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作品名稱　**DEVELOPMENT AND USE OF LASER 3D SCANNER OF PREMISES**

得獎獎項

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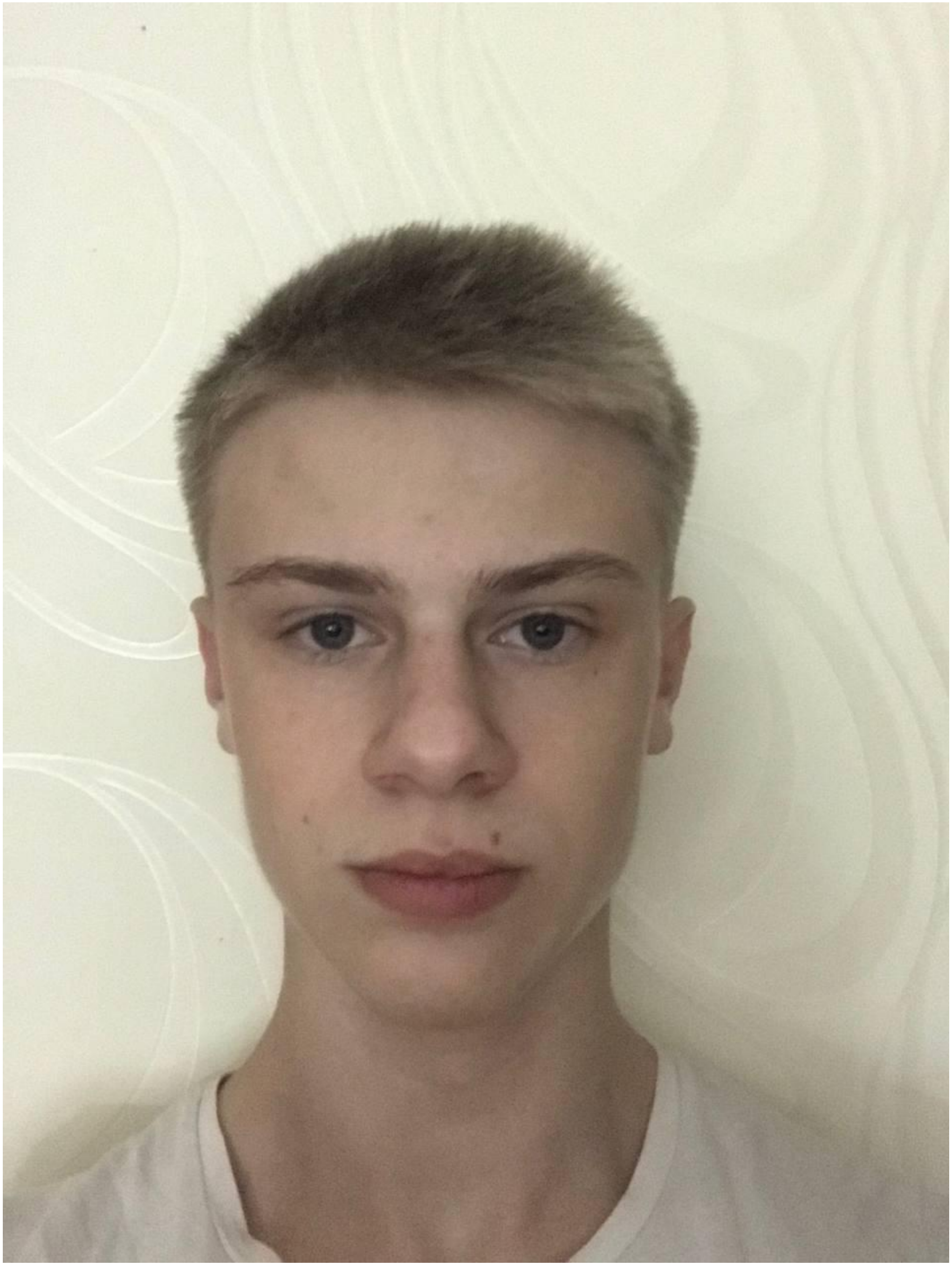
關鍵詞　**3D scanner、Lidar、Arduino**

作者照片



Abstract

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Development and use of a laser 3D room scanner

This research work is devoted to the stages of development and creation of a prototype of a laser 3D scanner model, programming of a controlling microcontroller, construction of 3D models of a scanned object.

In the course of the work, the market of 3D scanners, which are used to build three-dimensional models of premises, was analyzed, the equipment necessary for the development and creation of the prototype was analyzed, as well as the software necessary for the operation of the prototype. The result of the work was the creation of a laser 3D scanner based on an Arduino microcontroller using a Lidar type sensor that scans and builds 3D models of objects. This working model of the 3D scanner demonstrates good capabilities and turned out to be easy to use.

INTRODUCTION

The modern world cannot be imagined without art, in particular architecture. Currently, 3D design occupies a significant place in this industry .

Many monuments and old buildings need to be repaired and restored, after which it will be necessary to do quality control and check the smallest deviations from the design. 3D scanners are used for these purposes.

3D scanners used in construction and architecture typically use laser 3D scanning technology. Laser 3D scanning is a non-contact, non-destructive technology for obtaining a digital copy of physical objects using a laser beam. [2] The three-dimensional model is read with maximum accuracy. Application of such models is impossible for a person due to the fact that the object must be stationary during the procedure.[1]

However, factory solutions are excessively accurate and even more expensive when it comes to small objects: for repairing apartments or houses, for amateur scanning of small objects for their subsequent printing on a 3D printer, etc. So in my work, I try to make a cheap laser 3D scanner that would have enough accuracy for the given purposes.

Object of research: laser 3D scanner of our own production.

The subject of the reserch: the operation of a self-made scanner at home.

The purpose of the research: to develop a working prototype of a laser 3D scanner, cheaper than factory solutions.

Tasks:

1. Familiarize yourself with the principle of operation of the depth sensors such as Lidar and laser 3D scanners.
2. Offer a list of details, necesary to build the device.
3. Build a working model of the scanner, describe its design, program and shortcomings.
4. Show the results and prospects of using it.

In the course of work, it is also necessary to get acquainted with the basics of programming, the selected software, simple assembly of electronic circuits and the principles of operation of individual elements of the device.

CHAPTER 1. THE WORKING PRINCIPLE OF LIDAR SENSORS AND LASER 3D SCANNERS

Three-dimensional scanning is a new technology that appeared at the end of the 20th century. Prototypes were tested back in the 60s. They did not have a wide range of capabilities, but they coped well with the main task. In the 80s, the models were improved thanks to lasers. The capture of objects has also improved.

