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FUSION OF SENSORY DATA OBTAINED BY DIFFERENT EQUIPMENT INTEGRATED IN THE MOBILE MEASUREMENT PLATFORM

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Abstract: The paper presents an algorithm designed to make fusion of sensory data obtained by different equipment integrated in a mobile measurement platform. The measurement platform has been primarily designed to measure changes of road geometrical parameters and degradation of road surface over time. When measuring road surface degradation, data from the laser scanner, GPS receiver and INS are being fused. The fusion process results are a 3D model of a real object. It consists of point cloud and faces generated from them. In addition to explanation of some basic fusion-based terminology the paper also presents graphical algorithms usable for improvement of 3D models by adding photograph-based textures. Particular steps of the designed fusion algorithm have been practically implemented and tested.
Keywords: point cloud; surface creation; Matlab; fusion process; *.obj

1. INTRODUCTION

Data fusion process can be used in many areas of data processing. Many programmers implemented fusion process in their applications. There are currently lots of confusion and contradictions in terminology about systems with fusion process. They resulted from usages of various terms such as "sensor fusion", "data fusion", "information fusion", "multisensor data fusion" and "multisensor integration" in the technical literature, where these terms are used to indicate different techniques, technologies, systems and applications utilizing data from various information sources. Another source of confusion and uncertainty sometimes results from the fact that programmers utilize fusion principles without recognition of that.

Figure 1. Laser scanner LD-OEM1000 [2]

Figure 2. Mobile measurement platform [1]

Figure 3. Laser scanner LMS-400 [1]

In our work we use fusion of sensory data obtained by different equipment integrated in the mobile measurement platform (Figure 1). The mobile measurement platform consists of two lasers scanners, seven cameras, GPS receiver, server, switch and UPS. We use laser scanners for accurate measurement of space near the mobile measurement platform. The first laser scanner (Figure 2) covers the whole space – its angular range is 360 degrees and measurable distance range about 250 m. The second laser scanner (Figure 3) is used for accurate measurement of road surface. Its angular range is 70 degree and measurable distance range about 2.4 m.

The research project whose partial results we present is titled "Study of interactions of a motor vehicle, traffic flow and road". Practical experiments were carried out on the equipment acquired under the project ITMS-26220220089 "New methods of measurement of physical parameters and dynamic interactions of motor vehicles, traffic flow and road conditions", i.e. the project which has been financed from the European regional development funds. The presented research results have been obtained with the support of the Slovak grant agency VEGA. The current research is concentrated on creation of 3D models with texture of real

objects, for example 3D model of a tunnel, road, buildings or road surrounding area. It results from our intention to develop the measurement platform usable for collection of information about land communications, their surrounding areas and a traffic flow.
Fusion of data obtained by laser scanners and GPS receivers helps us to generate a 3D model of the measured area. The 3D model consists of a point cloud. When we fuse data obtained by the 70 degrees scanner and the GPS receiver, we are able to generate the 3D model of road surface. In case we fuse data obtained by the 360 degrees scanner and the GPS receiver, we are able to generate the 3D model of surrounding area. Subsequently, we can apply an algorithm for creation of surfaces in the obtained model. This algorithm produces a surface based on geometric properties of the individual points. Real textures may be applied to the 3D model. They are acquired using one of cameras providing information about road surface. Textures for the whole model covering the entire surrounding space are generated totally by six cameras.

2. INTRODUCTION TO THE FUSION PROCESS

More and more important applications are dependent on computer systems. Applications must communicate with the outside world. There are large arrays of applications in which such systems may be used, for example, systems in manufacturing, medicine, military systems, security and transport systems.
When we design systems working in real time, it is necessary to take into account at least the following aspects:

- ✓ Sensor impairments,
- ✓ Real-time requirements,
- ✓ Dependability requirements,
- ✓ Complexity management requirements.

