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# Data structures for industrial laser range sensors

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**Abstract – This paper describes the implementation of data structures based on data acquisition of active optical range sensors. At first, three available industrial laser sensors are introduced and compared exemplarly. Based on the raw data structure of these sensors an abstract data structure and the possibility of the evaluation of depth information are presented. Finally industrial applications are presented which are using the introduced data structure.**

**Keywords: laser range sensors, 3D models, data representations**

## I. INTRODUCTION

The evaluation of depth information from different sources is a very popular field of research in the data processing. Many lines of business and sciences, such as the automobile industry, medicine and physics are interested and involved in it. The difficulty consists in transferring point data sets to a reliable order so that it is possible to make evaluations over created surfaces.
Such datasets have a number of different sources: they range from a simple distance measuring system to complex 3D scanners for any-sized objects. These data structures could be used starting with simple counting tasks up to complex 3D registration and reconstruction algorithms of modern image processing [1][2].
This paper describes laser sensors in industrial environments which exist in different types of constructions. Especially laser sensors are introduced in detail in the following chapter. With the help of practically proven sensors a data structure for the representation in the computer is defined. It is easy to understand that these sensors are generating different types of information depending on manufacturer and on the functional principle. The next chapter describes usual operation modes of contactless optical sensors. Various laser sensors from industrial component suppliers will be evaluated to generate an abstract data model from their data acquisition methods.

## II. Industrial Laser range sensors

Many different 3D Scanning sensors are presently existing in the market [3]. This selection consists of sensor devices usually used in the automation and robotic industry.

### A. SICK LMS 400

The company Sick [4] is one of the world's leading producers of sensors for all sorts of industrial applications. The measuring principle of the LMS400 is based on the so called Time of Flight method with an additional phase difference analysis. The propagation time of the light and the used wavelength result in a phase shift between the beam sent and the beam received. This phase difference is converted into a frequency. The system determines the distance between the object and the zero point based on this frequency. The sensor is a 2D measuring system sending out and receiving laser beams in an angle of 70°.

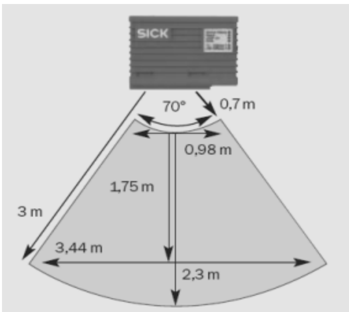


Figure 1 Sick LMS200 measurement range [4]

The laser measuring system LMS 400 is based on the LMS 200 and was developed for close ranges up to 3 meters. The LMS 400 has a distance resolution of 1 millimeters at a maximum measuring distance of 3 meters. Additional remission values are also transmitted. The measured sensor data is provided to a PC via Ethernet.

Table 1 Sick LMS400 Technical Specifications [4]

| | | |
|---|---|---|
| Measurement range (Z) | 700-3000 | mm |
| Accuracy (Z) | 1 | mm |
| Measurement range (X) | < 70 | ° |
| Sample Frequency | 250 Hz | 1/s |

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The typical angular resolution at 250 Hz is 0.1°. Lower sample frequencies slow down the measurement process. The measurement range starts with at 700 millimeters and has a constant resolution of 1 millimeters over the complete measurement range [5]. At a maximum usage of the angular range of 70° the lowest angular resolution of 0.1° yields an area of 700 values (in X).

### B. MEL M2D 75/30

The M2D from MEL [6] works according to the principle of triangulation. A pulsed laser diode and the line optics produce a laser line. The diffused reflecting light of the object is detected by a Charge-coupled Device array (CCD).

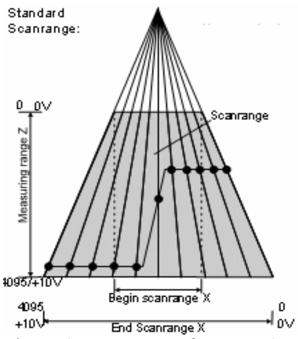


Figure 2 scan range of MEL M2D 75/30

The object's different height contours cause a deviation of the laser line which is evaluated trigonometrically. The distance of the Z axis is allocated to the respective X position of the sampling point. The profile of the sensor profile can be achieved as a representation of Z(X).