Contact sensors were also developed that digitized the surface of objects with a solid and complex structure. The equipment was developed according to the technologies of the military industry with the use of navigators. 3D scanners are used in design studios, automobile concerns and in the film industry. Scanners were also widely used in construction and architecture. [1]

As already mentioned, there are two types of 3D scanners: contact and non-contact. In its turn, non-contact ones are divided into active and passive.

Passive 3D scanners analyze the imprint of radiation through light. A laser beam is used as a light, which is based on a time-of-flight rangefinder. It calculates the distance and travel time of the shift there and back. It is used as a burst of light, and the time of its reflection is recorded using a detector. As you know, the speed of light is a constant value, and knowing the flight time of the shift in both directions, you can calculate the distance from the scanner to the object. Time-of-flight 3D scanners can measure up to 100,000 points in 1 second.

In active scanners, scanning of objects occurs by directing waves, presented in the form of a laser beam or structured light. Next comes the detection and analysis of the reflection. The scanner sends a beam to the object, and the camera records location data in coordinates. The movement of the laser is accompanied by fixation in the field of view of the camera in different places. Such three-dimensional scanners are nicknamed triangulation, since the beam, camera and the end point form a triangle. [1]

Our scanners have a Lidar-type depth sensor installed, as they are small in size, easy to use and program, and most importantly, inexpensive. The operating principle of Lidar is simple. The object (surface) is illuminated with a short light pulse, and the time it takes for the signal to return to the source is measured.

When you illuminate an object (surface) with a flashlight, you see the light that has reflected from the object and returned to your retina. Light travels very fast - 299,792,458 m/s, so turning on the light seems instantaneous. However, this is not the case. The light returns with some delay, which depends on the distance to the object (pict.1.1). [3]

The distance passed by the photon on the way to the object and back can be calculated using the formula:

$$s = \frac{\upsilon \cdot t}{2},$$

where s is the distance to the point;

υ is speed of light;

t is the flight time of the beam.

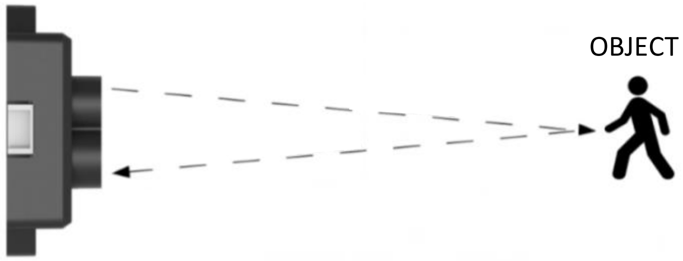


Fig. 1.1 – Schematic representation of Lidar sensor operation. [4]

Next, we use Lidar to find out the coordinates of the point. To do this, with the help of rotary mechanisms, we move the Lidar along the azimuthal and zenith angles. At the same time, such variables as distance to the point, azimuthal and zenith angles appear. In its turn, this leads to the formation of a spherical coordinate system, in which the point is determined.

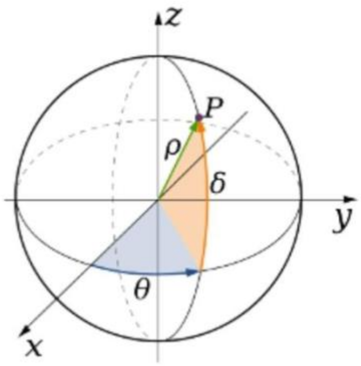
n order to translate everything into the usual Cartesian coordinate system for us, you need to know:

a) distance from Lidar to the point;

b) its horizontal inclination angle (azimuth);

c) vertical angle of inclination (zenith).

Using these formulas, we transfer the coordinates of the point from the spherical to the Cartesian system, and obtain its coordinates (x; y; z). Also, it is necessary to convert the angle values from degrees to radians (pict. 1.2).



$$\begin{cases} x &= \rho\cos\delta\cos\theta \\ y &= \rho\cos\delta\sin\theta \\ z &= \rho\sin\delta \end{cases}$$

Fig. 1.2 – Formulas for converting spherical coordinates of a point into Cartesian coordinates.

The formula for finding an angle in radians:

$$\alpha' = \frac{\alpha^{\circ} \cdot \pi}{180^{\circ}},$$

where α is the angle in radians;

α° is angle in degrees.

CHAPTER 2. THE EQUIPMENT OF THE DEVICE

Most scanners are equipped with rotary mechanisms, most often these are servo drives or stepper motors. In my first device I used servos as they are easy to use and easy to program. These were drives of the Corona DS 843 MG brand (pict.2.1).

Fig. 2.1 - Servomotor Corona DS 843 MG.

But later, in the second version of the scanner, I switched to using stepper motors Moons 14HK0402-73N (pict. 2.2), as they gave more accurate results.

Fig. 2.2 - Stepper motor Moons 14HK0402-73N.

Also, both in the first and second versions of the scanner, I used the Arduino Uno controller (Pict 2.3), and the software for it - Arduino IDE.

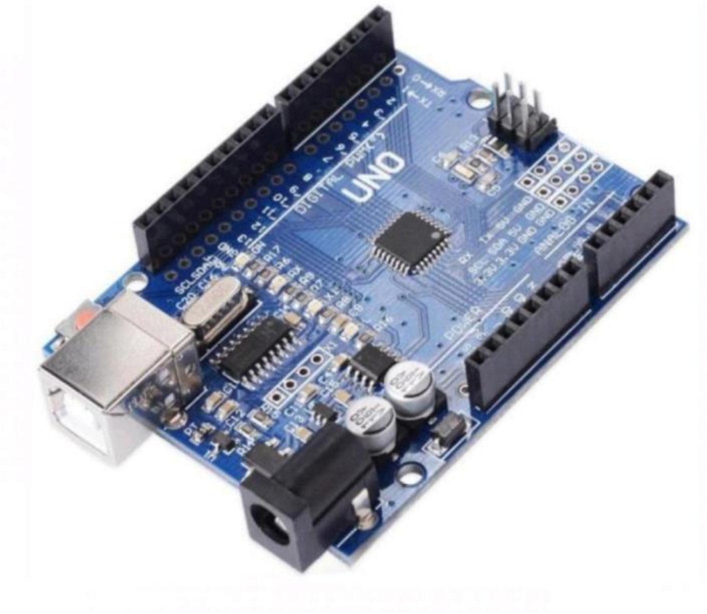


Fig. 2.3 - Controller Arduino Uno.

In the second version of the scanner, stepper motor drivers were also needed to control the stepper motors. I used the A4988 driver (Pict. 2.4). And as a basis for the scanner, I took an old robotic camera, which had the above-mentioned stepper motors.

