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Determination of Formulas for Processing of Measured Points Representing Road Surface Deformations

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ABSTRACT

The paper describes an initial approach adopted by the authors to create a system usable to monitor the road surface deformations in time and to model them in the 3D environment. To obtain measured data a 2D laser scanner is used to measure a distance of the real environment points. The main part of the paper deals with the derivation of formulas used by a measurement unit to calculate the point coordinates. The formulas result from and reflex a method of 3D measurement using an accelerometer and a gyroscope. The practical experiments have confirmed the ability of the measurement unit to scan the road deformation and the surrounding environment.

KEYWORDS: laser, scanner, visualization, 3D model

1. Introduction

The permanent growth of road traffic intensity affects adversely quality of roads. There are different defects of roads like cracks, potholes, longitudinal and transverse humps, ripples of surface, local declines or longitudinal beaten tracks. Each of them has a negative impact on comfort of driving and causes wear-out of some parts of road vehicles. A lot of measurement methods and devices have been developed and designed to measure road surface quality [1]. The trend is to move from manual measurement methods to those performed by electronic measurement devices.

The most sophisticated solutions are based on usage of contactless measurement methods based e.g. on measuring the fly time of a laser impulse which represents measured distance between the device and the road surface. In general, the laser scanner interface outputs the contour data on the recorded surroundings in the form of constant raw data. The 2D profiles of the surrounding area are scanned by the multiple pulsed infrared (IR) laser beams transmitted via a rotating lens head. Maximal pulse frequency of the laser diode in our case is 14.4 kHz to produce a maximal head rate of 15 times per second.

The raw data of the used laser scanner need processing before we can utilize them to measure road surface deformation and to record road surrounding area. The derivation of equations used for calculation of points coordinates are described below.

2. Method Suggestion for Data Processing

There are several possible approaches to how to perform particular measurements. This paragraph describes theoretical background for one of them as continuation of previously presented results [2].

2.1. The Basic 2D Measurement

Mathematical equations used for 2D measurement are based on parametric equation of a circle. Parametric equations of a circle are utilized to calculate x, y coordinates of the desired points (Fig.1). The mentioned equations are

$$x = \cos(\alpha) * r \qquad (1)$$

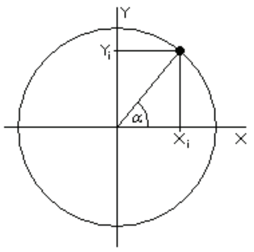

Fig. 1. The placement of a point in a circle

$$y = -\sin(\alpha) * r \tag{2}$$

Information about measured points of surrounding space is obtained from the laser scanner. There are data about an initial angle, a number of measured points, an angle difference between points and a distance between the laser scanner and a measured point. These values are used to calculate *x, y, z* coordinates by application of a suitable method.

According to the number of measured axes suggested approaches can be divided into:

- 2D measurement – scan of one profile of space;
- 3D measurement – scan of a whole space.

2.2. Automatic 3D Measurement Using an Accelerometer and a Gyroscope

The method of automatic 3D measurement of the road surface deformation expanded to include measuring of surround space is an automatic method able to handle the measurement device (for short MD) shift and the measurement device tilting in three axles. The movement of MD is recorded by the accelerometer and tilting of MD is recorded by the gyroscope.

The method of automatic 3D measurement using the accelerometer and gyroscope is based on automatic measurement of space selections with a given time interval. The shift of an initial point of the measurement caused by moving and tilting of the MD is counted when computing the coordinates as well. It is then possible to create 3D object composed of more measured space selections where the coordinates of all three axles depend on MD movement.

The accelerometer provides acceleration of the MD. It is appropriate to use the acceleration formulas to compute a trajectory of the MV in time *t* and acceleration *a*.

$$S = \frac{a * t^2}{2} \tag{3}$$

The method of automatic 3D measurement utilizing the accelerometer and gyroscope is based on automatic measurement of space selections with a given time interval between individual measurements. It is necessary to apply the modified acceleration formulas to compute the differentiation of moving in space. The differentiation of moving in space is computed for every axle.

