Original scientific paper

System for 3D Mapping using Affordable LIDAR

Veličko Krsmanović, Marko Barjaktarović, and Ana Gavrovska, *Member, IEEE*

***Abstract* — In this paper a new system for 3D (three-dimensional) mapping using affordable LIDAR (light detection and ranging) is presented. The implementation of LIDAR technology-based approach enables obtaining a point cloud as a representation of indoor surrounding. In recent years with the help of LIDAR this kind of sensing has found numerous applications across various industries. Here, a cloud of points is generated during room scanning using Arduino platform based rotating system. The obtained results are promising, and the proposed solution can find its practical application in different fields. Moreover, it can provide many possibilities for future experiments with surrounding mappings, image matching, autonomous driving, obstacle observation, collision avoidance, material type detection such as transparent ones.**

***Keywords* — LIDAR, sensor, affordable system, 3D, point cloud, computer vision.**

I. Introduction

RADAR technology bases its operating principle on the reflection of electromagnetic waves. Similarly, the radar concept can be used for light and obtaining image mapping which resulted in LIDAR (light detection and ranging) [1]-[3]. LIDAR is applied for distance measuring, where a target is illuminated by laser light. LIDAR emits light in the form of high power and spatial concentrated wave, using laser as a source. This light hits an object and reflects back to the sensor place. Next, a system measures time for that emitted pulse and calculates the distance between the LIDAR and the object. The measured time difference between a sent and registered beam is used for the 3D (three-dimensional) representation of the target. With scanning all directions in its surroundings, LIDAR generates a cloud of points. The points in space are found where reflection occurred. The main difference between LIDAR and radar is in spatial resolution which is in favour of LIDAR.

Paper received June 12, 2022; accepted October 25, 2022. Date of publication December 26, 2022. The associate editor coordinating the review of this manuscript and approving it for publication was Prof. Irini Reljin.

This paper is revised and expanded version of the paper presented at the 29th Telecommunications Forum TELFOR 2022 [1].

The research presented in this paper is partially funded by the Ministry of Education, Science and Technological Development, Republic of Serbia, No. 2022/200103.

Veličko Krsmanović is with the School of Electrical Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11020 Belgrade, Serbia (e-mail: vekismile93@gmail.com).

Marko Barjaktarović is with the Department of Microelectronics and Technical Physics, School of Electrical Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11020 Belgrade, Serbia (e-mail: mbarjaktarovic@etf.bg.ac.rs).

Ana Gavrovska is with the Department of Telecommunications, School of Electrical Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11020 Belgrade, Serbia (e-mail: anaga777@gmail.com; anaga777@etf.rs).

The most frequent application of LIDAR is generating high-resolution maps in different fields, from a stationary position or from a vehicle like a car, drone or airplane, where LIDAR is mounted. Applications include the field of geology, environmental monitoring, detection of deforestation, robot guidance, airborne laser swath mapping (ALSM), etc. With the advancement of technology, it has also been employed in handheld devices. In several recent years its significance is found in autonomous driving, which has led to a drastic reduction of LIDAR price and developing a new realisation without a scanning mechanism [2]-[6].

Generally, LIDAR technologies are considered of rather high-cost level [7]-[9]. For example, the prices of spinning mechanical LIDARs are of high cost for auto makers, but the trend is to introduce more cost-effective solutions where the new LIDARs are typically limited to 120 degrees [10]-[11]. This requires multiple stationary LIDARs pointing in different directions for building a 3D point cloud of surroundings.

Nowadays, cost-effective LIDAR systems are being considered for various industries. In UAV (unmanned aerial vehicle) industry LIDAR sensors are applied for remote sensing. Loading new cost-effective LIDARs on top of drones and their suitability are under consideration since previously LIDARs have been loaded on large aircrafts increasing the cost of the system. Power of fast processing electronics is making the pathway toward systems that are compact, fast, and low-cost. Some of non-mechanical solutions can be particularly of interest to decrease the usage of bulky components. The systems are developed for 3D indoor or outdoor monitoring while achieving a compact size and light weight [12]-[14]. Different wavelengths can be used for LIDAR based approaches, from ultraviolet to infrared. It can hit targets of various materials, including non-metallic objects, aerosols, clouds, ideally even molecules.