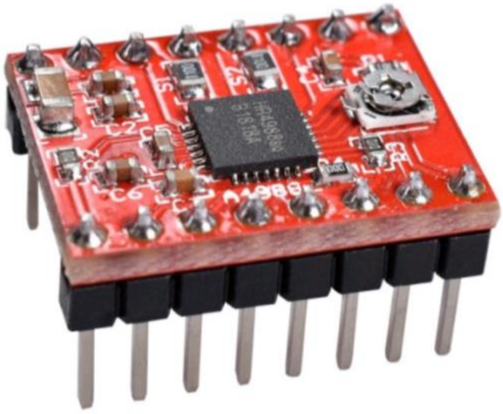


Fig. 2.4 - Stepper motor driver A4988.

The most important part of the scanner is Lidar. TF-Luna 8m Lidar is used (Fig. 2.5)

Fig. 2.5 - Lidar TF-Luna 8m.

As can be seen from the data in the table (Fig. 2.6): the total cost of the scanner does not exceed $100, which is a fairly small budget.

NAME	TF-Luna LIDAR	ARDUINO UNO	Сервопривод Corona DS 843 MG
PHOTO			
			

Fig. 2.6 – Cost of scanner components.

As already mentioned in point 2.1, I used the Arduino IDE to pair the controller with the Arduino Uno. This is an application for programming Arduino controllers. With its help, servo drives, stepper motors, Lidar and the function of converting the data stream from the installation to the COM port were programmed (Fig. 2.7).

```
    delay(5);
    k+=1;
  }
  delay(1);

   digitalWrite(dirPin1,HIGH); // Enables the motor to move in a particular direction
  // Makes 200 pulses for making one full cycle rotation
  for(int x = 0; x < 1200; x++) {
    digitalWrite(stepPin1,HIGH);
    delayMicroseconds(100);
    digitalWrite(stepPin1,LOW);
    delayMicroseconds(100);
    delay(5);
    if(x%12==0){
      g++;
      sendMeasurement();
    }
     }
  delay(5);

  digitalWrite(dirPin,HIGH); //Changes the rotations direction
  // Makes 400 pulses for making two full cycle rotation
  for(int x = 0; x < 24; x++) {
    digitalWrite(stepPin,HIGH);
    delayMicroseconds(100);
    digitalWrite(stepPin,LOW);
    delayMicroseconds(100);
    delay(5);
    k+=1;
  }
  delay(1);

   digitalWrite(dirPin1,LOW); //Changes the rotations direction
  // Makes 400 pulses for making two full cycle rotation
  for(int x = 0; x < 1200; x++) {
    digitalWrite(stepPin1,HIGH);
    delayMicroseconds(100);
    digitalWrite(stepPin1,LOW);
    delayMicroseconds(100);
    delay(5);
    if(x%12==0){
      g-=1;
      sendMeasurement();
    }
  }
  delay(5);
}
```

a)

```
-2 0 46
-1 0 47
0 0 48
1 0 47
2 0 47
4 0 48
6 0 48
7 0 47
9 1 48
10 1 47
12 1 47
13 1 46
14 1 45
16 2 46
17 2 44
18 2 44
19 2 42
21 2 41
21 2 40
22 2 38
23 3 37
23 3 35
23 3 33
23 2 30
26 3 32
25 3 29
26 3 28
30 3 30
31 3 29
31 3 27
30 3 25
28 3 22
27 3 19
27 3 18
25 3 16
27 3 16
28 3 15
28 3 14
29 3 14
29 3 12
28 3 11
28 3 10
27 3 8
26 3 7
29 3 7
29 3 6
29 3 5
30 3 4
31 3 4
```

b)

Fig. 2.7 - Arduino IDE: *a*) - the main page of the application and part of the code; *b*) - data flow on the COM port.

The Processing program (Fig. 2.8) was used to visualize data from the COM port. This application showed the direction of the beam from the Lidar to the point, and showed the points themselves that the device scanned (Fig. 2.9).

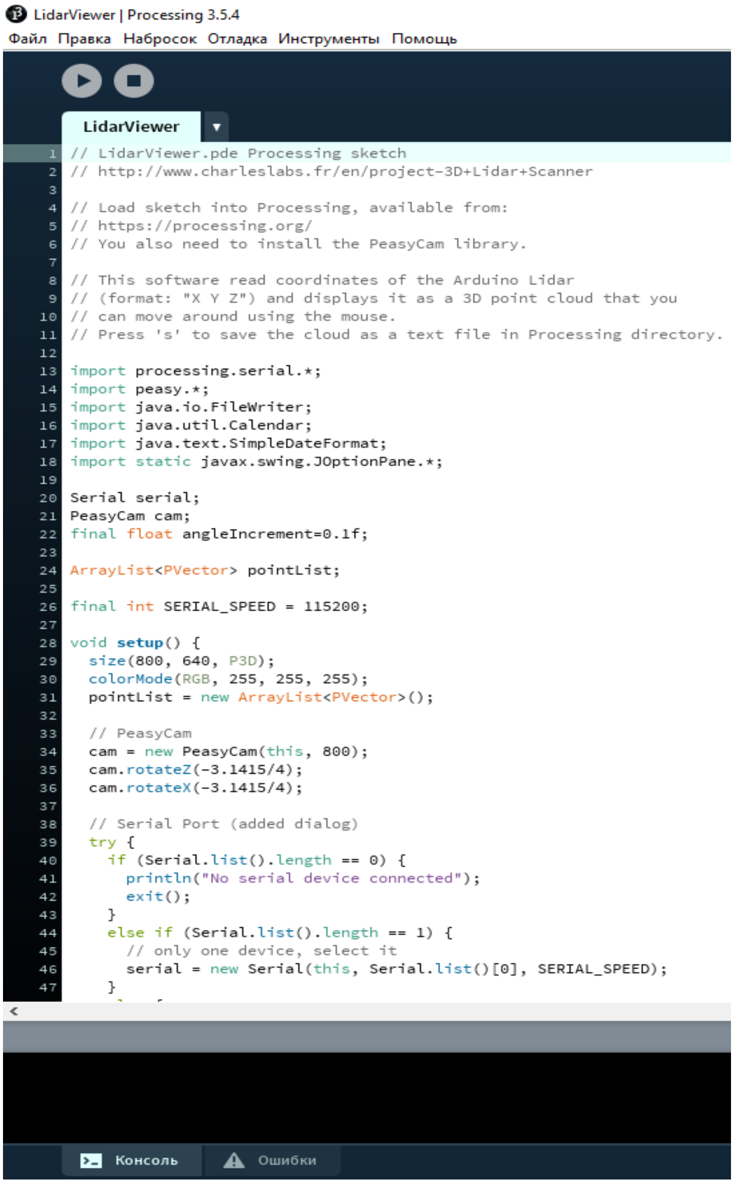


Fig. 2.8 - Main page of the application and parts of the Processing code. [5]

