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3D MODEL OF TUNNEL TUBE FOR MOBILE ROBOT NAVIGATION

3D MODEL TUNELOVEJ RÚRY PRE POTREBY NAVIGÁCIE MOBILNÝCH ROBOTOV

Abstract

This article deals with the design of an automated system for creating a 3D model of the environment with its texture. The method for creating a 3D model of the environment is based on the use of a 2D scanner for which the supporting hardware has been designed and constructed. The whole system extends the use of a 2D scanner that is embedded in a robotic system. Supporting hardware rotates the scanner around the scan axis. This will create a 3D model of the environment using a 2D scanner. Thus, the resulting 3D scan is formed by subsequent 2D scans, each shifted with respect to the previous one. It was necessary to design the appropriate software for hardware management to control the movement of the engine, the scanner, and process the measured data. The proposed system can be placed on various exploration robotic systems that map the space using the proposed method. Wheeled, band robotic systems or drones can be used to explore hard-to-reach environment.

Abstrakt

Tento článok sa zaoberá návrhom automatizovaného systému pre tvorbu 3D modelu prostredia s jeho textúrou. Metóda pre tvorbu 3D modelu prostredia je založená na použití 2D skenera, ku ktorému bol navrhnutý a skonštruovaný podporný hardvér. Celý systém rozširuje použitie 2D skenera, ktorý je osadený v robotickom systéme. Podporný hardvér má za úlohu spomínaný skener otáčať okolo osi skenovania. Týmto sa dosiahne vytvorenie 3D modelu prostredia za pomoci 2D skenera. Teda výsledný 3D sken budú tvoriť 2D skeny vždy posunuté o uhol voči tomu predchádzajúcemu. Pre riadenie hardvéru bolo nutné navrhnúť vhodný softvér, ktorý bude riadiť pohyb motora, skenera a spracovávať namerané údaje. Navrhnutý systém je možné umiestniť na rôzne prieskumné robotické systémy, ktoré budú pomocou navrhnutej metódy mapovať priestor. Môžu byť použité kolesové, pásové robotické systémy alebo možno použiť drony pre prieskum ťažko dostupného prostredia.

Keywords

3D model, object measurement, mapping robot system, 2D laser scanner, texture

1 INTRODUCTION

People are nowadays increasingly aware of the need to digitize the surrounding world. For example, digitization of historic buildings can help preserve cultural heritage for future generations, and based on these data, it is also possible to design procedures for renovating them. In addition, it

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provides many other benefits. Making virtual tours, the cities can be presented to potential visitors and thus develop tourism. Virtual models can also be useful in designing town plans. The digitization of industrial halls allows subsequent analysis and optimization of the production process.

The current trend of digitization, digital mapping and three-dimensional space, offers new possibilities for developers and programmers and simplifies their work. Applications commonly used to view different graphical formats also begin to support formats that allow three-dimensional rendering. Standards have also been developed for the internal structure of these files.A good (albeit not very recent) overview of scanning methods designed to perform 3D scans using a 2D laser scanner is given in [1]. The authors differentiate among 4 distinct scanning methods, namely [1]:

– Pitching scan: it operates on a horizontal scan plane and is pitching up and down,

– Rolling scan: the scan is rotating around the center of the scanner,

– Yawing scan: it operates on a vertical scan plane and rotates around the upright z-axis, the scanner is turned to the side,

– Yawing scan top: it is the same as yawing scan, but the scanner is turned upwards.

Naturally, each of the approaches provides a different field of view, but it should also be noted that the rotation of the 2D sensor leads to an accumulation of points along the rotation axis (the points are more densely distributed in that region) [1]. The scanning approach employed in the present article would fall into the category of yawing scans under this classification. The points would be most dense around the vertical rotational axis. There is also a slight distinction in our case in that we use a 360° scanner as opposed to the 180° scanners considered in [1].2D laser scanners have frequently been applied to mapping 3D environments in the past, since 3D scanners are still considered too expensive for applications in mobile robotics. There is a number of works that employ them in various ways – either just for mapping, or for simultaneous localization and mapping (SLAM). Among such works, we can mention at least [2], [3], [4]. When the 2D scanner is mounted on a moving robot, of course, sophisticated post-processing is needed in order to match and align the individual scans properly. In the present work, we do not address the matching and alignment issues, we require the scanning platform to remain stationary for the duration of the scan, which results in a single 3D scan with a high order of precision.However, we can give [2] as an instance of a system that also does matching and alignment. To this end, the authors use the extended Kalman filter to track the 3D position of the robot. This information is then used to help with the matching and alignment of the 3D scans acquired using a rolling 2D scanner. A similar approach – also based on the extended Kalman filter – is taken in [4]. Having said that, in the following we will focus more narrowly on the ways in which various authors use 2D scanners to perform 3D scanning, and we will leave the matching and alignment aspects aside.

