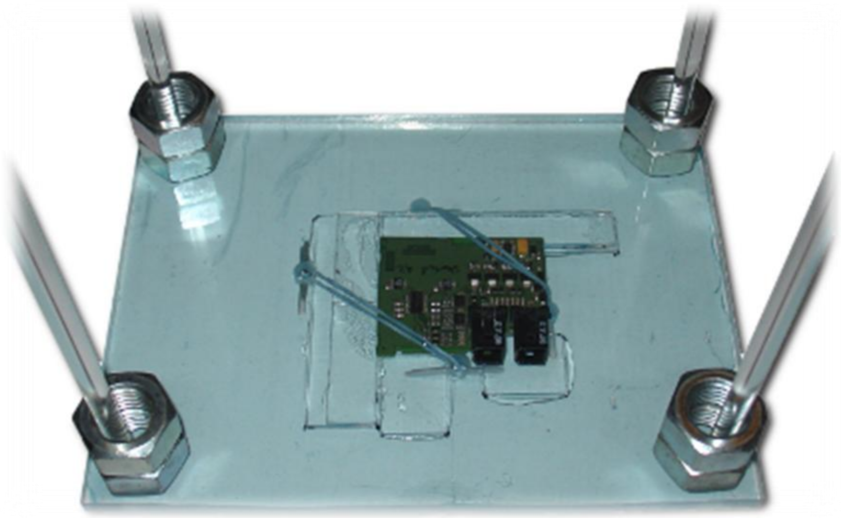

Automotive 3D Sensor for Gear Lever Units

Strategies, Technology, Comparisons and Testing.

Master of Science Thesis in the Master Degree Program Computer Security, Network Communication and Digital System Engineering

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Göteborg, Sweden, June 2010

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3D sensor för växelspakslådor
Strategier, teknologi, jämförelser och test.

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Cover:
The cover picture shows a test rig that was constructed during the project, constructed to test magnetic sensors and their reactions in magnetic fields. The nuts in the image worked as distances between the bottom board and other upper boards. More information can be found in section 5.2.

Department of Computer Science and Engineering
Göteborg, Sweden, June 2010

Abstract

This thesis investigates 3D sensing techniques, which in this case means techniques to continually track the position of an object that moves around in a three dimensional space. The goal is to explore the area of 3D sensing, possibly finding or developing a reliable sensor that can handle 3D sensing while catering to the demanding criteria of the automotive industry. Robustness, reliability, flexibility and cost efficiency are a few of the general demands, but there are also delimitations to what the sensors need to handle. Most notably there is only a need to track a single object, an object of the designer's choice, moving in a confined space. The main application for the sensor is tracking the position of the lever in a gearbox unit.

Possible techniques that can be used to monitor a 3D position is explored and analyzed as well as commercially available sensor solutions that try to achieve the same goal.

This report is of an exploring character and the focus is 3D sensing research and analysis, as well as magnet sensor comparison. It also treats testing of magnet sensors in regard to automotive demands. The magnet sensors compared use the Hall effect or the magnetoresistive effect. The testing of the sensors could not be carried out within the thesis time frame.

Keywords: 3D-sensor, automotive, GLU, Gear lever unit, Hall effect, magnetoresistance, sensor.

Sammanfattning

Detta examensarbete utreder metoder att detektera en position i 3D, vilket i detta fall innebär teknik som kontinuerligt följer ett objekts position när det rör sig i ett tredimensionellt rum. Målet är att undersöka 3D-detektionsområdet och om möjligt hitta eller utveckla en pålitlig sensor som kan hantera 3D-detektering samtidigt som den uppfyller de krävande krav bilindustrin ställer. Robusthet, pålitlighet, flexibilitet och kostnadseffektivitet är några av de övergripande kraven, men det finns även begränsningar av vad sensorn behöver klara av. En viktig begränsning är att den bara följa ett enskilt objekt valt av konstruktören som rör sig i ett avgränsat utrymme. Det främst tänkta användningsområdet för sensorn är att spåra växelspaksläget i en bil.

Möjliga tekniker att övervaka 3D-läget är utforskade och analyserade tillsammans med på marknaden tillgängliga sensorer som är tänkta att uppnå samma syfte.

Denna rapport är av en undersökande karaktär och fokus är på undersökning och analys av 3D-detektering samt att jämföra magnetsensorer. Rapporten behandlar även testning av magnetsensorer med hänsyn till bilindustrikrav. Magnetsensorer som jämförts använder Halleffekten eller magnetoresitiv teknik. Testning av sensorerna hann inte äga rum inom examensarbetets tidsramar.

Nyckelord: 3D-sensor, bilindustri, GLU, växelspak, Halleffekt, magnetoresistans, sensor.

Preface

This report is the conclusion of a thesis work conducted at the Department of Computer Science and Engineering, Chalmers University of Technology, Göteborg, Sweden as part of the Master of Science Degree Program in Computer Security, Network Communication and Digital System Engineering.

This thesis work has been performed at the company QRtech AB during 2009 and 2010.

We especially want to thank

- Andreas Magnusson for being our supervisor at QRtech, mentoring us during this thesis work and helping us to solve problems.
- Mattias Gudasic at Kongsberg Automotive for being our contact and counselor.
- Arne Linde at Chalmers for being our examiner, giving us tips and help, as well as feedback on the report.

In addition, we would like to thank QRtech AB and all the employees there for your kindness and the privilege to conduct our master thesis work among you.

Göteborg, June 2010

Alfred Carlsson　　　　Peter Malmerfors

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List of abbreviations

Term	**Definition**
ADC	Analog to Digital Converter
CGS	centimeter-gram-second system
DAC	Digital to Analog Converter
DSP	Digital Signal Processing
G	gauss (CGS **B**-unit) 1 T = 10 000 G
GLU	Gear Lever Unit. The gear lever and the box it is built into.
MR	Magnetoresistive
Oe	Oersted (CGS **H**-unit) 1 Oe = 1000/4π A/m
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
SMD	Surface Mounted Device
SOIC	The 'Small Outline Integrated Circuit', or SOIC, is a small rectangular surface-mount plastic-molded integrated circuit package with gull wing leads. The leads protrude from the longer edge of the package. It is one of the most commonly used surface mount packages today.
T	Tesla (**B**-unit)
TC	Temperature Coefficient
TDFN	The Thin Dual Flat No Leads package, or TDFN, is a very small and thin square-shaped or rectangular surface-mount plastic package with no leads. Instead of leads, it uses metal pads along two sides of the package body for electrical connection to the outside world.
TSSOP	The Thin Shrink Small Outline Package, or TSSOP, is a rectangular surface mount plastic package with gull-wing leads. It has a smaller body and smaller lead pitch than the standard SOIC package. It is also smaller and thinner than a TSOP with the same lead count.

Chapter 1

Introduction

This report aims to deliver an analysis of possible 3D sensing alternatives, specifically those appropriate for use in an automotive setting to detect a gear lever position. Three of the more promising sensor alternatives will be tested and analyzed in greater depth. This chapter will describe the background to the project and the reasons for carrying it out. It will also mention related work such as possible trends in the automotive industry to move towards a more advanced gear lever unit design, as well as the delimitations put in place to make sure the work was confined within a reasonable framework.

1.1 Background

When this report was written, cars still had a long way to go on their journey from purely mechanical to electronically monitored and controlled. Still, it was well on its way, and this report is an analysis of the current possibilities regarding one of the steps on that road.

A car needs to know, electronically, which gear it is currently in. The current technology uses a simple on/off sensor for each distinct position of the gear lever. This means that every Gear Lever Unit (GLU) needs hardware designed specifically for its gear lever setup. The number of gears, the placement of the distinct lever positions and the GLU layout in general changes from model to model and a technology shift from simple on/off sensors to 3D-sensors could make it possible to keep the same sensor layout no matter how the gear lever unit is designed. The only thing that would need to be changed from model to model then would be the software analyzing the sensor data. This has a great potential of reducing costs, which is why Kongsberg Automotive asked for some research into 3D-sensor technology for use in GLUs. The written result of that research is this report.

Kongsberg Automotive (KA) is a company that develops, manufactures and markets systems for gearshift, clutch actuation, seat comfort, stabilizing rods, couplings and components. KA is a global company and is working as a supplier towards the automotive business worldwide.

QRtech is doing most of the electronic development of KA and the main work on this thesis was done there. QRtech has its focus on development and industrialization of electronic and software products and have developed products for both Swedish and international customers for the last 10 years. Automotive applications are dominating, and several European vehicle manufacturers have electronics and software developed by QRtech in their cars and trucks.

What has been done before this?

Most gear lever units manufactured today are implemented using magnetic sensors to detect the position of the gear lever while a few use micro switches, Reed sensors and/or optical sensors. E.g. an undisclosed car manufacturer we know of is using Hall sensors to detect the discrete gear positions and another undisclosed car manufacturer we know of is utilizing a magnetoresistive technology enabling them to detect the position of a lever in a two dimensional space. To our knowledge, few products on the market utilize techniques based entirely on sensors without the cable gear system in place. The automotive industry is using the existing sensor system to give additional information to the vehicle about what gear is in place. The cable system, however, is the one shifting the actual gear in the gearbox.

Downsides of the existing solutions

Today the electronics has to be custom made for each gearshift model, with additional cost for development. By using a standard setup of PCB and equipment for all the different gear shifters, and differentiate them by loading different software, great sums of money can be saved. If the technology proves to be mature and safe enough, the cable system might be abandoned totally which leads to; less production costs, saving manufacturing mounting costs, reduced repair costs, saved in-vehicle space which might be used for other purposes.

1.2 Purpose and goal

There is a need to investigate more flexible and cost efficient gear shifting systems and the goal of the project is to investigate 3D sensor technologies, trying to find alternatives suitable for gear level units. The 3D sensor solution should work as a direct alternative to the current sensor technology. A part of the goal is to analyze different solutions and explain why some solutions work better than others. Another part is to develop suitable tests for comparisons between the more promising alternatives and conduct them. The final purpose is to give the students working on this project valuable practice and knowledge in the fields of machine oriented programming, reliable data communication, embedded systems, dependability, distributed systems and digital electronics.

1.3 Delimitations

This thesis work is aimed at surveying the market of potential 3D-position sensors and similar techniques. It is not part of this thesis work to develop a fully functional 3D-sensor gearshift. During the research phase, many different 3D sensor alternatives might be considered, but the alternatives that are already commercially available and fit for an automotive environment should receive focus. It is acceptable to research a new solution, but only commercially available alternatives may be chosen for the test phase. The tests conducted just need to focus on the most relevant aspects and do not need to be all encompassing.

1.4 Related work

Other than the prototypes described as potential 3D sensors in this report, we have not been able to find any other related work, and no survey of the available solutions for electronically measuring the position of a gear stick position.

Chapter 2

Method and analysis

The project behind this report was split into two different parts:

- exploring possible gear lever sensing techniques and
- analyzing the alternatives showing most potential

This chapter briefly describes our approach to these tasks. It first tells of how we broke down the problem into smaller bits, and then gathered information about the different ways of solving those problems. By combining the different bits and pieces of information from different sources, a picture opened up, viewing various ways the tasks could be treated. The techniques and sensors were analyzed and compared and test specifications were written to accommodate the different aspects needed to be evaluated. Finally the different sensor solutions were analyzed as a whole.

2.1 Problem break down

The problem was split into the following tasks:

- Build up knowledge about 3D sensor technology as well as current gear lever sensing technology.
- Compare different techniques, sensors and implementations.
- Evaluate how the sensor can be implemented in a shifter.
- Write test specifications based on automotive requirements.
- Design hardware, electronic hardware, and software for sensor evaluation.
- Perform tests according to the test specifications written.
- Suggest a "best approach" for the development of a new gear lever sensor.
- Write report.

These items were put in a project plan and worked on throughout the project.

2.2 Method

To solve the main task, the problem was divided into sub tasks and different methods were used for different types of tasks. Specific scientific methods were not deliberately chosen beforehand.

Information gathering

Many different sources were searched, both on the Internet, at the library, and through meetings with experts within the subject. In the beginning, the face-to-face contacts proved very valuable to sort out what kind of information one could envisage to acquire. Quite quickly we were introduced to a whole new knowledge area and gained insight into both the mechanic, electronic, and magnetic aspects of the gear lever unit as well as the fundamental mathematics and physics that the sensor systems are based upon. Apart from the physics provided by the courses taken at Chalmers, specialized information was scarce at the university, and even thorough searches at the university library provided modest information to continue work on. Instead, we had to focus our information gathering procedures to the Internet, where a wide variety of information was available. Not all of it relevant though, far from it, and critical selection of sources and relevance of the information had to continually take place. We found that our specific subject was not widely popular, but the building blocks for the construction of a 3D sensor solution of the gear lever unit did exist. Manufacturers providing sensors that resembled the type that could fit within the scope of the subject were all contacted and asked if they had any research going on not available on their web pages. This was done in order to survey the whole market of potential sensors and trying to understand what was going on in the industry.

Information management

By combining the information gathered from different manufacturers with the physics known, and the hints and tips from experts, we were able to sort out solutions that were showing potential to solve the problem at hand. Different technologies of positioning were evaluated and implementations using the sensors we found were calculated in theory.

Comparison of the sensors

The different sensors discovered to be of interest to the project were compared to one another according to a set of characteristics that had been worked out in collaboration with Kongsberg Automotive, our mentor, and our examiner. The aim of the comparison was to give each contender an equal analysis and try to find the specifics making one stand out in relationship to the others.

Writing test specifications

The solutions proposed in the previous phase are dependent on the performance of the individual sensors. Some of them are difficult to compare to one another, since the data sheets are not consistent in what kind of information the different manufacturers supply. The sensors also are not constructed in the same way, do not always work in the same manner, and measure different magnitudes. The solutions of positioning need to make sure that the sensors are task fit and that different aspects of their operation are not looked over. The sensors thus needed to be tested according to the demands given by the positioning solutions elaborated, but also be tested according to the demands provided by the industry requesting the positioning system in the first place. Kongsberg Automotive have exhaustive test documents detailing miniscule test aspects of all the products in their production towards the automotive industry. By examining them and adjusting them to fit our context, we had a supply of tests that are relevant and feasible to conduct. The tests planned needed structures and environments to be performed, and to oblige those demands, a test rig, electronic hardware, and software, needed to be custom fit for the task. In conjunction with Kongsberg Automotive the test rig was to be constructed and built, however, it was not without complications, due to misunderstandings and other difficulties, leading to severe delays. In the end, the construction of the test rig and the surrounding difficulties took so much time from the project that the actual testing never took place.

Analysis of the sensors

The results of the test phase were to be used in addition to the specifications supplied, in order to decide if the sensors were capable of being used for the project purpose. Then a conclusion of the project was written and the reasons for continued work within the subject were proposed.

Chapter 3

Investigating 3D Sensing Techniques

The aim of this report is to explore 3D sensing solutions for an implementation in GLUs and compare the alternatives. This chapter will try to analyze the ideas, strategies and techniques behind positioning of a known object. It will not focus only on 3D sensing but rather on flexible ways to monitor the position of an object, for usage in a GLU setting.

The flexibility of the sensor solution is more specifically the ability to have identical sensing hardware in different GLUs, just changing the software to fit the specific gear lever positions. A single sensing solution that can handle varying gear lever setups require a sensor that can detect all possible lever position within a certain volume adjacent to the sensor hardware, which leads us to analyze a 2D/3D positioning problem.

3.1 Positioning in general

The initial aspect will be to look purely at the positioning problem.

In order to avoid getting stuck in preconceived ideas regarding positioning, the analysis begins by evaluating the subject of positioning very generally, while still having the approximate requirements of a working, attractive solution in mind. The following part of the report is meant to be useful as a basis when thinking about new positioning solutions.

To detect the position of an object one needs to receive information **describing** the position of the object, or information **affected** by the position of the object. Let us name the carrier of this information a “signal”.

The signal can be

1. from an external source, e.g. ambient light when considering optical sensors.
2. naturally emanating from the object, e.g. radiation or magnetic fields
3. actively sent by the object, e.g. if the object itself knows and transmits its position
4. sent by the sensing unit, affected by the object and then returned, e.g. radar.

Interesting signal types that we know of

- **a.** Touch (mechanical interconnection)
- **b.** Light emission (including “invisible” light e.g. heat/infrared)
- **c.** Sound waves, e.g. ultrasound
- **d.** Radio waves
- **e.** Passive magnetic fields
- **f.** Electromagnetic fields (actively generated)
- **g.** Gravitational pull
- **h.** Smell and taste (substance concentration and chemical effects)

Combining different ways to transmit signals with possible types of signals result in possible solutions for information transmission.

However, any information will not do. Deciding the position of an object requires the information to be relevant, and a technique for deducting the position from the information received by the sensor.

The target application in this analysis is to detect the position of a gear lever, and it may therefore be practical to sort positioning techniques in the following four categories:

- 3D positioning
- 2D positioning
- 1D positioning
- Joystick (lever) specific positioning

A deep analysis of all possible combinations of signal types and signal transmission techniques would be very interesting, but would be of such a scope that is would not fit within this project. Instead, the following part will present a subset of those techniques and strategies that are of major interest, sorted by the categories mentioned above.

3.1.1 3D-positioning techniques

3D positioning would be the most flexible of the four mentioned solution categories, allowing great freedom when designing the GLU. The gear lever would not need to be a lever at all but could be shaped freely. It would not even need to be attached to the GLU. But regardless of these possibilities, the most probable and imminent implementation of a GLU with 3D sensors would probably be one that looks just like a GLU of today, on the outside. The difference will be that the set of sensors that was previously used to detect a gear lever position is replaced with a single 3D sensor.

3D sensing is the preferred technique because of the design possibilities and will be given most of the attention in this chapter, but other techniques will be looked at as well for comparison. While great freedom to design can result in the most attractive GLU available on the market from a customer perspective, other aspects are very important as well in the automotive industry, e.g. reliability and cost effectiveness. Different solutions have different strong and weak points. But first of all, let us look at 3D sensor solutions.

There are several ways to create 3D positioning sensors and on the following pages are a few examples of high interest.

3D positioning from a pair of 3D angle sensors

This way to detect a 3D position is based on two individual 3D angle sensors. A 3D angle sensor is a sensor that measures the angle to an object in three dimensions. Much like a compass, but in three dimensions.

To get the idea of how to measure a 3D position using two 3D angle sensors, imagine having two separate floating arrows (the 3D angle sensors) always pointing at a movable object. The arrows (sensors) have static and known coordinates. Now, the movable object cannot change position without affecting the way the arrows point and the pair of arrows will point in a unique way for each position.