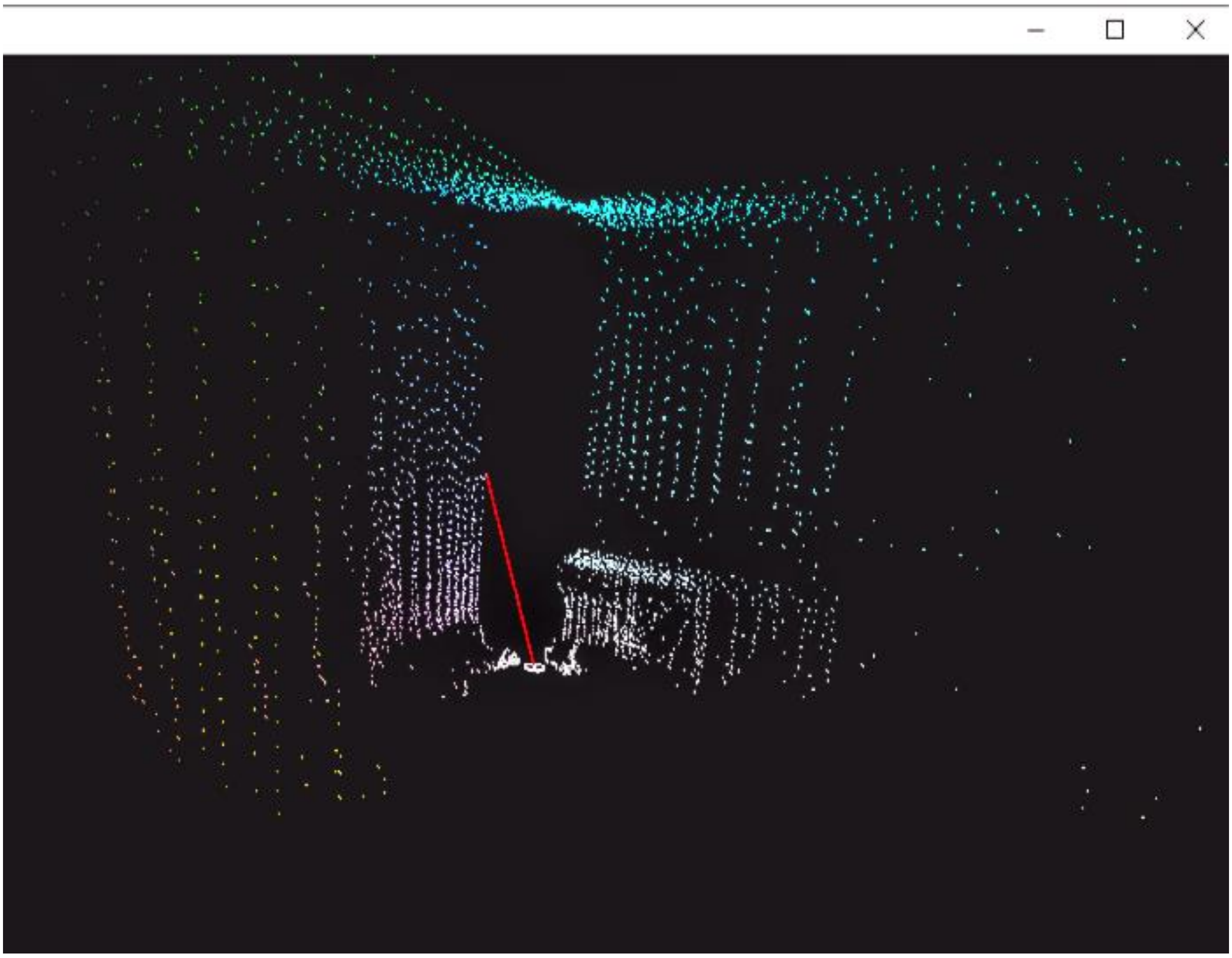


Fig. 2.9 – Visualizer of data from the COM port in the form of a cloud of points.

CHAPTER 3. SCANNER PROTOTYPES

3.1 Description of the first prototype

In the first version of the scanner (Fig. 3.1), cheap, small and easy-to-program servo drives were used. It took just over three weeks to build, including the time spent learning how to program the servos and Lidar.

The scanner looked like this: two servos, one mounted to return horizontally and the other mounted to the first to return vertically; Lidar is attached to the second servo.

Since I did not have the opportunity to make a perfect mount for the device, that is, the ability to print the mount on a 3D printer, it was decided to simply glue it all as accurately as possible to the axes of turns and points, the distance to which the Lidar counts as zero.

For convenience, a stand was made from a children's constructor for the glued system. As it turned out later, this design additionally damped the vibration from the operation of the rotary mechanisms

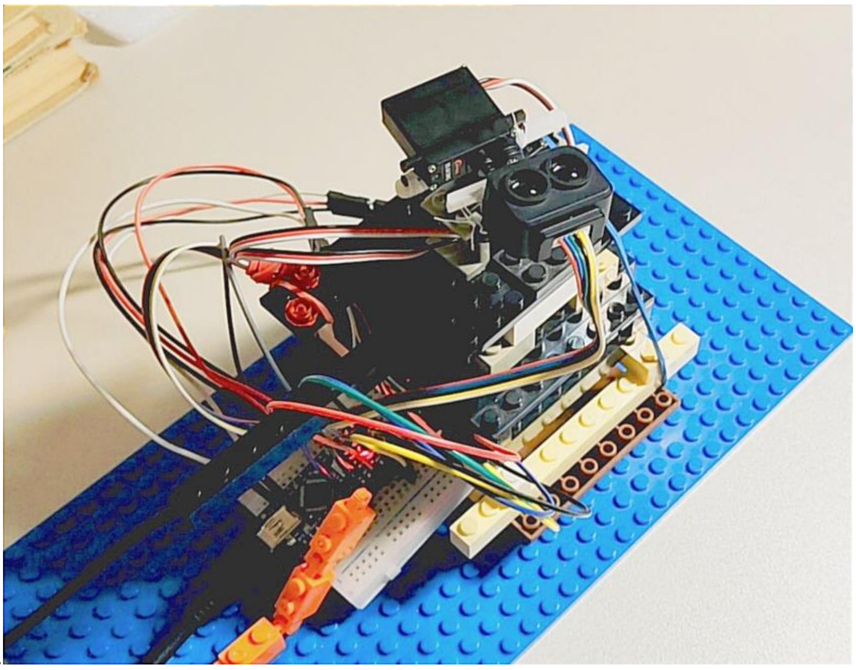


Fig. 3.1 – Final version of the first prototype.

