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On the trade-off between data density and data capture duration in 3D laser scanning for production system engineering

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Abstract

3D laser scanning is a technology for capture of spatial data in three dimensions. The technology originates from the field of surveying and has since been spread to several other application areas. In the realm of production system engineering, 3D laser scanning is primarily used to verify equipment installation. Lately applications for the 3D scan data are emerging also when it comes to the planning of the installations and the use of the equipment. The motivation for using 3D scan data in the case of planning is primarily to have up-to-date and verified spatial data, including any undocumenter alterations from drawings and models. The process of capturing 3D scan data requires access to an unmoving production system which can be costly, either due to stopping produciton or by accessing it during nights or weekends. The more detailed the data collection is, the more time is required. Therefore there is a need to accurately define and plan the minimum data density requirement. This paper evaluates the effect of data density, and thus data collection duration, in a production system application. Data capture duration is shown to impact the usability of the resulting data. To further understand the trade-off and be able to use it as decision support there needs to be an analysis of the additional time and data storage costs created by increasing the number of scan locations.

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Keywords: 3D scanning; Virtual; Production; Point cloud

1. Introduction

3D laser scanning has emerged as a key technology for capturing spatial data in several areas during the last few decennia. In the realm of production system engineering, 3D laser scanning is primarily used to verify equipment installations. Lately applications for the 3D scan data are emerging also when it comes to the planning of installations and the use of the equipment. One example is path planning of robot operations [1], another is layout planning [2, 3].

However, the process of capturing 3D data is not straight forward. The process relies heavily on the survey engineer who captures the data and the conditions under which the capture process takes place. 3D laser scanning requires stillness in the scene that is captured. Thus, ongoing production activities can prove troublesome. If the geometries in the scene are geometrically complex and numerous, more data captures are required to get comprehensive spatial data of the entire scene. Likewise, requirements on high level of detail can slow the process down as more measurements have to be recorded during each capture. Often the access to an unmoving production system is costly and needs to be condensed in duration. Therefore, there is a need to optimize the trade-off between data density and data capture duration.

This paper explores the trade-off between data density and data capture duration in a typical production system engineering setting using 3D laser scanning technology. The evaluation is based on a number of 3D scan data sets collected from a mixed levels of automation production cell. The data sets are different on a number of properties: resolution, number of scan positions, and colourized or not. The data capture process and resulting level of detail is measured quantitatively to explore the trade-off between the two. The results are evaluated from a production system engineering point of view considering documentation of as-is conditions and verification of virtual factory model. Mainly, this paper presents a method of measuring the density of data captured and puts less focus on the later application of the captured data and thus the

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properties of the end result. However, the data sets are also evaluated from a visual perspective to paint a richer picture of the influence of the data capture setup.

Section 2 gives an introduction to spatial data capture, focusing on 3D laser scanning. Section 3 describes the experimental setup. Section 4 presents the results from the experiment. Section 5 discusses the results and concludes the findings. Section 6 contains a note on future work.

2. Theory

This section gives an overview of technology used for spatial data capture and in particular the technology used in this study, 3D laser scanning, or Lidar as it is also named.

2.1. Spatial data capture

There are a number of different technologies available for capturing spatial data. They are traditionally structured into tactile methods and non-contact methods [4]. Tactile technologies are characterized by high precision, low data capture speeds and limited reach. Furthermore they require physical contact with the object being measured, thus some effect on the object is inevitable.

This physical contact could prove especially troublesome if the measured object has a soft and yielding structure [4]. A common type of tactile sensor is the Coordinate Measurement Machine (CMM), which is based on linear movement axes. Another type of tactile sensor, which is more mobile, is the articulated robotic arm. CMM machines are programmable and sometimes used in production facilities for in-line automated measurement of products. The robotic arms are used for lower volume products as they typically require a manual operator.

Non-contact methods exist in a number of forms, a common classification is active and passive non-contact sensors. Active sensors emit a media which interacts with the objects to be measured, examples are structured light scanners and 3D lasers scanners (which are covered more in-depth under heading 2.2). There are also examples of non-contact measurement techniques that are passive. Photogrammetry is one such example. Where 2D photos of an object are taken from different angles and analysed in combination to calculate 3D geometries.