Various systems restrictions can be removed using sensor fusion.
Applications using fusion brings many advantages over conventional sensory systems.
Applying sensor fusion we can get the following benefits:

- ✓ Durability and reliability,
- ✓ Advanced spatial and temporal coverage,
- ✓ Uncertainty reduction / increase credibility,
- ✓ Reduction of uncertainty and insecurity,
- ✓ Resistance to interference,
- ✓ Improve the resolution.

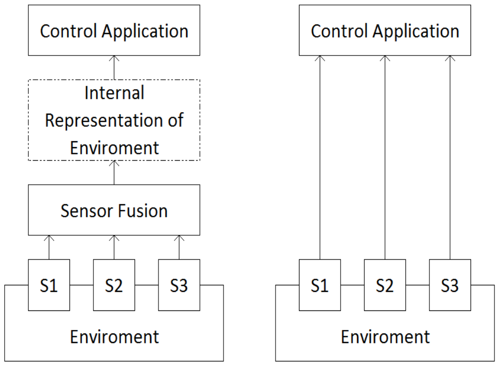

Figure 4. Difference between sensor fusion (left) and multi sensor integration (right)

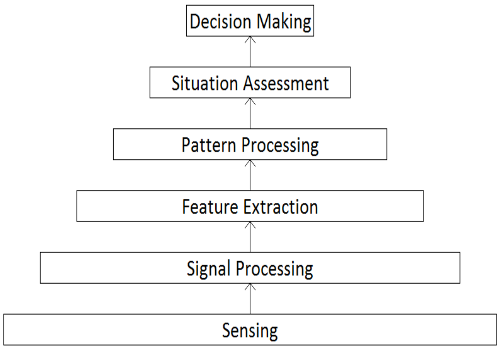

Figure 5. Waterfall fusion process model

One of the very frequently used terms is the term "multisensor integration". It utilizes the cooperation of sensory data to achieve system tasks. Unlike it, the "sensory fusion" processes data from sensors into one common internal representation of environment. The following picture (Figure 4) gives explanation of difference between sensor fusion and multisensor integration.
S1, S2 and S3 are sensors that provide information about the environment. The output of the sensor fusion process is an internal representation of environment. This internal representation represents an input into a control application. If information from sensors is directly entering the control application we talk about "multi-sensor integration".

3. WATERFALL FUSION PROCESS MODEL

The waterfall fusion process model is based on pre-processing of data at lower levels. In the following picture (Figure 5.) we can see phases of waterfall fusion process model.
Our computational process is based on using the waterfall fusion process model. First level sensing: all sensors are at this level; it is the same as a physical layer. Level signal processing: the algorithm uses data pre-processing at this level. Level feature extraction: the algorithm extracts only important data. Level pattern processing: the algorithm calculates a 3D model.
We use these four levels fusion approach that results in the 3D model. For example, at the situation assessment level we can define the hole length and our algorithm calculates position of this hole in road surface. Then at the decision making level the algorithm sends massage with information about the hole to an on-board unit.
The obtained model is more accurate in analysis; however, its main limitation is inability to use feedback of data flow.

4. FUSION IN THIS WORK

Our measurement unit is primarily designed to measure changes in geometrical parameters of the road and degradation of road surface over time. The secondary function of this unit is to measure surrounding area and environment around the measured road as a part of the actual measurement performed. The concept of the measurement unit is based on obtaining measured data and their rapid processing together with its graphical interpretation suitable for the following analysis.

Data about measured points of surrounding space is obtained by two laser scanners, seven cameras, GPS receiver and INS. The control program calculates the cloud of points. The output of the mobile measurement unit is a 3D model saved into the output file. In the following picture (Figure 6.) we can see a block diagram of the mobile measurement platform.

The laser scanner is connected via Ethernet interface to the local network. The user is connected to scanner through the network. We use communication type client - server for communication with the laser scanner. The laser scanner is a TCP/IP server and control application is a TCP/IP client.

Analysis of data received from the laser scanner was performed with the following settings:

- ✓ Scanning frequency 5 Hz,
- ✓ Angular resolution 72 degrees,
- ✓ 360 degrees measurement.