The modified acceleration formulas:

$$\Delta S_X = \frac{\Delta a_X * \Delta t^2}{2} \tag{4}$$

$$\Delta S_Y = \frac{\Delta a_Y * \Delta t^2}{2} \tag{5}$$

$$\Delta S_Z = \frac{\Delta a_Z * \Delta t^2}{2} \tag{6}$$

The modified acceleration formulas are used to compute the shift of the zero point of the coordinates of the *n*-th space selection.

$$zero\_X_n = zero\_X_{n-1} + \frac{\Delta a_{Xn} * \Delta t^2}{2} \tag{7}$$

$$zero\_Y_n = zero\_Y_{n-1} + \frac{\Delta a_{Yn} * \Delta t^2}{2} \tag{8}$$

$$zero\_Z_n = zero\_Z_{n-1} + \frac{\Delta a_{Zn} * \Delta t^2}{2} \tag{9}$$

Mathematic equations for automatic 3D measurement using the accelerometer and gyroscope are based on acceleration formulas and parametric equations of a sphere. The parametric equations of the sphere are being used to compute *x, y* and *z* coordinates of the point of the interest (Fig. 2) which is defined by the radius and the angles between coordinates *x, z* and the point itself.

Then equations for coordinates of the point in sphere can be defined as follows:

$$x = x_0 + r * \sin(\alpha) * \cos(\beta) \tag{10}$$

$$y = y_0 + r * \sin(\alpha) * \sin(\beta) \tag{11}$$

$$z = z_0 + r * \cos(\alpha) \tag{12}$$

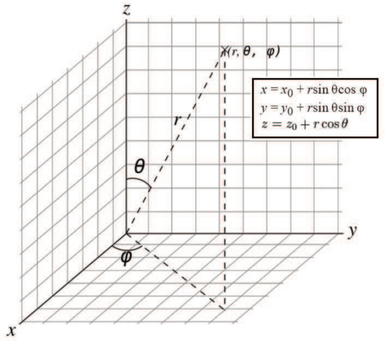

Fig. 2. Coordinates of the point in the sphere

The laser scanner provides data representing measured points using initial angle, counts of measured points, angle difference between points and distances between the laser scanner and measured points. It is necessary to modify the parametric equations of a circle, particularly computing of the *i*-th measured point in the *n*-th space selection to apply these data. The angle which is between the measured point and *x* axle is given by sum of mechanical rotation of the laser scanner, initial angle and multiple of the serial number of the measured point in a given space selection and angle difference.

The value of computing cycle repeating is set on the base of the number of measured points. Computing is repeated so many times how many measured points exist. The sequential number of the particular measured point is incremented in every computing cycle of the space selection.

Then the modified equations for computing of the *i*-th measured point in the *n*-th space selection can be defined as:

$$x_{in} = d_i * \sin[(\alpha_0) * \pi * 2/360] * \cos[(\beta_0) * \pi * 2/360] \quad (13)$$

$$y_{in} = d_i * \sin[(\alpha_0) * \pi * 2/360] * \sin[(\beta_0) * \pi * 2/360] \quad (14)$$

$$z_{in} = d_i * \cos[(\alpha_0) * \pi * 2/360] \quad (15)$$

$$r'_{in} = \sqrt{x_{in}^2 + z_{in}^2} \quad (16)$$

$$x'_{in} = r'_{in} * \cos[(\gamma_0 + i * \Delta\gamma_i + 90) * \pi * 2/360] + zero\_X_n \quad (17)$$

$$y'_{in} = y_{in} + zero\_Y_n \quad (18)$$

$$z'_{in} = r'_{in} * -\sin[(\gamma_0 + i * \Delta\gamma_i + 90) * \pi * 2/360] + zero\_Z_n \quad (19)$$

The main advantages of the automatic 3D measurement using the accelerometer and gyroscope are possibility to measure the whole space through measurement of space selections, ability to create a 3D model of the measured space and minimal control needed. On the other hand, what is disadvantageous is a higher number of the computing cycles; a need to use external gyroscope and accelerometer and high dependency between accuracy of the accelerometer and gyroscope and final results accuracy. The method of automatic 3D measurement using the accelerometer and gyroscope is able to handle a motion and tilting of the MD.