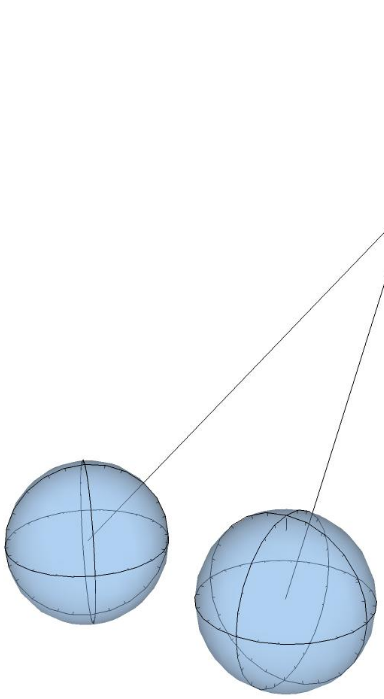


Fig 3-1. 3D positioning technique using two 3D angle sensors.

The 3D *angle* sensor itself can be implemented in different ways, e.g. by using two 2D angle sensors placed orthogonally to each other. See the section below about a 3D positioning sensor using only 2D angle sensors to get an idea of why two orthogonal 2D angle sensors could make a 3D angle sensor.

The math behind technique revolves around finding the intersection between two lines in three dimensions. This may sound simple, but because of the risk that the lines will be slightly skewed (not intersect) the math can become rather complicated. (Wolfram) Since this complication appears as soon as there are small measurement errors, the fault tolerance can be considered low.

3D positioning from one 3D angle sensor and distance measurement

Combining information from a 3D angle sensor with a sensor that can measure the distance to the object will enable 3D positioning. The 3D angle sensor will point toward the object, creating an infinite line on which the object should be found. The distance sensor data will limit the object position to the surface of a sphere around the distance sensor where the sphere radius is the distance to the object. As long as the surface of the sphere never intersects the aforementioned line in more than one point, that intersection will be the position of the tracked object. If it is possible to limit the space in which the object may move, which it is in many applications of a 3D sensor solution, the surface of the sphere will always intersect the line in one point only.

As long as the 3D angle sensor is within the imagined sphere around the distance sensor, the line can only intersect the sphere surface in one point. This means that the distance between the two sensors needs to be smaller than the distance between the object and the distance sensor, which will be easy to guarantee in almost all implementations.

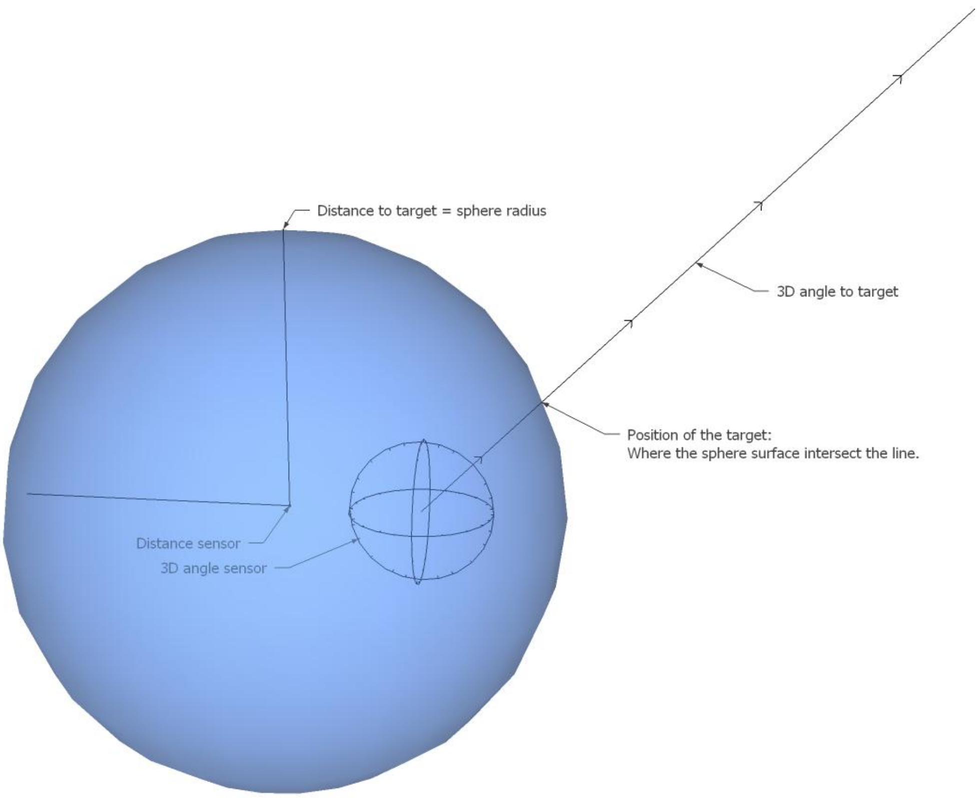


Fig 3-2. Using a distance sensor and a 3D angle sensor for 3D positioning.

The math behind this technique revolves around finding the intersection between a line and a sphere surface. Knowing the absolute positions of the sensors, the math becomes quite simple.

An infinite line through a three-dimensional space that passes through the point (x_0, y_0, z_0) has parametric equations: (Wolfram)

$$\begin{aligned} x &= x_0 + at \\ y &= y_0 + bt \\ z &= z_0 + ct \end{aligned} \quad \text{(Equation 3.1)}$$

Where a, b and c must not all be zero.

The surface of a sphere with radius R can be described in Cartesian coordinates by: (Wolfram)

$$x^2 + y^2 + z^2 = R^2 \quad \text{(Equation 3.2)}$$

The point of intersection will fulfill both equations. Inserting the first equation into the second equation gives:

$$(x_0 + at)^2 + (y_0 + bt)^2 + (z_0 + ct)^2 = R^2 \Rightarrow \quad \text{(Equation 3.3)}$$
$$t^2(a^2 + b^2 + c^2) + t(2ax_0 + 2by_0 + 2cz_0) + {x_0}^2 + {y_0}^2 + {z_0}^2 - R^2 = 0$$

This is a second order equation from which t_1 and t_2 can be calculated. It becomes a second order equation because the line considered is infinite and it will therefore intersect with the sphere in two points.

Inserting t_1 and t_2 respectively in into Equation 3.1 will result in two possible points where the object may be. When considering the direction indicated by the measurement from the 3D angle sensor, only one of the points will remain as a valid solution.

The math will remain the same even if the sensors measurements would become slightly erroneous. The line will still intersect the sphere, but the position of the object will not be entirely correct. As a result, this 3D sensing technique will not suffer much from small sensor faults. Adding more distance sensors will increase the ability to discover and correct errors while keeping the math simple. Adding more 3D angle sensors will introduce the risk of skew lines, which is harder to handle gracefully.

3D positioning from three 2D angle sensors

Another way to detect a 3D position is through the use of three 2D angle sensors. A 2D angle sensor can measure the angle to an object in two dimensions, much like a compass. Using three such sensors all locked on a specific object, placed in orthogonal planes, they will report a unique triple of angles for each position of the object.

How a position can be derived from the three 2D angle sensors is described by the images and descriptions below.

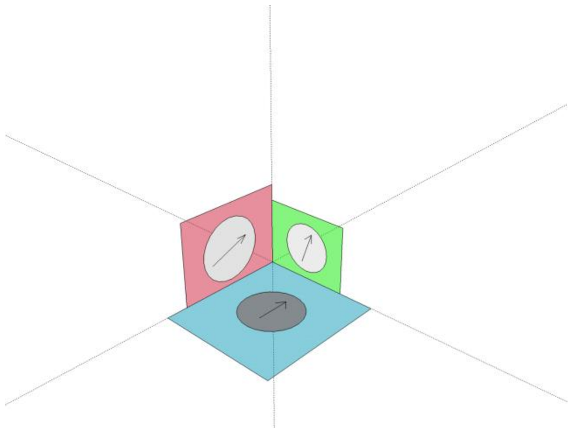


Fig 3-3. Three 2D angle sensors, placed orthogonally.

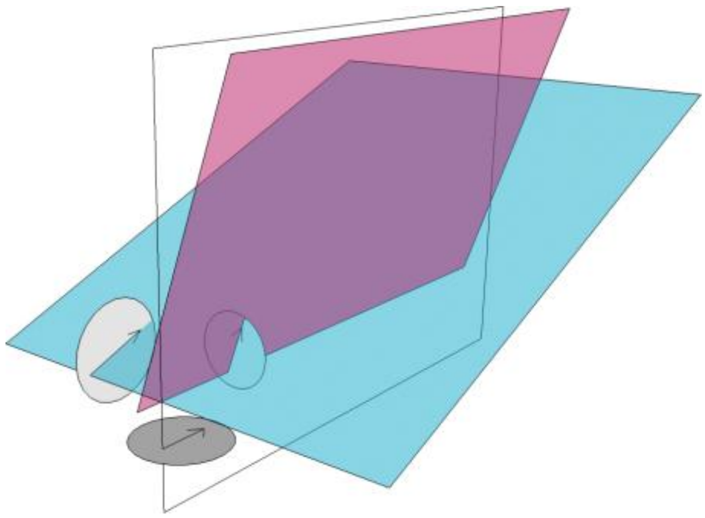


Fig 3-4. Each 2D angle sensor created a plane of possible positions based on its measured angle.

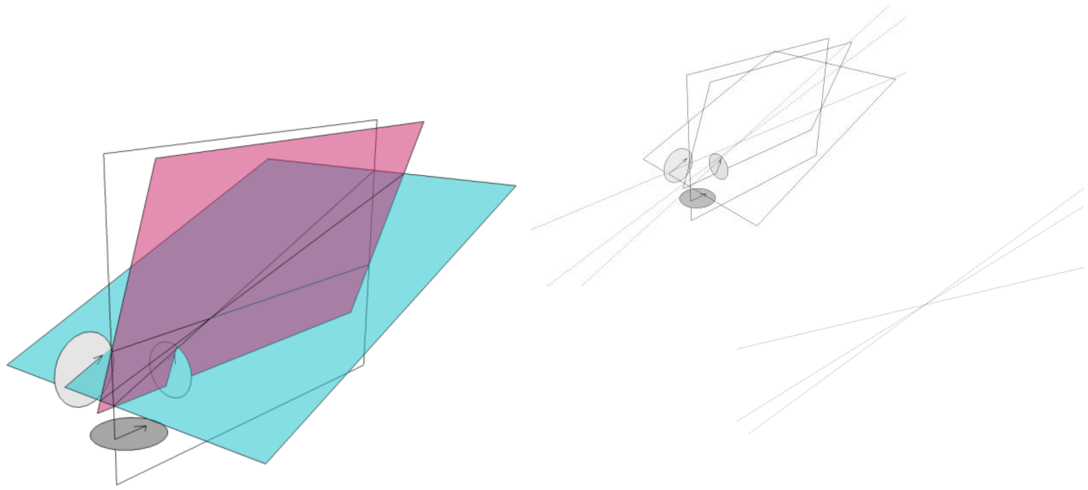


Fig 3-5. Intersections.
The planes will intersect (since all three sensors are tracking the same object), creating lines where each two planes intersect. All three planes will intersect in a single point and that will be the position of the tracked object. This will be the only position where all three sensors agree that the object may be positioned. The positioning works since the object cannot move without changing at least one of the sensor values and each position will be associated with a unique triple of angles.

Only two intersecting lines are needed to get a fixed position and it might therefore be tempting to think that only two sensors are needed. However, remember that with two sensors there would only be two planes intersecting each other, and therefore only one line. A third plane will intersect both other planes, creating two new lines, and all three lines will intersect in one point, as long as the sensors are correctly tracking the same object. It is enough to consider only two of the lines when calculating point of intersection though, which simplifies the math needed to determine the position of the object.

Solving the problem straight up can be done as follows though, according to (Wolfram):

Let three planes be specified by a triple of points $(x_{i\,j}, y_{i\,j}, z_{i\,j})$ where $i, j = 1,2,3, i$ denotes the plane number and j denotes the jth point of the ith plane. The point of concurrence (x, y, z) can then be obtained straightforwardly (if laboriously) by simultaneously solving the three equations arising from the coplanarity of each of the planes with (x, y, z), i.e:

$$\begin{vmatrix} x & y & z & 1 \\ x_{i1} & y_{i1} & z_{i1} & 1 \\ x_{i2} & y_{i2} & z_{i2} & 1 \\ x_{i3} & y_{i3} & z_{i3} & 1 \end{vmatrix} = 0 \qquad \text{(Equation 3.4)}$$

for $i = 1,2,3$ using Cramer's rule.

Since the three planes will intersect each other even if there are minor measurement errors, the technique will handle that kind of trouble without much trouble. Additional, redundant angle sensors could be added to for error checking.

3D sensor from distance measurement using three or four sensors

Yet another way to discern the position of an object in three dimensions is through the use of distance data. Knowing the distance between the object and four different points with a known position in space is enough to calculate the position of the object, as long as the known points are chosen with some care. (No triple of the known points may be on a line, and all four sensors may not be placed in the same plane) Having only three known points and distances will result in two possible 3D positions, one on each side of the plane that the three points lie in, unless the object is in the same plane too resulting in just one possible position. Three known points and distances is therefore enough if it is possible to limit the movement of the object to one side if that plane.

To understand why this works, think of the known points as sensors continually measuring their distance to the object. Each individual distance sensor will tell us that the object is somewhere on the surface of a sphere surrounding that sensor, a sphere in which the sensor is the center point, and the radius of the sphere is the distance to the object.

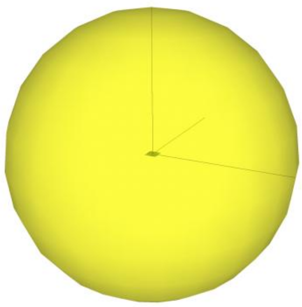


Fig 3-6. A distance sensor. The object is somewhere on the surface of the sphere.

When two sensors are considered, the two sphere surfaces will intersect and create a point or a circular intersection on which the object will be found.

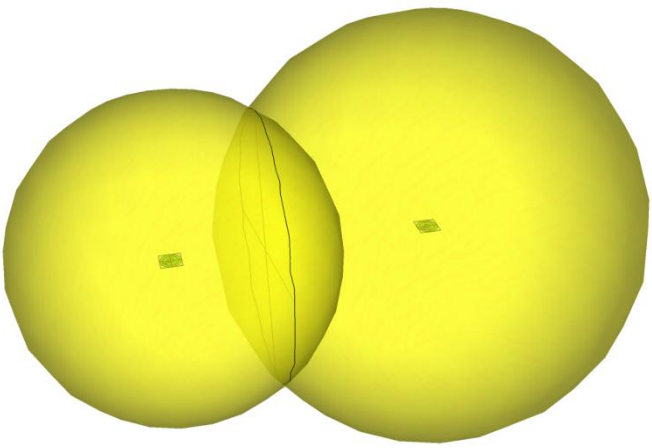


Fig 3-7. Two distance sensors measuring its distance to an object. The object must be somewhere on the circle that is created where the two spheres intersect.

All spheres that intersect each other will have a circular intersection, with a maximum possible radius equal to the smallest radius of the two spheres and a minimal radius of zero (a point). When a third sensor is considered, this third sphere surface will intersect the previous intersection, the circle, in *at most* two points.

As Fig 3-9 shows there will be three circles of intersections when three spheres intersect and the circles will intersect each other in two points. This will only hold true as long as the sensors are not all placed on a single line. If that would be the case, two of the spheres would always intersect the third sphere in a shared circle and no new information would be gained by using a third sensor.

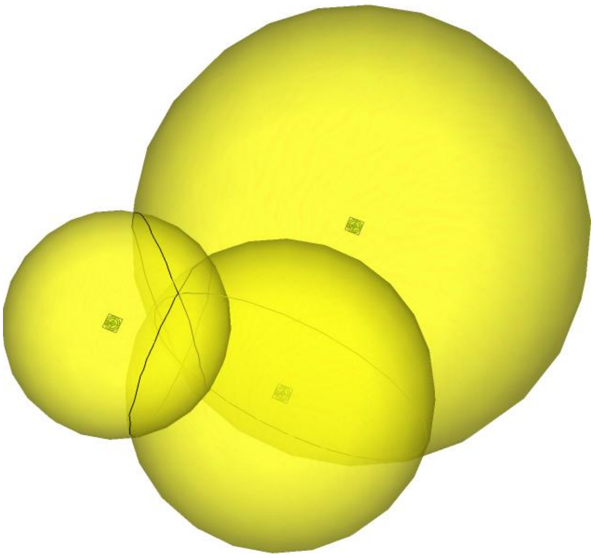


Fig 3-9. Three spheres intersecting each other.

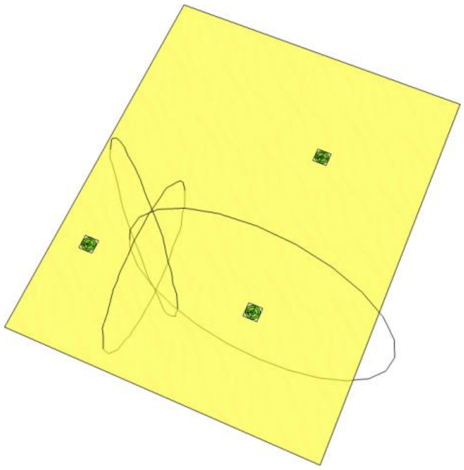


Fig 3-8. Circular intersections of the three spheres.

The intersections will result in one or two points, two points being the normal case. These two points will be separated by the plane that the three sensors lie in.

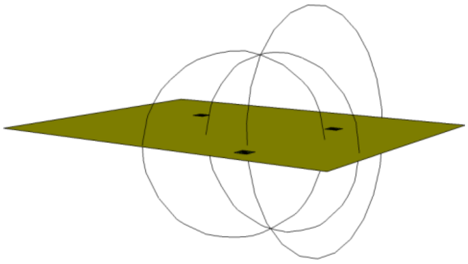


Fig 3-10. Intersections from three spheres, divided by the plane in which the spheres' center points lie.

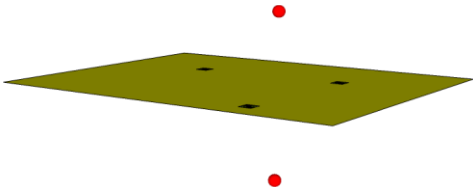


Fig 3-11. Two possible positions of an object tracked by three distance sensors.

