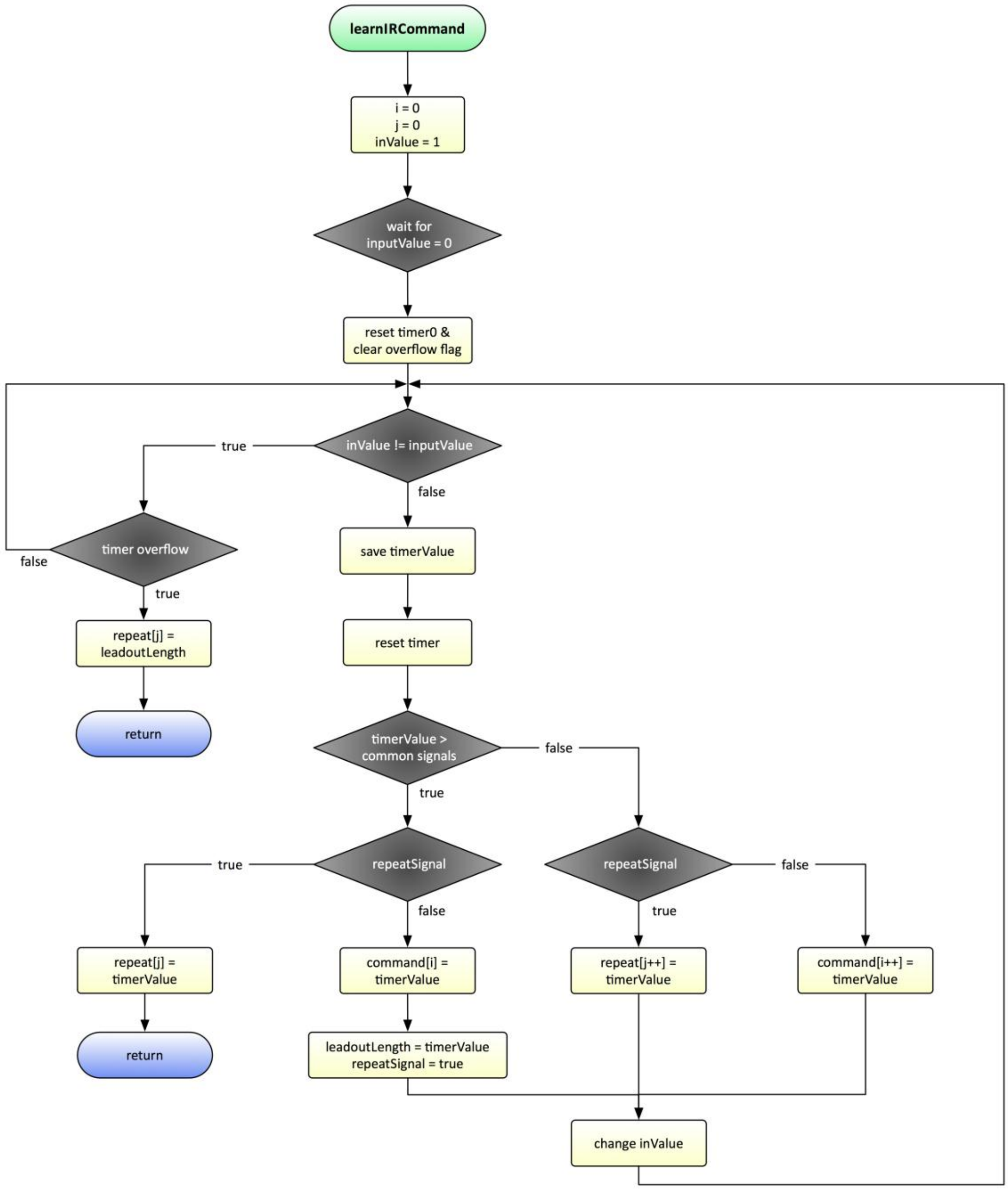


Figure 5.38. Flowchart describing the* learnIRCommand() *subroutine.

Learning RF commands

In order to copy RF commands from a remote, the subroutine *learnRFCommand()* was written. A flowchart of the subroutine can be seen in Figure 5.39.

As described in section 2.2, RF commands could be sent in three various ways. In the electronics that is aimed to be controlled the signal will be pulsed by turning the frequency on and off, meaning sending ones and zeroes with different time intervals. When called, the *learnRFCommand()* starts a timer and register all ones and zeroes while they are timed. However, in the air there are always a lot of RF signals being sent, which causes the RF receiver to register a lot of distortion. To account for the distortion the *learnRFCommand()* are looking for a certain start combination of a one and a zero with specific length. After that combination is registered the signals are stored in an array called *command[]*. When the signal is complete, it ends with a long zero. When a longer than normal zero is detected a specific length of a zero is stored in the last position of the *command[]* array and the subroutine will end and returns *command[]*, which will be sent to the smartphone application via Wi-Fi.

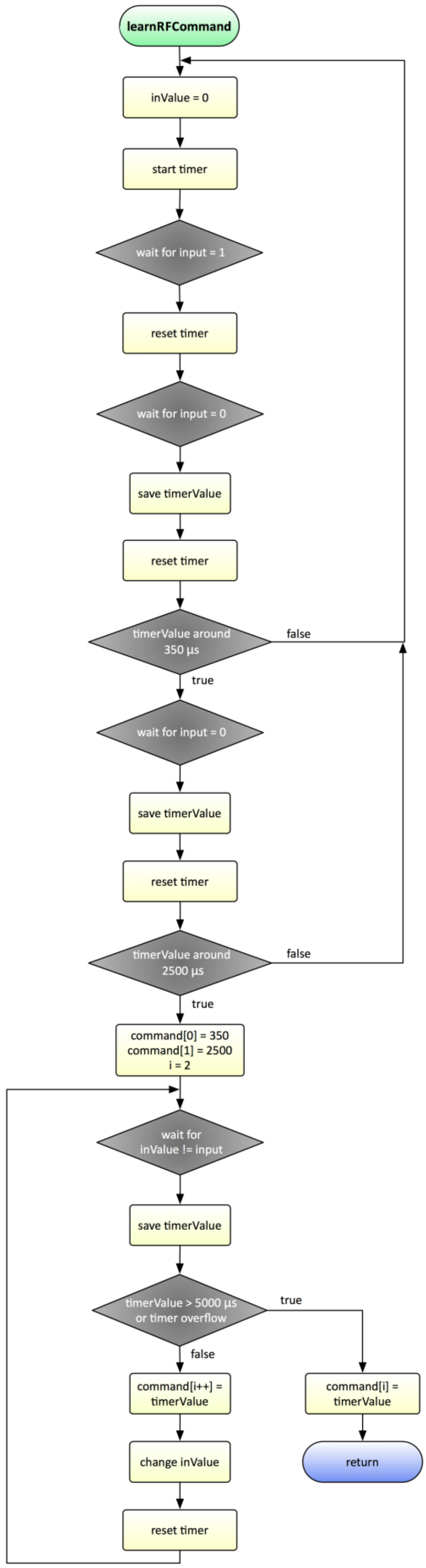


Figure 5.39. Flowchart describing the* learnRFCommand() *subroutine.