3. Implementation of the Measurement Unit

This paragraph gives some implementation details.

3.1. An Approach to Processing of Measured Scanner Data

The measurement data can be processed in the following ways:

- Off-line processing – the collected data are being processed after measurement and coordinates are computed from collected data.
- On-line processing – the data are being processed and coordinates are being computed during the measurement.

The measurement device which measures road surface degradation in time and scans surrounding space has been realized experimentally. There are several steps of data processing:

- Analysis of data obtained from the laser scanner;
- Computation of the number of bytes in data structure of the packet;
- Computation of angle difference;
- Computation of the number of measured samples;
- Computation of the initial scanning angle;
- Computation of the measured distance;
- Determination of a measured point coordinates;
- Development of measurement unit software for on/line processing;
- Visualization of measured data.

The essential part of realization of the measurement unit discussed in this paper is indicated by bold letters.

3.2. Results of Experimental Measurements

The primary usage of the MD is focused on measurement of road surface deformations and scanning of the surrounding environment. Ability of the MD to record road surface deformations (roughness) and local environment has been proved by experiments inside the university buildings. Several photos as obtained in [2] are shown below.

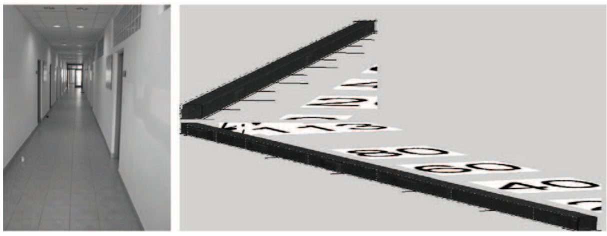

Fig. 3. Photo of the measured corridor and its 3D model with distance labelling

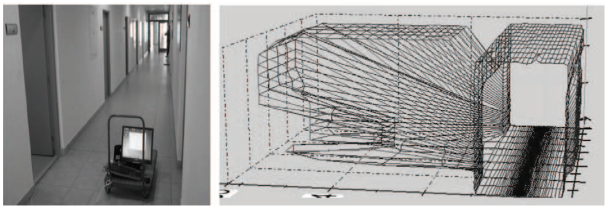

Fig. 4. Photo and the corresponding 3D model of the corridor having the door opened

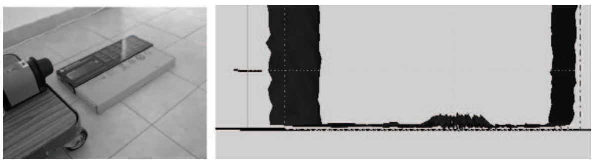

Fig. 5. Photo and the corresponding 3D model of two small boxes representing roughness occurrence

4. Conclusions and Future Studies

The derived formulas applicable in the method of automatic 3D measurement using the accelerometer and gyroscope have been confirmed by experimental measurements. In this case the third axis has been incremented in time. The mentioned equations have been successfully utilized to compute points coordinates based on a set of obtained raw data. The re-calculated coordinates have been simply visualized. The results of measurements have proved that the laser scanner working on the base of the TOF (Time of

Flight) method is able to record both unevenness (roughness) of the road surface and surrounding space.

In the case of the laser scanner used there was a limit of the maximum scanning frequency and scan accuracy for small distances (lower than 1 meter). As a better solution it seems to use a higher frequency scanner. For the maximum velocity of scanner head rotation (15Hz) velocity of the system as a whole may not exceed 15 km.h^{-1} to reach distance of profiles 10 cm. This condition is a reasonably limiting factor for the application to be developed. Velocity could be doubled by usage of 2 scanners having the same parameters.

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