It is often the case that it is known beforehand on which side of that plane the object will be, which means that only three sensors are needed to calculate the 3D position. If this is not known beforehand a fourth sensor will be needed, but it must not be placed in the same plane as the other sensors. Placing it in the same plane as the three other sensors would only give redundant information since the new sphere would intersect the same two points as the other spheres. Placing it outside of that plane would bring new information however and a single intersection point could be decided.

This same idea is used in the Global Positioning System, although implemented slightly differently. The satellites are the known positions in space and the distance to these points are calculated based on information **sent** by these satellites and **received** by the object. The information sent is the position of the satellite and exactly at which time the message was sent from the satellite. Based on the time it takes for this message to travel from the known point in space to the object, the distance can be calculated. Therefore, no information regarding the object itself is needed. The position of the object naturally affects the signal in such a way that the position can be calculated. However, this requires very careful synchronizing the clocks between the sender and the receiver, or worse precision and additional calculations. (Langley, 1991) Even though there are a few differences between the methods, the mathematics needed to solve the positioning problem is very similar.

For a good analysis of the math behind this kind of positioning, see the reference (Wikimedia_GPS, 2010) and further, the references given there.

Slight measurement errors will cause the intersections to skew and the math becomes complicated when this is considered and compensated. Adding more sensors will increase the fault tolerance but the error handling will remain as a substantial part of the calculations.

3.1.2 Other interesting positioning techniques. (Not 3D)

While a 3D positioning solution would be the most flexible one, it is not necessarily the best one when all aspects are considered. To get a good idea of what the competing solutions may offer in comparison, this section will be about solutions that try to solve the same problem, lever position sensing, but in a simpler less flexible fashion. Generally, these solutions will cost less and be just as reliable but not have the same level of flexibility, which limits the possible GLU designs.

2D positioning techniques

2D positioning is very similar to 3D positioning but handles one dimension less. Simpler may sometimes be better though, and usually cheaper. A very important characteristics of the 2D positioning technique is that is retains one of the crucial benefits of the 3D sensor solutions. It is still possible to keep the same hardware sensor layout from GLU model to model. If the number of gears change, or the gear lever positions, all that needs to be changed on the GLU sensor side is the software that interprets the lever positions. Below is an example that shows how a 2D positioning sensor could be used to detect a lever position.

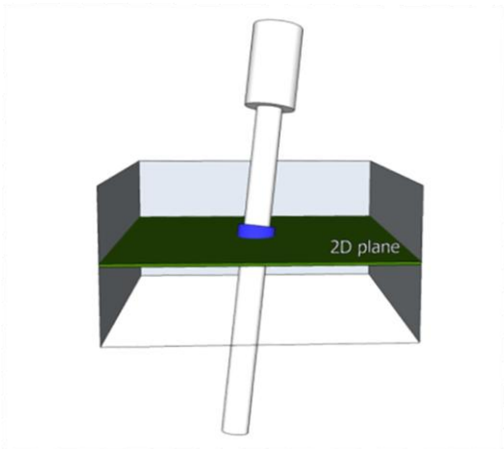


Fig 3-12. Example showing how a 2D sensor can be used in a GLU.

This implementation requires that each gear has a unique lever position in a plane, but this is very commonly the case.

Two examples of 3D sensing techniques are

- Distance measurement from two sensors
- Angle measurement from two 2D angle sensors

2D positioning using distance measurement could be implemented by putting distance sensors in two adjacent corners of the 2D plane. The distance measurements would result in possible positions corresponding to a quarter of a circle for each sensor. The precision could vary based on where the object would be positioned though.

Angle measurement from two 2D angle sensors could be implemented in the same manner, by placing two sensors in adjacent corners of the 2D plane. They could be placed further away from each other and the plane without measurement problems, but not closer together than the corners of the plane. This technique was used in a related project to implement 2D positioning and it worked quite well.

Overall, there seems to be very few downsides using a 2D sensor solution instead of a 3D sensor. This might be why most of the readymade solutions found on the market focus on 2D sensing and not 3D. Another reason behind this could be the added complexity of a 3D sensing solution though.

1D positioning techniques

Positioning in one dimension is easy, reliable, tested and cheap, but far from the flexibility of a 3D sensor. It might still be usable as a method for gear detection though. There is no math behind these solutions, just plain sensors.

It might be possible to use 1D positioning and still offer some of the flexibility of the advanced alternatives though. Consider the following example; Make the gear lever into a control knob, perhaps like following.

Fig 3-13. BMW car computer control knob. [1]

Instead of controlling the car computer, the knob would electronically control the gearbox. Available gears could be shown on a display above or around the knob. Turning clockwise would gear up, anti-clockwise would gear down. By using an electromagnet to vary the resistance in the knob it can be programmed to manage any number of gears and tuned to maximize the chance of a "good feeling" when shifting gears. Programming the device for different gear setups would be easy. The problem with this solution lies in getting customers to accept and like a new way to shift gears instead of the commonly used lever interface.

Joystick specific positioning techniques

Assuming that the lever will remain as the dominating and most accepted way to interact with the gearbox of a car for some time is probably not a bad idea. It might therefore be well worth it to consider if there are sensor setups that are made specifically for levers and still have the traits wanted.

There are a few attempts at complete solutions on the market already, but these will be analyzed in chapter 4, 'Analysis of “out of the box” 3D sensors'. Instead, this part will present an example of a simple, yet possibly very good solution.

Keeping track of a lever position can be done through the use of two simple, wired, cheap angle sensors. Construct the lever in a way that makes sure the lever only changes the angle of two axles when moving around, and keeping track of those angles is enough. That will make the sensor setup just as independent from gearbox setups as any 3D sensor, the changes of gears or lever positions being handled in software.

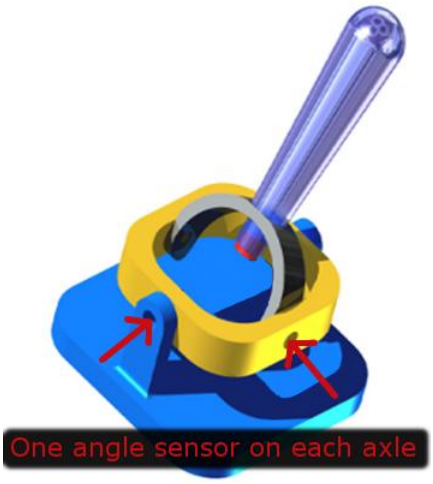


Fig 3-14. A joystick specific sensor solution based on very simple angle sensors. [2]

3.2 Existing sensor technology

In order to understand the functions of sensors treated in this report, the most common sensor types will be described here, focusing mainly on Hall effect sensors and magnetoresistive sensors.

Hall sensors

A Hall sensor is a transducer, i.e. a device that converts one type of energy or physical attribute to another. In this case, the transducer converts a magnetic field level into electrical form. It uses the Hall effect discovered by Edwin Hall in 1879 (Hall, 1879). If an electrical current is applied in an electrical conductor and a magnetic field is applied perpendicular to the current, across the conductor there will be a voltage difference – the Hall effect. This effect has thus been known for a long time, but the first real application was in the 1950s, and increased in usage with the development of semiconductors and integrated circuits.

General features of Hall effect sensors according to (Honeywell)

• True solid state

• Long life (30 billion operations in a continuing keyboard module test program)

• High speed operation - over 100 kHz possible

• Operates with stationary input (zero speed)

• No moving parts

• Logic compatible input and output

• Broad temperature range (-40 to +150°C)

• Highly repeatable operation

Magnetoresistance

In 1857, Lord Kelvin published an article describing how the resistance in a magnetic electric conductor decreases if magnetic field lines are applied in parallel to the conductor. In addition, he showed how the resistance in the same conductor increased if magnetic field lines were applied orthogonally to the conductor. The phenomenon, called (anisotropic) magnetoresistance (MR), shows small changes in the resistance and is used in some sensors for linear positioning and angle sensing. The development of nanotechnology made the field evolve into giant magnetoresistance (GMR) which, for example, has been applied in the read-out heads in hard disk drives. This was awarded with the Nobel Prize in Physics 2007 (The Royal Swedish Academy of Sciences, 2007).

Comparison between Hall effect and Magnetoresistance according to (Honeywell)

1. Both technologies are compatible with integrated circuit processing and may be used to make totally integrated single-chip sensors.

2. MR is roughly 100 times more sensitive than the Hall effect in silicon. Furthermore, it is adjustable through selection of film thickness and line width.

3. The Hall effect is highly linear with no saturation effects out to extremely high fields.

4. The Hall effect occurs for fields applied perpendicular to the plan of the all element. The magnetoresistive effect occurs in the plane of the thin film perpendicular to the long direction of the resistive elements.

5. Both effects occur for time-invariant fields and may be used to construct zero speed sensors.

	Hall	MR
Process technology	Silicon IC	NiFe thin film
Sensitivity	10 uv/v/g	2 mv/v/g
Saturation field	None	10 – 100g
Linearity	< 1%	$\cos^2 \Theta$
Sensitive axis	Perpendicular to plane of chip	Parallel to plane of chip
Output for constant field	Yes	Yes

Reed sensors

This switch is constructed of two metal reeds in a sealed glass envelope as seen in Fig 3-15. In a normal state, the reeds do not touch each other, but when a magnetic field is applied, the reed contacts close. When the magnetic field is not present anymore, the contact is open again. The switch can also be constructed to operate in the opposite way, i.e. to normally be closed and open when a magnetic field is present. The reed switch was invented at Bell Laboratories in 1936 by W.B. Ellwood. The reed switch is not very complicated and as such the usage is quite limited. It is mostly used in mechanical systems as proximity switches in burglar alarm systems, or bicycle speed sensors.

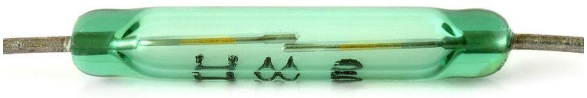


Fig 3-15. A Reed sensor [3]

According to (Johnston, 2000) advantages of reed switches are their small size, they require just a small amount of magnetic force, and they are cheap and easily obtainable. Disadvantages of reed switches are that they are rather fragile and also that they cannot handle large currents or voltages which cause them to spark, weld, or lose their springiness.

To our knowledge, this kind of technique is limited to functioning as the early Hall effect sensors, that is, it cannot be used in any other way than as a pure switch, making it unsuitable for this project.

3.3 The physics of magnetism

This section describes the fundamental physics that is helpful to understand when considering how the magnetic sensors are functioning. Of special interest for the understanding of how the magnetic sensors function are the topics about the Hall effect and the magnetoresistive effect in the end of this subchapter.

Magnetic field

The most common way of describing the effect of the magnetic field **B** is to put it into the context of what effect it has on a particle. According to (Serway, 2000, p. 908) this particle has an electric charge *q*, moves with the velocity **v** inside the magnetic field **B** and experiences a magnetic force $\mathbf{F}_B$. $\mathbf{F}_B = q\mathbf{v} \times \mathbf{B}$, the × being the cross product.
The **B**-field is measured in T (tesla) in SI, but in several instances of resources concerning magnetic sensors, the cgs unit G (gauss) appears. 1 T = 10 000 G. Since the tesla is a fairly big unit, the most applications involving magnetic sensors use strengths spanning 20 mT – 150 mT.

Magnetization and magnetic field strength

"The magnetic state of a substance is described by a quantity called the magnetization vector **M**. The magnitude of this vector is defined as the magnetic moment per unit volume of the substance." "The total magnetic field **B** at a point within a substance depends on both the applied (external) field $\mathbf{B}_0$ and the magnetization of the substance."
$\mathbf{B} = \mathbf{B}_0 + \mu_0\mathbf{M}$
"The magnetic field strength represents the effect of the conduction currents in wires on a substance." "The magnetic field strength is a vector defined by the relationship $\mathbf{H} = \mathbf{B}_0/\mu_0 = (\mathbf{B}/\mu_0) - \mathbf{M}$."
$\mathbf{B} = \mu_0 (\mathbf{H} + \mathbf{M})$
"The quantities **H** and **M** have the same units. In SI units, because **M** is magnetic moment per unit volume, the units are (ampere)(meter)^2/(meter)^3, or amperes per meter."
Another unit for the **H**-field is in the cgs system the Oe (oersted). 1 Oe = 1000/4π A/m. In vacuum 1 Oe = 1 G, while in a substance with the permeability μ it is 1 Oe = μ G.
All the quotations are gathered from (Serway, 2000, pp. 957-958).

Ferromagnetism

"A small number of crystalline substances in which the atoms have permanent magnetic moments exhibit strong magnetic effects called ferromagnetism. Some examples of ferromagnetic substances are iron, cobalt, nickel, gadolinium, and dysprosium. These

substances contain atomic magnetic moments that tend to align parallel to each other even in a weak external magnetic field. Once the moments are aligned, the substance remains magnetized after the external field is removed.“
“All ferromagnetic materials are made up of microscopic regions called domains, regions within which all magnetic moments are aligned.”
Quotations from (Serway, 2000, p. 960).

Magnetic hysteresis

The ferromagnetic substance’s magnetization is dependent on the magnitude of the applied field, but also on the history of the substance. (Serway, 2000, p. 961) describes how ferromagnetic materials have a “memory” of what has happened before, and behave according to what state it is in at the moment. The word hysteresis is derived from an ancient Greek word meaning “to lag behind”.
Think of a piece of unmagnetized ferromagnetic material, for instance iron. If the magnetic field strength **H** is increased, for example by increasing the current in the material, the magnitude of the total magnetic field **B** also increases. At origo (O) in Fig 3-16 the domains containing the magnetic moments are all randomly oriented and the field produced by the ferromagnetic material is zero. As the magnetic field strength **H** increases, the domains become more aligned until the point (a) where almost all of the domains are aligned with each other. The material is approaching saturation, the state where all the domains are totally aligned. At this state, the magnetic field strength can be reduced to zero, but as the figure shows, at point (b) the material still has a magnetic field **B**. The material has been magnetized by the alignment of a large number of its domains. The whole of the magnetic field **B** is produced by the magnetic material itself, and the material is said to have remanent magnetization. If the **H**-field is reversed to the point of (c), the domains have reoriented themselves so that the material is no longer magnetized, **B** = 0. A continued reversing of the **H**-field makes the material saturated in the opposite direction to the first. Also, if the **H**-field was to be removed, the material would show remanent magnetization of the same polarity. The further increase of the **H**-field would lead to the point of (a) again.

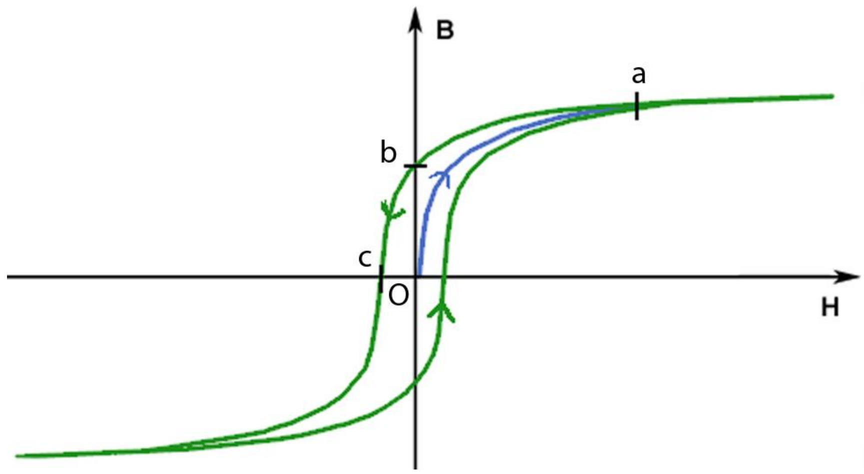


Fig 3-16. Magnetic hysteresis loop.

Magnetic saturation

As said by (Serway, 2000, p. 961), magnetic saturation is the state when an increase in applied external magnetizing field H cannot increase the magnetization of the ferromagnetic material any more, and thus the total magnetic field B is leveled off. When some magnetic sensors saturate, mostly the kind based on the Hall technique, the linearity error increase since the curve flattens off. Most sensors of that kind thus need to operate within a specific region of the magnetic field to give reasonable output.

Permeability of free space

The permeability of free space is an ideal physical constant representing magnetic permeability in vacuum. In (Serway, 2000, p. 939) it is defined as $\mu_0 = 4\pi \times 10^{-7}$ T·m/A

Other kind of hysteresis in magnetic sensors

Hysteresis effects are also found in other areas where a similar behavior to the magnetic hysteresis is desired. For example (Wikipedia, 2010, p. Hysteresis) tells that a simple magnetic sensor might serve as a switch, and in order for the output to be stable within a certain interval of magnetic influence, there is often a threshold value to put it in one state. Even if the measured magnetic field is below this threshold value, the output signal will stay the same within a certain interval, to accommodate for example mechanical vibrations moving the magnet small distances.

Magnetic energy product

The performance of a specific magnet, that is the stored energy in the magnet, is typically measured in units of MGOe (megagauss-oersteds). However, as stated in (Wikipedia, 2010, p. Oersted) it may sometimes also be listed in the SI units of J/m3 where one MGOe would roughly be equal to 7957.747155 J/m3.

Intensity of magnetization

It is not uncommon to see magnetization expressed in the unit tesla, which is the unit for the magnetic field **B**. According to (Wikipedia, 2010, p. Magnetic susceptibility) it is internationally called intensity of magnetization and is defined as $\mathbf{I} = \mu_0\mathbf{M}$. Thus the magnetic field **B** can be expressed as $\mathbf{B} = \mu_0\mathbf{H} + \mathbf{I}$.

Magnetic flux

The product of the magnetic field **B** normal to an area *dA* times that area is defined as the magnetic flux, $\mathbf{B} \cdot d\mathbf{A}$, where the perpendicular vector $d\mathbf{A}$ has a magnitude equal to the area *dA* (See Fig 3-17). According to (Serway, 2000, pp. 951-952) the total magnetic flux through an area is $\Phi_B \equiv \int \mathbf{B} \cdot d\mathbf{A}$. In some contexts, the B-field is called magnetic flux density because of its properties in reference to magnetic flux.

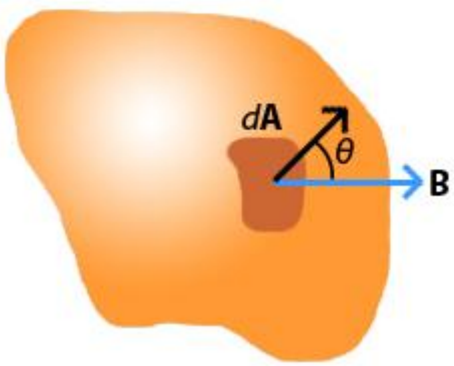


Fig 3-17. A surface, and the area *dA*. The magnetic flux through *dA* is B • *d*A.