This paper presents a new affordable 3D mapping system based on LIDAR sensor and Arduino platform. The explanation of both hardware and software is given, as well as the explanation of applied method for point cloud calculation. The obtained simulation results are discussed and followed by a suggestion for future work and possible improvements.

The organization of this paper is as follows. In Section II, LIDAR technology is considered for the development of a new affordable system for indoor point cloud generation. Hardware consists of electronic and mechanical components, and they are briefly explained in Section III. Details about the image acquisition and the cloud point visualization are given in Section IV. Experimental results are presented in Section V. Finally, conclusions can be found in Section VI.

II. LIDAR System Development

Generally, there are lots of different considerations for the development of a LIDAR system [10]-[14]. The most common range is from 250 to 1000 nm since it is used because all parts can be realized in silicon technology. For military applications the band from 1500 to 1550 nm is usually of interest, because this range does not correspond to visible light and cannot be detected without appropriate equipment. Typically, light is reflected by backscattering in LIDAR systems [7]-[8].

There are two ways of detection: direct energy detection and coherent detection. The first method measures the amplitude change, while the second measures the change in phase. Thus, a LIDAR system can utilize the principle of detection such as direct detection when a sensor reacts to a change in amplitude. It can also use coherent detection when the receiver measures a change in phase between a sent and registered beam. LIDARs dedicated to mobile platforms, like UAVs, satellites or cars, also have additional sensors like GPS and IMU (inertial measurement unit), This is done in order to compensate the influence of using a point cloud-based approach and also to georeference point cloud data. Depending on wavelength, light can be reflected from various materials even from molecules, providing information about the atmosphere. It can target a variety of objects of different materials.

Pulses from laser frequently return with multiple echoes. When a material is not fully opaque, one part of photons returns from the object's surface and another part enters the material. Then, it partially reflects again, and so on. The first echo comes from the nearest point. These echoes can be categorized according to LIDAR application. Solid state photodetectors (SPD) are the main technology for the photodetection, where avalanche silicon photodiodes are employed. As a result, a point cloud is generated. One typical example is a point cloud created by Velodyne LIDAR sensor, with the application for autonomous vehicles and driver assistance [8].

A LIDAR is already used in many domains like construction, autonomous driving, geodesy, environmental monitoring, agriculture, terrain mapping, etc. Applications in climatology are of importance since a LIDAR can provide data for monitoring change of glaciers (or snow cover) and for the detection of deforestation. Moreover, the characteristics of forests and vegetation can be monitored, where a Leaf Area Index can be found [6].

New systems are oriented towards affordable, fast, and efficient solutions for indoor and outdoor point cloud mapping [12]-[14]. The goal of this work is to develop a new LIDAR system that is affordable for indoor 3D mapping based on Arduino platform and Garmin LIDAR Lite V3 [15], which is an optical distance measurement sensor. This sensor has been selected for system prototypes dedicated to robot operating, bicycles, and wind turbine blades [16]-[18].

III. Hardware of the Proposed 3D Mapping System

The proposed LIDAR system for 3D mapping is consisted of electronic and mechanical components. It is based on Arduino platform as one of the most common selections for developing a system prototype. The main electronic component is the Garmin LIDAR Lite V3 which is chosen for system development due to its excellent characteristics. Some of mechanical components are made using 3D printing. Mechanical rotation is needed in order to obtain a 3D map of indoor surrounding.

The proposed Arduino based 3D mapping system is presented in Fig.1.