3.2 Current problems of the first prototype and their solutions. Intermediate conclusions

Undoubtedly, there were failures at almost every stage of building the device. Most of the time it was code issues since I had never programmed anything before. But the main problems were the following:

1. Mastering the Arduino IDE and Processing software
2. Servo programming and Lidar. Integration of one code into another, calibration of the device.
3. Assembeking schemes and understanding the principle of operation with the controller.

After analyzing the solution and solving the problem, the device was assembled. But after the first test scans, the inner surface of the box, which has a shape close to a rectangular parallelepiped measuring 100×40×50 sm, was scanned, and the following result was obtained (Fig. 3.2).

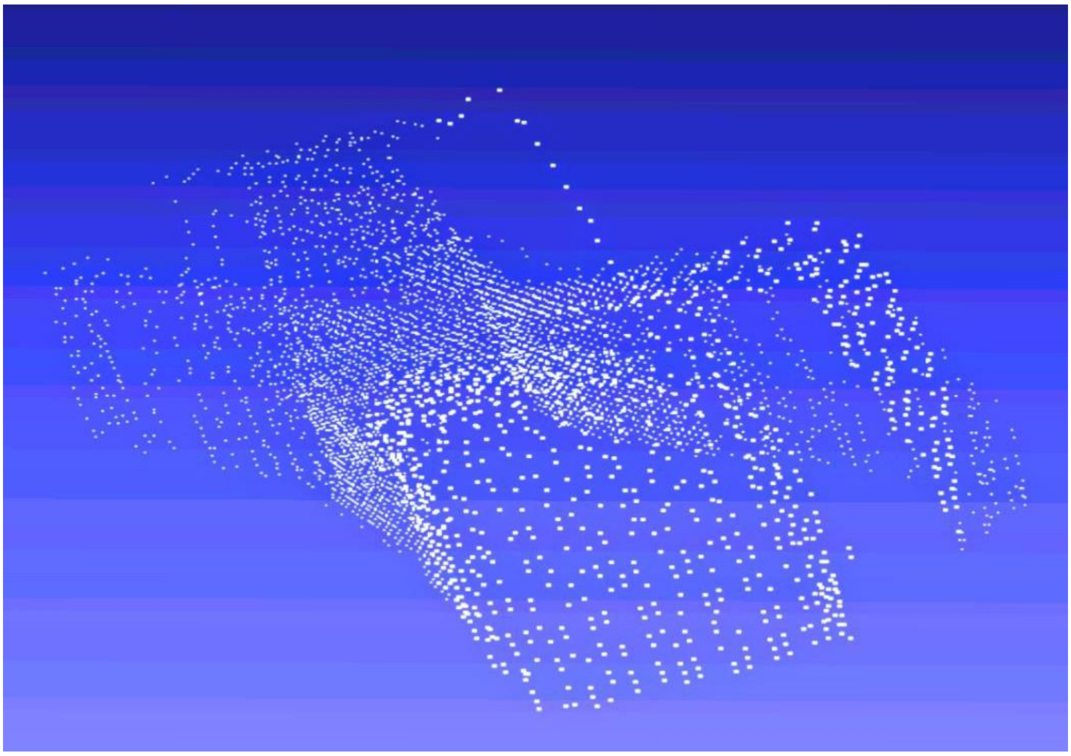


Fig. 3.2 – Distorted scan of a rectangular box.

Based on this, the following conclusions were made:

1. The distance from the Lidar to the rotation axes greatly affects the scanning accuracy.
2. The used servos turn to an angle that does not correspond to the declared one (it turned out that the servos turn only 163°, while the code is designed for 180°)

3. The accuracy of servo drives is too low for sufficient scanning quality.

3.3 Description of the working scanner model

In the second version of the scanner, due to the poor operation of the servo drives, it was decided to switch to the use of stepper motors. Also, to solve the issue with shifted axes, the basis for the scanner was taken from an old robotic camera. For simple and reliable control of stepper motors using Arduino, two stepper motor drivers described in the chapter 2 had to be added to the components.

Now the scanner had the following appearance (Fig. 3.3): a frame from a robot camera, which, with the help of stepper motors, could rotate 360° in azimuth, and more than 180° in zenith. Lidar is fixed at the intersection of these two axes. As before, everything is controlled with the help of the Arduino controller, only with some differences in the code. The connection scheme of the main components of the scanner is shown in Fig. 3.4.

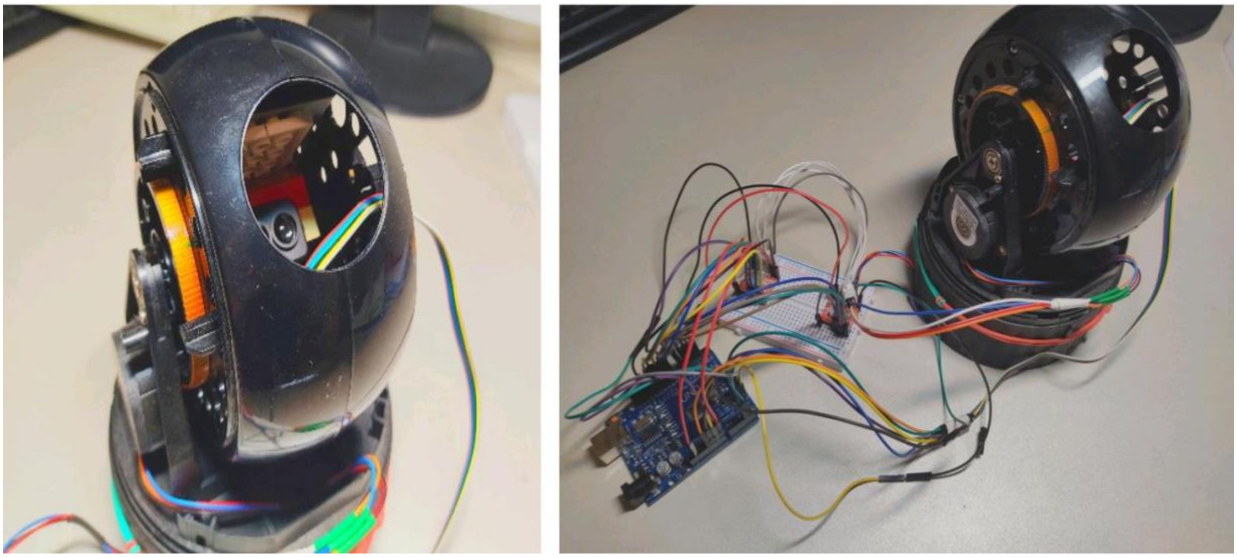


Fig. 3.3 – A working model of the scanner.