Table 2 MEL M2D 75/30 [6]

| | | |
|---|---|---|
| Measurement range (Z) | 90-165 | mm |
| Accuracy (Z) | 0.16 | mm |
| Measurement range (X) | 30 | mm |
| Sample Frequency | 110 | 1/s |

At a measurement range of 30 millimeters (in X) the sensor 75/30 has a resolution of 0.1 millimeters. In the measurement range of 75-90 millimeters the resolution is 0.16 millimeters. The sensor works with a sample frequency of 55Hz in the full screen mode (566 lines) and 110Hz in the half resolution mode (283 lines).

### C. MicroEpsilon ScanCONTROL 2800

The laser sensor ScanCONTROL 2800 from MicroEpsilon [7] uses the triangulation principle for the two-dimensional recording of profiles. A laser line is projected onto the object. High-quality optics maps the light of this diffusely reflected laser line to a Complementary Metal Oxide Semiconductor (CMOS) matrix. The controller calculates the distance information (Z axis) along the laser line (x-axis) and distributes both in a two-dimensional coordinate system. ScanCONTROL 2800 consists of a compact sensor and an intelligent controller which distributes the two-dimensional profile information and sends it via FireWire interface to the PC.

Table 3 MicroEpsilon ScanCONTROL 2800 25X [7]

| | | |
|---|---|---|
| Measurement range (Z) | 62.5 – 87.5 | mm |
| Accuracy (Z) | 0,01 | mm |
| Measurement range (X) | 1000 | Points |
| Sample Frequency | < 1000 | 1/s |

Like other sensors the ScanCONTROL 2800 is able to work with higher speed and higher precision at a measurement range of 25 millimeters. The sensor resolution of 0.01 millimeters depends on the scan frequency. Test scans were taken with a resolution of 1000 points and 95Hz.

## III. Sensor data acquisition

Depending on an industrial application of the sensors different measurement ranges have to be selected. Therefore a direct comparison of the properties is hardly possible. The choice of the measurement range rather plays a subordinate role for the data representation described in this paper. Distance sensors produce simple distance values representing the z coordinate of a Cartesian coordinate system in a fixed relation to the sensor. For a 2D laser range sensor the results are represented in the X Z plane.
The laser triangulation sensor M2D 75/30 of MEL delivers linearized data in x and z with values between 0 and 4095 (figure 2). The intensity value ranges from 0 to 254. These values have to be scaled depending on the sensor measurement range. The measurement range for MEL M2D 75/30 is defined for x values between -20 and 20 millimeters (end scan range is 40 millimeters) and for z values between 90 and 165 millimeters. The values are transferred directly into a coordinate system, which is shown in figure 3 based for X and Z in millimeters.

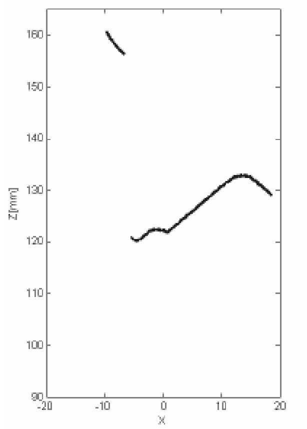


Figure 3 MEL M2D 75/30 laser scan

The Sick LMS400 uses the principle of phase shift (continuous wave). The packages with the measured values are transferred in an Ethernet telegram to a PC. The most important values of this telegram are the start angle (4 bytes) and 2 bytes for the angle step width. For every angle step the distance is encoded in 2 bytes. These distances have to be multiplied by the transferred scaling factor to scale the value to millimeter range. The remission values are transferred for every angle step to values between 0 and 255. The value of 255 correlates with a full reflection.
The linearized distance d is a result of this relation:

$$\mathrm{d} = d'\cos(\varphi_{Start} + \Delta\varphi) \qquad (4)$$

In this way the test scans can be compared to other scans. A height profile of the Sick LMS400 is presented in figure 4.