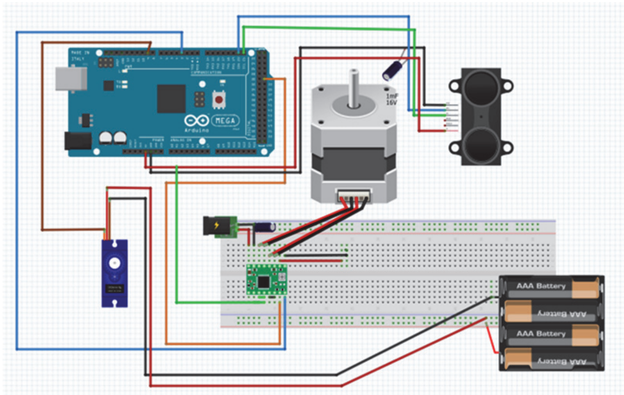

Fig. 1. The proposed Arduino based 3D mapping system.

A. Electronic components of the proposed system

The Garmin LIDAR Lite V3 sensor is used for system development. The characteristics of this sensor are shown in Table 1. This is a compact powerful and lightweight ranging and proximity sensor with low power consumption [18].

Table 1: The characteristics of Selected LIDAR v3 sensor.

No.	Specification	Values
1	Range	40 m
2	Resolution	±1cm
3	Accuracy <5m	±2.5cm
4	Accuracy >5m	±10cm
5	Update Rate	270Hz typ.650Hz FastM
6	Repetition Rate	50Hz def,500 Hz Max

The Garmin support is used for calibrating LIDAR-Lite v3 sensor [19]. It requires minimal accompanying hardware, and a user can make appropriate configurations for system development. Namely, some variables can be configured so decisions can be made in order to obtain specific accuracy, range for making measurements and similar. The LIDAR uses a laser transmitter, 905 nm, 4 mRadian x 2 mRadian air divergences, and an aperture of 12.5 mm. Also, it can apply I2C technology. It enables measuring a time difference between a moment when a light beam is transmitted and a corresponding moment when it is detected after being reflected.

Each time difference measure is converted to a distance value according to the speed of light. In order to make measurements, receiver bias is primarily corrected [19]. Ambient conditions regarding the light may affect measurements, so the adequate corrections are also needed for obtaining sensitive acquisition. The processing unit processes the so-called coded signature for a signal and expects appropriate feedback. A set sensitivity should enable the detection of different materials expected in indoor circumstances, where both reflective and non-reflective surfaces can be found.

The device sends a reference signal from the transmitter to the receiver. The signal is stored on the receiver side. The time delay is set for a zero distance in order to recalculate delay in a periodic manner when measures are made. For making measurements, a series of acquisitions is performed. Since a signal is stored by a receiver it is possible to carry out a matching procedure with the signal being transmitted.

When matching exists, the result is recorded. The following acquisition is added to the previous result. When the corresponding reflection (feedback) signal returns to the receiver, acquisitions are repeated. The validity of each measurement is tested by thresholding. The valid one is when the peak value is higher than noise.

The acquisition is performed until the peak signal reaches its maximum. When the maximum value is not reached by the feedback, the device stops after a predefined number of acquisitions. Strength of the beam is calculated from the maximum value, and the threshold is found from the noise level. A made measurement is considered valid when a signal peak is higher than the threshold, and this leads to distance calculation. If this is not the case, the measurement is not acknowledged - NACK or 1cm. The device deletes the signal for the next measurement, and a new sequence is gathered. This is, in general, how the device works.

System is based on Arduino platform, where Arduino Mega is selected for the central control unit. The Arduino Mega 2560 is chosen for the prototype, and it represents a microcontroller board based on the ATmega2560 microchip technology. The main characteristics are the following: sixteen analog inputs, 54 digital input/output pins, four serial ports. It also provides a Universal Serial Bus (USB) connection.

The servo motor that drives a LIDAR sensor is also needed since it is an important component of the system. These servo motors are designed to be used in various control and robotic systems, especially in order to provide precision in the control of speed and positioning. It is a closed loop system. They operate in a power range from several watts to several hundred watts. For the prototype SG90 9g servo motor is applied in the proposed system.

Moreover, a stepper motor is a part of this prototype LIDAR system. Generally, stepper motors are implemented for different applications, like in 3D printers and computer numerical control (CNC) machines. A stepper motor, also known as a step or stepping motor, is an electric DC (direct current) motor which divides a full rotation into a number of steps. These steps or increments are equal and useful in order to provide precise positioning.