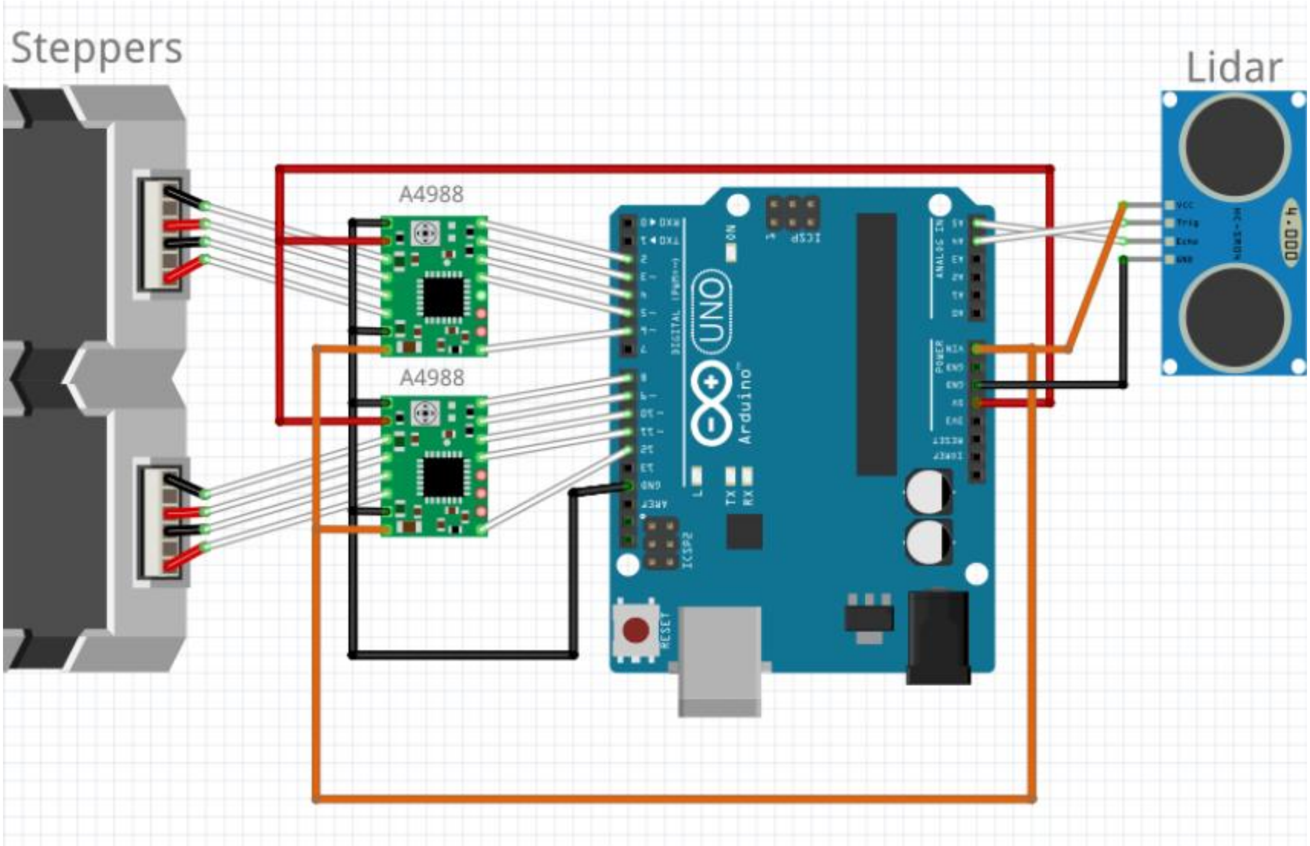


Fig. 3.4 – Connection scheme of all scanner components to Arduino. Made by FRITZING.

3.4 Current problems and results

As before, assembly of the scanner was constantly accompanied by problems with programming, but in addition, there was a problem with the operation of the engines. It turned out that this was due to insufficient power supply of the system. Using another power supply unit (9V) with a higher output voltage solved this issue.

Also, all the shortcomings of the previous prototype were removed, and trial testing of the system on the same box this time showed a good result (Fig. 3.5).