5.3.4 Using CAD models and renders for a more detailed visualization

In order to be able to make a final decision on one of the case design concepts, the four winning concepts needs to be described in more detail. For this purpose, CAD models has been constructed, which can be used to create renderings where the product designs are put in a context, such as a variety of living rooms in different styles. The renders can be shown to future potential customers in order to communicate the concept ideas more accurately. This should also lead to a more accurate response with the customers' opinions on aesthetics, quality impressions and degree of matching with their living rooms, which could be elicited in another survey similar to the one described in the concept selection section (5.2.2).

A set of renderings have been performed, showing the intentions with the material selections for the concepts. As previously described in the concept generation section (5.2.1), the intended materials are a brushed metal look for "The Flute" and a high gloss black plastic for "The Toast", "The Brick" and "The Sphere". These renders can be seen in Figure 5.40.

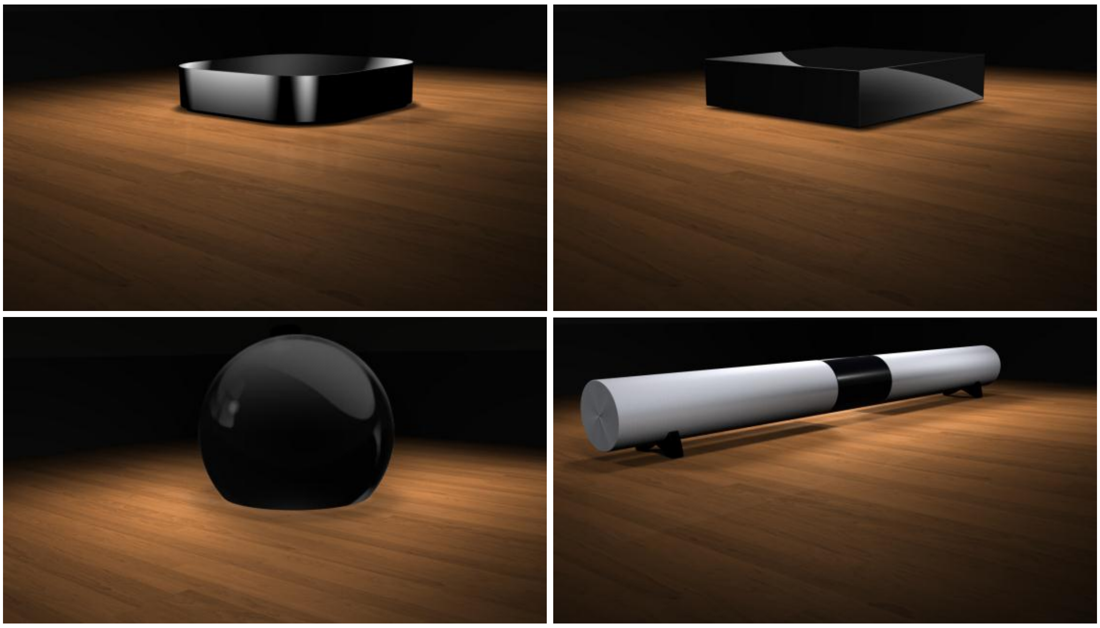


Figure 5.40. Renders of the four winning design concepts from the concept generation, created to give an impression of the thought on material selection.

5.4 Testing and refining the design

After the circuit diagram had been assembled and programmed, it needed to be tested to make sure it worked as it is supposed to do. To be able to study the signals that were sent out and obtained with RF and IR, an oscilloscope was used. Adjustment was done in the program until the seen outputs and inputs of the microcontroller were showing the same signals as expected. When the result was satisfying the signals for IR and RF was tested on real products; a *Microsoft MCE remote* with receiver and *Apple* *remote* for the IR and a *NEXA* remote and wireless switch for the RF. Together with the oscilloscope the program was adjusted until the product worked together with the real products.

The Wi-Fi communication was tested by the use of a router. The router was used to upload a webpage that could be viewed and edited by a web browser on a computer or smartphone. The webpage worked as a mediator to send and receive instructions from the microcontroller. To test and troubleshoot all the programming, an *Explorer 18* demo board was used. The demo board was mainly used to trace the progress by lighting different diodes depending on where in the code instructions were executed and to show specific values on variables. For this purpose a prototype was assembled as is seen in Figure 5.41. The prototype is not meant as a final product; it is rather to be used for testing and demonstration of the solution.

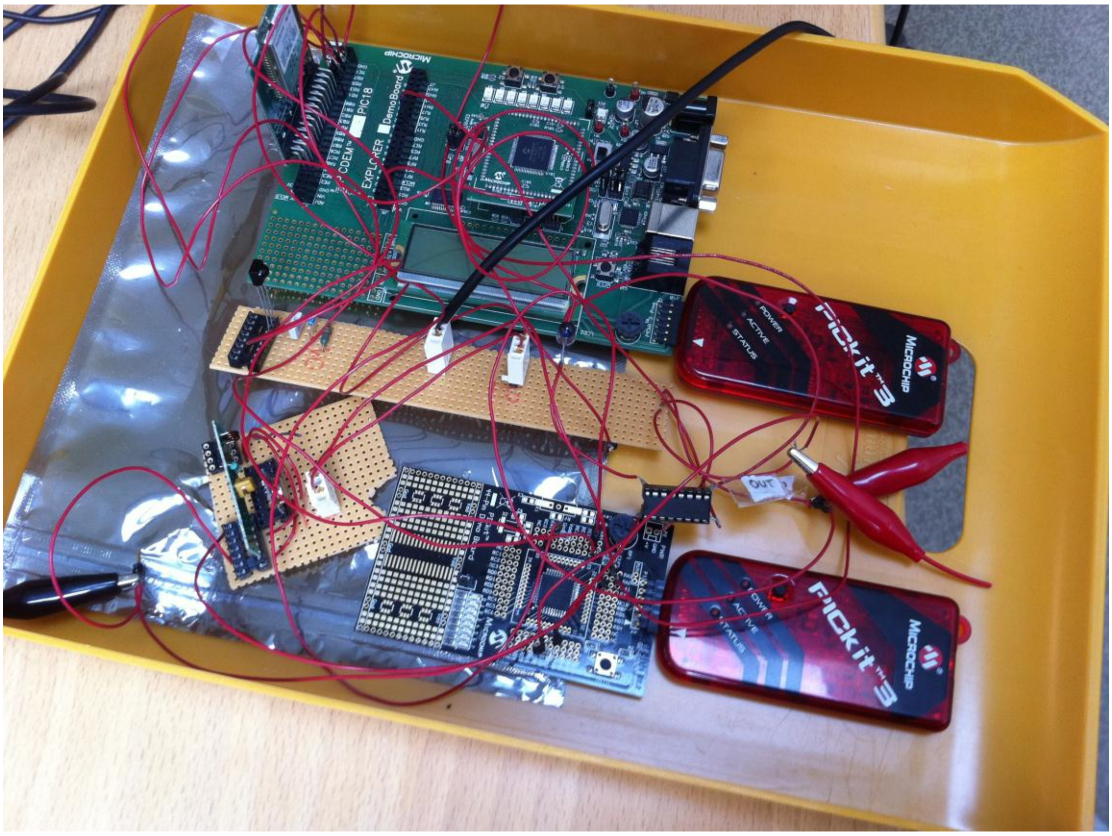


Figure 5.41. The prototype that was used for the testing and refinement of the detail design.