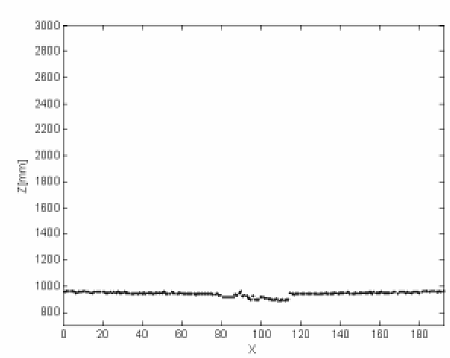


Figure 4 Sick LMS400 laser scan

This profile was produced with an angular resolution of 0.125° for a scanning part of 24°. The distance measuring range starts at 0.7 meters and goes up to 3 meters. In this case the surface of a slightly deformed object has been scanned in a distance of approximately 1 meter.
Concerning the format of the data transmission the ScanCONTROL 2800 is not fundamentally different from the other sensors. A special byte array is transferred by Firewire and can be stored with a driver function. This byte array is predefined by a certain data structure (PURE_PROFILE). The data structure consists of 4 bytes per scan value. The first 2 bytes contain the X value and the next 2 bytes the corresponding Z value (distance to X). This very similar order of the data can be visualized in an X-Z plane. In the figure 5 a laser scan of 1000 Points was scaled to the measurement range of 40 millimeters in order to compare it with the MEL M2D 75/30 scan.

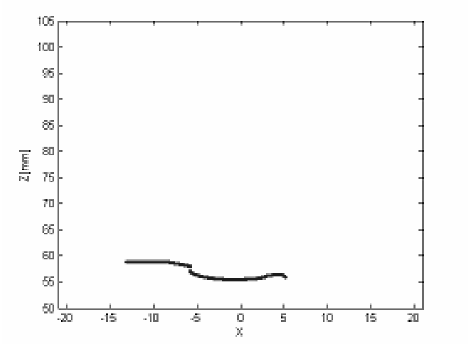


Figure 5 MicroEpsilon ScanControll 2800 25X laser scan

All these sensors provide a scan profile in the X Z plane. With the help of a linear movement of the sensor in Y direction over an object three-dimensional data can be generated. Besides local information of the single scan points the intensity values could possibly help to identify properties of the surface. The intensity values of the points are often used for filtration of the point clouds and for the detection of faulty points. To increase the accuracy of the scans the measurement rates often have to be decreased. If possible, the distance between the object and the sensor has to be reduced.

## IV. Data representation

A general range image consists of a simple net of points. The smallest part of a 3D scan is a scan point. This abstraction has the advantage that the representation of the sensor data is completely independent of the selected laser sensor. The most important advantage of laser range sensors is that the values of the Z axis can be directly equated with the distance (e.g. in millimeters). Additionally an intensity value can be assigned to every point of most sensors scaled between 0 an 1. Concerning the introduced 2D sensors the X values are given by the resolution and the provided measurement range. Results for every point in a height profile are defined in the following way:

$$\mathrm{P} = (\mathrm{X}, \mathrm{Y}, \mathrm{Z}, \mathrm{I})\,. \qquad (5)$$

A scan point differs from a height profile only due to the missing Y coordinate. The missing information for the Y coordinate of a laser line can only be assigned with the help external sources like robot axis and incremental encoders. The intensity value of the unordered point clouds is often not included in the point representation (computer graphics). All introduced sensors always take complete height profiles. In the data structure this is reflected by a point list.

$$\mathrm{L} = \{\mathrm{P1}, \mathrm{P2}, \ldots \mathrm{Pn}\}\,. \qquad (6)$$

The list of points sorted by X coordinate includes exactly the number of entries n according to the resolution of the sensor. It is possible to assign an Y value independently to every point. In the simplest case Y will increment if the sensor is orthogonally moved to the X Z plane. The movement in the Y-direction is possible with an independent resolution. In this case the Y coordinate is equal in the data structure for each laser line. A 3D range image is constructed with a sequential storage of laser lines. The range image

$$H = \{L1, L2, ...Ln\} \quad (7)$$

consists of a list of laser stripes ordered by the Y coordinate. Every range image is a list of laser lines, in which the number of laser lines is different. The data structure of a range image will contain an ordered point list, if the sensor is moved orthogonally in Y- direction.

There are well known data structures in the computer graphics sciences for 3d range images. The most general and often used data structure is the storage of unordered point clouds. The main goal of many algorithms in computer graphics is the reconstruction of surfaces from given point clouds. The data structure described above is a specialization of the generally used point cloud definition. For further interpretations also methods for unstructured point clouds can be used.

The data structures are implemented in object-oriented C++ classes. An Unified Modeling Language (UML) notation for this data structure is shown in diagram 6.