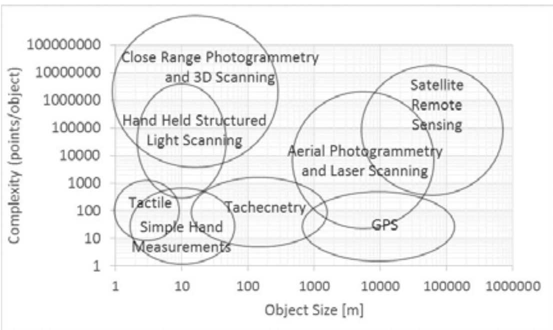

Fig. 1. Overview of spatial data capture technologies based on scale and complexity properties of the captured object (adopted from [5])

2.2. 3D laser scanning technology

3D laser scanning was developed in the field of surveying, and has historically been used for surveying build sites and civil construction sites. Today it is used in a number of different topic areas. The common denominator for the usage is digitizing the physical world either for documentation and preservation or for analysis and sharing across geographical distances. Examples of areas of use are transportation [6], forensics [7], architecture [8], archaeology [9], and production system engineering [2, 3, 10]. It is a type of 3D imaging technique based on active optical measurements. A laser emitter is directed along a trajectory out of the centre of the measurement device. The returned reflection beam is sampled to gauge the distance to the nearest surface of that given trajectory. By systematically sweeping the complete environment around the device, while logging direction and distance measures, a comprehensive sampling of the surrounding surfaces is achieved.

There are two main types of techniques used for distance measures in 3D laser scanners, time of flight and phase shift. Time of flight measures are achieved by emulating a pulse on the emitted laser and then registering the time of flight, which elapses until the emitted pulse is reflected back into the sensor. Phase shift measurements are more continuous in nature, typically three waveforms are overlaid on the emitted laser beam, the reflected beam is then measured for its three phases, and the shift of each phase is used to compute the distance to the reflecting surface. There is a physical limitation inherent from this technique, where ambiguity in n-number of wave lengths that has passed since emitting the beam cannot be resolved. Therefore phase based 3D laser scanners typically have a range limitation of one to a few hundred meters. This is not the case for time of flight based systems, which in turn has a, traditionally, lower rate of data capture.

When measuring scenes with multiple objects in them there is typically a need for several data captures from different positions. This introduces the problem of combining independent sets of measurement data. For this purpose surveyors typically use reference objects. These also serves the purpose of determining known positions on the object or site that is being measured. In a factory, the known positions of interests are known locations with respect to the factory's internal coordinate system. Examples of reference objects are spheres and checker boards, see Fig. 2 below.

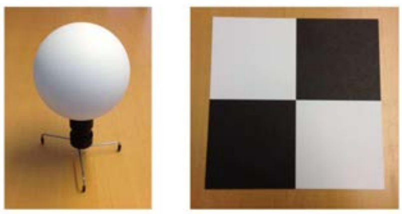

Fig. 2. Objects used as references in 3D laser scanning, left: Sphere, right: checker board

The reference objects are positioned to be captured from two or more scanning positions and then used for fixing common points in space and linking the independent data sets together. In recent years the ever improving software algorithms and computer processing capacity are starting to make reference objects redundant for the sole purpose of linking data sets, this is instead achieved through aligning overlapping measurement data. However, for the purpose of linking the measurement data to known physical locations, the references are still necessary.

3. Experiment setup

This section goes over the method of data capture and details the resulting data. Then follows a description of the workflow surrounding the processing of the data and the analysis steps that were used to evaluate the results.

3.1. Data capture

The subject of the experiment is a mixed levels of automation production cell. It contains four industrial robots, a conveyor system, and three manual workstations with material facades. A 3D laser scanner was used to capture data of the production cell at different resolution settings and different number of capture positions. The data was captured from an increasing number of locations and combined, starting with one central location and then adding two plus two surrounding locations. The device used was a Faro Focus3DS120 [11]. The data collection was performed using two different detail level settings, one which was faster and less detailed and one with more detail whilst slower. The high level of detail setting records about 44 Million points in one data capture. The setting denoted as low level of detail records approximately 7 M pts during one capture. In addition, the data at each location and detail level was captured both in colour and grey scale. The complete setup for data capture and the resulting data sizes and capture durations can be found in Table 1 below.