When working with magnetic sensors, one mostly encounters a plane of area A, where the uniform magnetic field **B** makes an angle θ with d**A**. This special case leads to that the magnetic flux through that plane becomes $\Phi_B = BA \cos \theta$. So if the angle $\theta = 0$, that is, the field is perpendicular to the plane as in Fig 3-18, the flux becomes BA, which is the maximum value. On the other hand, if the angle $\theta = 90°$ as in Fig 3-19, the field is parallel to the plane and the flux is zero. Magnetic flux is measured in Wb (weber), which corresponds to $T \cdot m^2$.

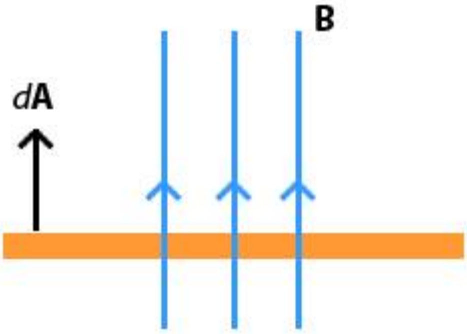


Fig 3-18. Magnetic field perpendicular to the plane, making the magnetic flux through the plane maximum.

Fig 3-19. Magnetic field parallel to the plane, making the magnetic flux through the plane zero.

Curie temperature

At a certain temperature a ferromagnetic magnet loses its residual magnetization, (Serway, 2000, p. 963) says that the domains lose their position and reposition themselves in a random manner. This should not pose a problem for this particular project, since the temperatures required to reach the so-called Curie temperature are higher than what the sensors themselves are specified at. Even so, it might be noted that the maximum practical operating temperature in air is lower than the Curie temperature to make sure that the characteristics of the magnet do not drift. The following table is taken from (Sura Magnets) and shows some common magnetic materials and their Curie and maximum temperatures, respectively.

Material	Curie temperature °C	Maximum temperature °C
Neodymium	310	150
Samarium cobalt	750	300
AlNiCo	860	540
Ferrite	460	300

The Hall effect

This is a phenomenon which makes it possible to measure the magnitude of the magnetic field. As described in (Serway, 2000, pp. 925-927) and as seen in Fig 3-20. The Hall effect, a flat conductor where a current I is present reacts to the magnetic field **B** applied. The charge carrying electrons experience a magnetic force accumulating them at one side of the conductor and creating an excess of positive charge at the other side of the conductor. This potential difference is what is called the Hall voltage V_H and can be measured with a voltmeter. This system is built into some of the sensors measuring the magnetic field, and as seen it is only sensitive to magnetic field lines that are not parallel to the conductor. There are ways of circumventing that limitation however, as seen in section 4.1.4. A ratiometric linear Hall effect sensor gives an output proportional to the magnetic field applied.

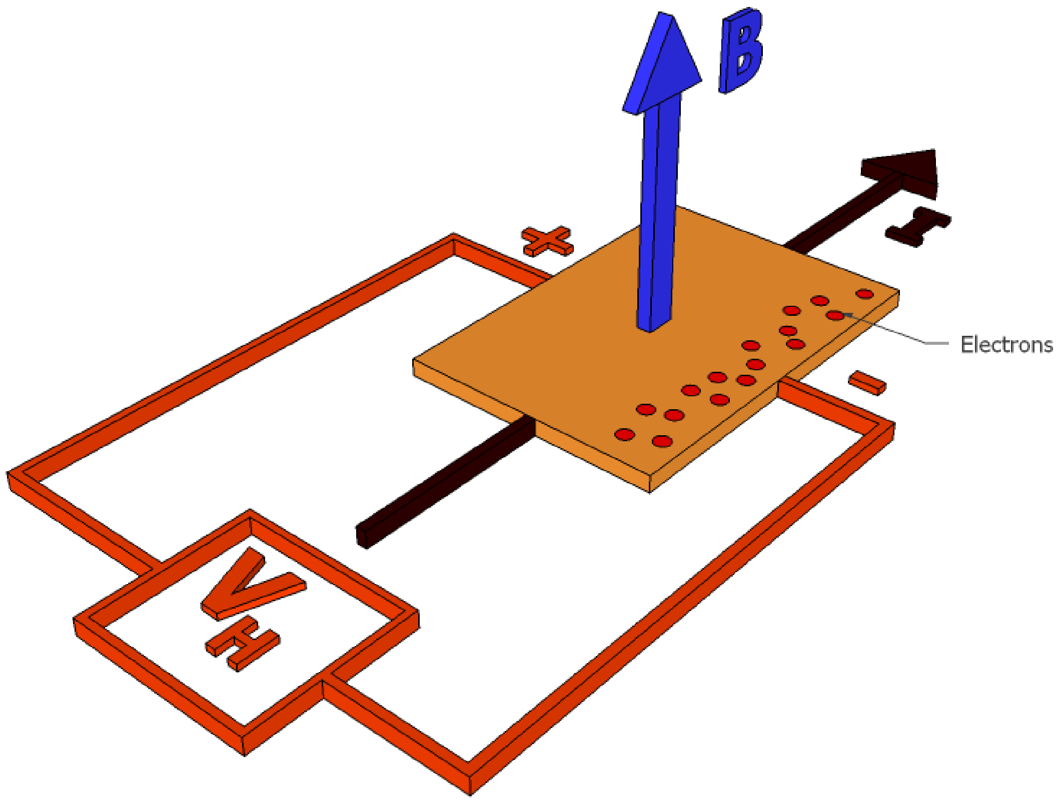


Fig 3-20. The Hall effect

Magnetoresistance effect

This is another way of measuring the magnetic field. Consider Fig 3-20 but instead of measuring the voltage V_H, the resistance in the conductor is measured. When the electrons are moved to one side of the conductor as a consequence of the magnetic field, the electrons travel a slightly longer path and the resistance in the conductor increase. The level of the resistance is proportional to the angle of the magnetic field lines, and this is used in the magnetoresistive magnetic angle sensors. Most often those kinds of sensors have a Wheatstone bridge like Fig 4-3 with four conductors and provide an output that is representing the angle between the plane of the sensor and the target magnet.

3.4 Implementing the techniques

Chapter 3.1 described possible techniques to handle the positioning problems and assumed the existence of sensors without caring about the technology within those sensors. However, no matter how thoroughly and well described a solution may be, it will not work without the building blocks that it depends on. In this case, the building blocks are:

- wired angle sensors
- touchless angle sensors that can measure the angle to a distant object
- touchless distance measuring sensors

When considering the steep requirements of the automotive industry when it comes to reliability over time, fault tolerance, managing temperature change, humidity, etc it quickly diminishes the alternatives. Looking at the most commonly trusted sensor technologies in the automotive industry today, on the demands and on the possible solutions with their specifications it was decided that magnetic sensors was the best sensor solution available and it will therefore be the focus in this report.

A downside to the magnetic technologies is that permanent magnets that are used sometime change their magnetic signature during its lifetime, most commonly by diminishing in strength. To compensate for this, a GLU sensor solution can either use electromagnets with a constant charge, or automatic calibration procedures that adapt to the changing footprint of the permanent magnets. Calibrations could be done at regular service intervals, or possibly even as often as every time the car starts with a confirmed lever position.

Chapter 4

Analysis of "out of the box" 3D sensors

While it would have been much fun to design a new technology for 3D positioning, no alternatives were found that could have been developed quickly and cheaply enough to satisfy the requests that were given by the job initiator Kongsberg Automotive. The automotive industry generally prefers mature and verified technologies and we did not find a way to produce such a product within the scope of this project. Ideas to explore further can be found in chapter 3 of the report - *Investigating 3D Sensing Techniques*.

After concluding that magnetic sensing was the most promising technology, all companies found of interest were contacted regarding existing 3D sensors and possible development within the area. Companies that were considered interesting can be found in Appendix B. Even though not all of them answered and small, cheap, reliable 3D sensing is still far from being a commonplace technology, a few interesting alternatives were still found:

- Austria Micro Systems (AMS) angle sensor
- Honeywell angle sensor
- Measurement specialties (MEAS) angle sensor
- Melexis 3D sensor
- Micronas angle sensor
- Paragon joystick sensor

While only Melexis' and Paragon's sensors were somewhat worthy of being considered true 3D-sensors out of the box, they can all be used as building blocks when designing a gear level sensor.

Following now is a brief study of each sensor, which will be used as a basis for choosing three sensors for further testing and analysis.

4.1 The sensors

Five of the sensors share several fundamental similarities, such as that they are all constructed to be surface mounted on a PCB. The five sensors need a supply of 5 V and their output is some kind of representation of an angle, distance or position of a close-by magnet. They measure the magnets whereabouts using either the Hall effect or the magnetoresistive effect as described in section 3.2.

The one sensor that does not quite fit in among the other candidates is the Paragon sensor system which is almost stand-alone. It does not use the same technologies as the other sensors and it has been impossible for us to obtain the necessary document to make a serious judgment of its functions. What we have understood from the very slim amount of information given us, is that it features some induction sensing constructed of a transmitter at the bottom end of the gear stick and an antenna-receiver below that transmitter. The manufacturer claims that it is a fully working system, but has been unable to provide us with more evidence of that claim. Since it gives the impression to be an interesting solution, we have included it in this report, but it is not possible to test it and is therefore excluded from that section.

The five SMD sensors have been compared in Fig 4-1. Table comparing the five selected SMD sensors below showing several similarities despite different implementation methods in the internal electronics.

	Sensor name	**Sensor type**	**Package**	**Temperature range**	**Angular accuracy**	**Output**
AMS	AS5163	Hall	TSSOP14	-40 °C to +150 °C	0.022° per 360°	analog or PWM
Honeywell	HMC1512	MR	SOIC8 SMD	-40 °C to +125 °C	±0.1° per 180°	analog
MEAS	KMT36H	MR	TDFN-8	-40 °C to +125 °C	±0.5° per 360°	1 in 3 analog
Melexis	MLX90333	Hall	SOIC8 or TSSOP16	-40 °C to +150 °C	no data	analog, PWM or serial
Micronas	HAL3625	Hall	SOIC8 SMD	-40 °C to +170 °C	±1.0° per 360°	analog

Fig 4-1. Table comparing the five selected SMD sensors

As seen, all of the sensors provide analog ratiometric output, and two of them add the functionality of PWM signal, and the Melexis sensor is the only one providing true digital serial signal.

4.1.1 *Austria Micro Systems (AMS) angle sensor*

Sensor name: AS5163 – 12 bit Automotive Angle Position Sensor
Sensor type: Hall element sensor

Description

The AS5163 is said to be using a spinning current Hall technology for sensing the magnetic field distribution across the surface of the chip. Further, the manufacturer says that it provides accurate high-resolution absolute angular position information through Sigma-Delta A/D conversion and DSP algorithms. It calculates the angle and magnitude of the Hall array signals and the DSP can give information about if the used magnet is moved towards or away from the device's surface.

Implementation (how it can be used in a GLU)

The sensor is clearly stated as automotive classed, and even mentioned to be used as a gearbox transmission sensor. However, to our understanding, the sensor needs to be used in coordination with a vertically magnetized rotating magnet as shown in Fig 4-2. Typical magnet (6x3 mm) and magnetic field distribution as the AS5163 registers it., moving in very close proximity to the sensor. It might be the case that the sensor can give valuable output in a setup similar to the Honeywell sensor, but that is just an assumption and cannot be clearly derived from any information supplied by the manufacturer.

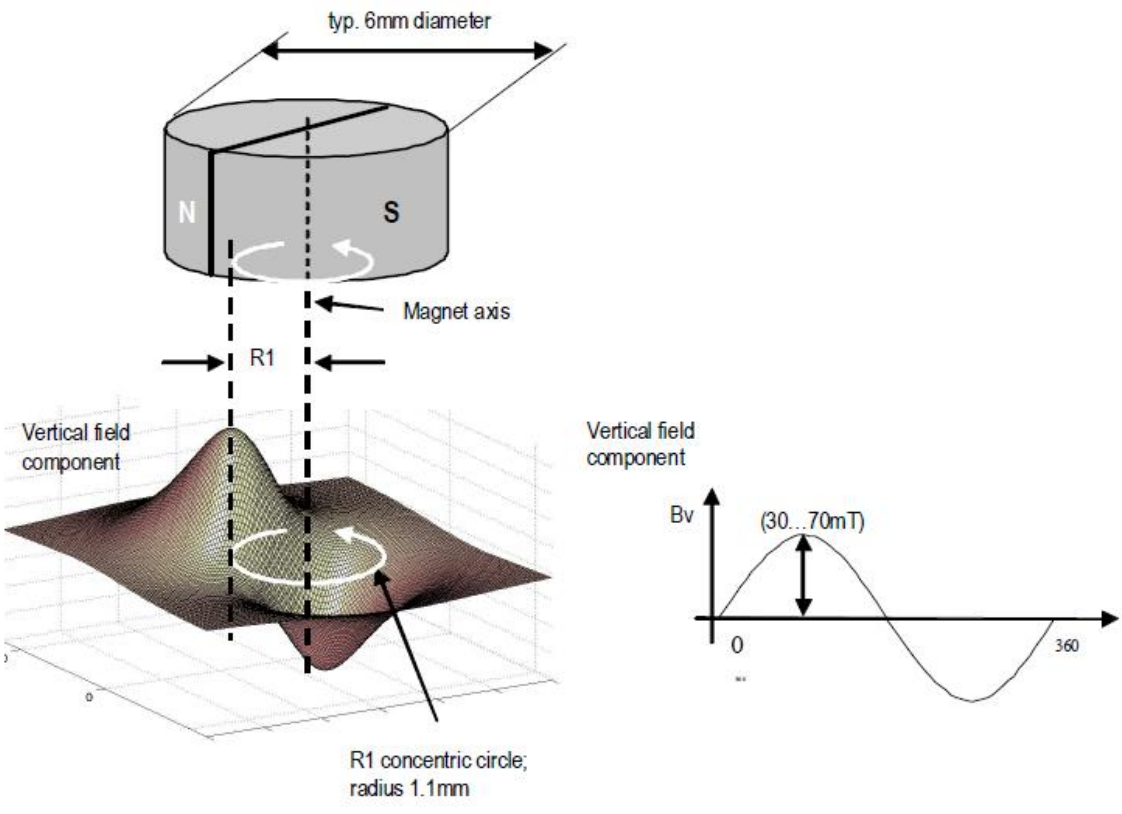


Fig 4-2. Typical magnet (6x3 mm) and magnetic field distribution as the AS5163 registers it. [4]

More information about this sensor can be found in Appendix B.1

4.1.2 Honeywell sensor

Sensor name: HMC1512 Magnetic Displacement Sensor
Sensor type: Anisotropic Magnetoresistive for linear, angular or rotary displacement.

Description

The HMC1512 contains dual saturated-mode Wheatstone bridge elements co-located to provide an extended range of angular displacements. The bridge elements change their resistance when a magnetic field is applied across the silicon die with the thin films of magneto-resistive ferrous material forming the resistive elements. The magnetoresistance is a function of cos2 Q where Q is the angle between the applied magnetic field (M in Fig 4-3. Basic sensor bridge schematic.) and the current flow direction in the thin film. When the applied magnetic field becomes moderate (50 Oe or larger), the magnetization of the thin films align in the same direction as the applied field; and becomes the saturation mode. In this mode, Q is the angle between the direction of the applied field and the bridge current flow, and the magnetoresistive sensor is only sensitive to the direction of the applied field (not amplitude).
The sensor is in the form of a Wheatstone bridge in Fig 4-3. Basic sensor bridge schematic.. The resistance (R) of all four bridge legs is the same. The bridge power supply Vb or Vbridge, causes current to flow through the bridge elements as indicated in the figure.

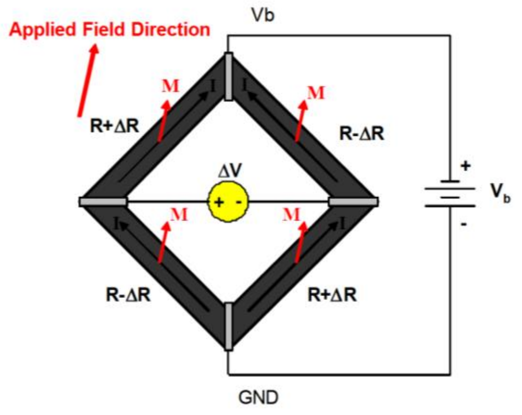


Fig 4-3. Basic sensor bridge schematic. [5]

Implementation (how it can be used in a GLU)

By using two sensors, the pair of angles will be unique for each 3D position of the tracked object and the position can be decided.

More information about this sensor can be found in Appendix B.2

4.1.3 *Measurement Specialties (MEAS) angular sensor*

Sensor name: KMT36H 360 degrees Angular Sensor
Sensor type: Magnetoresistance effect sensor

Description

The sensor uses the anisotropic magnetoresistance field by measuring the magnetic field direction with three Wheatstone bridges, each with a 120 degrees phase difference. In the case of a rotating magnet, the three bridges will produce three sinusoidal output signals with a period of 180 degrees, phase shifted by 60 degrees field angle. To calculate the field angle, the constructor needs to use a modified arctan algorithm on the combined three outputs.

Fig 4-4. KMT36H 360 degrees angular sensor. [6]

Implementation (how it can be used in a GLU)

The manufacturer has supplied a brief indication of how the sensor can be used as a gearshift position sensor by application of a standard magnet at the end of the gearshift. In this way, the manufacturer claims that the sensor can detect nine different positions. The setup consists of two sensors working together, and by combing the two angles a unique position is calculated.