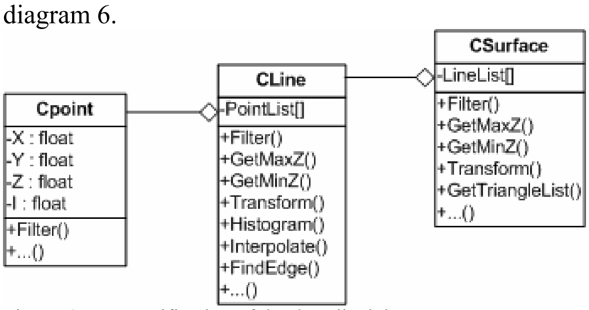


Figure 6 UML notification of the described data structure

Besides the described properties of a scan point it is for example possible to implement a filter function. With the help this filter function the point values can be checked with a threshold analysis in order to determine if this point is valid. Apart from this functions element operators are provided for comparisons between points, lines and surfaces (not included in the diagram). The laser lines contain a list of the points represented in the class “CLine”. General functions are filtration, histogram creation, transformations, min/max and regression functions. Depending on application the class has the possibility to implement other methods. Concerning the parameterization of the laser line different interpolation methods can be implemented [16]. The implementation of the range images in the class “CSurface” also contains usual methods for the transformation and filtration mentioned above. The most common use cases are methods for surface reconstruction. There are several approaches like Delaunay triangulation [8], spline based algorithms which are used in different fields of application [16][10]. Also registration methods like the iterative closest points (ICP) algorithms [9] could be easily implemented.

## V. Industrial Applications

The data representations for laser scans have the advantage that there are already ordered data structures existing which can be evaluated. Due to the stored intensity a point can be validated and verified with the help of a class method.

It is possible to develop different evaluations on a laser line. These line interpretations strongly depends on the application. Some applications in the industrial image processing were shown in this section. Many of them profit from the introduced data structure.

In the automobile industry robots are often used in the production lines. The precision of robots is mostly sufficient. But if the work piece has an alternating position, the process can not be permanently repeated. Usually the position of the work piece related to the robot position has to be determined very exactly. In order to solve this problem it is possible to use distance sensors providing characteristic points of the work piece. The line sensors recognize a laser line contour. With the help of this contour an edge point has to be extracted. This edge can be used to determine the position and orientation of the robot tool later on. The calculation of the edge coordinates based on regressions and contour extraction. In different range image applications many further methods belong to 2D Template Matching [11][12] [13]. Data structures for 3D surfaces arise from moving 2D sensors but also from 3D distance sensors [14]. Most applications [15] are using line sensors which are moved on external axes. An classic industrial application for laser range sensors is the measuring of volumes and geometries of (endless) production lines. In the automobile industry the geometry and volume of the sealing mass of car windows is checked with the help of laser range sensors, directly after they have been applied by the corresponding device. One example which uses the introduced data structure is shown in figure 7.

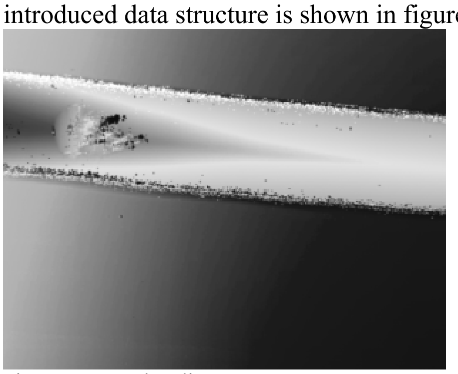

Figure 7 scanned sealing mass

During the scan the complete applied sealing mass is evaluated. With the help of a simple integration the volume of the applied mass is determined. A further application can be seen in figure 8.

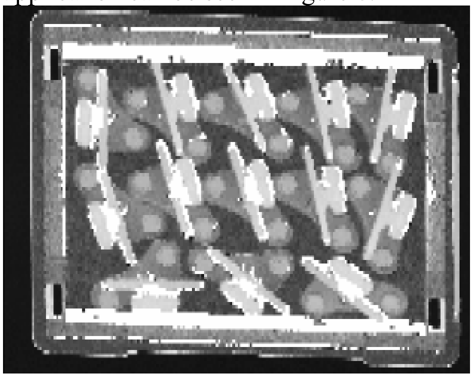

Figure 8 3D scan of door joints

Single door joints are represented in a box. In this picture the grey value always corresponds to the direct distance between the objects and the sensor. In order to achieve this, the Sick LMS 400 was moved linearly with a robot. Based on this distance information the positions of the parts are determined by 3D matching with CAD models.
Another application for the ScanControl2800 can be seen in figure 9.