In [3] the authors use a pair of 2D tiltable scanners (i.e. the pitching setup) mounted at the front and the back of a mobile robot in order to create a 3D map of the environment (the intended application is autonomous mine mapping). The scans are acquired in a stop and go fashion. Each scan takes 8.9 seconds. The field of view of each scanner is 180° horizontally and 60° vertically with the resolution of 361 points in the horizontal and 341 points in the vertical direction. Paper [4] also uses the pitching setup. In this case, the 2D scanner is rotated in the angular range of 270° with the number of steps being 601. Since each 2D scan has the angular range of 180° and it itself produces 361 points, the resolution is 361 points horizontally times 601 points vertically. It takes about 1 minute to create a complete scan in this way [4]. As an instance of a paper that uses yawing, we can mention [5]. There the resulting 3D scanner has a field of view of 360° horizontally and 67.5° vertically and the resolution of 537 points horizontally and 270 points vertically. The acquisition time is about 6.75s in this case. A notably different approach is taken in [6]. There the 2D scanner is mounted on the robot in a fixed position, angled towards the ground. The 2D slices that make up the 3D scan are formed as the robot moves forward. Regrettably, paper [6] neglects to mention details such as the resolutions of the resulting scans and the overall speed of scanning, so we cannot make any quantitative comparison with the above-mentioned approaches.

A further instance of a system, which uses pitching, is presented in. The interesting feature of this solution is the use of a four-bar linkage on which the 2D scanner is mounted – this provides the required movement. Since the movement of the scanner is not simply rotatory in this case, a linkage transformation is applied to recover its position and thus also the correct positions of the measured points. One way in which the present work differs significantly from all the above-mentioned approaches is that it combines the 3D scan with textures collected using a rotating camera. This not only increases the interpretability of the 3D scan considerably, but also significantly contributes to providing a more faithful reconstruction of the original scene. A paper, which is comparably close to the present work in the fact that it also combines a 2D scanner with a (stereo) camera, is [7]. There, however, the camera is used with the express purpose of improving SLAM precision and not for collecting textures, or providing scene reconstructions. As a sample of other interesting applications of 3D scanning using 2D scanners, we can mention [8], which uses the scanner to do 3D plant structure phenotyping, or [9], [10], which use such scanners to map rough terrain with the intent of performing autonomous navigation, drivability assessment and other related tasks.

The proposed method for creating a virtual space model is based on the measurement and processing of spatial data. This issue is addressed by several expert groups who have achieved significant results. Researchers at the Technical University of Košice, the Institute of Geodesy, Cartography, and Geographic Information Systems, carried out the measurement of the Urban Tower (Figure 1) using the Trimble VX Spatial Station and the Leica ScanStation 2. The Urban Tower is a gothic bell tower at St. Elisabeth´s Dome in Košice. The Trimble VX Spatial Station was scanned from four positions and from three positions by the Leica ScanStation 2. The individual points in which the measurements were made were placed into a common coordinate system. The resulting cloud of points has reached 43.64 million points, with 8 million points remaining after filtration [11].