Measurement was started after setting parameters of the laser scanner. It sent the following message:

“<02><02><02><02><00><00><00><1f><73><52><41><00><62><00><0c><081><0ba><01><01><12><0de><00><00><04><080><00><05><00><00><00><0e9><02><08a><02><080><02><080><02><091><08a>”.

The message is typically in a hexadecimal form.

On the base of multiple measurements and their analysis the following description of the received packet may be presented:

<02><02><02><02> - used transmission protocol,
<00><00><00><1f> - quantity of transferred bytes,
<73><52><41><00><62><00><0c><081><0ba><01>
<01> - head of transmitted data,
<12><0de> - serial number of the measured frame,
<00><00>
<04><080> - angular resolution - now 72 degrees,
<00><05> - quantity of samples,
<00><00> - initial angle,
<00><0e9> - first measurement,
<02><08a> - second measurement,
<02><080> - third measurement,
<02><080> - fourth measurement,
<02><091> - fifth measurement,
<08a> - checksum - XOR from data.

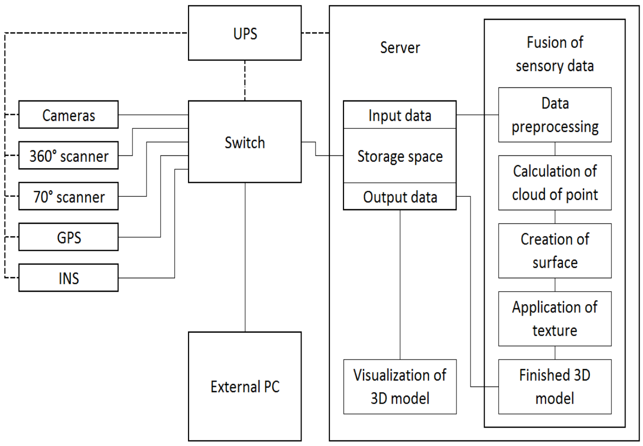

Figure 6. Block diagram of the mobile measurement platform

To calculate a cloud of points we use our own algorithm utilizing the equations (1) [3] proposed on the base of received data analysis. These equations enable to fuse data obtained by the laser scanner, GPS receiver and INS. The choice of the particular source laser scanner depends on the intended application.

Data obtained by the laser scanner:

- ✓ Initial angle α_{0n},
- ✓ Serial number of the current point i,
- ✓ Angle resolution $\Delta\alpha_n$,
- ✓ Distance between object and laser scanner d_{in}.

Data obtained by the GPS receiver: Position of the mobile measurement platform x_{0n}, y_{0n} and z_{0n}.

Data obtained by the GPS receiver: Rotation of the mobile measurement platform in each axe α_{rn}, β_{rn} a γ_{rn}.

$$
\begin{aligned}
x'_{in} &= d_{in} * \sin\left[\frac{(\alpha_{0n} + i*\Delta\alpha_n + \alpha_{rn} + 90)*\pi}{180}\right] * \cos\left[\frac{\beta_{rn}*\pi}{180}\right] + x_{0n} & r'_{in} &= \sqrt{y'^2_{in} + z'^2_{in}} & x_{in} &= x'_{in} \\
y'_{in} &= d_{in} * \cos\left[\frac{(\alpha_{0n} + i*\Delta\alpha_n + \alpha_{rn} + 90)*\pi}{180}\right] + y_{0n} & \gamma'_{in} &= \arccos\left[\frac{y'_{in} * 180}{r'_{in} * \pi}\right] & y_{in} &= r'_{in} * \cos\left[\frac{(\gamma_{rn} + \gamma'_{in})*\pi}{180}\right] \\
z'_{in} &= d_{in} * \sin\left[\frac{(\alpha_{0n} + i*\Delta\alpha_n + \alpha_{rn} + 90)*\pi}{180}\right] * \sin\left[\frac{\beta_{rn}*\pi}{180}\right] & & & z_{in} &= r'_{in} * \sin\left[\frac{(\gamma_{rn} + \gamma'_{in})*\pi}{180}\right] + z_{0n}
\end{aligned}
\qquad (1)
$$

Similar equations for calculation of trajectory were used in the publication [5]. We are able to calculate trajectory of the mobile measurement platform using video information. This method is described in the publication [4].