The stepping motor is controlled by DC pulses to generate the rotation. The pulses are assigned to internal coils, where an increment is made so the motor moves one step forward. In other words, it is making a microstep. Not knowing the position is a characteristic of the stepper, while a servo motor directly deals with positions.

The reference position can be defined, and a stepping motor can be set to the reference even by external forces. This is not the case with servo motors, where they are firstly initialized according to the reference position in order to make a measurement. When continuous rotation is needed, stepper motors are not an adequate choice due to using discrete steps for rotation generation. This issue may be resolved by microstepping. The microstepping increases the resolution of stepper motor. In the proposed system, here, NEMA 17 350mA is used.

A stepper driver is also implemented, and it has a role of dealing with currents on two adjacent coils which have to be in an adequate relationship. Since Arduino platform is selected, a sufficient current level is required for operating the stepper. The A4899 stepper driver is selected for compatibility with a selected motor. It uses a voltage of 12V, and a peak current of 350mA.

B. Mechanical components of the proposed system

Besides electronic components, mechanical components are inevitable. The proposed system needs to perform scanning. In order to provide an appropriate mechanism, some mechanical components are realized using 3D printing. These parts are made of PETG (polyethylene terephthalate glycol) material. A more elastic and flexible material is TPU (thermoplastic polyurethane) which is used for the manufacturing of belt.

Stereolithography is a process that enables the physical reproduction of 3D models. Thus, stereolithography CAD (computer-aided design) software is applied for this process. Three-dimensional parts are in the so-called STL format which is a file format commonly used for 3D printing. It is a native format in the CAD software created by 3D systems and supported by many other software packages [20].

Generally, 3D printing and computer-aided manufacturing are very useful in rapid system development. Mechanical components are planned within the CAD software for 3D printing, where STL formats enable efficient design of system's components.

A slip ring component is realized in order to perform mechanical rotation. To be more precise, the intention is to use an electromechanical device which enables an electrical signal to be transmitted. The signal is being transmitted from a stationary part to a rotating part.

Slip rings are widely used in robotics and for automation tasks. This is also an indispensable part because the system is designed in order to rotate around its axis.

IV. Generation of Point Clouds using the Proposed LIDAR 3D Mapping System

The complete constructed LIDAR based 3D mapping system is shown in Fig. 2. It is consisted of the stepper motor and the servo motor that drives a LIDAR sensor.

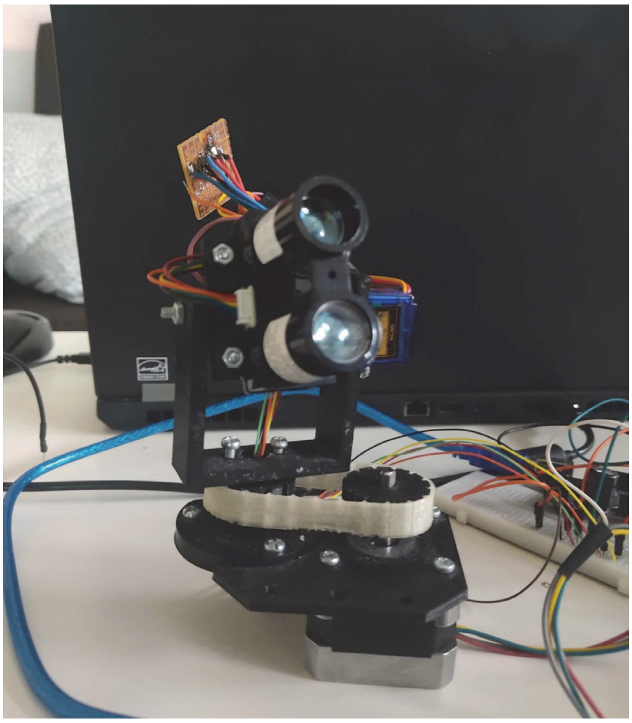

Fig. 2. The complete proposed system.