For the purpose of this paper, the analysis focuses on the low level of detail captures in grey scale. But the data set is presented in its entirety together with depictions of the resulting visualisation to illustrate and interpolate out from the studied set. In Fig. 3 is an image of the most complete data set, constructed from five scans on high quality settings with colour. In Fig. 4 is a view of the same location based on one scan with the low quality setting and no colour capture.

Table 1. The data capture setup with resulting data sizes and process duration

No. of Scans	M pts.	Colour [MB]	Grey scale [MB]	Colour [mm:ss]	Grey scale [mm:ss]
1	7.1	56.63	21.83	02:45	01:04
2	14.2	113.26	43.66	05:30	02:08
4	28.8	226.52	87.32	11:00	04:16
1	44	171.15	136.35	05:51	04:05
2	88	342.3	272.7	11:42	08:10
4	166	684.6	545.4	23:24	16:20

Fig. 3. Example of data captured using high level of detail in colour from five scan locations

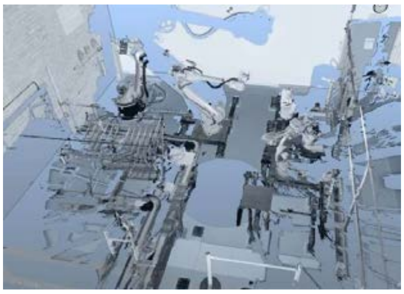

Fig. 4. Example of data captured using low level of detail in grey scale from one scan location

The locations for data capture where organized in a star pattern, initially the 3D scanner was placed for one central scan. Then going outwards in four directions as was allowed by the equipment in the scene four additional locations were chosen. Figure 5, is an illustration of the scan locations visualised using the captured data.

3.2. Processing and analysis steps

The workflow when preparing and analysing the data starts with the process of registering and combining the data from the scanner. This was done using Faro Scene Version 5.5.3.38662 [11]. During this process each individual set of measurement data was aligned to the same coordinate system using sphere reference objects.

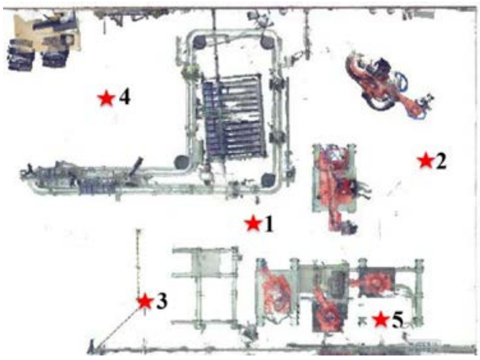

Figure 5 Top view of the locations chosen for the data capture

The data was cleaned by removing any data points positioned outside of the enclosure of the room containing the production cell. The data sets were then exported individually to the neutral standard file format .e57 [12]. The five scan data sets with lowest level of detail in grey scale were used for the purpose of this study.

The .e57 files were loaded into the software Cloud Compare, Version: 2.5.5.2 [13]. To compare the effect of having one or more data captures, five data sets were created consisting of one, two, three, four, and finally all five data captures respectively. Using the software's *cloud sub sample* algorithm (Edit - Subsample) on the space method setting five reduced versions of each of the five data set were generated. The space settings used was 2 mm, 5 mm, 10 mm, 50 mm, and 100 mm. This was done to create versions of the data suitable for conducting analysis of the systems spatial properties in a production system engineering setting. The number of points in each data set was used to represent the data density, as the spatial envelope of the data sets is constant regardless of the number of data points.

Then, to gauge the effect of adding additional scan locations to the central one, the data point count from each of the five data sets was compared to analyse the increase in density as a function of the data capture duration. In each step of increasing the number of scans the resulting number of data points was compared to the number of data points in the previous step. This process was repeated until all five density levels were covered. The added data density was plotted in a saturation graph, indicating the percentage of additional data points resulting from the iteration of adding a scan location.

4. Result

Here follows a presentation of the results gained from analysing the data sets. In Fig. 6 is a plot of the data volume and capture duration for the scanning of the production cell. Adding colour to the capture process increases the time requirement for data capture with 100 – 40 % depending on the capture quality and number of locations. The relative time increase reduces as the quality setting is increased.