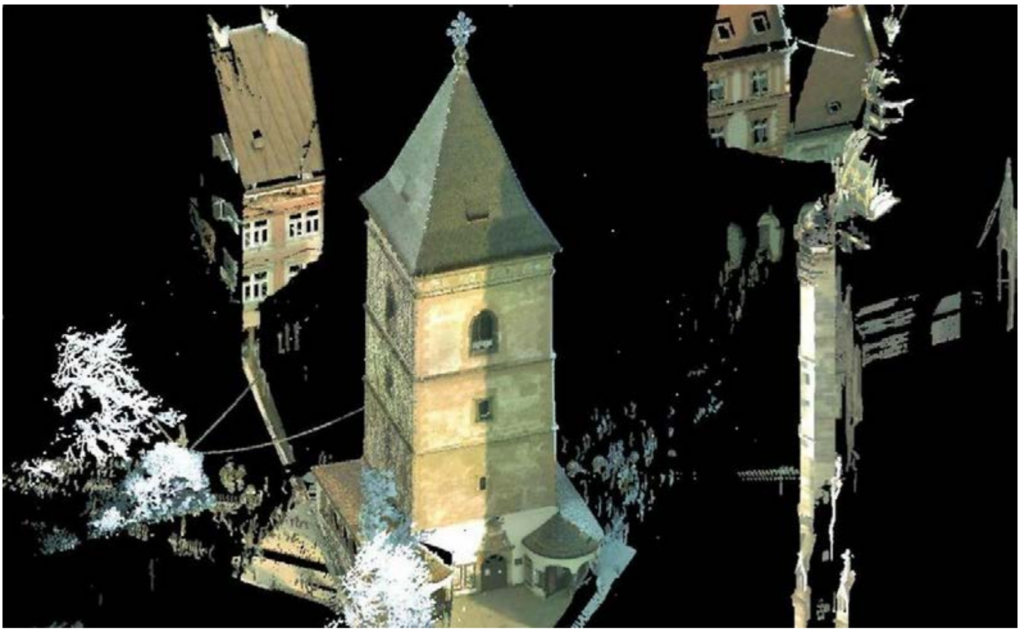

Fig. 1 3D model of the urban tower

A 3D object model can also be created from photographs. This method is used by several authors, some focused on smaller objects (e.g. historical vases, statues) [12], some on larger objects such as buildings or mountains (Figure 2).

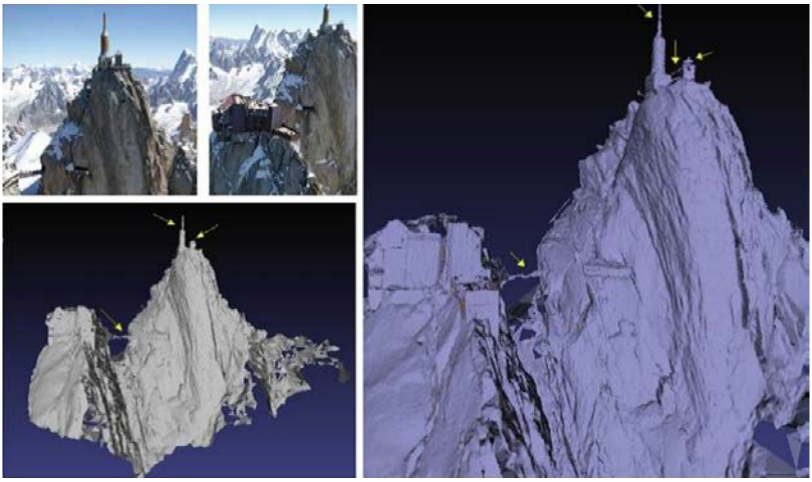

Fig. 2 3D model of mountains [13]

If we need to create a three-dimensional model of the outer environment, stable, terrestrial laser scanners can be used to measure the space around the scanner and then programmatically create a virtual model of the scanned space. The virtual model can then be used for a variety of purposes – for example, to measure the size of the objects being scanned in the model, or to observe the interrelationships between the objects. If structures and installations alongside the track intersect into the area in which the vehicles are moving, there is a risk of collisions of vehicles with these objects with possible damage to vehicles and off-road objects or injury to passengers. Some off-road objects may hinder the driver´s view and the virtual model will help to discover them.

One of the systems which utilize the measurement and analysis of the ground plan for the navigation is the system Voyage II. Authors dealt with 2D simultaneous localization and mapping (2D SLAM) which has been used to calculate the optimal trajectory of the robotic system. The dimensions of the surrounding space were captured by lidar VLP-16, inertial measurement unit (IMU), GPS and encoders placed on motors. Adaptive Monte Carlo localization has been used to navigate the robot in the obtained map. In outdoor environment, the readings from GPS were used to navigate the robot.

This work proposes a design of an automated system for capturing the 3D model of the environment including its texture. The method of capturing the 3D model of the environment is base on 2D scanner with an aid of the designed supplementary hardware. Resultant 3D model can be used for various purposes such as navigation along precomputed trajectory, searching for collisions between the moving objects and the environment, searching for defects on the surface of the objects, object classification etc. which is not the objective of this article.

2 THE METHOD FOR CREATION OF 3D MODEL

The algorithm is based on scanning and camera data acquisition. After converting the data from the scanner, we obtain the 3D model of the environment as a cloud of points. By fusing these data and data from the cameras, we get a 3D model with the texture corresponding to the environment. The created model can then be used for space navigation or virtual space exploration.