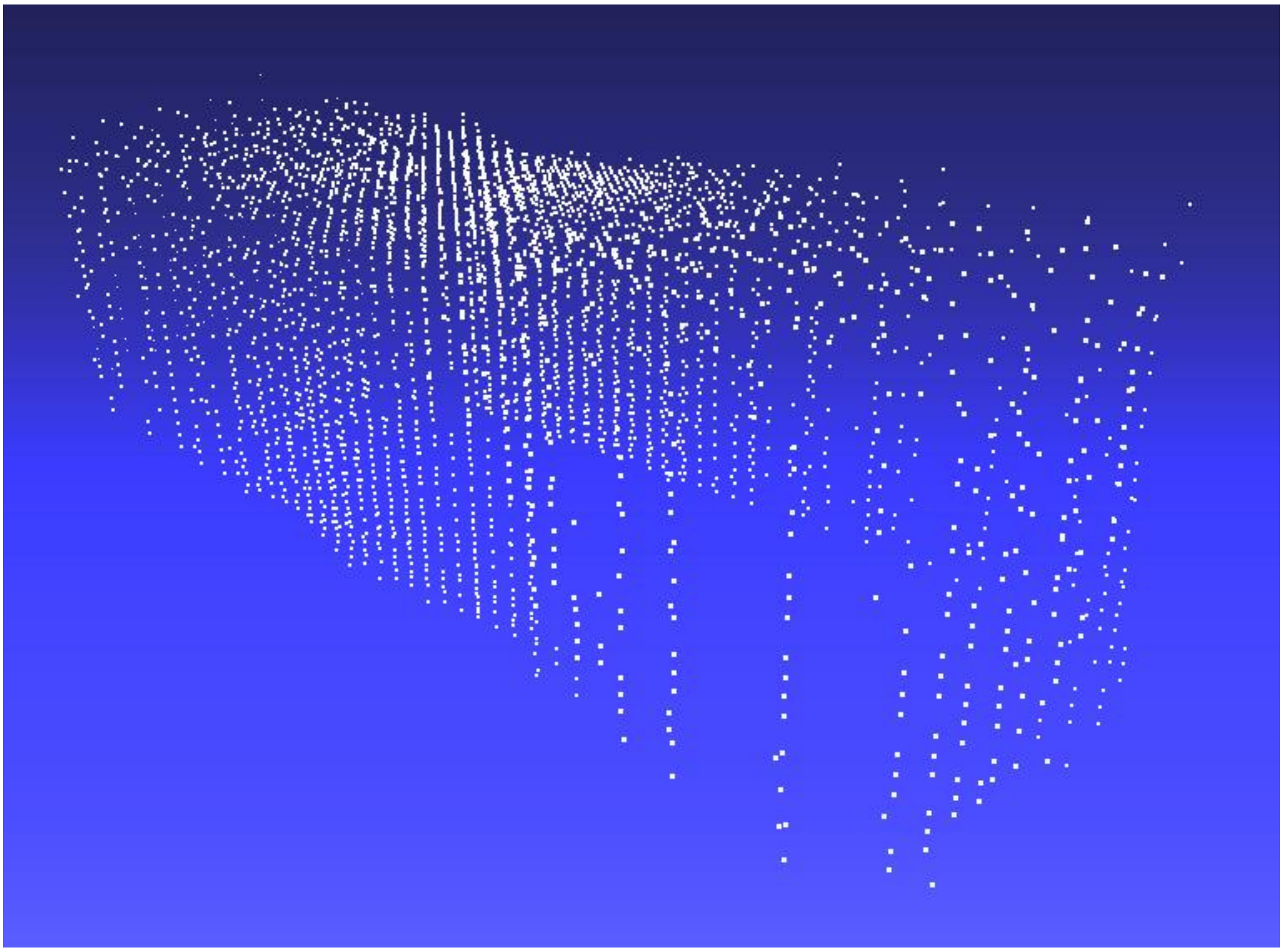


Fig. 3.5 – Scanning the box with a working scanner model.

3.5 Software component of both prototypes

The program for both prototypes is almost identical (Figure 3.6), except for different codes for servos and stepper motors, and some minor changes. The code consists of three main parts:

1. Device rotation program (different for two versions of the scanner)
2. The program for measuring the distance to a point using Lidar (the same)
3. A program that converts the received data about a point into its coordinates (XYZ)

The first part of the code is built according to the following principle: the rotary mechanism (hereinafter {1}), located along the vertical axis, makes n number of steps of m° each so that m×n°=180°. After that, the second turning mechanism (hereinafter {2}), located along the horizontal axis, makes one turn by k°. Next, {1} again does m steps by n°, but in the opposite direction, after which {2}, returns by another k° - the cycle is closed. Thus, in one cycle, the mechanism does $k\frac{100\%}{90}$ of the entire work.

```
void loop() {
  delay(DELAY_BETWEEN_SAMPLES);
  //Sweep Yaw servomotor
  for (yawAngle = 0; yawAngle <= 180; yawAngle += YAW_STEP) {
    servoYaw.write(yawAngle);

    //Sweep Pitch servomotor. The direction depends on the current directory
    if(pitchAngle < 90){
      for (pitchAngle = 0; pitchAngle <= 180;pitchAngle+= PITCH_STEP){
        servoPitch.write(pitchAngle);
        sendMeasurement();
      }
    } else {
      for (pitchAngle = 180; pitchAngle >= 0;pitchAngle-= PITCH_STEP){
        servoPitch.write(pitchAngle);
        sendMeasurement();
      }
    }
  }
}
```

```
void loop() {
  digitalWrite(dirPin,HIGH); // Enables the motor to move in a particular direction
  // Makes 200 pulses for making one full cycle rotation
  for(int x = 0; x < 24; x++) {
    digitalWrite(stepPin,HIGH);
    delayMicroseconds(100);
    digitalWrite(stepPin,LOW);
    delayMicroseconds(100);
    delay(5);
    k+=1;
  }
  delay(1);

   digitalWrite(dirPin1,HIGH); // Enables the motor to move in a particular direction
  // Makes 200 pulses for making one full cycle rotation
  for(int x = 0; x < 1200; x++) {
    digitalWrite(stepPin1,HIGH);
    delayMicroseconds(100);
    digitalWrite(stepPin1,LOW);
    delayMicroseconds(100);
    delay(5);
    if(x%12==0){
      g++;
      sendMeasurement();
    }
     }
  delay(5);

  digitalWrite(dirPin,HIGH); //Changes the rotations direction
  // Makes 400 pulses for making two full cycle rotation
  for(int x = 0; x < 24; x++) {
    digitalWrite(stepPin,HIGH);
    delayMicroseconds(100);
    digitalWrite(stepPin,LOW);
    delayMicroseconds(100);
    delay(5);
    k+=1;
  }
  delay(1);

   digitalWrite(dirPin1,LOW); //Changes the rotations direction
  // Makes 400 pulses for making two full cycle rotation
  for(int x = 0; x < 1200; x++) {
    digitalWrite(stepPin1,HIGH);
    delayMicroseconds(100);
    digitalWrite(stepPin1,LOW);
    delayMicroseconds(100);
```

a) *b)*

Fig. 3.5 – The first part of the code for: a) – the first prototype;

b) - of the second prototype.

The second part of the code is the distance measurement, which occurs after each rotation of {1} by n°. That is, $k\frac{100\%}{90}$ is also a part that uses m of surface in one cycle.

The third part of the code (Fig. 3.6) is a composite function that converts data from {1}, {2} and Lidar, first into a variable, and then into point coordinates using the formula described in chapter 1.

```
void sendMeasurement(){
  delay(DELAY_BETWEEN_SAMPLES);

  // Get spherical coordinates
  if( tflI2C.getData( tfDist, tfAddr)) // If read okay...
    {
      // Serial.print("Dist: ");
       r= tfDist;
      // Serial.println(r);         // print the data...
    }
    else tflI2C.printStatus();          // else, print error.
  r = tfDist;
  theta = (float)k * 0.15 * PI / 180.0f;
  phi = (float)g * 1.8 * PI / 180.0f;

  // Convert and send them
  sprintf(s,"%d %d %d\n\0",(int)(r*cos(phi)*cos(theta)),(int)(r*cos(phi)*sin(theta)),(int)(r*sin(phi)));
  Serial.print(s);
  //Serial.print(r);
}
```

Fig. 3.6 – The third part of the code (actually, the data conversion function).

In fact, the scanner works according to the principle described in Fig. 3.7.