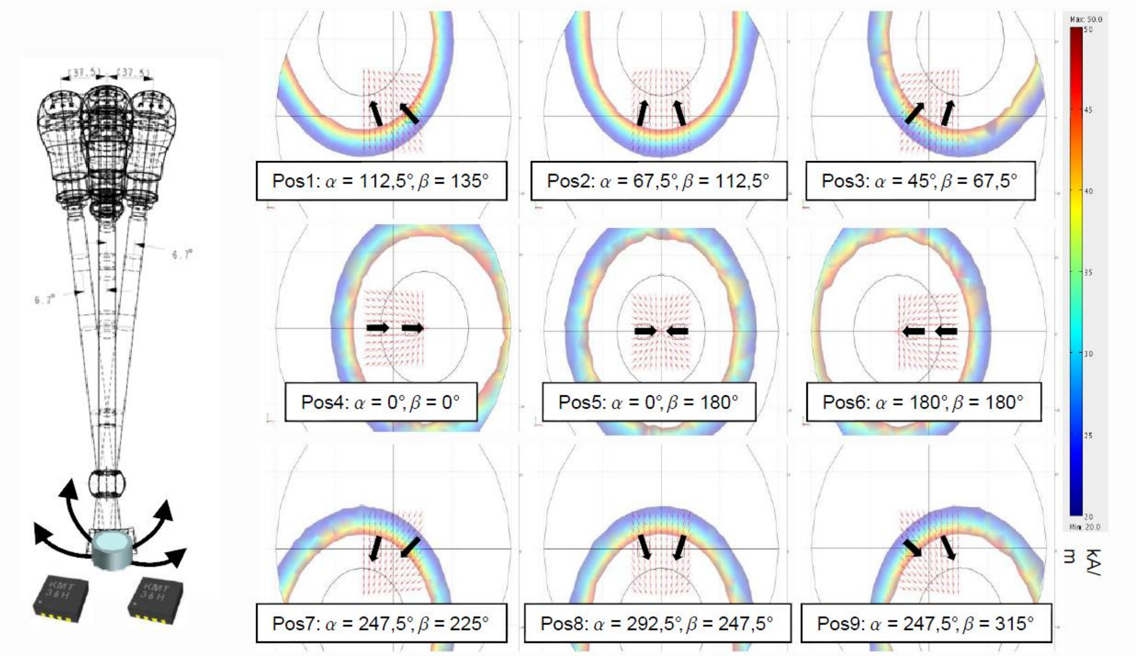


Fig 4-5. Using the KMT36H angle sensor in a joystick setting. [7]

More information about this sensor can be found in Appendix B.3

4.1.4 *Melexis 3D sensor*

Sensor name: MLX90333 - Triaxis 3D-Joystick Position Sensor
Sensor type: Hall effect sensor of a special design, patented by Melexis. Claims to be an "Absolute 3D position sensor".

Description

The TriAxis sensor is using two pairs of conventional Hall sensors measuring the magnetic flux orthogonal to the sensors surface, B_x and B_y. By using a self-invented integrated component called an IMC (Integrated Magnetic Concentrator) disk, the flux applied in parallel to the sensor surface is transformed into an orthogonal field that can be measured by the Hall sensors.

The output of the sensor is not a freeform 3D position though, but just two angles. This gives 2D positioning, but assuming we know the distance to the object a 3D position can be attained. The two angles and the distance to the object can be interpreted as spherical polar coordinates.

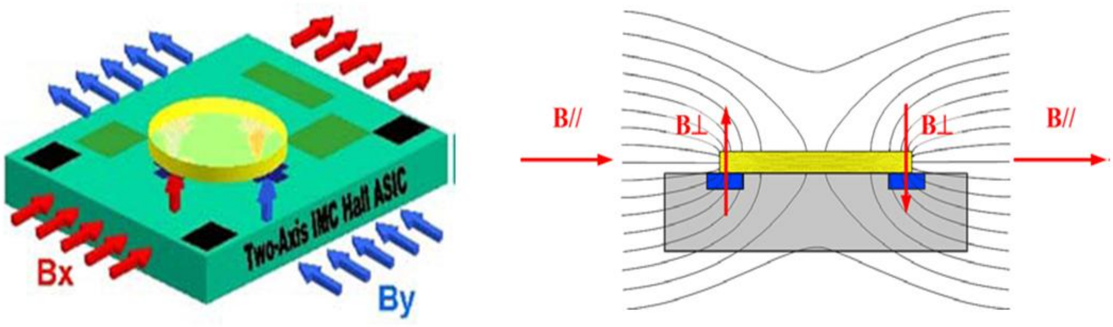


Fig 4-6. The MLX90333 turns the magnetic field lines to increase magnetic flux [8]

Implementation (how it can be used in a GLU)

Melexis has a suggested joystick implementation called Gimbal, with a fixed distance to the magnet, but it should be possible to attain true 3D sensor data from the sensor using the 3 components of the magnetic field that are measured. It seems that by utilizing the digital serial signal, the user is supplied with the entire 3D information.

Fig 4-7. MLX90333 in Gimbal configuration [9]

More information about this sensor can be found in Appendix B.4

4.1.5 Micronas angle sensor

Sensor name: HAL 3625 Programmable Direct Angle Sensor
Sensor type: Vertical Hall-plate technology measuring rotation angle.

Description

The vertical Hall-plate technology provides the ability of measuring the magnetic fields in the chip plane and directly measure rotation angles in a range of 0 to 360 degrees. As seen in Fig 4-8. Block diagram of the HAL3625, on the chip there are two vertical Hall plates which measure the two magnetic field components BX and BY. Internally the direct angle is calculated using the inverse tangent function and converted into linear, ratiometric analog output voltage. It is said to have low temperature drift. It has integrated wire-break detection working with pull-up or pull-down resistor.
The sensor can be adjusted to the magnetic circuit by programming of the non-volatile memory. Several characteristics like gain and offset of X- and Y-channel, zero-angle position, phase shift between X- and Y-channel, output slope and offset and clamping levels can be tuned.

Implementation (how it can be used in a GLU)

The sensor can be used in a similar way as the Honeywell HMC1512. That is, by using two sensors and computing the angle between the two of them, the position can be measured.

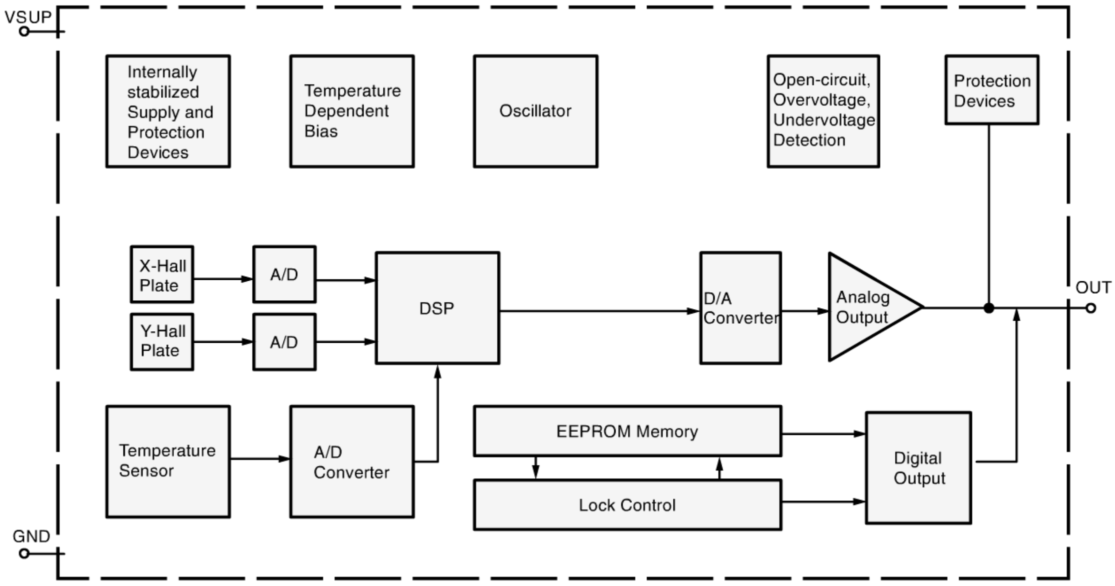


Fig 4-8. Block diagram of the HAL3625 [10]

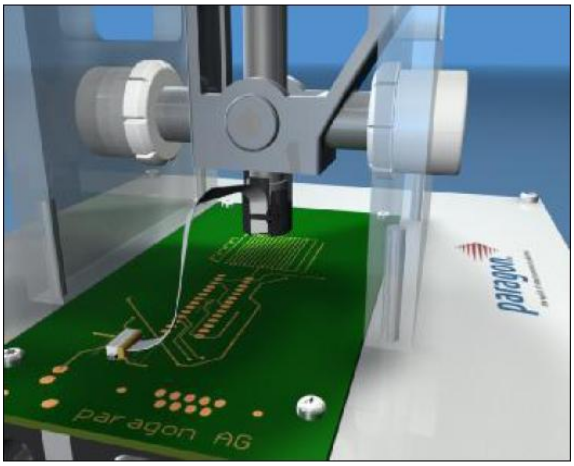
More information about this sensor can be found in Appendix B.5

4.1.6 Paragon joystick sensor

Sensor type: Not clear. Probably some kind of induction or transferring of signals from the end of the shift stick to an antenna on the PCB.

Description

In spite of several email and phone requests, we have not been successful in obtaining data sheets or any kind of in-depth information about this solution. Paragon seems to be careful of disclosing information revealing the true nature of operation. Perhaps patent issues are involved somehow. According to paragon, the sensor is no-touch, no-wear and reads positions continuously in three dimensions. It uses high frequencies and paragon claims that it makes the sensor virtually immune to interference and requires no additional protection. It is made up of a PCB with the electronics and a receiver part which seems to act as a receiver antenna of sorts, receiving signals from the bottom end of the gearshift stick. The transmitter at the bottom of the gearshift stick is connected to the PCB by a cable. In the material, the sensor also detects rotations along the vertical axe.



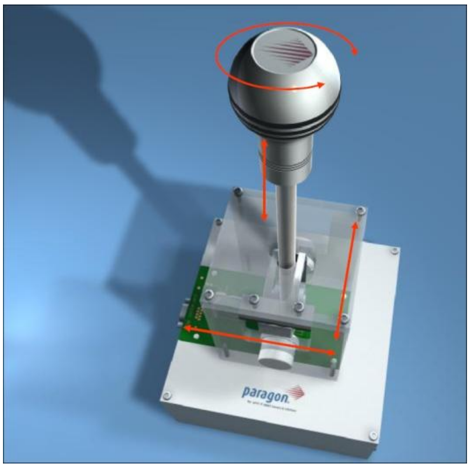


Fig 4-9. Paragon joystick sensor. [11]

Implementation (how it can be used in a GLU)

This sensor solution claims to be a fully working system meeting the demands of the automotive industry and solving the GLU lever positioning problem. The information provided claims that the existing assemblies can be re-configured in the software for use on future platforms, without the need for a complete redesign.

More information about this sensor can be found in Appendix B.6

4.2 Choosing three sensors for further testing

After evaluation of the preceding sensors, three of them were chosen for further investigation. The Paragon joystick sensor, though claiming to be a true 3D sensor, was not chosen due to the unwillingness of the manufacturer to let us access elementary information of its operation. Based on the vague information we have received, the concept might be working, but it has never been proved and it is a custom-built system. The reader might want to continue the investigations, but we decided to focus our strength on components readily available on the market, thoroughly specified and included in existing applications.

Thus the five remaining sensors are:

- Austria Micro Systems (AMS) angle sensor
- Honeywell angle sensor
- Measurement specialties (MEAS) joystick sensor
- Melexis 3D sensor
- Micronas angle sensor

Out of these three sensors were to be chosen. The Melexis sensor was a definitive candidate since it claims to be an absolute 3D sensor, and to our knowledge, the only one in the setup that could give both distance and angle.

The four sensors left are very comparable to one another, even though both Hall and magnetoresistance sensors are among them. Out of them, the Micronas sensor is said to utilize a new technology that makes it different from the other three, who share similar setup. It is interesting to see if this so-called new technology will make a difference, as a result the Micronas sensor was chosen.

Judging from the information gathered about the AMS sensor, it might be difficult to use it in a setup not involving a rotating magnet in close proximity to the sensor. We have not been totally convinced that it is restricted to such operation, but even in contact with the manufacturer, we have just had hints of its usability for our purposes. It is consequently excluded from further testing, but is by that not said to be unusable for related intentions.

The MEAS sensor’s main drawback is its complicated output built up by three outputs that need to be combined, while the other sensors have a single output containing all the information needed. In addition, compared to the Honeywell sensor, the MEAS sensor has slightly poorer angular accuracy.

Consequently, we chose the Honeywell sensor to represent the older, but experienced technology used as angle sensor in which a point in space can be traced by using two or three sensors depending on degree of freedom desired.

Chapter 5

Testing and analysis

This chapter deals with how to find out if the sensors chosen are purpose fit. The three sensors that were screened out in 4.2 are:

- Honeywell angle sensor
- Melexis 3D sensor
- Micronas angle sensor

Hence, we have, in the order above, one magnetoresistive angle sensor, one 3D sensor utilizing the Hall effect, and a Hall effect angle sensor. These three sensors cover the different technologies applied in the majority of position sensors used in popular applications globally.

Testing needs to take place in order to ensure the sensors can manage the temperature, humidity, magnetic disturbances, and other exterior interferences. But also to confirm that their declared specifications are true, that they work together with the equipment in the GLU without any problems, that they do not produce noise that disturb the measurement gathering circuits. Most of all, one needs to find out what kind of information can be collected from the sensor, and can it be used to pinpoint a point in space? Is it accurate, repeatable and trustworthy?

The sensors share similar inputs and outputs, as well as standard voltage levels, making it easier to facilitate a testing environment where the sensors can be tested in comparable conditions. The sensors can be fastened to a prefabricated PCB with surrounding electronics simplifying connection and operation.

In addition, a test rig has been built in acrylic glass, to fix the PCB with the sensor on it in a certain position and then expose it to magnetic influence in a controlled and standardized manner. This is facilitated by the use of acrylic glass plates running up and down poles built in the test rig, and the plates have specified locations to place magnets. The magnets can be selected from a wide collection of strengths.

5.1 General test categories

The test phase is divided into several categories of which each deals with certain aspects of sensor weaknesses, strengths and limits. All of these categories presuppose the sensor is fastened to the PCB. In some categories, the PCB card is attached to a GLU dummy, which is supposed to act as a standard GLU with a permanent magnet attached to the stick. Some of the test categories are quite difficult, not to say impossible to carry out on an individual basis. In those cases, Kongsberg Automotive have their own test facilities equipped with robot arms, temperature chambers, and humidity chambers for example.

5.1.1 Reference data gathering

Gathering of standard measured data for use in later analysis. Measured data together with input data to the system sets the framework of expected behavior.
In practice, it means to measure and store data while the input data is manipulated according to a defined pattern.

Implementation

The PCB is fixated in the test rig and one of the upper plates is placed within a certain distance above the PCB. On the upper plate there are markings specifying the exact locations of magnet placement. The magnet is placed on one of the markings and the output of the sensor is recorded, the magnet is moved to a different marking and then the output of the sensor is once again recorded. This procedure is continued until all the markings have been visited and recorded. After this, the upper plate is moved to a higher placement, and the magnet position and sensor output recording is repeated.

Comment

This test category is fairly uncomplicated to administer, making it a task for the authors to do and not something the Kongsberg Automotive test facilities should carry out.

5.1.2 Lifespan drift test

The sensors need to be verified to give consistent outputs during their whole lifespan. If some kind of drift in the outputs would be detected, arrangements must be made to find out what the reason for the drift is. Should it prove to be the sensor, it would most probably disqualify this sensor from further testing.

Implementation

At the end of each test, the initial test is to be repeated and the two results compared with the intention of assuring no drift has occurred during operation. More importantly, after all tests have been performed, the first reference data gathering procedure will be repeated and compared in order to make certain the sensor has not changed characteristics during the whole test cycle.

Comment

This test category is integrated into all the other tests but is compiled under this category in order to give a thorough picture of how stable the sensors are during their operating duration.

5.1.3 Noise characteristics and accuracy

The sensors produce some amount of noise in addition to the actual output. The output needs to be checked to see if this noise is obstructing the vital information in any major way. The noise may also make the pinpointing of the target vague, the noise affect the accuracy, and therefore the margins for a discrete magnet location might have to be surrounded by a bigger or smaller area where another discrete magnet position may not be placed.

Implementation

Analyze the measured reference data to determine the normal noise characteristics, and at what frequency the noise appear. Is it constant? Find out how the noise is spread out and are there any outliers worth mentioning? In addition, the need for a filter is to be investigated and in the case of the existence of such, the filter type, function, and strength is to be considered.

Comment

The noise characteristics is gathered from the reference data and as such carried out in an uncomplicated behavior without the need of an advanced test facility.

5.1.4 Normal and extreme temperature test

Find out if the sensor output is stable despite a change in environment temperature. Of most importance is the behavior within the specified temperature range of -40°C and 80°C, but it is also of interest to find out how the sensor behaves just outside the intended temperature range, i.e. between -50°C and 125°C. Will an extreme temperature make the sensor malfunction?

Implementation

The PCBs with the sensors are individually placed in GLU dummies inside temperature chambers that are capable of in a controlled manner change the temperature to the desired degree for a prolonged duration. The sensors are subject to a constantly changing magnetic influence simulated by a mechanical construction moving the GLU stick in a predefined manner.

Comment

These kinds of tests are quite difficult and time consuming, making them more suitable for testing managed by professionals. In our case Kongsberg Automotive have can provide temperature test facilities, which can be used to test the subject matter in a controlled environment during extended periods.

5.1.5 Sensitivity to exterior interference

A group of tests designed to determine how magnitude and accuracy are influenced by exterior interference and environment changes such as; differing and static magnetic fields; rapid temperature changes; and vibrations and humidity. From the results, it is possible to identify what risks are present to the system.

Implementation

As for the magnetic field interference, this kind of tests are to be carried out by setting the sensor up in the test rig with a target magnet on the first upper plate. By noting what output the sensor gives to this stimulus, the second upper plate is mounted above the first upper plate. Then another magnet is placed in different positions on the second upper plate to see if the sensor changes it output, and if so, in what way and how much. The target magnet will follow the same test pattern as the reference data gathering test, and the interference magnet configurations will be changed into different places, distances, and strengths. In addition to these tests, a test where the test rig setup is going through the reference data gathering while a powerful electromagnet is operating nearby, steadily alternating the effect of the magnetic field interfering the sensor, will show how sensitive the sensor is to irregular magnetic fields.

The rapid temperature change tests are conducted in an analogous way to the tests in 5.1.4 with the difference that the temperature changes are much faster.

The vibration test is conducted by the PCB fastened in the GLU dummy is subject to heavy vibrations in a vibrations module while a robot arm is moving the gear stick occasionally following a predefined pattern.

The humidity test is performed by the PCB fastened in the GLU dummy is put inside a humidity chamber resembling the temperature chamber, while a robot arm is moving the gear stick occasionally in a predefined pattern.