5.5 Verifying the final solution

To make sure that the final solution has been successful and to identify what could have been done better the requirements specification should be considered once again.

The product was lined up as a checklist to verify what requirements and desires that was met. The verification methods were proceeded as specified for each subject on the requirements specification.

5.5.1 Verifying against the requirements

The following list presents the requirements and whether or not they have been achieved as well as a comment on why.

- **The system must be able to send infrared signals**
  Yes. The communication station is able to send infrared signals via an IR-Diode.

- **The system must be able to send radio frequency signals**
  Yes. The communication station is able to send RF signals via a RF transmitter.

- **The remote control signal range should be sufficient**
  No. The communication station is able to send RF signals well over 10 meters and through walls, however the IR signals are not able to travel the distance of 10 meters.

- **The volume of the external unit should not be to large**
  Yes. The casing designs are within the target volume of 150x150x150[mm].

- **The price should not put the remote in the luxury segment**
  Unknown. A price calculation has yet to be performed but the materials have been chosen with awareness to keep the price to a minimum.

- **The system must be able to receive, translate and pass on commands**
  Yes. The communication station is able to receive a command through a web interface and translate the signal to be able to forward it.

- **The communication station must be able to connect to a smartphone**
  Yes. The communication station is able to connect to a smartphone through Wi-Fi via a web interface.

- **The remote should not need to be pointed in a specific direction**
  Yes. The smartphone can be pointed anywhere since it is connected via Wi-Fi.

- **Laws and regulations must not be broken**

Unknown. No material in the communication station is breaking any laws or regulations. The complete bill of material has not been set.

- **Copyright and patent infringement must be avoided**
  Unknown. A patent search is yet to be conducted.

- **The communication station should not require service more often than every six months**
  Unknown. No power source has been chosen, which makes the calculation of required service impossible to perform.

- **The product should be UV resistant**
  Unknown. No material in the communication station is sensitive to UV light; however the complete bill of material has not been set.

- **The product should work in normal room temperature**
  Unknown. No material in the communication station is sensitive temperatures below 10 degrees Celsius or above 15 degrees Celsius; however the complete bill of material has not been set.

- **The product should not be considered noisy**
  Unknown. Nothing in the communication station is making any noise, however the complete bill of material has not been set.

5.5.2 Verifying against the desires

The following list presents the desires and whether or not they have been achieved as well as a comment on why. The desires are listed in order of importance according to the weighing matrix.

- **Using the remote should not interfere with other communication from the smartphone**
  Yes. The smartphone can use other communication as usual. The Wi-Fi connection can still connect to the internet since the communication should go through a router.

- **The remote control should be started up and connected as fast as possible**
  Yes. The communication station connects as fast as possible and the restraints for connection time lies in the smartphone.

- **The IR diode should have as wide a sight as possible**
  Unknown. The final casing has not been decided but the products have been chosen to give a wide sight.

- **The remote should have as long range as possible**

No. The communication station does not achieve the requirement in this area.

- **The price should be as low as possible**
  Unknown. A price calculation has yet to be performed but the materials have been chosen with awareness to keep the price to a minimum.
- **The device design should blend in with a living room environment**
  Yes. Four design concepts have been approved for blending in through surveys with potential customers.
- **The product should give a good quality impression**
  Yes. Four design concepts have gotten an approved quality impression through surveys with potential customers.
- **The device should be aesthetically appealing**
  Yes. Four design concepts have gotten an approved aesthetics impression through surveys with potential customers.
- **The system should be cordless**
  Unknown. The communication station is meant to be cordless but no power supply has been chosen.
- **The remote should be usable even when not in the same room as the equipment**
  Yes. The remote will work with Wi-Fi and thus be usable from within a wide area to the router.
- **The product should be place able on any vertical or horizontal surface**
  Unknown. The chosen concepts for the casing all have the ability to implement a fastening device for placing on a wall or ceiling, but the final solution is not yet determined.
- **The communication station should connect to the smartphone via Internet connection**
  Yes. The communication station can connect via the internet as long as there is an internet connection available for the router.
- **The product should be stable where it stands**
  Unknown. The communication station has not been fully produced to be able to test the stability.
- **The communication station should run preprogramed instructions without a smartphone connected**
  No. There is no memory inserted for this application
- **The system should consume as little power as possible**

Unknown. The power supply has not been decided.

- **The system should be able to send Bluetooth signals**
  No. The system is not able to send Bluetooth signals.
- **The communication station should provide feedback when receiving commands**
  Unknown. The communication station has been designed to allow room for an easy implementation of diodes to provide feedback, but no specific design has been set.
- **The product should be as environmentally friendly as possible**
  Unknown. The materials have been chosen with respects to as low negative environmental impact as possible but the complete bill of material is not complete.

6 THE SUSTAINABILITY ASPECT

This chapter discusses the sustainability aspect of the product, covering the three dimensions of sustainability: *environmental, social* and *economic*.

6.1 The environmental and economic dimensions

One of the key features of the product is the utilization of smartphone technology, where a multi-touch user interface, powerful processors and internet connectivity is already developed. Since these expensive features are embedded in the smartphone, the universal remote control developed in this project will not need to include any of them, which leads to a lower price to the customers as well as less components and material for manufacturing, when compared to stand-alone universal remote controls where all functionality is included in the actual remote.

The communication station is not dependent on just one smartphone, which means that the same communication station can be used with several different brands of smartphones, and will not need to be replaced when buying a new phone. Even though the smartphones is upgraded and gets new versions of the software, the communication station should be able to stay the same as long as it can connect to the smartphone via Wi-Fi. Since no new hardware would be needed for such upgrades, no new materials needs to be used and no physical transports will be needed either. All-in-all this ensures a long lifetime of the product and thus adds to both economic and environmental sustainability.

Another feature of the finished version of the communication station could be an internal memory for storing scheduled activities for equipment in the home. In this way lights and appliances can be turned off at programmed times in order to save energy.

6.2 The social dimension

The feature of storing scheduled activities could also serve as a parental control filter. Parents could in this way block certain content for their children's remote controls by not allowing them to change to certain channels during certain times.