Figure 9 3D profile of tire identification

With the help of a three dimensional scan the identifications on a car tire shall be verified with character recognition. Due to the different illuminations and low height of the identification the reconnaissance is very difficult for a conventional image processing. The ScanControl2800 is suitable for this task, because high resolution is needed. For the evaluation the height information is converted to grey values comparable to figure 9. The grey scaled pictures are transmitted to known optical character recognition systems (OCR).

## VI. Conclusion

Common laser range sensors as described above provide metric calibrated sensor data in a two dimensional measurement field. The introduced data structures in this paper were defined by this sensor data. The data structures are implemented hierarchically as classes in C++. It is important for industrial applications to make implementations of different evaluations very simple and useable; therefore the data representation has to be efficient too.

The described data structures are used successfully in many applications and are more and more improved continuously.

## REFERENCES


[1] P. Biber, W. Strasser, "nScan-Matching: Simultaneous Matching of Multiple Scans and Application to SLAM", *IEEE International Conference on Robotics and Automation*, 2006.

[2] I.-K. Lee, "Curve reconstruction from unorganized points" *Computer Aided Geometric Design, 17(2):161–177*, 2000.

[3] W. Boehler, A. Marbs, "3D Scanning Instruments", *Proceedings of The CIPA WG 6 International Workshop On Scanning For Cultural Heritage Recording, Greece, pp.9-12.*, 2002.

[4] Sick Sensor Intelligence, "Operation Instructions", *Fig. 3: Principle of operation of the LMS400 laser measurement system, p.19*, http://www.sick.com , 2006.

[5] F. Blais, J.-A. Beraldin, and S.F. El-Hakim, "Range Error Analysis of an Integrated Time-of-Flight, Triangulation, and Photogrammetry 3D Laser Scanning System" *SPIE Proceedings, AeroSense, Orlando, FL. April 24-28, Volume 4035. NRC 43649*, 2000.

[6] MEL Mikroelektronik GmbH, „Datasheet M2D Ethernet Sensor", *Mikroelektronik GmbH, Breslauer Str. 2, D–85386 Eching, Germany*, www.melsensor.de ,2006.

[7] MicroEpsilon Micro-Optronic Messtechnik GmbH: „LLT Dll-Interface description", *Micro-Optronic Messtechnik GmbH, Lessingstr. 14, 01465 Langebrück OT. Dresden*, www.micro-epsilon.de , 2006

[8] M. Gopi, S. Krishnan, C. Silva, „Surface reconstruction based on lower dimensional localized Delaunay triangulation", *Computer Graphics Forum 19(3):C467–C478*, 2000.

[9] P. Besl and N. McKay, "A method for registration of 3-d shapes", *IEEE Transactions on Pattern Analysis and Machine Intelligence, 14(2):239–256*, 1992.

[10] H. Hoppe, T. DeRose, T. Duchamp, J. McDonald, W. Stuetzle: "Surface reconstruction from unorganized points", *Computer Graphics, 26, Nr. 2*, 1992.

[11] F. Lu and E. Milios, "Robot pose estimation in unknown environments by matching 2d range scans", *In CVPR94, pages 935-938*, 1994.

[12]L. J. Latecki, R. Lakaemper, X. Sun, D. Wolter: "Building Polygonal Maps from Laser Range Data", *Int. Cognitive Robotics Workshop, Valencia, Spain*, 2004

[13] C. Baillard, C. Schmid, A. Zisserman, and A. Fitzgibbon, "Automatic line matching and 3D reconstruction of buildings from multiple views", *In ISPRS Conference on Automatic Extraction of GIS Objects from Digital Imagery, IAPRS Vol.32, Part 3-2W5, pages 69–80*, 1999.

[14] Weingarten, J., Gruener, G. and Siegwart, R, "A State-of-the-Art 3D Sensor for Robot Navigation". *Proceedings of IROS, Sendai*, 2004.

[15] Oliver Wulf, Bernardo Wagner "Fast 3D scanning methods for laser measurement systems" *Institute for Systems Engineering, University of Hannover, Germany*, 2003

[16] K. Rohr, H. S. Stiehl, R. Sprengel, W. Beil, T. M. Buzug, J. Weese, and M. H. Kuhn, "Point-based elastic registration of medical image data using approximating thin-plate splines," *in Visualization in Biomedical Computing (VBC'96), pp. 297–306*, 1996.