The stepper motor is used for movements, where a shaft corresponds to the azimuth angle, noted here as θ. The position of servo motor of the system is determined by zenith angle, noted as ϕ. The mentioned angles are coordinates in a spherical coordinate system. A spherical coordinate system with corresponding notations is shown in Fig. 3.

Constant rotation of the platform with LIDAR and motors is provided with the slip ring. LIDAR transmits data to the Arduino with measurement of the distance from the LIDAR to the object.

The angular position of servo motor corresponds to angle ϕ, and this angle is fixed for one full circle which is performed by the stepper motor. The increment value of the stepper motor is defined in advance. If resolution is set to be higher for point cloud generation, the acquisition time is longer. The servo motor changes its position to a new value of angle ϕ when stepper motor finishes one circle.

A point cloud is a representation of the points in 3D space where the reflection of signal occurred. The position of each point is determined by the coordinates of the Cartesian system (x, y, z). The position of the servo motor described by ϕ, stepper motor θ, and distance to the object r, correspond to 3D coordinates in the Cartesian system which can be found.

In order to determine and visualize each point in a point cloud, the exact position's coordinates must be represented in the Cartesian coordinate system, where equations in (1) represent a transformation from a spherical to the Cartesian system and equations in (2) show how to get back to the spherical system:

$$x = r\cos(\theta)\sin(\phi),\ y = r\sin(\theta)\sin(\phi),\ z = r\cos(\phi), \quad (1)$$

$$r = \sqrt{x^2+y^2+z^2},\ \theta = \arctan\frac{y}{x} = \arccos\frac{x}{\sqrt{x^2+y^2}},$$

$$\phi = \arctan\frac{\sqrt{x^2+y^2}}{z} = \arccos\frac{z}{\sqrt{x^2+y^2+z^2}}. \quad (2)$$

A program for controlling a rotating platform with a sensor and for communication between the LIDAR and Arduino is written using Arduino IDE (integrated development environment). On the other hand, a point cloud is visualized using the well-known Processing software, dedicated for 3D modelling and image manipulation [21].

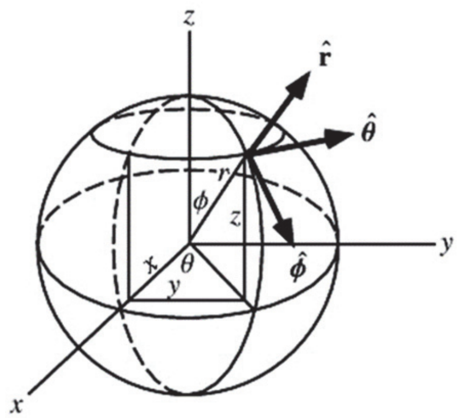

Fig. 3. Spherical coordinate system.

V. Simulation Results

System is initialized after uploading the arduino.ino code. After pressing the play button, acquisition starts with the simultaneous drawing on the computer display with processing.pde code. Points appear in real time and each point/dot represents one physical entity in the space. In this paper, in order to make point generation easier to follow, a red line is introduced to show points currently plotted on the display.

When a sweep finishes, the program generates an image saved as jpg file. This image represents a current point cloud. The program also saves a text file with the coordinates of all points where reflection occurred in that scan. Points from previous scans stay in the memory and each following scan improves representation of the surroundings in 3D space by introducing more points to the point cloud. This process can take up to six minutes, but an operator can decrease the time interval for generating a point cloud since it depends on the total number of scans.

Fig. 4 shows points obtained in the first scan during the acquisition performed in the room, i.e., indoor environment. In Fig. 5 the fourth scan is presented with the corresponding number of collected points.