Yet another use of scheduled activities could be to give the impression that someone is home when they are actually on vacation, by simply turning on/off lights at reasonable times. This could be used as a security measure to keep thieves away.

Since many people own a smartphone, chances are that several members of a family might be able to control the communication station with their own smartphone. This would also mean that several people in the couch can have equal control of the TV instead of only one person having master control. This could of course lead to arguments as to what to watch, just as before, but in this situation everyone in the argument will at least have equal rights.

7 DISCUSSION

The outcome of the project, together with the process that led to it, will now be discussed. Following the process discussion, a short discussion of the choice for project supervisor and a few concluding remarks is presented as well.

7.1 The development process

One of the most important purposes of the *market analysis* was to specify the requirements of the product. The means to achieve this goal included interviews with people within the intended product market segment as well as a survey conducted to gather quantitative data on equipment that commonly occurs in living rooms. Sending the survey to friends through Facebook was very resulting, since more than 50 per cent of the asked persons submitted answers and the rate of elaborate responses was also high. However it can be argued that a survey to friends through Facebook can only be used once, since it would be annoying for the friends to receive a lot of surveys, which would not only render less responses but could also generate an irritation towards the sender. The usage of internet forums on the other hand was not a good idea since it rendered very few responses. Posting a survey like this on other forums should be done with considerations to the regulations of the site, since it could be seen as commercial for the product, which in most cases is not allowed.

Since the data gathered from this study had such high quantity, it provided a clear view on what type of equipment to focus the development towards, and the opinions expressed in the voluntary questions provided a great load of ideas for the functionality of the product. Of course, more replies would always be appreciated but to get that, other sources of people would have to be found, which probably would not be as time effective as the survey sent through Facebook. Altogether this analysis gave a solid ground to stand on when formulating the product requirement specification.

The *concept generation and selection* was iterated twice, once for the electronics and functionality, and once for the product design. This division was done for structural and priority purposes, since it was preferred to be able to focus on one step at a time, and to do the tasks with the highest priority first. The electronics and functionality was considered as more important and was therefore completed before starting on the casing development, which resulted in an unfinished casing design. The methodology for concept selection was based on the group members experience from previous projects and adapted to fit this one, which caused the selection process to be conducted quickly. An example of an adaptation can be seen in the weighing matrix where a point system from negative 2 to positive 2 was used instead of 0, 0.5 and 1. The negative values could possibly be misinterpreted as saying that the desire is actually something you want to avoid, when in fact it only means that the other desire is more important. This misunderstanding could of course be avoided by using a value from 1 to 4 instead, but we felt that our choice was the more logical one. The advantage of having a higher resolution and avoiding giving two desires the same importance still weighs up for this possible misunderstanding.

A good result was reached with the methods used, but of course some things were found along the way that probably could have improved our methods. For example, when performing the survey on design concepts the materials for each concept were not completely defined beforehand, and all the concepts were visualized with only a hand sketch. This made it hard to communicate an exact image of the concepts and the people we asked would probably have gotten a better image of the concepts in their heads if they had been defined a bit further. However, since we were present when the survey was performed, we were able to explain our thoughts and answer questions that the participants had. The results from the survey should therefore still be accurate enough. Another example is that the brainstorming sessions for design concepts could probably have involved more people in order to generate an even wider range of ideas, but a trade-off had to be made between time and accuracy and since the functionality of the product was prioritized, the time for the design concepts were a bit limited. The product design is however not yet a finished chapter and is therefore further mentioned in the plan for future work.

The *detail design* consisted mostly of programming the functionality. We in the group were not very experienced in the field of low-level programming before this project, which might make the project seem like an odd choice for us to take on, but we do however consider the field of embedded system very interesting because of the endless possibilities it entails which made it easier to learn. An expert in the area could though have been of much use for consultation to easier avoid speed bumps in the troubleshooting of the code. Using the PICkit 3 together with the tutorials was a quick and efficient method for getting introduced to low-level programming for PIC microcontroller, and extending these tutorials with added on functionality using trial-and-error resulted in a good foundation to rely on when programming the functionality.

The transition from detail design into a *testing and refinement* phase was done quite seamlessly, since the programming in the detail design were test-and-refine oriented in its nature. Both IR and RF are dependent on accurate timing, and programming for saving and sending out a perfectly timed signal was therefore achieved through iterations where tests and measurements were included in each run, with the use of receivers and an oscilloscope. These measurement tools were critical in this phase, since there was no way of knowing what was wrong and what to correct in the code before the signal could be visualized in some way. The LEDs on the development board was also used to represent the contents of an 8 bit variable binary, which was useful in order to look at the values of timers and other numeral variables. However, this kind of testing would have been much easier to perform if a development board with a display were used from the start, where a few lines of text could be printed by the program.

7.2 Project supervision

Every project needs a supervisor, and since the process of developing a product from a "blank canvas" into a working prototype is a considerably big project, a person with knowledge of the full scope of product development was preferred when deciding on a supervisor for this project, which is why the choice fell on an assistant professor in Product Development. Meetings with the supervisor were scheduled regularly during the course of the project, where the progress of the project since the last meeting were detailed, followed by discussions on the future plans in order to ensure that the project kept on moving in the right direction. Organizing the work flow and the structure of the report is a big part of the project and the meetings with the supervisor provided good support when doing this work. The other big part of this project was assembling the electronics and programming the functionality of the product in the detail design phase. An alternative approach would have been to choose a supervisor more suited for support in that area. A great deal of time would probably have been saved in configuring the hardware if an electronics/low-level-programming expert had been available to answer questions and guide us through the troubleshooting processes. This alternative would probably have led to a more advanced solution in the detail design, but also probably at the cost of more difficulties in following the theory and methodology of product development, resulting in less focus being put on the process instead. After all, this thesis project is conducted at the department of product development and the focus should thus be on the development process, rather than on computer or electrical engineering, and the feeling is therefore that the right choice of supervisor was made.

7.3 Concluding remarks

In summary, a lot of knowledge within the field of embedded systems has been gathered and put to use throughout this project. Embedded systems were not a very well explored field for us in the group from the start, but the results of the project has yet been satisfying. We believe that a broad general knowledge of technology, such as what our education provides us with, together with enthusiasm and a keen interest in learning about new fields can go a long way when pursuing a career as an engineering consultant (as both of us are), and this project could be seen as a successful test of that theory.

During the two years of studies in the Product Development master program, an intuition for methodology and key aspects to consider during development processes has gradually been built up. This intuition, together with the course literature collected over the years, has formed a formidable framework of knowledge that has proven to be a very useful asset when taking on a new project. We in the group believe that the ability to divide any given product idea into a set of tasks and subtasks that can be worked through systematically is a valuable skill to possess when moving on to the work life. That skill is what this project has been all about to test, and even though the resulting product is not yet at a stage where it can be released on the market, we do feel confident about the results of the process so far and we believe that following through with the enclosed plan for future work would result in a product well suited for the market's demands.