Then the algorithm for surface generation may be applied to the model. To do that, generally two basic approaches may be used.

The first approach is based on knowledge about the geometry of points in the 3D model. Information about geometry of each measured point is saved into the external file. Saving is performed during computation. One point related record in the external file consists of:

- ✓ Serial number of the measured plate,
- ✓ Serial number of the measured point,
- ✓ Information about uses of the point for surface creation.

The second approach doesn't have information about geometry of any point. Creation of surface is based on finding the nearest point. To find it, the algorithm uses information about distance and axes difference between points. From these data then the algorithm is able to create a relevant surface. This kind of algorithm is computationally more demanding than the algorithm mentioned in the first possible approach. The advantage is the possibility to create surfaces from already generated overlapping models.

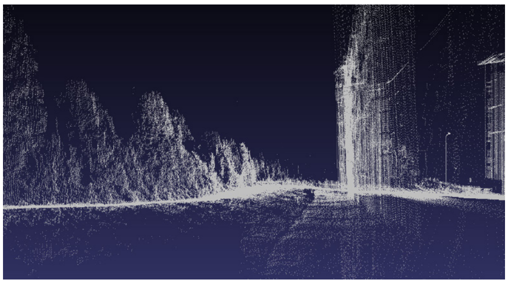

Figure 7. The cloud of measured points representing a part of the University Campus

Algorithm implementation assumes knowledge of the output file format – we use the OBJ format. It is proper for visualization of measured objects in the three- dimensional space. The OBJ format is also compatible with a lot of imaging software tools. What is more, internal structure of the OBJ format file is freely available and data storage is simply algorithmizable. The internal structure of OBJ format is defined by vertices of the object, edges of the object and edges of texture applied to the objects.

Application of texture on a created model is the last step of our fusion process. Texture, which is applied to the measured object, is in format .jpg.

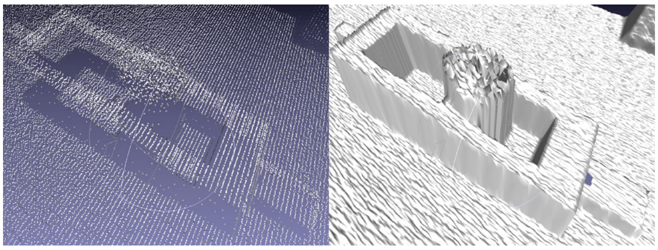

Figure 8. The cloud of measured points representing a real object (left), surfaces of the real object (right)

5. MEASUREMENT RESULTS

Particular steps of our fusion algorithm have been implemented, practically tested and their correctness confirmed. In the picture (Figure 7) we can see the 3D model representing a part of the University Campus. It is an output of our fusion process. The data for fusion process was obtained by the laser scanner (360 degree), GPS receiver and INS. In the picture (Figure 8) we can see the 3D model representing a real object on the road surface. This model is output of our fusion process. The data for fusion process was obtained by the laser scanner (70 degree), GPS receiver and INS. The algorithm for surface generation was applied to this model. We can also use it to generate surface of building (Figure 9).

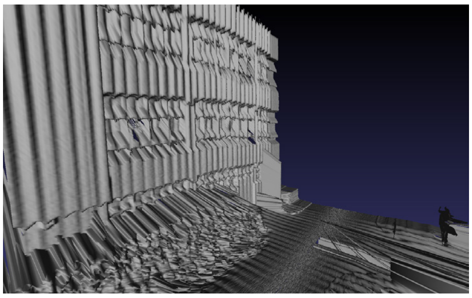

Figure 9. Surface of building

6. CONCLUSIONS

This paper presents the use of fusion data obtained by different equipment integrated in the mobile measurement platform. Described data fusion process makes us possible to generate 3D models of measured areas with corresponding textures. The obtained models may further be used in different applications in various sectors of human life and help with solving different tasks – from e.g. road repair to architect designs.

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