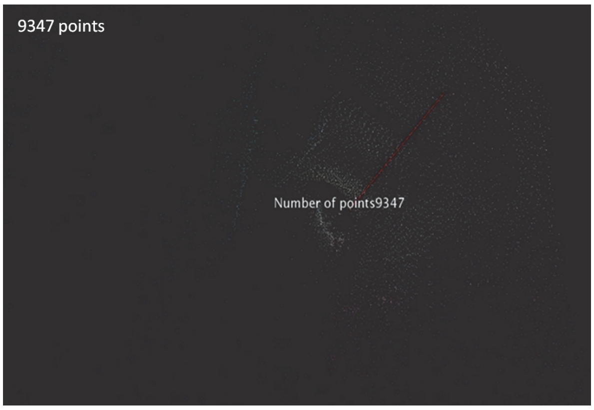

Fig. 4. The first scan with 9347 points.

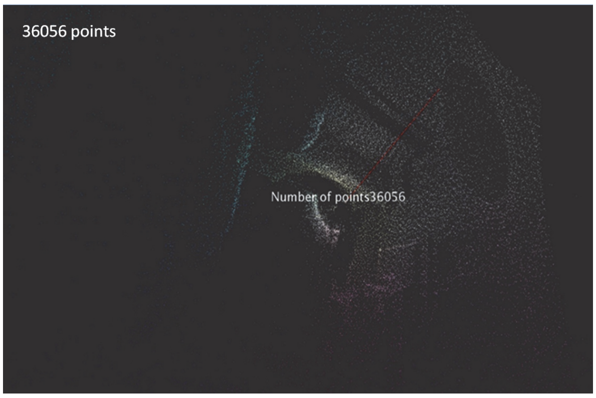

Fig. 5. The fourth scan with 36056 points.

As already mentioned, with more performed scans the number of points in the image will be higher. This is demonstrated in Fig. 5. After the fourth scan the shape of the sofa is clearly recognizable. Objects closer to the LIDAR have more concentrated points, which help object recognition. Indoor visualization is obvious, where in Fig. 6 the surroundings with a visible sofa and noticeable window area are shown.

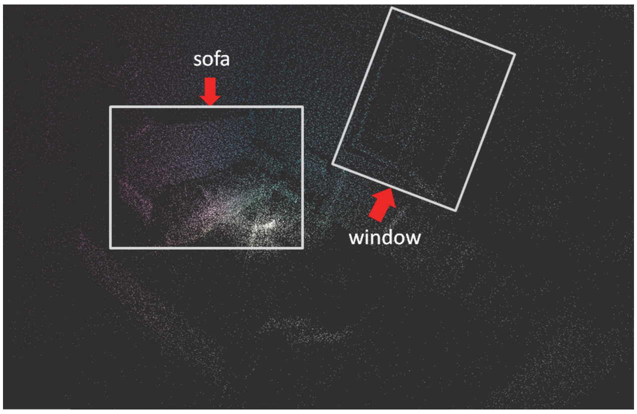

Fig. 6. Indoor surrounding with visible sofa and window area.

For future experiments, point cloud data is stored in a text file. Thus, after making a record it is possible to reproduce points from this file, where each point is represented via three coordinates. This is illustrated in Fig. 7.

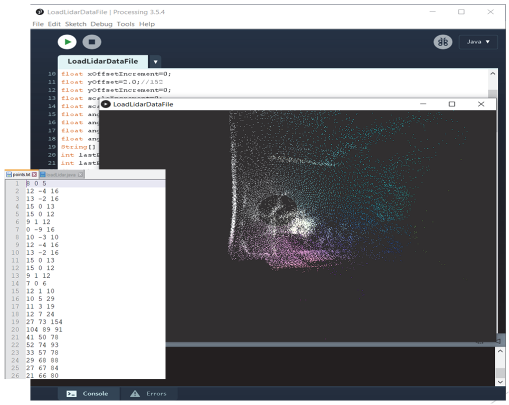

Fig. 7. Text file with recorded data.

Moreover, there are some effects that can be seen during scanning. For example, if there are some transparent objects like windows the reading may not be reliable, as demonstrated in Fig. 8. The presented points are the result of window reflection. In the point cloud, one can notice some points in the area that corresponds to the empty space, and this is the consequence of reflections in the window area. This is also shown in Fig. 9. Similar effect can occur when a light beam hits a small object or if an operator is moving during the acquisition procedure. The last can be compensated using an IMU approach at the platform with the LIDAR. If a material of a surface is highly reflective, there is a possibility that points are not registered because the LIDAR's pulse is not reflected back to the sensor. In the immediate sensor vicinity, some points can be noticed due to the proximity of the apparatus, the workstation or other close object.