8 CONCLUSION

A communication station, acting as a link between a smartphone and the remote controlled equipment in a living room, has been developed. The communication station can receive commands from a smartphone via a Wi-Fi connection and then forwards these commands through an IR diode or an RF transmitter, depending on the type of equipment that is to be controlled.

Except receiving signals from the smartphone, the communication station can also recognize correctly formatted IR or RF commands and send them to the smartphone in order to store them for later use.

The resulting functionality of the product, as well as the design for it, is based on a market analysis which included a number of around 300 participants in different steps along the development process.

The development was done in close connection to a software group which developed a user interface for the product, in the form of an Iphone application. Together with this collaborating group, a working prototype of the intended product has been produced in order to be able to demonstrate its functionality.

The basic functionality of the product has been finished but further details such as final design solution and advanced functionality is still left to work on in future development. When this is done a cost analysis can be performed in order to minimize the cost of the final product.

9 REMAINING DEVELOPMENT WORK

This chapter describes what is left to be done with this product before it can be released on the market. The most of the needed improvements was found while verifying the product against the requirements specification and some other improvements was located during the development and refining of the product.

9.1 Electronics development

Further development could be performed on the electronics of the product, here follows some of the areas of improvement that were located.

The effect of the IR diode needs to be improved to make sure it sends out signals that can travel at least 10 meters. This could be achieved through the Darlington transistor, but further knowledge is needed before the desired effect could be reached.

The frequency to receive and transmit IR signals is done in 38 kHz. The frequency works for almost all usually used frequencies ranging from 36 to 40 kHz, since there is an approximate 10 per cent permitted accuracy failure. The device could though be enhanced by recognizing the correct frequency to minimize the flaw in the sent signal to make it even more reliable.

The prototype is manufactured by material that has been easy to obtain. The parts of the product needs to be chosen together with a supplier to get a cheaper prize a more specific solution oriented composition of the subsystems. The parts also needs to be chosen to minimize the energy consumption to make the product last longer without having to change the battery.

A complete circuit board needs to be manufactured to be able to minimize the product and order it to make it more production friendly.

A production ready solution needs to be tested for reliability to make sure that the product would keep working as planned for a long period of time. The tests must make sure that the product is not dangerous by suddenly igniting or exploding because of current or voltage flaws. The test should make sure that the product is not affected by normal room temperatures, ultraviolet light and make sure it is not delivering any noise.

A power source needs to be defined to make the product last as long as possible with the right current and voltage without affecting the size or cost too much.

A Bluetooth device could be implemented in the product to be able to control even more devices such as a PlayStation 3™.

A memory unit could be implemented and programmed to be used for storing instructions that could be run on a schedule automatically without the user having to control the functions.

9.2 Casing development

A final solution for the concept has not yet been chosen. This is the first development work that needs to be pursued. The four chosen concepts need to be developed further to be able to evaluate more thoroughly. They need to be designed with CAD or by simple real mock-ups to make it more suitable for aesthetic evaluation.

The casing should be designed in detail to make room for the electronics and to make an exact geometry with specific material to be able to find suitable suppliers. Fastenings for the product could be designed to make the product place able on a wall or a ceiling. The casing needs to be optimised for manufacturing and assembly to minimize the cost and manufacturing time.

What parts of the product that is supposed to be produced internally or outsourced should be decided. For the internal production the tooling and manufacturing processes needs to be specified to be able to start a full scale production. The manufacturing processes would be depending on aimed production size.

9.3 Miscellaneous

A patent search needs to be performed as well as laws and regulations needs to be analysed to make sure that nothing is preventing the product from being released on the market.

The market need for this kind of product should be examined to be able to assume the amount of units that should be produced, which could be useful when selecting parts and manufacturing processes

The product could use promotion for example through advertisement or key users to increase the demand for it on the market.

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Appendix A. Web questionnaire

Frågeformulär

Din ålder	[ ]
Ditt kön	○ Man ○ Kvinna
Har du iPhone, iPod Touch, iPad eller Androidmobil? (lista över Androidmobiler)	○ Ja ○ Nej ○ Nej, men planerar att skaffa
Har du trådlöst nätverk hemma?	○ Ja ○ Nej
Har du TV?	○ Ja ○ Nej
Har du digitalTV-box?	○ Ja ○ Nej
Har du DVD- eller Blu-ray-spelare?	○ Ja ○ Nej
Har du stereo/ljudsystem med fjärrkontroll?	○ Ja ○ Ja, inbyggd i min DVD-/Blu-ray ○ Nej
Har du HTPC med fjärrkontroll?	○ Ja ○ Nej
Har du någon annan sorts mediabox (Apple TV, Boxee, Squeezebox eller liknande)?	○ Ja ○ Nej
Har du projektor?	○ Ja ○ Nej
Har du projektorduk som kan styras med fjärrkontroll?	○ Ja ○ Nej
Har du fjärrkontroll för styrning av belysning, markiser, air condition eller liknande?	○ Ja ○ Nej
Om ja, vilket märke på fjärrkontrollen?	[ ]

Har du någon övrig utrustning med fjärrkontroll?

Har du en universalfjärrkontroll?

- Ja
- Nej

Om nej, varför inte?

- För dyrt
- Har inget behov
- Tror inte att det skulle fungera
- Annan anledning

Om ja, vilka prylar styr du med den? (flera kan väljas)

- TV
- Ljudsystem
- DigitalTV-box
- HTPC
- DVD
- Blu-ray
- Mediabox
- Projektor
- Projektorduk
- Belysning
- Annat

Vad har du för fjärrkontroll (märke/modell)?

Extra frågor

Inget krav, men vi skulle verkligen uppskatta om du svarar även på så många av dessa som möjligt, så utförligt som du känner för.

Du som har en universalfjärrkontroll:

Vad tycker du fungerar bra med den?

Vad tycker du fungerar mindre bra med den?

Vilka funktioner använder du mest?

Finns det några funktioner du sällan eller aldrig använder?

Finns det något du saknar på den?

Har du något förslag på hur den skulle kunna göras bättre?

Du som inte har en universalfjärrkontroll:

Vad skulle kunna få dig att köpa en?

Din Emailadress

Ifall det skulle vara några oklarheter i dina svar så kontaktar vi dig gärna. Fyll i din emailadress om du tycker detta är okej.