Comment

All of these tests demand quite a bit of specialized equipment, all of which are available at Kongsberg Automotive’s test facility. Temperature tests and especially vibration and humidity tests are very prone to the surrounding electronics and mechanics working as expected. In our test systems the PCB is not purposely designed for the particular sensor and the total GLU where the tests will be carried out is not a finalized structure. Therefore, those test results will probably be of less value than other tests, which do not rely to such a degree on the surrounding electronic environment. The vibration tests and humidity tests are consequently discarded until some theoretical later stage where such tests would present feasible results.

5.1.6 Operative distance capacity

Tests to determine in what way the sensor behaves when the object of measurement moves in different directions and manners. What happens when the distance is increased in the direction that is not measured by some sensors? What happens when the magnet is tilted or turned? What is the maximum distance in which the magnet position can be reliable measured without being severely interfered by magnetic disturbances?

Implementation

This category of tests is carried out by fixating the PCB in the test rig and moving the target magnet away from the sensor by increasing the distance of the upper plate and the bottom plate. Extreme values for magnet distance while still providing reliable output is noted. Then the procedure is repeated but this time with the addition of exterior interferences of permanent magnets on the second upper plate, or an electro magnet creating a constantly changing magnetic field, to see if the sensor behavior varies.

The tilting and turning tests are carried out by running the reference data gathering procedure and at each point tilt the magnet to one side, and then tilt it back and instead turn it one fourth of a full turn and record what difference this makes to the output of the sensor.

Comment

The tests in this category can easily be administered and does not need an advanced test facility.

5.2 Test rig

To facilitate the testing, a structure, or rig, was constructed. The entire rig is made of acrylic glass and features a bottom plate with a holder to fix the PCB in a certain position. In the four corners of the bottom plate, there are poles, which are fitted with two upper plates. By using different sized distances, the upper plates can be fixed at certain heights without moving to the sides, and thus standardized measuring can take place by insertion of magnets at predefined positions on the first upper plate. The second upper plate is used to fix on an even greater height and simulates magnetic disturbance sources in the immediate area of the sensor.

5.2.1 The bottom plate

The bottom plate is 198 mm x 270 mm and has a thickness of 10 mm. In the four corners of the bottom plate there are 190 mm long poles with diameters of 10 mm that are used to slide the upper plates on.

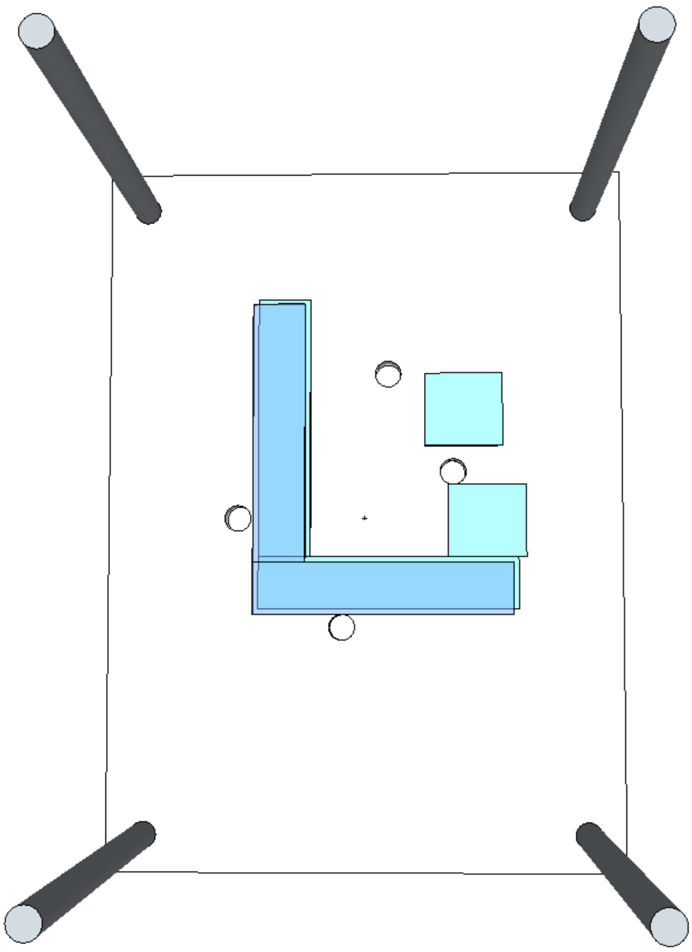


Fig 5-1. The bottom plate of the magnetic field disturbance test rig.

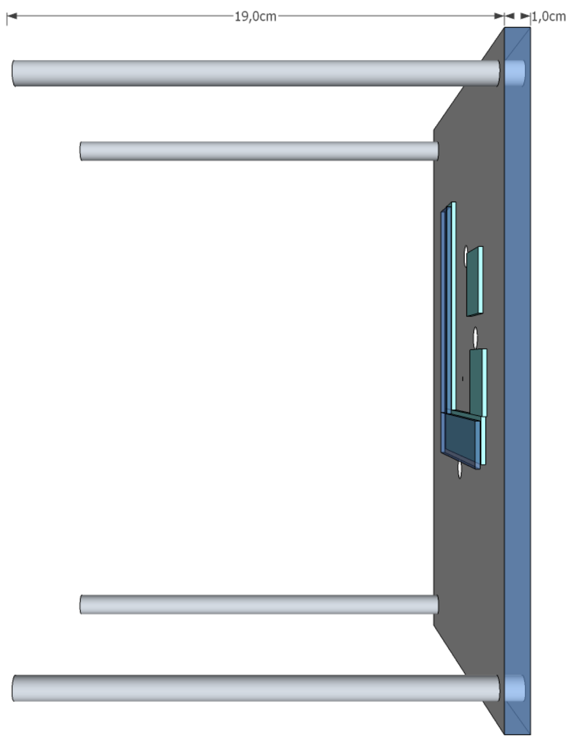


Fig 5-2. The bottom plate from the side

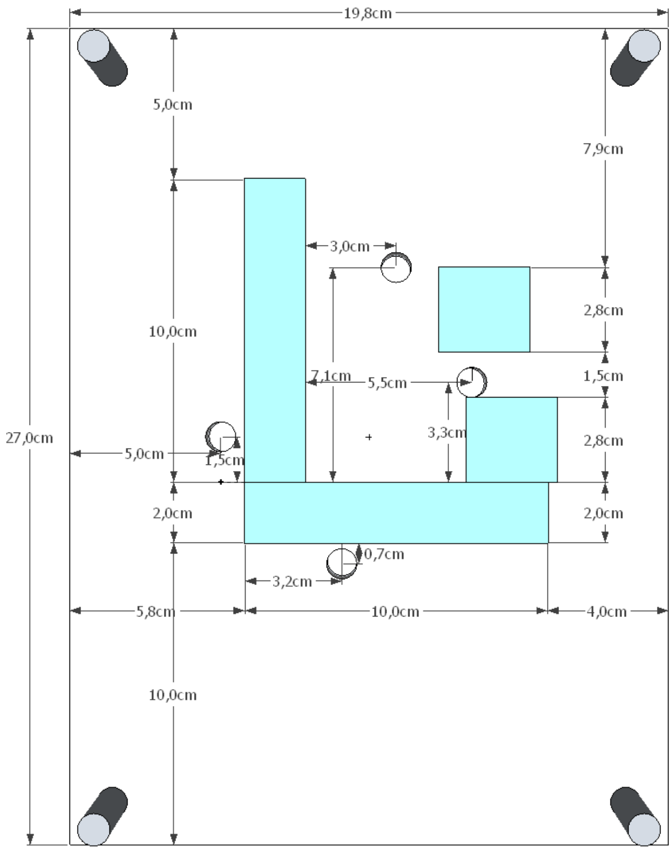


Fig 5-3. The bottom plate measurements

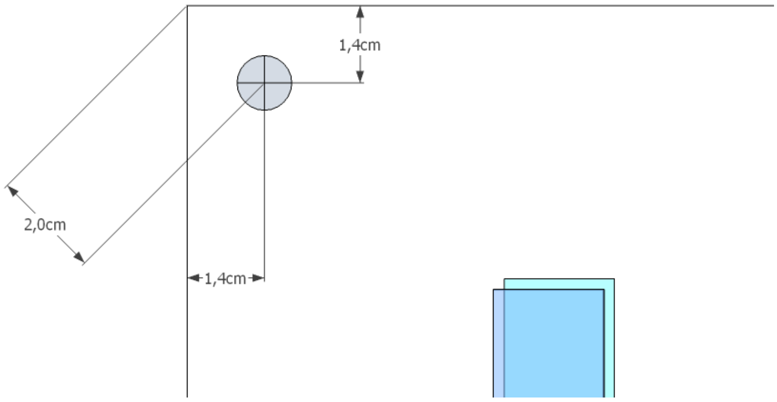


Fig 5-4. The bottom plate pole placement measurements

5.2.2 The PCB holder

On top of the bottom plate there is a PCB holder made of acrylic glass. It is designed specifically for the PCB for the sensor test. It features two levels on top of the bottom plate. The first level is 2 mm thick and the PCB is supposed to rest on this level. On top of that level there is a second level 2 mm thick, and it is shifted 2 mm to the side compared to the first level. In this way a 2 mm ledge appears on the first level, which the PCB rests upon, while the second level forms a wall that fixates the PCB in a predefined and standardized position. There are four holes running though the whole bottom plate. They are used to pull through rubber bands and fixate the PCB. The holes have a diameter of 10 mm.

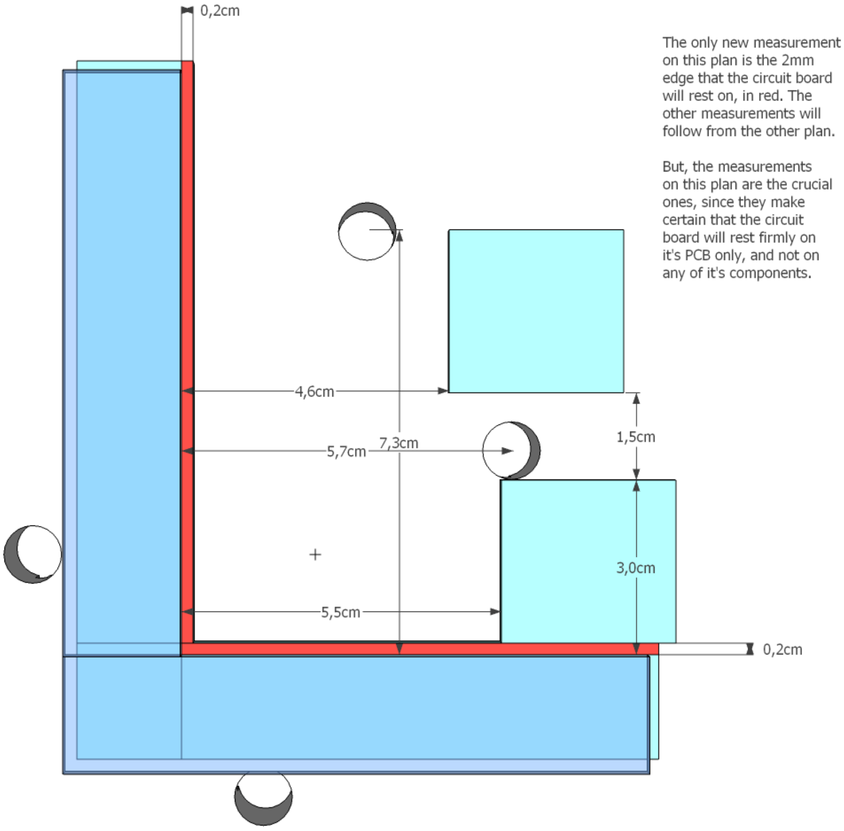


Fig 5-5. Test rig PCB holder.

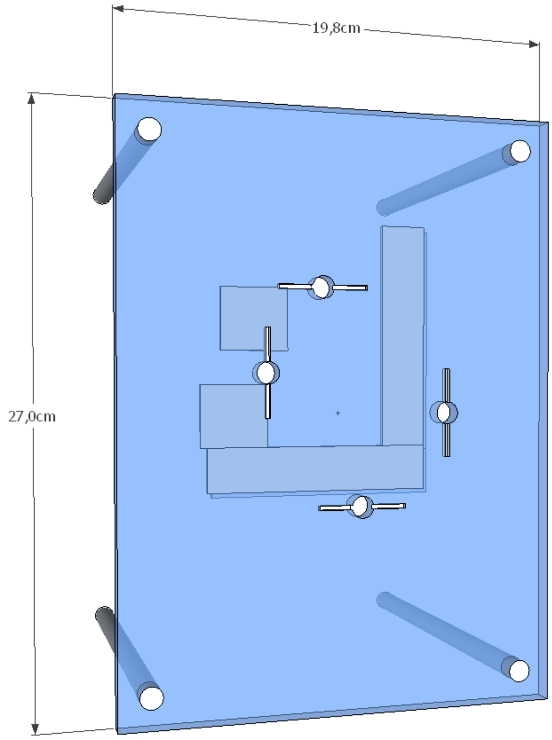


Fig 5-6. The back of the bottom plate revealing the rubber band holes

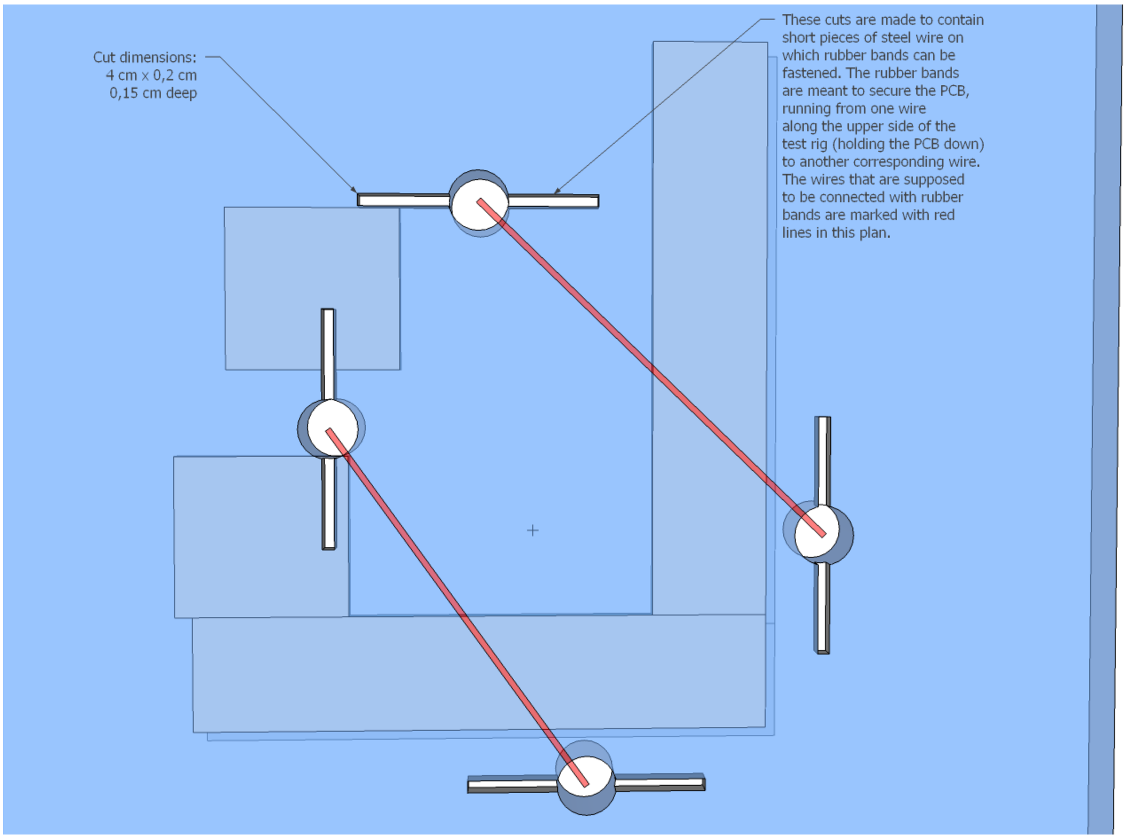


Fig 5-7. Magnification of the back of the bottom plate with the rubber band holes and special cuts

5.2.3 The upper plates

The two upper plates share the same outer dimensions as the bottom plate, 198 mm x 270 mm, except for the thickness, which is just 5 mm.