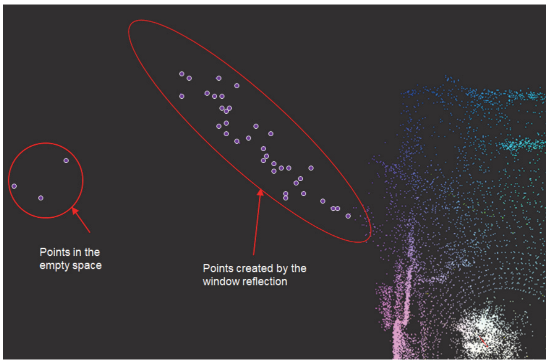

Fig. 8. The issue found while window scanning.

Besides Fig. 8, another representation of the scanning result is given in Fig. 9. Points due to window reflection around the window area are specific and can enable the localization of transparent areas. The obtained results are promising for future experiments with different materials and objects of different transparency levels.

Although 3D printed parts have a satisfying quality and obtained results are promising, metal parts can be used to improve robustness and to lower measurement uncertainty. A good choice would be aluminium since it is strong and light. An additional improvement in terms of durability can be achieved by using a high-quality rubber belt. Also, a servo motor with a smaller step can further improve the system. For object detection platforms with higher processing capabilities than Arduino can be used. The system can be even applicable for outdoor cases, where power supply like a power bank can be used. A memory card can be selected for storage or a wireless connection can be used to send data directly to the user.

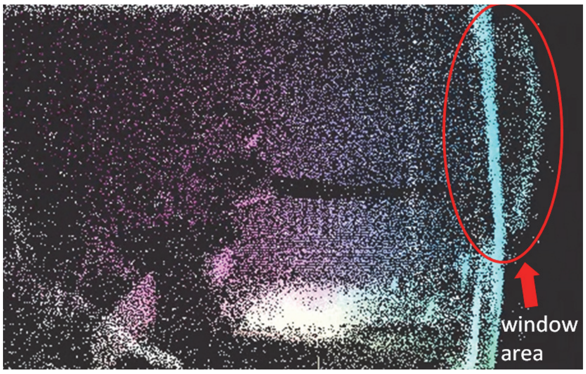

Fig. 9. The scanning result around the window area.

This system has the potential to be a commercial product, especially if it is mounted on a mobile platform like a car or UAV. In addition, a similar device can be applied for obstacle detection to prevent collision/impact.

Compared to other systems like [16]-[18], [22] this system considers indoor surroundings and both reflective and non-reflective objects. Also, there are systems based on photogrammetric technologies that may be also useful for obtaining maps based on stereo imaging. Even though they are cost-efficient solutions, the proposed LIDAR based approach enables high precision in 3D mapping.

VI. Conclusion

In this paper a new LIDAR and Arduino based system for 3D mapping is proposed. It is designed for mapping indoor surroundings using a LIDAR sensor. Output of the system is a generated point cloud image of environment or a corresponding sequence of images. In this paper a window area case is shown, where scanning is different compared to other cases due to a specific material. For future experiments data is stored within a text file. Thus, there is a possibility for reproducing previously recorded data. So, the integrity of cloud points is preserved. The proposed system can be considered affordable due to the relatively low cost of its components which are widely available on the market. Among the components of the developed system, the LIDAR sensor is with a relatively higher price compared to other components, but still represents one of the best cost-efficient choices offered by manufacturers.

The 3D mapping system provides a complete scan of the room, i.e., indoor environment with a possibility to visualize both reflective and non-reflective parts. The main advantage of this system is obtaining point clouds in a real-time manner.

Future work will be based on the proposed prototype system since it can be further improved for different circumstances and experiments. It can be adapted for a mobile platform as well. Software possibilities are expected to be improved for experimenting with different obstacles and materials based on acquired text files.

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