Email:

Skicka in dina svar

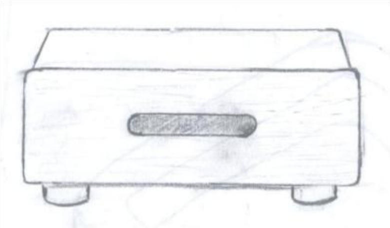
Appendix B. Requirement specification

ID	Requirement	Purpose	Metric/Evaluation	Weig	Type
D01	The system should be able to send Bluetooth signals	To be able to control a PlayStation 3	**Yes/No**		Wish
D02	The device should be aesthetically appealing	To attract buyers	Discuss with designers at Industrial design		Wish
D03	The price should be as low as possible	To attract buyers	Materials should be chosen to keep the price well under 1500 SEK		Wish
D04	The communication station should run preprogramed instructions without an Iphone	To be able to simulate a populated house when the user is on vacation for example	An extra memory should be available		Wish
D05	The system should be cordless	To ease for customers, and for a cleaner look	**Yes/No**		Wish
D06	The communication station should connect to the Iphone via Internet connection	To be able to program recordings and such even when not at home	**Yes/No**		Wish
D07	Using the remote should not interfere with other communication from the phone	To not hinder the normal use of the phone	Testing		Wish
D08	The remote control should be started up and connected as fast as possible	To reduce waiting time	Testing		Wish
D09	The remote should have as long range as possible	To be able to use the remote from as large distance as possible	Test and measure		Wish
D10	The remote should be usable even when not in the same room as the equipment	For extra convenience	Testing		Wish
D11	The system should consume as little power as possible	To save energy and enable the use of a battery as power source if possible	Measure		Wish
D12	The IR diode should have as wide a sight as possible	To be able to choose the placement of the device as freely as possible	Testing		Wish
D13	The device design should blend in with a living room environment	To not draw too much attention to the communication station	Engineering assessment		Wish
D14	The communication station should provide feedback when receiving commands	For the user to know that the commands has been received	Testing		Wish
D15	The product should give a good quality impression	For stability and to give a quality feel	Measure		Wish
D16	The product should be stable where it stands				Wish
D17	The product should be as environmentally friendly as possible				Wish
D18	The product should be place able on a wall or ceiling				Wish
R01	The system must be able to send infrared signals	To be able to control the most basic equipment (TV, receiver etc.)	**Yes/No**		Requirement
R02	The system must be able to send radio frequency signals	To be able to control electronic switches remotely	**Yes/No**		Requirement
R03	The remote control signal range should be sufficient	To be a useful product	**>= 10 meters**		Requirement
R04	The volume of the external unit should not be to large	To easily be able to place it in the living room	Less than 3375 cm2 (15x15x15)		Requirement
R05	The price should not put the remote in the luxury segment	To attract younger customers with a smaller budget	Maximum 1500 SEK		Requirement
R07	The system must be able to receive, translate and pass on commands	To be able to send the correct commands to the corresponding device	**Yes/No**		Requirement
R08	The communication station must be able to connect to Iphones	For it to be able to be controlled through the Iphone interface	**Yes/No**		Requirement
R09	The remote should not need to be pointed in a specific direction	To avoid usability issues	**Yes/No**		Requirement
R10	Laws and regulations must not be broken	To not be an illegal product	Comparison of bill of material with the LAW		Requirement
R11	Copyright and patent infringement must be avoided	To avoid lawsuits	Patent search		Requirement
R12	The communication station should not require service more often than every six mo	The user should be able to ignore the communication station as much as possible	Calculations		Requirement
R13	The product should be UV resistant	To not be damaged by sunlight when placed on a window sill			Wish
R14	The product should work in normal room temperature	To handle most indoor scenarios	10 to 15 degrees celsius		Wish
R15	The product should not be considered noisy	To not annoy the user	Sound level < 10dB(A)		Wish

Appendix C. Casing concept questionnaire

Sätt ett betyg på minst 1 och max 5. Tänk på att detta är skisser. Sätt betyg efter hur ni tror att slutprodukten skulle se ut.

The Amp

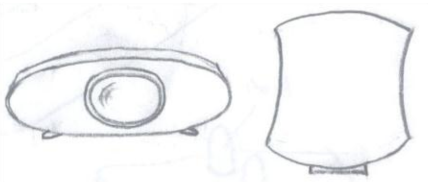


Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

The Projector



Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

The Flute

Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

The Book

Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

The Lighthouse

Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

Sätt ett betyg på minst 1 och max 5. Tänk på att detta är skisser. Sätt betyg efter hur ni tror att slutprodukten skulle se ut.

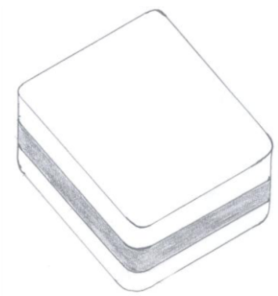
The Beacon

Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

The Burger

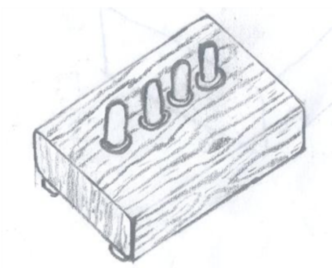


Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

The Valve Amp

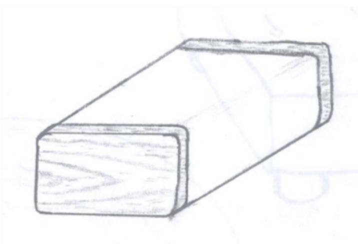


Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

The Punsch Roll



Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

Sätt ett betyg på minst 1 och max 5. Tänk på att detta är skisser. Sätt betyg efter hur ni tror att slutprodukten skulle se ut.

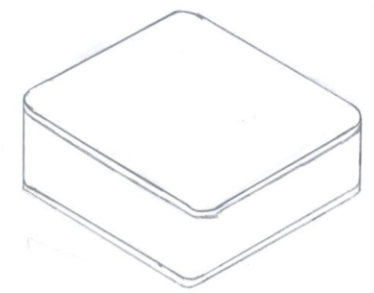
The Sphere

Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

The Sandwich

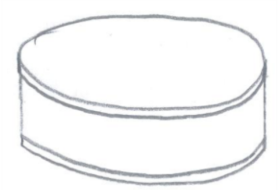


Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

The Puck

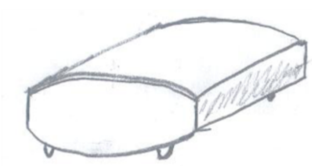


Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

The Chest



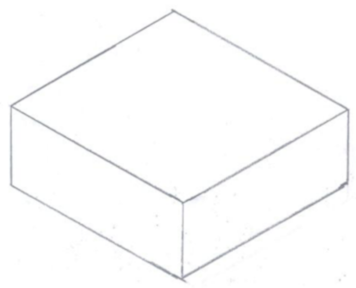
Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

Sätt ett betyg på minst 1 och max 5. Tänk på att detta är skisser. Sätt betyg efter hur ni tror att slutprodukten skulle se ut.

The Brick

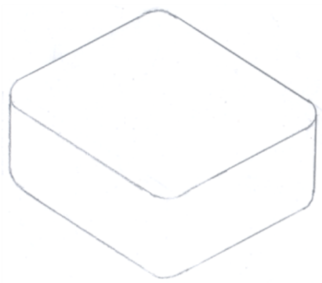


Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

The Toast



Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

The Robocop

Estetiskt tilltalande ...