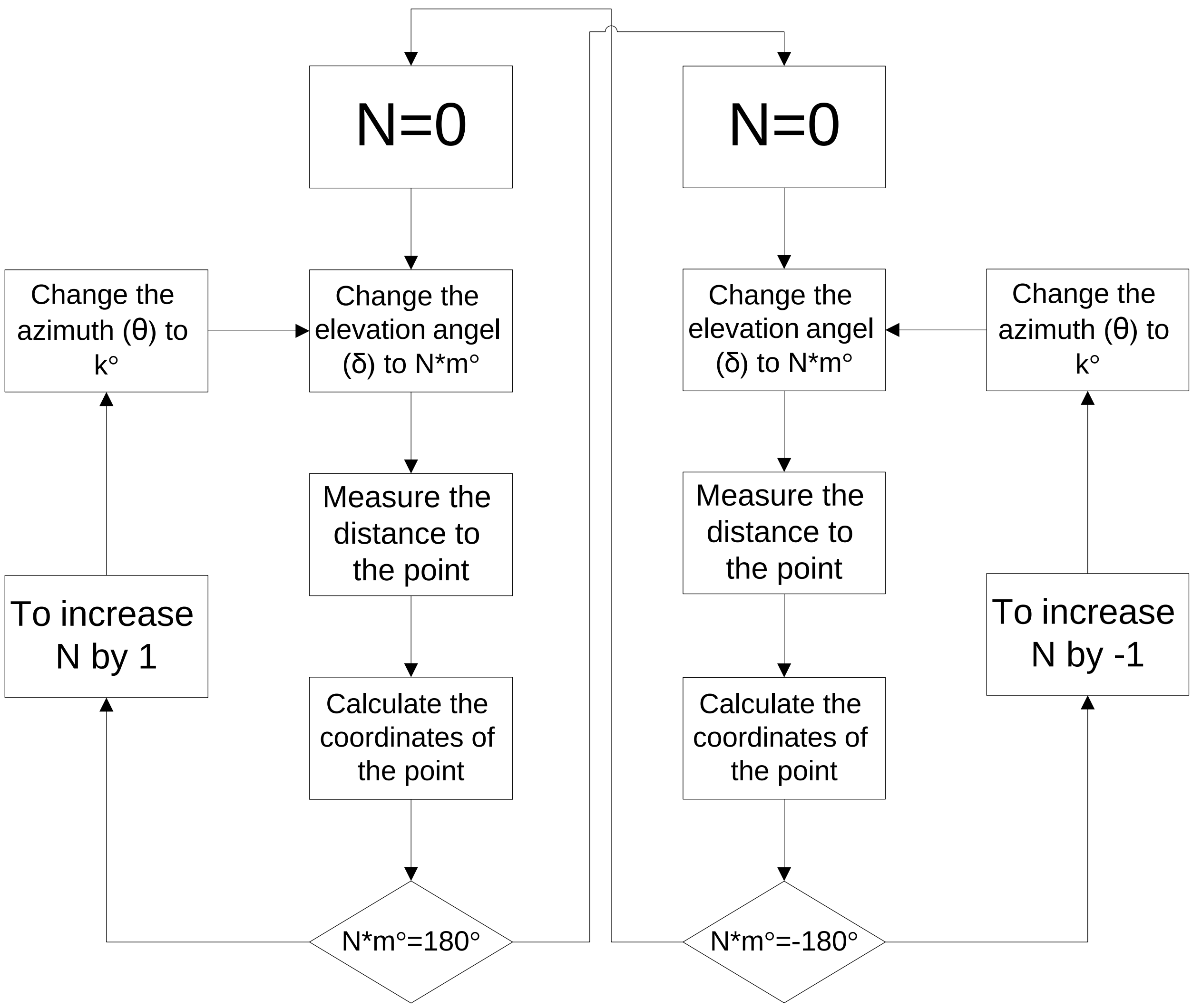
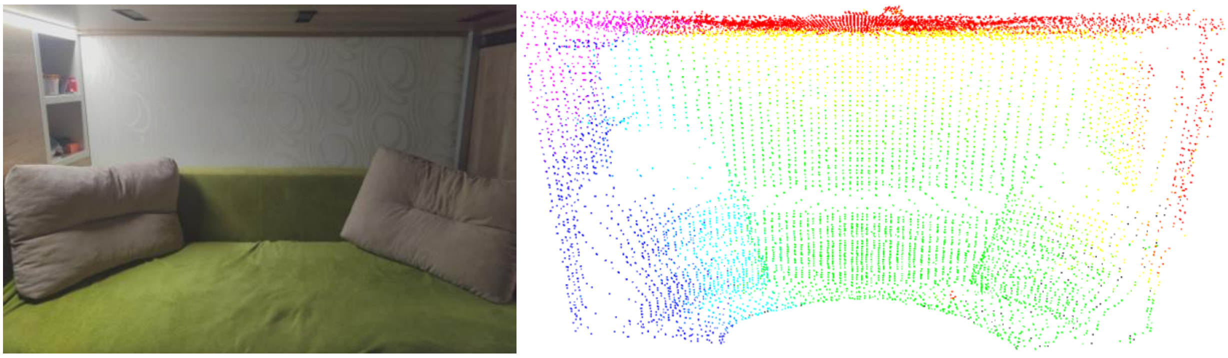


Fig. 3.7 – Code block diagram.

CHAPTER 4. RESULTS AND PROSPECTS OF DEVELOPMENT

Some relief part of the room was chosen as an illustrative example of the use of the scanner (Fig. 4.1 a).



a) *b)*

Fig. 4.1 - *a)* – photo of the scanned part of the room,

b) – the used part of the room

As can be seen in Fig. 4.1 b, the number of points is greater than in the test scan of the box, despite the fact that the area covered is half as small. As it is clear from this, the created device has a variable resolution, and the maximum number of points is 92,160,000 points per hemisphere. For example, during the test scan of the box, the resolution was only 5,000 points, and when scanning part of the room (Fig. 16 b) - 200,000 points. So, the scanner is suitable both for approximate scanning of the interior for designers, and for very precise scanning, for example, of external facades of buildings, in order to control dimensions.

The assembled device is quite promising: by replacing stepper motors with more expensive and accurate ones, as well as using Lidar with a smaller error (± 5 mm), you can achieve results quite close to factory scanners. And if you replace the Lidar with a more accurate one, then the installation can really be used in industry, architecture, design, geology or archeology, while its price will still be an order of magnitude lower than in modern factory solutions.

CONCLUSIONS

During the work there were:

1. Made a literature review, which considered the principle of operation of Lidar-type depth sensors and 3D scanners.
2. Proposed and described the list of parts necessary for building your own scanner.
3. Two new working prototypes created.
4. Described the structure of two scanner prototypes, current problems, their programs and shortcomings.
5. Demonstrated the results of the scanner, as well as the prospects for its use were described, subject to the replacement of the used Lidar with a more accurate one.

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【評語】100040

1. This work is devoted to the development and creation of a prototype of a laser 3D scanner model，programming of a controlling microcontroller，construction of 3D models of a scanned object. Efforts are made in the design and implementation of the scanner and the function of the prototype is demonstrated.
2. In the course of the work，the market of 3D scanners，which are used to build three-dimensional models of premises，was analyzed，the equipment necessary for the development and creation of the prototype was analyzed，as well as the software necessary for the operation of the prototype.
3. It is suggested to assess the status of the art in this competitive field including the use of flash type lidar and some other mechanical design to illustrate the unique features the proposed approach. It is also recommended to evaluate and compare the performance in terms of resolution and scanning speed.