The HW solution (Figure 3) is based on using laser scanner LD-OEM 1000 manufactured by the SICK company. This laser scanner is rotated using rotating platform with the stepper motor Wexta. Our laser scanner LD-OEM 1000 can scan 360° space in one axis. This scanner is used either to perform localization or to map space during movement. In order to create a system that resembles a terrestrial scanner using a 2D scanner, we need to ensure that it rotates around another axis. The LD-OEM 1000 laser scanner used in our system scans the space in the vertical axis. By placing it on a templet that is rotated by the engine around the horizontal axis, we have reached the condition of rotation around another axis. The principle of scanning the space is that the scanner performs a vertical scan, and when finished, the motor rotates the scanner around the axis of measurement by the specified angle. It scans and turns again until all the desired values are found. The engine is controlled by a microprocessor. The important thing is to maintain the correct sequence of commands and not to get a bad measurement or suffer loss of data. The 3D Modeling System consists of two basic subroutines. The first controls the engine, the second the scanner.

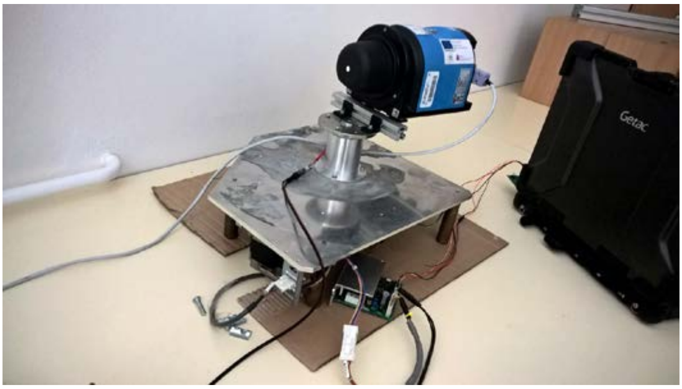

Fig. 3 HW implementation - testing in the laboratory

The *x* coordinate of the point is equal to the multiple of the angle (α) of the cosine and the radius (r). The *y* coordinate of the point is equal to the multiple of the sine of the angle (α) and the radius (r).

The parametric circle equations for calculating one point on a circle are:

$$x = x_0 + r.\sin\alpha, \quad (1)$$

$$x = x_0 + r.\cos\alpha. \quad (2)$$

The laser scanner provides data of the measured points using the initial angle (α_0), the number of measured points, the angle difference between the individual points ($\Delta\alpha$) and the distance between the laser scanner and the measured points (r). To calculate the *i*-th point's coordinates, the parametric equations of the circle need to be adjusted. The angle α is given by the sum of the constant, expressing the mechanical rotation of the laser scanner, the initial angle, and the multiplicity of the sequence number of the point and the angular difference. Based on the number of points measured, the recirculation of the calculation cycle is set. The calculation is repeated as many times as there are measured points. The reference number of the measured point is incremented in each calculation cycle. These give us a 2D cross-section of the space in the form of a point cloud. They are used for linear measurement of the space during constant motion. To calculate a 3D model for a system that mimics the terrestrial scanner, the equation needs to be extended by incremental rotation of the scanner after each measurement. After creating a cloud of points from the measured space, the texture is created and applied. To create the texture we have designed a method based on adaptive data selection. We had to take into account the speed of camera's movement, the distance of the recorded objects from the camera to calculate the camera's amplitude, and also the fps of the camera used (the number of images recorded per second). Taking into account all the design factors, we expected the output of this formula to be the number and width of the video image to be selected and used in the panorama. Parameters of the LG G3 camera are following: a 13 megapixel camera with laser focus, we can choose from multiple resolutions for recording video, namely Slow Motion, where the camera records 120 fps, and we also have the HD-1280x720 / FullHD-1920x1080 / UltraHD -3840x2160 resolution. With these resolutions, the camera records with 30 FPS. We used the FullHD resolution of 1920x1080 pixels at 30 FPS.

3 PRACTICAL MEASUREMENT AND TESTING

As an output format, we chose .obj format. This format is suitable for viewing objects in the three-dimensional space. The advantage of the .obj format is also in its compatibility with multiple display software. The internal structure of the .obj file format is freely available and data storage is very easy to algorithm processing. The inner structure is determined by at least the top of the edges of the objects. Other parameters are the edges of objects, or the points and edges of the texture applied to the objects.