Kvalitetskänsla ...

Smälter in I ditt vardagsrum ...

Tack för din medverkan!

Appendix D. Program source code

```
/** C O N F I G U R A T I O N   B I T S ******************************/
#pragma config FOSC = INTIO67, FCMEN = OFF, IESO = OFF                      // CONFIG1H
#pragma config PWRT = OFF, BOREN = OFF, BORV = 30                           // CONFIG2L
#pragma config WDTEN = OFF, WDTPS = 32768                                   // CONFIG2H
#pragma config MCLRE = ON, LPT1OSC = OFF, PBADEN = OFF, CCP2MX = PORTC      // CONFIG3H
#pragma config STVREN = ON, LVP = OFF, XINST = OFF                          // CONFIG4L
#pragma config CP0 = OFF, CP1 = OFF, CP2 = OFF, CP3 = OFF                   // CONFIG5L
#pragma config CPB = OFF, CPD = OFF                                         // CONFIG5H
#pragma config WRT0 = OFF, WRT1 = OFF, WRT2 = OFF, WRT3 = OFF               // CONFIG6L
#pragma config WRTB = OFF, WRTC = OFF, WRTD = OFF                           // CONFIG6H
#pragma config EBTR0 = OFF, EBTR1 = OFF, EBTR2 = OFF, EBTR3 = OFF           // CONFIG7L
#pragma config EBTRB = OFF                                                  // CONFIG7H

/** I N C L U D E S **************************************************/
#include "p18f45k20.h"
#include "delays.h"
#include "12 CCP PWM.h"  // header file
#include <stdio.h>
#include <string.h>

/** V A R I A B L E S ************************************************/
#pragma udata udata1   // declare statically allocated initialized variables
int RFCommand[100];

#pragma udata udata2
int RFCommand2[55];

#pragma udata udata3
int RFCommand3[100];

#pragma udata udata4
int RFCommand4[55];

#pragma udata udata5
unsigned int IRcommand[80];

#pragma udata udata6
unsigned int IRrepeat[125];

#pragma udata
unsigned int i2, i3, j2, k2, k, inValue, temp, i, j, l, m, repeatSignal, leadoutLength,
timerStartValue, signalLength;
unsigned int timerValue, state2, state3, state4, state5, state6, state7;
long int bigTimer;

/** D E C L A R A T I O N S ******************************************/
#pragma code  // declare executable instructions

void main (void){
      TRISD = 0;
      LATD = 0;                  //Clear all bits on the D port to be sure it is clean
      ANSEL = 0x00;              //Set PORTA as digital inputs
      TRISA = 0xFF;              //Configure PORTA bits as inputs
      OSCCONbits.IRCF = 0b111;   //Set the clock frequency to 16 MHz

      inValue = 0;

      TMR0H = 0;                 //Make sure the Timer0 IF flag doesn't get set to early
      INTCONbits.TMR0IF = 0;     //Clear the Timer0 IF flag to be sure

      state2 = PORTAbits.RA2;
      state3 = PORTAbits.RA3;
      state4 = PORTAbits.RA4;
      state5 = PORTAbits.RA5;
      state6 = PORTAbits.RA6;
      state7 = PORTAbits.RA7;
      while(1){
        LATD = 0;

        if(PORTAbits.RA2 != state2){
                state2 = PORTAbits.RA2;
                LATDbits.LATD2 = 1;
                learnRFCommand();
```

```
        }
        if(PORTAbits.RA3 != state3){
                state3 = PORTAbits.RA3;
                LATDbits.LATD3 = 1;
                sendRFCommand();
        }
        if(PORTAbits.RA4 != state4){
                state4 = PORTAbits.RA4;
                LATDbits.LATD4 = 1;
                learnRFCommand2();
        }
        if(PORTAbits.RA5 != state5){
                state5 = PORTAbits.RA5;
                LATDbits.LATD5 = 1;
                sendRFCommand2();
        }
        if(PORTAbits.RA6 != state6){
                state6 = PORTAbits.RA6;
                LATDbits.LATD0 = 1;
                learnIRCommand();
        }
        if(PORTAbits.RA7 != state7){
                state7 = PORTAbits.RA7;
                LATDbits.LATD1 = 1;
                sendIRCommand();
        }
      }
}

//------------------------------------RF--------------------------------------

void learnRFCommand(void){
      T0CON = 0b10001000;                //Set the Timer0 and start it
      while(1){
        while(PORTAbits.RA1 != 1);
        INTCONbits.TMR0IF = 0;
        TMR0H = 0;
        TMR0L = 0;
        while(PORTAbits.RA1 != 0);
        temp = TMR0L;            // TMR0H requires a read of TMR0L in order to be set proper
        timerValue = TMR0H;
        TMR0H = 0;
        TMR0L = 0;
        timerValue = (timerValue << 8) + temp;
        if(timerValue > 1350 && timerValue < 1450){
                while(PORTAbits.RA1 != 1);
                temp = TMR0L;
                timerValue = TMR0H;
                timerValue = (timerValue << 8) + temp;
                if(timerValue > 9800 && timerValue < 10200){
                        RFCommand[0] = 350*4;
                        RFCommand[1] = 2500*4;
                        for(i2 = 2; 1; i2++){
                                TMR0H = 0;
                                TMR0L = 0;
                                while(PORTAbits.RA1 != inValue);
                                temp = TMR0L;
                                timerValue = TMR0H;
                                timerValue = (timerValue << 8) + temp;
                                if (timerValue > 20000 || INTCONbits.TMR0IF == 1){
                                        inValue = 0;
                                        RFCommand2[i2-100] = timerValue;
                                        return;                                        }
                                if (i2 < 100)
                                        RFCommand[i2] = timerValue;
                                else
                                        RFCommand2[i2-100] = timerValue;
                                inValue = ++inValue & 1;
                        }
                }
        }
      }
}

void sendRFCommand(void)                 //sending the stored RF command
{
      T0CON = 0b10001000;                //Set the Timer0 and start it
      for(k2=0; k2 < 8; k2++){
        for(j2 = 0; j2<i2; j2++){
                if (j2 < 100){
                        SendRF1(RFCommand[j2]);
                        SendRF0(RFCommand[++j2]);
```

```
                }
                else{
                        SendRF1(RFCommand2[j2-100]);
                        SendRF0(RFCommand2[++j2-100]);
                }
        }
      }
}

void SendRF1 (unsigned int number)
{
      LATDbits.LATD6 = 1;
      number = 0xFFFF - number;
      TMR0H = number >> 8;
      TMR0L = number & 0x00FF;
      while (INTCONbits.TMR0IF == 0);
      INTCONbits.TMR0IF = 0;
}

void SendRF0 (unsigned int number)
{
      LATDbits.LATD6 = 0;
      number = 0xFFFF - number;
      TMR0H = number >> 8;
      TMR0L = number & 0x00FF;
    while (INTCONbits.TMR0IF == 0);
      INTCONbits.TMR0IF = 0;
}

void learnRFCommand2(void)
{
      while(1){
        while(PORTAbits.RA1 != 1);
        INTCONbits.TMR0IF = 0;
        TMR0H = 0;
        TMR0L = 0;
        while(PORTAbits.RA1 != 0);
        temp = TMR0L;           // TMR0H requires a read of TMR0L in order to be set proper
        timerValue = TMR0H;
        TMR0H = 0;
        TMR0L = 0;