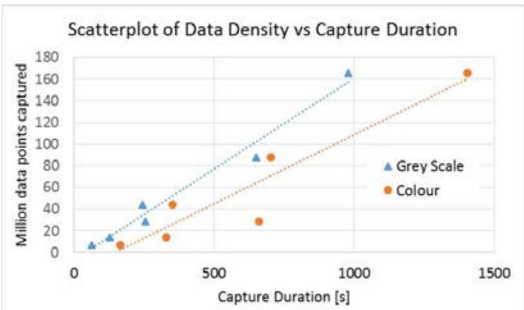

Fig. 6. Relationship between data volume and capture duration

Table 2. Data filtering and resulting measurement data point count

No. of scans	Spatial filtering None	2 mm	5 mm	10 mm	50 mm	100 mm
1	6.35E+06	5.65E+06	4.00E+06	2.07E+06	1.67E+05	4.84E+04
2	1.29E+07	1.05E+07	5.43E+06	2.54E+06	1.95E+05	5.54E+04
3	1.92E+07	1.53E+07	7.61E+06	3.28E+06	2.29E+05	6.36E+04
4	2.55E+07	2.02E+07	9.06E+06	3.64E+06	2.47E+05	6.79E+04
5	3.19E+07	2.43E+07	1.02E+07	3.96E+06	2.59E+05	7.08E+04

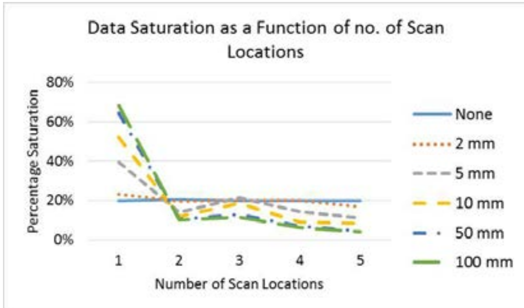

Fig. 7. Data saturation as a function of no. of scan positions visualised for the different spatial filter settings

The processed data and resulting sizes can be found in

Table 2. "None" indicates the full, unfiltered data set as exported from Faro Scene. There is a 1:450 density ratio between the unfiltered and the 100 mm filtered data sets.

To further understand the increased density in data gained from carrying out additional scans a plot of the stepwise added number of data points is presented in Fig. 7.

There is a clear drop in added value to be found in all but the two densest data sets. The gain seems to grow steadily until the 50 mm and 100 mm sets which follow quite similar curves.

5. Discussion and conclusions

This work represents a first attempt at quantifying the trade-off between data density and data capture duration in 3D laser scanning for production system engineering. Data capture duration is shown to have some impact on the usability of the resulting data. See for example visualisations in Figure 3 and Figure 4 as well as the data saturation graphs in Figure 7. To further understand the trade-off and be able to use it as decision support there needs to be an analysis of the additional time and data storage costs created by increasing the number of scan locations.

Using such cost data in combination with the results presented here could enable pareto front type of decision models that can guide the selection of number of scans. But again, there needs to be an objective function to determine a good level of data saturation based on the intended use of the data.

For visualisation of the data, colour information becomes useful. For geometry analysis, the colour adds no tangible value. However working with the data is simplified with the added likeness and ease of recognition that colour information provides.

3D laser scanning, as any new tool can add value, however it needs to be integrated into current work practices and accepted by a broad base of users. This can be achieved by changing the work procedure or by adopting the tool. The acceptance can be achieved by good performance or strong champions with a lot of trust capital from others in the organization.

6. Future Work

The next step will be to look beyond the experimental setup in an academic environment and into industry use cases. Only then can real user needs be weighed against the time requirement for capturing high fidelity data both in respects of level of detail and likeness in visualisation. The aim would be to give a framework of requirement recommendations for a given application. A sort of use-based digitalisation strategy guide that matches the intended use of the data with a suitable scope of data capture.

Further on, an interesting topic is the aspect of incremental data collection, i.e. to capture a lower level of detail initially and then increase the level of detail at need, perhaps only for select parts of the studied system. This would reduce the risk of unnecessary interference with ongoing production and potentially reduce the overall data capture duration. Issues related to incremental data capture could for example occur when physical updates of the real environment have taken place since the initial data capture.

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