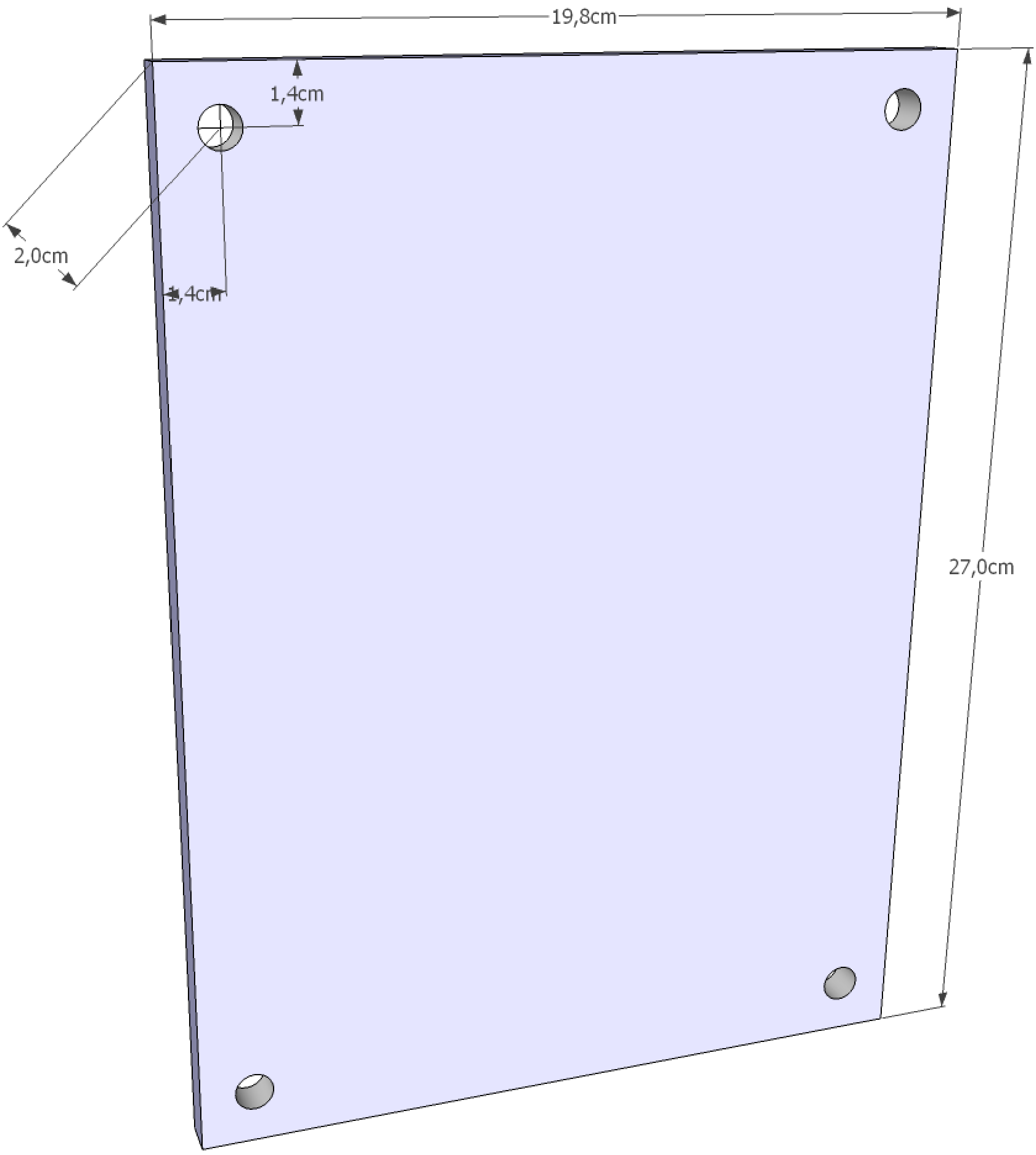


Fig 5-8. Test rig upper plate

5.3 Test cancelation

The construction of the test rig proved more difficult than anticipated. At first we were told that the internal workshop at Kongsberg Automotive could easily construct it upon a simple hand drawn request. After a long time of probing our contact there for more specific notice regarding the matter, it turned out that the workshop was unable to produce it at our circumstances and time limits, since they had a full workload. We were told that there was another workshop in town that could easily produce the test rig we desired, but after lengthy phone conversations and mail correspondence we were told that it was difficult, time consuming and possibly expensive. The busy schedule of the workshops and the minimal monetary gain from such a small order seemed to make things difficult.

After prolonged working to get the test rig in place we were faced with the fact that the test rig construction was not the piece of cake we had been told. Instead, we had to take the task on ourselves. By designing our test rig in a way that we could build it up from scratch using standard acrylic glass pieces and drill holes in appropriate places and then glue the pieces together, we wound up with the test rig needed for the tests planned. This extra work, and the long-drawn-out initial waiting, took a lot of additional time, and in the end, it was decided to cancel the planned tests.

We received samples of the three chosen sensors and tried the Melexis sensor in a different test setup, where it seems to perform well, but no standardized tests have taken place. The Micronas sensor also was tried in another setup, and was deemed to work as expected under those circumstances. In order to conduct the full testing in the test rig, an old PCB with electronics for angular measurement was to be tweaked into our purpose of slightly different data gathering and customized for the three different sensors. The time to accomplish the transition of the PCB into a full-feathered test-board was also underestimated and the task proved more difficult than anticipated.

The old PCB was controlled by a micro controller programmed in C. To facilitate the change of functionality it had to be reprogrammed in a certain way. Building up knowledge of the programming language and gaining insight into the workings of the code also took more time into account than projected, leading to termination of this task before completion in line with the other problems encountered during the test phase.

All things considered, the test phase could not be completed within reasonable time and in order to manage to get together a report within realistic timeframes, we were faced with the fact of having to cancel the tests.

Chapter 6

Conclusions and discussion

This chapter will sum up the conclusions drawn from the work done throughout the project as well as analyze the questions, thoughts and ideas that arose during the same time.

The questions that were asked before the work began will be answered to the extent possible. Because the testing phase could not be completed within the timeframe of the project, the conclusions will be based on facts and theory, but not on empirical testing done specifically by the authors of the report. The discussion section will treat questions like how our method worked, what went wrong and what went right. There is also a section titled "Further work" which explains how this thesis work can be extended and built upon, furthering the goals of investigating 3D-sensors for automotive gear lever units.

6.1 Conclusions

The initial plan was to not only explore the area of 3D sensing, identify the most fitting sensing solutions and the most promising sensors for further testing but also to conduct tests on the sensors and answer questions based on the tests. Because of delays throughout the project it was decided that it would not be possible to conduct the tests within the scope of this thesis work and the focus of the report is therefore of a more investigating character. This also means that the main value of the report is found in the problem exploration itself together with the test preparations and not just within the conclusions.

3D positioning techniques

Positioning in three dimensions can be solved in several ways, as described in chapter 3. It seems very possible to implement attractive solutions for the automotive industry based on the techniques described there, but such an implementation would not fit within this thesis work. One of the main goals of the thesis work was to find sensing solutions already available on the market or of such character that they could easily be implemented with high reliability and dependability from the start.

Best available sensor technique

According to the investigations done throughout this project the best sensor technique available when it comes to constructing 3D sensors, built or implemented in accordance with the demands of the automotive industry, is the magnetic sensor technique. As a result of this, all of the readymade sensors analyzed in this report are of magnetic type.

Most interesting magnetic sensors

The most interesting magnetic sensors found, suitable in positioning solutions, are described in chapter 4. Additionally, the three most promising ones of those are chosen and the reasoning behind it is described there.

Best solution for the task

Selecting the best possible solution is entirely based on the problem that needs to be solved. The main advantage of using 3D sensors is the great freedom it grants to design GLUs almost any way desired. Because of this it is very "future proof" in the sense that it is not bound to usage in GLUs with the design of today, but can be used in future cars almost no matter how the gearbox interaction will be conducted.

If the main reason behind the search for a new solution is the switch from a solution based on "one sensors for each gear lever position" to a single sensor hardware setup that can be reused in many different gearbox setups, then 3D sensing is probably not a solution we would recommend to a GLU manufacturer. Instead, we would recommend the very simple, cheap and reliable technique described in sections 3.1.2, subsection *"Joystick specific positioning techniques"*, which is a technique that sensor-wise only requires two 1D angle sensors. The main downside of that technique is that it requires a lever to operate the gearbox, but since this at this day is the dominating way to interact with a gearbox this is not seen as a big drawback.

6.2 Discussion

During the information-gathering phase we had much to consider. This was a whole new subject matter to both of us. It was not entirely straightforward to avoid being sidetracked into a specific solution, instead of keeping our eyes open to all the different solutions available. The sensor industry is predominantly accentuating magnet sensor technology for purposes as the one this project has, but we wanted to be certain there were no other technologies that could just as well be used for the undertaking.

The sensor manufacturing companies are walking a fine line explaining difficult topics in a way that potential customers easily can understand, and at the same time explaining them in a correct physical manner. Sometimes the facts are obscured in a way that makes it very confusing to decipher them. For example, the two predominating magnetic sensor technologies: the Hall effect sensing and magnetoresistance angle sensing. At first, we believed that these two technologies were fundamentally different and it was just after delving deep into the physics books that it stood clear that they are very similar in theory, yet differently applied.

When designing the test specifications it was not always obvious what aspects to focus on, since several of the tests used in the production facility of KA were constructed to test the complete system to be tested, for example a GLU. We did not want a sensor to perform low or even fail due to our own setup. The PCB we were working on was not the PCB the sensor would be used on in a future implementation for example. In addition, vibration, humidity, and a briefly considered dust and liquid test, which the production samples are going through, would most likely not give important results but instead fail due to the temporary setup.

As can be read in the conclusions, it is very important to ponder what the unique benefits are of a 3D sensor solution and compare it to other solutions before deciding to go for 3D sensors. Is the added complexity of a 3D sensor worth it?

6.3 Further work

The natural next step to take in the further work of investigating the possibilities of implementing a gear lever unit with a three dimensional sensor should be picking up where we left off, preparing and executing the tests that were canceled due to lack of time. The results from such tests would provide valuable data of how the sensors compare to one another and how they act in an environment similar to the actual setting of a GLU. The testing would probably require between one and two months of full time work.

The steps needed to conduct the testing could be as follows:

- Finalize the hardware and software needed for the testing
- Construct a number of identical PCB:s for concurrent tests
- Create step by step instructions for testing procedures, enabling others to conduct them
- Conduct the testing procedures, using a test rig and external help such as KA test facilities, EMP labs, etc.

- Analyze and compare the test results to competitive systems

Another possible extension to the project would be to implement a new 3D sensing technique based on the suggestions and examples from chapter 3.

Chapter 7

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Chapter 8

Figure acknowledgement

Most of the figures in this report have been crafted by the authors using the programs Google Sketchup and Adobe Photoshop. Some of the figures, however, have been copied from various sources, mainly magnet sensor data sheets. The sources of those figures are specified here. The copyright belongs to the respective owners of the images and their usage in this report is based on the Swedish law 1960:729 §23 which can be applied to the usage of publically available images in a scientific setting such as a master thesis. Specifically note the comments to §22 that refers to §23. Source: https://lagen.nu/1960:729#P22S1

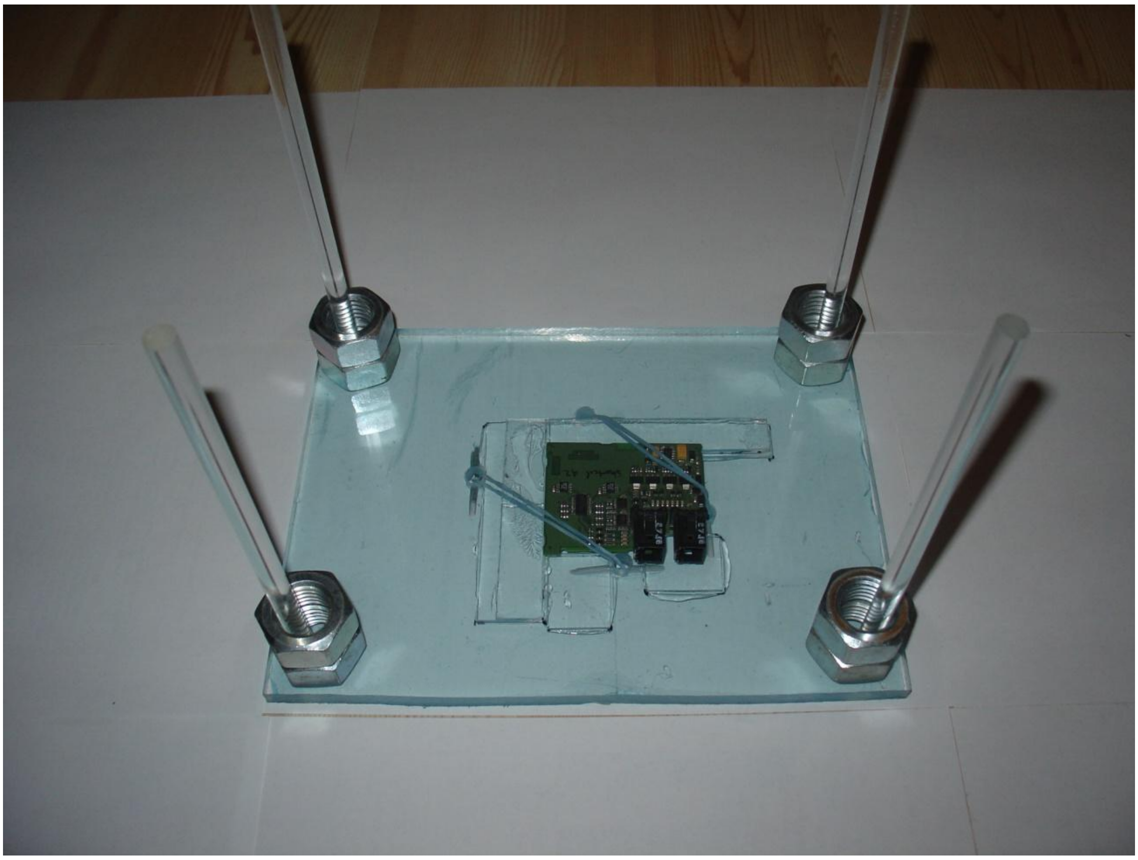
All public image sources were available as of 2010-04-28.

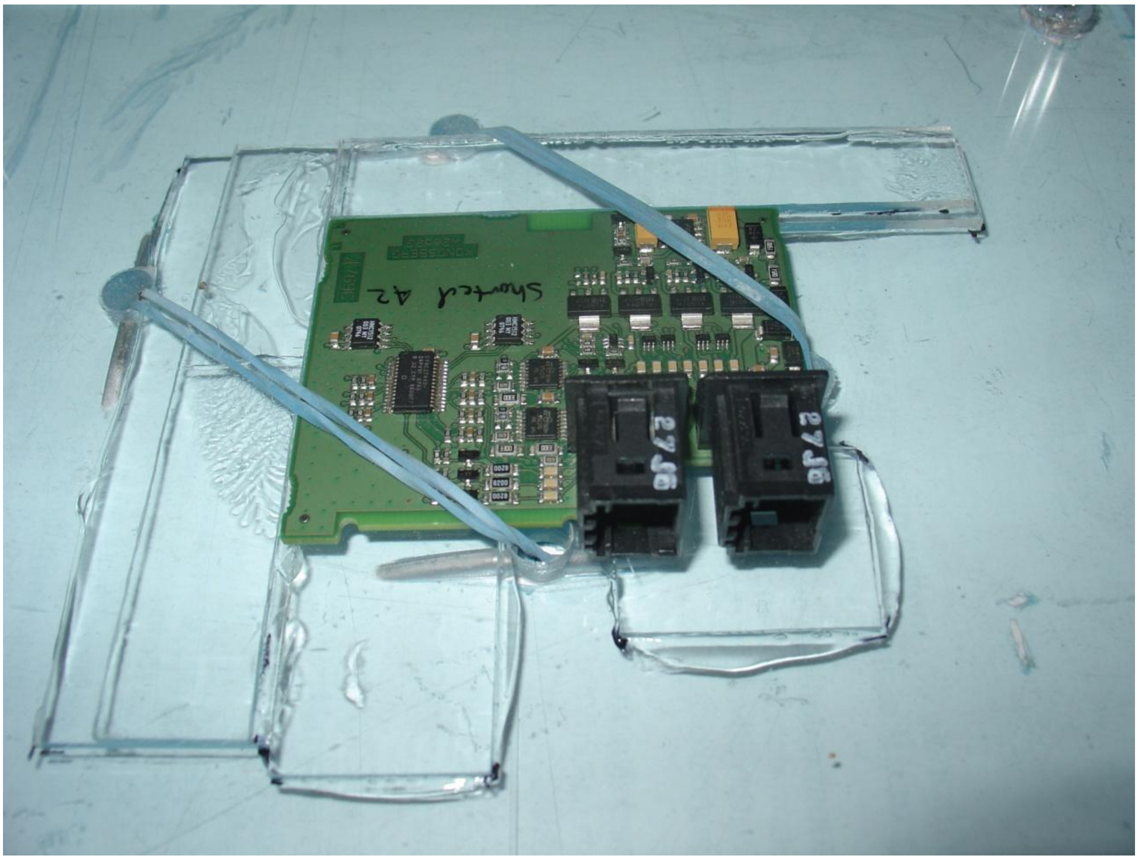
Figure reference	**Figure source**
[1] Fig 3-13	Photo of a BMW iDrive control knob. http://www.bmw.com.my/com/en/newvehicles/1series/5door/2007/allfacts/ergonomics/navidrive.html
[2] Fig 3-14	Figure showing the Melexis MLX90333 sensor in a joystick setup. The text and arrows on the image are added by the authors of this report. http://www.melexis.com/prodfiles2%5C0002922_MLX90333_GimbalJoystick.jpg
[3] Fig 3-15	Reed sensor picture taken by André Karwath. http://en.wikipedia.org/wiki/File:Reed_switch_(aka).jpg
[4] Fig 4-2	Sensor description taken from AS5163 data sheet from Austria Micro Systems. http://www.austriamicrosystems.com/eng/content/download/18708/347371
[5] Fig 4-3	A Wheatstone bridge sensor schematic. At page 5, from data sheet at: http://www.magneticsensors.com/datasheets/hmc1501-1512.pdf

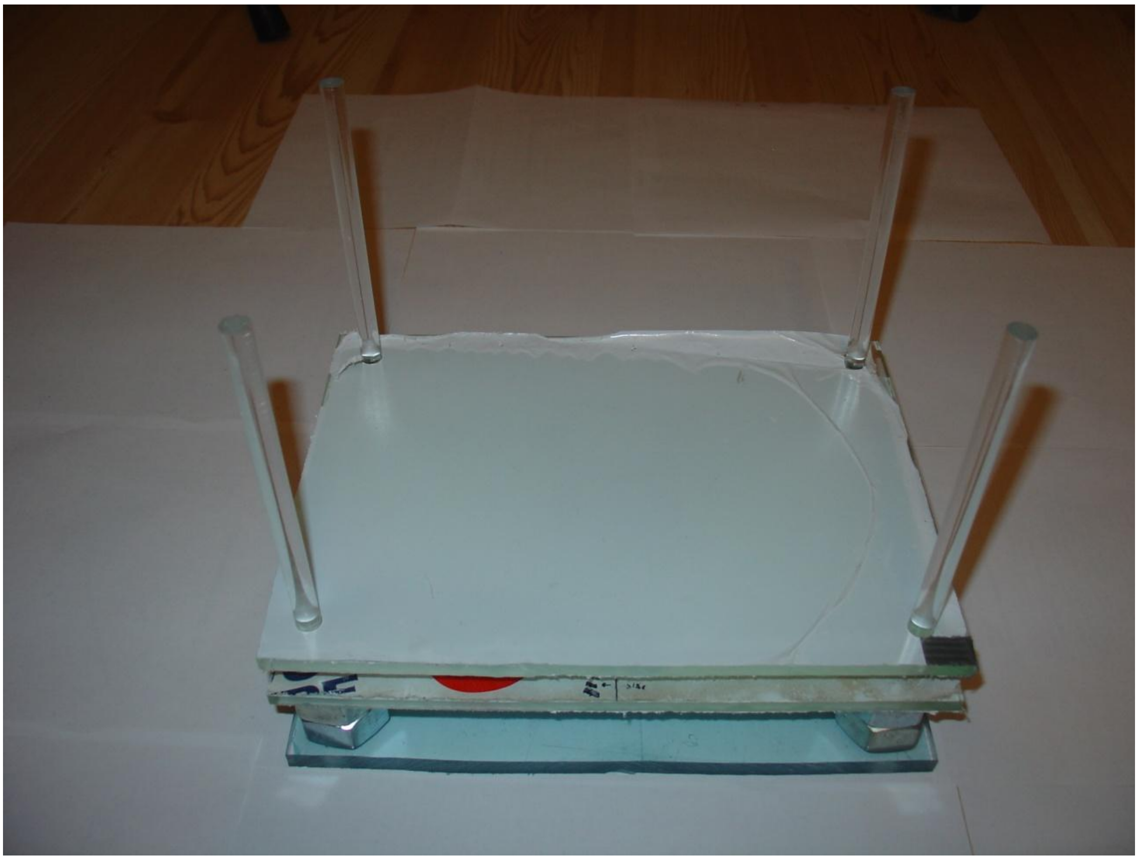
[6] Fig 4-4	An image of the KMT 36H sensor shell. At page 1, from specification sheet: http://www.meas-spec.com/downloads/KMT36H.pdf
[7] Fig 4-5	Image describing how the KMT36H can be used in a joystick setting. The source is a presentation delivered by MEAS to Kongsberg Automotive and can to our knowledge not be found in publically available sources at the date of this report. Note that any implementation based on this image may cause patent infringement.
[8] Fig 4-6	A pair of images showing the Integrated Magnetic Circuit technique used in the Melexis MLX90333 sensor. Can be found in the MLX90333 datasheet available at: http://www.melexis.com/Assets/MLX90333_Datasheet_5276.aspx
[9] Fig 4-7	Figure showing the Melexis MLX90333 sensor in a joystick setup. http://www.melexis.com/prodfiles2%5C0002922_MLX90333_GimbalJoystick.jpg
[10] Fig 4-8	Image showing a block diagram of the Micronas HAL3625 sensor. Found at: http://www.micronas.com/en/automotive_and_industrial_products/by_function/hal_3625/product_information/index.html
[11] Fig 4-9	A pair of images describing the Paragon joystick sensor. The images are from a document sent to the authors after requesting more information from Paragon about their "3D position sensor" that is mentioned in the document found here: http://www.paragon-online.de/en/index.php?a=284