        timerValue = (timerValue << 8) + temp;
        if(timerValue > 1350 && timerValue < 1450){
                while(PORTAbits.RA1 != 1);
                temp = TMR0L;
                timerValue = TMR0H;
                timerValue = (timerValue << 8) + temp;
                if(timerValue > 9800 && timerValue < 10200){
                        RFCommand3[0] = 350*4;
                        RFCommand3[1] = 2500*4;
                        for(i3 = 2; 1; i3++){
                                TMR0H = 0;
                                TMR0L = 0;
                                while(PORTAbits.RA1 != inValue);
                                temp = TMR0L;
                                timerValue = TMR0H;
                                timerValue = (timerValue << 8) + temp;
                                if (timerValue > 20000 || INTCONbits.TMR0IF == 1){
                                        inValue = 0;
                                        RFCommand4[i3-100] = timerValue;
                                        return;                         }
                                if (i3 < 100)
                                        RFCommand3[i3] = timerValue;
                                else
                                        RFCommand4[i3-100] = timerValue;
                                inValue = ++inValue & 1;
                        }
                }
        }
      }
}

void sendRFCommand2(void)       //sending the stored RF command 3 and 4
      {
      for(k2=0; k2 < 8; k2++){
        for(j2 = 0; j2<i3; j2++){
                if (j2 < 100){
                        SendRF1(RFCommand3[j2]);
                        SendRF0(RFCommand3[++j2]);
                }
```

```
                else{
                        SendRF1(RFCommand4[j2-100]);
                        SendRF0(RFCommand4[++j2-100]);
                }
        }
      }
}

//------------------------------IR----------------------------------------

void learnIRCommand (void)
{
      T0CON = 0b10000100;               // Initialize timer0 with prescaler 1:64
      INTCONbits.TMR0IF = 0;            // Clear timer0 interupt flag
      TRISBbits.TRISB0 = 1;
      PORTDbits.RD1 = 1;
      while(PORTBbits.RB0 != 0);        // Wait for the command to start
      PORTDbits.RD2 = 1;
      inValue = 1;
      i = 0;
      k = 0;
      TMR0H = 0;
      TMR0L = 0;
      INTCONbits.TMR0IF = 0;            // Clear interupt flag
      while(1)
      {
        while(inValue != PORTBbits.RB0)
        {
                if(INTCONbits.TMR0IF == 1)      // If timer overflows, command is finished
                {
                        if(repeatSignal == 0)
                        {
                                IRcommand[i] = leadoutLength;           // Add lead out
signal
                                PORTDbits.RD6 = 1;
                        }
                        if(repeatSignal == 1)
                        {
                                IRrepeat[k] = leadoutLength;
                                PORTDbits.RD5 = 1;
                        }
                        inValue = 0;
                        return;         // and return the completed command
                }
        }
        temp = TMR0L;           // TMR0H requires a read of TMR0L in order to be set proper
        timerValue = TMR0H;

        INTCONbits.TMR0IF = 0;                          // Clear interupt flag
        TMR0H = 0;
        TMR0L = 0;

        bigTimer = (timerValue << 8) + temp;
        bigTimer = bigTimer*121/400;                    // value correction
        signalLength = bigTimer;

        if(signalLength > 0x0150)
        {
                int times = 1;
                if(repeatSignal == 1)
                {

                        while(signalLength > 0x0240)
                        {
                                signalLength = signalLength/2;
                                times = times*2;
                        }
                        while(times > 2)
                        {
                                IRrepeat[k++] = signalLength+181;
                                IRrepeat[k++] = 0;
                                times--;
                        }

                        IRrepeat[k] = signalLength;
                        inValue = 0;
                        return;
                }
                times = 1;

                while(signalLength > 0x0240)
                {
```

```
                        signalLength = signalLength/2;
                        times = times*2;
                }
                while(times > 2)
                {
                        IRcommand[i++] = signalLength;
                        IRcommand[i++] = 0;
                        times--;
                }

                IRcommand[i] = signalLength;

                repeatSignal = 1;
        }
        else
        {
                if(repeatSignal == 1)
                        IRrepeat[k++] = signalLength;
                else
                {
                        IRcommand[i++] = signalLength;  // Store the signal length in the
command array
                }
        }

        inValue = ++inValue & 1;
      }
}

void SendIR1 (unsigned int number)
{
      if(number > 0)
      {
        bigTimer = ((number*100)-77);
        number = bigTimer & 0x0000FFFF;
        bigTimer = (bigTimer & 0xFFFF0000) >> 16 +1;
        do
        {
                number = 0xFFFF - number;
                CCP1CON = 0b01101100;
                TMR0H = (number & 0xFF00) >> 8;
                TMR0L = number & 0x00FF;
                while (INTCONbits.TMR0IF == 0);
                INTCONbits.TMR0IF = 0;
                bigTimer--;
        } while(bigTimer > 0);
      }
}

void SendIR0 (unsigned int number)
{
      bigTimer = number;
      bigTimer = ((bigTimer*100)-192);
      number = (bigTimer & 0x0000FFFF);
      bigTimer = (bigTimer & 0x00FF0000) >> 16;
      do
      {
        number = 0xFFFF - number;
        CCP1CON = 0b01101000;
        TMR0H = (number & 0xFF00) >> 8;
        TMR0L = number & 0x00FF;
        while (INTCONbits.TMR0IF == 0);
        INTCONbits.TMR0IF = 0;
        bigTimer--;
      } while(bigTimer > 0);
}

void sendIRCommand(void)
{
      TRISD = 0xFF;
   // Set RD7/P1D pin output so P1D PWM output drives LED7
    TRISDbits.TRISD7 = 0;

    // Set up 8-bit Timer2 to generate the PWM period (frequency)
    T2CON = 0b00011100;         // Postscale = 1:4, timer on

      PR2 = 210;                        // 38 kHz modulation
      aCCPR1L = 0x69;                   // 38 kHz modulation
    CCP1CON = 0b01101100;               // 38 kHz modulation
```

```
        T0CON = 0b10001000;                 // set timer0 for sending signals

        TMR0H = 0;

        j = 0;
        while(j<i)
        {
          SendIR1(IRcommand[j++]);
          SendIR0(IRcommand[j++]);
        }

        j = 0;
        while(j<k)
        {
          SendIR1(IRrepeat[j++]);
          SendIR0(IRrepeat[j++]);
        }
        TRISD = 0;
}
```