The object of the scanning was the AB210 room, located at the Department of Control and Information Systems at the Faculty of Electrical Engineering and Information Technology, University of Žilina. This measurement was performed with a scanning resolution of 0.25° scanner and an engine shift of 0.108°. The scanner was not placed in the center of the room during scanning to show the difference when measuring close and distant objects. Non-dotted areas represent the areas where the scanner did not scan. It is due to the shading caused by some object (such as desk, cabinet, etc.). Figure 4 shows photo and resulting 3D models of the scanned areas.

The algorithm was practically tested on the test object (laboratory on UNIZA). From this measurement, a texture and a 3D model were created in the form of a cloud of points. The texture was applied to the model (Figure 5) which created the resulting 3D model with the corresponding texture (Figure 6).

Fig. 4 Real photo of the scanned space, preview of the resulting 3D model

Fig. 5 Photo from the practical testing

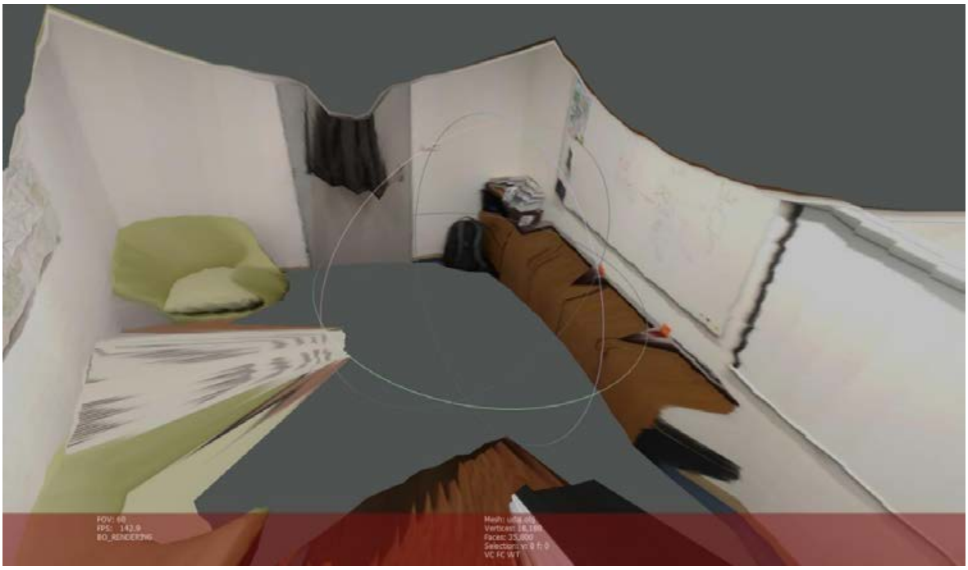

Fig. 6 The final 3D model with the appropriate texture

3 CONCLUSIONS

In this article we have proposed a method for the measurement of a full 3D model of the environment including its visual texture. The method merges two sets of data into a single fused result. First, the algorithm processes data from a 2D laser scanner mounted at the top of a rotational platform driven by a stepper motor. The output of the laser scanner (the 2D profile in polar coordinates) with the rotational angle of the platform is converted into a 3D cloud of points. Then, the image captured by a camera is transformed into a texture, which is applied to the obtained 3D model.The obtained 3D model of the real environment can be used for various purposes in robotics, reconstruction of buildings, historical documentation or in providing virtual reality, which is especially suitable in dangerous areas where humans would be exposed to excessive danger, but they can control a robot remotely while its movement can be visualised inside a textured 3D model. The main advantage of our method is its simplicity (360 degrees of view during one scan without the need to change the position of the scanner) and its high precision (the error of the measured position is in the order of millimetres for indoor applications). There are many applications which use captured 3D models of the real objects. Besides the navigation of the robotic system in real environment and visualization of its movement the 3D model can be used for:

- searching for collisions between moving objects in the environment,
- searching for defects on the surface of the objects,
- classification of the objects by their shape, …

Main advantage of the proposed solution copared to the commercially available terrestrial scanners is the structure of the output 3D model of the object. The most important difference is that many terrestrial scanners provide the model as a cloud of colored points while our system provide the model composed of surfaces with applied texture. This difference is signifficant at closer scale when the model becomes easily readable and contains more information. This increases its usability in mentioned applications.

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