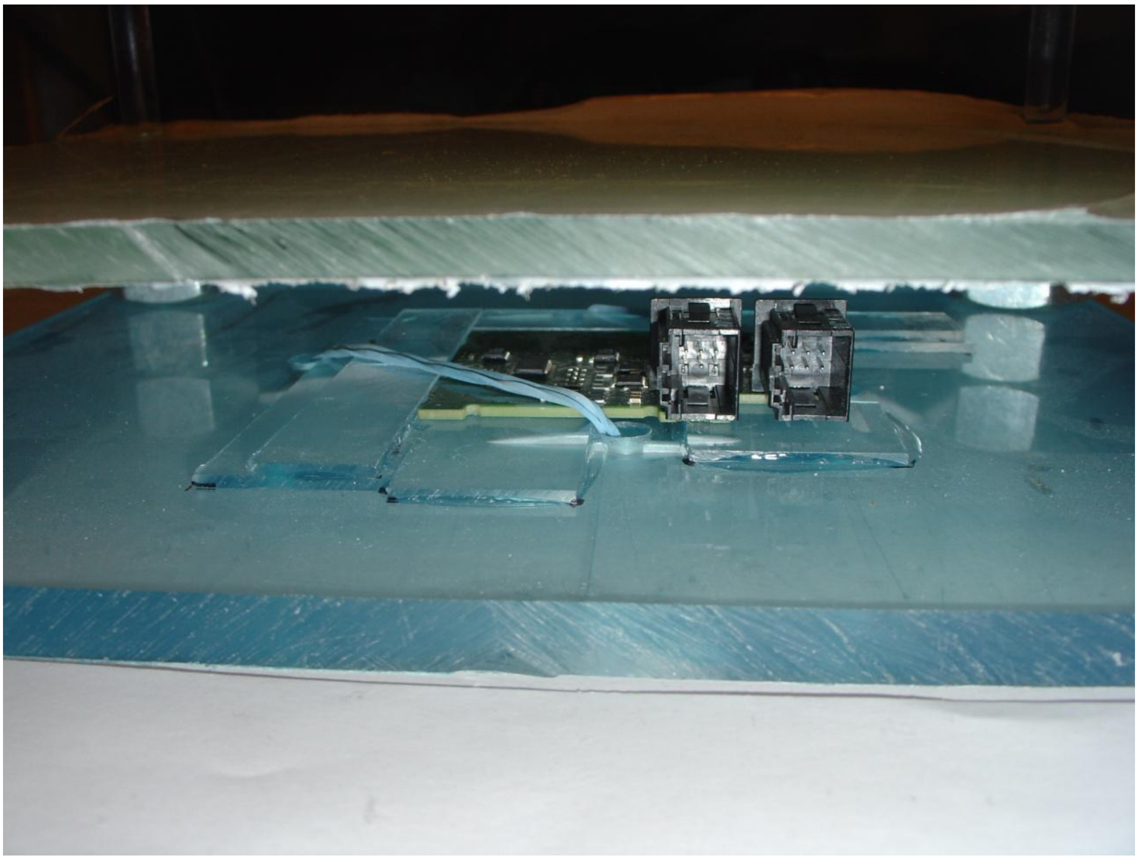
Appendix A

Test rig pictures




Shorted A2





Appendix B
Additional sensor info

B.1 Austria Micro Systems (AMS) angle sensor

Sensor name
AS5163 – 12 bit Automotive Angle Position Sensor

Sensor type
Hall element sensor

Description
The AS5163 is said to be using a spinning current Hall technology for sensing the magnetic field distribution across the surface of the chip. Further, the manufacturer says that it provides accurate high-resolution absolute angular position information through Sigma-Delta A/D conversion and DSP algorithms. It calculates the angle and magnitude of the Hall array signals and the DSP can give information about if the used magnet is moved towards or away from the device’s surface.

Implementation (how it can be used in a GLU)
The sensor is clearly stated as automotive classed, and even mentioned to be used in as a gearbox transmission sensor. However, to our understanding, the sensor needs to be used in coordination with a vertically magnetized rotating magnet as shown in Fig 4-2. Typical magnet (6x3 mm) and magnetic field distribution as the AS5163 registers it., moving in very close proximity to the sensor. It might be the case that the sensor can give valuable output in a setup similar to the Honeywell sensor, but that is just an unfounded assumption and cannot be derived from any information supplied by the manufacturer.

Additional (somewhat unsystematic)information

Manufacturer
Austria Microsystems AG, HQ in Schloss Premstaetten, Austria. 1000 employees.

Output
12 bit PWM or 12 bit ratiometric analog output

Integral non-linearity (optimum) 360 degree full turn
+-0.9 degrees Maximum error with respect to the best line fit. Centered magnet without calibration, Tamb = -40 to +150°C.

Integral non-linearity 360 degree full turn
+-1.4 degrees Best line fit = (Errmax – Errmin) / 2 Over displacement tolerance with 6mm diameter magnet, without calibration, Tamb = -40 to +150°C

Transition noise

0.06 degrees RMS

Magnet

The AS5163 works with a variety of different magnets in size and shape. A typical magnet could be 6mm in diameter and ≥2.5mm in height. Magnetic materials such as rare earth AlNiCo/SmCo5 or NdFeB are recommended. The magnetic field strength perpendicular to the die surface has to be in the range of • +-30mT to +-70mT (peak).

Magnet placement

The magnet's center axis should be aligned within a displacement radius of 0.25 mm. The typical distance from the sensor surface is 0.5mm to 1.5mm, but larger distances can be accomplished as long as the required magnetic field strength stays within the defined limits.
However, a magnetic field outside the specified range may still produce usable results, but the out-of-range condition will be indicated by an alarm forcing the output into the failure band.

Manufacturer information

(Austria Micro Systems)

B.2 Honeywell sensor

Sensor name
HMC1512 Magnetic Displacement Sensor

Sensor type
Anisotropic Magnetoresistive for linear, angular or rotary displacement.

Description.
The HMC1512 contains dual saturated-mode Wheatstone bridge elements co-located to provide an extended range of angular displacements. The bridge elements change their resistance when a magnetic field is applied across the silicon die with the thin films of magneto-resistive ferrous material forming the resistive elements. The magnetoresistance is a function of cos2 Q where Q is the angle between the applied magnetic field (M in Fig 4-3. Basic sensor bridge schematic.) and the current flow direction in the thin film. When the applied magnetic field becomes moderate (50 Oe or larger), the magnetization of the thin films align in the same direction as the applied field; and becomes the saturation mode. In this mode, Q is the angle between the direction of the applied field and the bridge current flow, and the magnetoresistive sensor is only sensitive to the direction of the applied field (not amplitude).
The sensor is in the form of a Wheatstone bridge in Fig 4-3. Basic sensor bridge schematic.. The resistance (R) of all four bridge legs is the same. The bridge power supply Vb or Vbridge, causes current to flow through the bridge elements as indicated in the figure.

Implementation (how it can be used in a GLU)
By using two sensors and computing the angle between the two of them, the position can be measured.

Additional (somewhat unsystematic) information

Manufacturer
Honeywell International Inc., HQ in Morristown, NJ, USA. 128 000 employees.

Output
Ratiometric linear analog

Sensitivity
Vb=5 volts, field=80Oe, @ zero crossing 2.1 mV/°

Resolution
BW=10Hz, Vb=5 volts 0.05 deg

Noise Density
@1Hz, Vb=5 volts 70 nV/sqrt Hz

Hysteresis Error
Field > 80 Oe, Vb=5 volts 30 □V (0.017 deg)

Manufacturer information
(Honeywell, 2009)

B.3 Measurement Specialties (MEAS) angular sensor

Sensor name
KMT36H 360 degrees Angular Sensor

Sensor type
Magnetoresistance effect sensor

Description
The sensor uses the anisotropic magnetoresistance field by measuring the magnetic field direction with three Wheatstone bridges, each with a 120 degrees phase difference. In the case of a rotating magnet, the three bridges will produce three sinusoidal output signals with a period of 180 degrees, phase shifted by 60 degrees field angle. To calculate the field angle, the constructor needs to use a modified arctan algorithm on the combined three outputs.

Implementation (how it can be used in a GLU)
The manufacturer has supplied a brief indication of how the sensor can be used as a gearshift position sensor by application of a standard magnet at the end of the gearshift. In this way, the manufacturer claims that the sensor can detect nine different positions. The setup consists of two sensors working together and by combing the two angles, a unique position is calculated.

Additional (somewhat unsystematic) information

Manufacturer
Measurement Specialties, Inc. HQ in Hampton, VA, USA. 2200 Employees.

Output
Three analog sinusoidal signals that need to be combined to calculate the angle.

Hysteresis (Repeatability)
0.15 – 0.3 degrees at H = 25 kA/m

Manufacturer information
(Measurement Specialties)

B.4 Melexis 3D sensor

Sensor name

MLX90333 - Triaxis 3D-Joystick Position Sensor

Sensor type

Hall effect sensor of a special design, patented by Melexis. Claims to be an "Absolute 3D position sensor".

Description

The TriAxis sensor is using two pairs of conventional Hall sensors measuring the magnetic flux orthogonal to the sensors surface, B_x and B_y. By using a self-invented integrated component called an IMC (Integrated Magnetic Concentrator) disk, the flux applied in parallel to the sensor surface is transformed into an orthogonal field that can be measured by the Hall sensors.

The output of the sensor is not a freeform 3D position though, but just two angles. This gives 2D positioning, but assuming we know the distance to the object a 3D position can be attained. The two angles and the distance to the object can be interpreted as spherical polar coordinates.

Implementation (how it can be used in a GLU)

Melexis has a suggested joystick implementation called Gimbal, with a fixed distance to the magnet, but it might be possible to attain true 3D sensor data from the sensor using the 3 components of the magnetic field that are measured. It seems that by utilizing the digital serial signal, the user is supplied with the entire 3D information.

Additional (somewhat unsystematic) information

Manufacturer

Melexis N.V. HQ in Ieper Belgium. 700 employees.

Output

12 bit selectable ratiometric analog, PWM, or 16 bit serial protocol

Analog output resolution

0.025 %VDD/LSB

Output stage noise

0.05 %VDD

Manufacturer information

(Melexis)

B.5 Micronas angle sensor

Sensor name

HAL 3625 Programmable Direct Angle Sensor

Sensor type

Vertical Hall-plate technology measuring rotation angle.

Description

The vertical Hall-plate technology provides the ability of measuring the magnetic fields in the chip plane and directly measure rotation angles in a range of 0 to 360 degrees. As seen in Fig 4-8. Block diagram of the HAL3625, on the chip there are two vertical Hall plates which measure the two magnetic field components BX and BY. Internally the direct angle is calculated using the inverse tangent function and converted into linear, ratiometric analog output voltage. It is said to have low temperature drift. It has integrated wire-break detection working with pull-up or pull-down resistor. The sensor can be adjusted to the magnetic circuit by programming of the non-volatile memory. Several characteristics like gain and offset of X- and Y-channel, zero-angle position, phase shift between X- and Y-channel, output slope and offset and clamping levels can be tuned.

Implementation (how it can be used in a GLU)

The sensor can be used in a similar way as the Honeywell HMC1512. That is, by using two sensors and computing the angle between the two of them, the position can be measured.

Additional (somewhat unsystematic) information

Manufacturer

Micronas GmbH, HQ in Zurich, Switzerland and Freiburg, Germany. 920 employees.

Output

Ratiometric linear analog

Integral non-linearity error of output signal

+-0.1% of VDD

Ratiometric error of output signal

+-0.2%

Output response time

1 ms (slow mode)

Output noise

0.2 degrees rms

Manufacturer information

(Micronas)

B.6 Paragon joystick sensor

Sensor type

Not clear. Probably some kind of induction or transferring of signals from the end of the shift stick to an antenna on the PCB.

Description

In spite of several email and phone requests, we have not been successful in obtaining data sheets or any kind of in-depth information about this solution. Paragon seems to be careful of disclosing information revealing the true nature of operation. Perhaps patent issues are involved somehow. According to paragon, the sensor is no-touch, no-wear and reads positions continuously in three dimensions. It uses high frequencies and paragon claims that it makes the sensor virtually immune to interference and requires no additional protection. It is made up of a PCB with the electronics and a receiver part which seems to act as a receiver antenna of sorts, receiving signals from the bottom end of the gearshift stick. The transmitter at the bottom of the gearshift stick is connected to the PCB by a cable. In the material the sensor also detects rotations along the vertical axe.

Implementation (how it can be used in a GLU)

This sensor solution claims to be a fully working system meeting the demands of the automotive industry and solving the GLU lever positioning problem. The information provided claims that the existing assemblies can be re-configured in the software for use on future platforms, without the need for a complete redesign.

Manufacturer

paragon AG. HQ in Delbrück Germany. 600 employees.

Manufacturer information

(paragon)

Appendix C
Sensor manufacturers

There is a cluster of sensors that can be used as building blocks in the custom design of a 3D-sensor. Several companies manufacture the kind of sensors we desire and here is a non-exhaustive list of different companies we have considered.

Manufacturers of usable magnetoresistance-sensors and Hall-sensors

Austria Microsystems Produces angle sensors and linear sensors. Working on their own solution to detect the gear by using angle measuring sensors.
http://www.austriamicrosystems.com/eng/Products/Magnetic-Encoders/Rotary-Encoders

Micronas
They make angular and linear sensors. The new HAL3625 is of a new kind of angular sensors and measures 360 degrees. Even though the technology being used is new, the functionality seems to be similar to existing angular sensors.
http://www.micronas.com/automotive_and_industrial_products/index.html

MEAS
They make sensors for the automotive business. They manufacture 360 degrees MR-angular sensors as well as positional AMR sensors.
http://www.meas-spec.com/position-sensors.aspx

Infineon
Nothing about 3D-sensors can be found on their website. Linear position and angular position can be measured by using their products. Analog and digital interface. 360-degree GMR-product on the way.
http://www.infineon.com

Honeywell
HMC1512 gives field direction instead of field strength. Is capable of greater variation in distance than ordinary Hall-sensors. They also have proximity position and linear position sensors.
http://sensing.honeywell.com/index.cfm?Ne=2308&ci_id=154353&N=3059&la_id=1

Allegro
Manufactures ordinary linear Hall-sensors.
http://www.allegromicro.com

TT electronics OPTEK Technology
Produces ordinary through-hole linear Hall-sensors. Also makes the Autopad which is a complete solution to measure rotating applications. Seems like they have built some kind of GLU-sensor, but it is difficult to determine if it is a realistic product for our situation.
http://www.optekinc.com/

NXP (Philips)
MR-angular sensors, Hall sensors.
http://www.nxp.com

Analog Devices
Produces Hall-sensors and accelerometers. They have the AD22151G: Linear Output Magnetic Field Transducer which gives an output voltage being proportional to the magnetic field orthogonally to the upper side of the IC.
http://www.analog.com/en/mems-and-sensors/lvdt-sensor-amplifiers/products/index.html

Diodes inc
Manufactures Hall-switches, MR angular sensors and linear sensors.
http://www.diodes.com/

Maxim
We have been told they manfacture angular sensors, but such cannot be found on the website. Makes sensor controllers and temperature sensors.
http://www.maxim-ic.com/

Manufacturers of Hall and magnetoresistance sensors of less significance to this project

Hamlin
Big manufacturer of sensors, but for built-in applications.
http://www.hamlin.com/

CLARE
Only makes Hall-switches
http://www.clare.com/__85256A3900731315.nsf/0/7C2AEF71FCE50AD385257566004F7AF2?Open&Highlight=2,hall

STMicroelectronics
Single chip standalone accelerometer, that is, a tilt sensor of sorts, for example to turn the picture in the compact camera or mobile phone.
http://www.st.com/stonline/products/literature/ds/14752.htm

ZMD
Seems to not make products we can use, manufactures some kind of sensor controller.
http://www.zmd.de

Cherry
They make products aimed at automotive. They are competent within inductive sensors. Seems to not produce sensors for pcbs, but they have distance measuring using Hall-sensors, Reed-switches and angular sensors for built-in applications.
http://www.cherry.de/english/switches_controls/sensoren.htm

CTS
American company who provides complete modules, whereof only uninteresting rotation sensors.
http://www.ctscorp.com/automotive/rotary/noncontacting.htm

ROHM
Manufactures less advanced Hall-sensors.
http://www.rohm.com