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лазерної скануючої системи у завданнях 3D-моніторингу
(тема)

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1. Тема роботи Розробка фотосенсорного підсилювача для узгодження оптичного сигналу лазерної скануючої системи у завданнях 3D-моніторингу

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1. Development and implementation of spot scanning storage system using DC motor motion algorithms as a basis

2. Development of a program for implementing filters for the received signal and recognition of signal peaks

3. Development of a computer program for triangulation, transformation and visualization of 3D coordinates

4. Перелік питань, що потрібно опрацювати в роботі

Introduction

1. Analysis of existing devices and scanning systems in 3D monitoring tasks

2. Analysis of problems of system use of technical vision in the tasks of 3d-monitoring

3. Analysis of photosensor amplifier design methods for laser signal scanning optical signal matching in 3D monitoring tasks

4. Experimental studies

Conclusions

List of the sources and references

Applications

5. Перелік графічного матеріалу із зазначенням обов'язкових креслеників, схем, плакатів, комп'ютерних ілюстрацій:

1. Topic of qualification work

2. Goals and objectives of qualification work

3. Analysis of existing devices and scanning systems in 3D monitoring tasks
4. How signals are being received, filtered and converted
5. How signals are being received, filtered and converted
6. Use of laser scanning systems in the field of artificial vision
7. Use of laser scanning systems in the field of artificial vision
8. How it operates
9. Reason behind this research
10. Transimpedance amplifier
11. Description of the experiments
12. Laser scanning and data collection experiment
13. Triangulation and mapping of objects
14. Conclusions

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РЕФЕРАТ

Пояснювальна записка кваліфікаційної роботи має: 78 с., 40 рис., 17 табл., 2 додатка, 48 джерел.

ЛАЗЕРИ, ПІДСИЛЮВАЧІ, ОПТИЧНІ СИСТЕМИ, ЗОРОВІ ДАНІ, МІСЬКЕ
СЕРЕДОВИЩЕ, ПЕРЕШКОДИ

Об'єкт дослідження – скануюча система.

Предмет дослідження – системи фото сенсорного підсилення.

Мета кваліфікаційної роботи – розробка системи підсилення для оптоелектронних сигналів, отриманих фотодатчиком у апертурі сканування третього прототипу Системи технічного зору (TVS3) з використанням підсилювача транзімпедансу.

Методи дослідження – теоретичний аналіз, числові розрахунки, математичне моделювання, статистична обробка даних, аналіз геометрії, огляд принципів тріангуляції.

У даній роботі проведено огляд особливостей світлового та магнітного спектру, огляд особливостей віддзеркалення та фотоелектричного ефекту, проведення аналізу можливостей використання фото датчиків та підсилювачів, розробка інтерфейсу для контролювання позиціонування двигунів та лазерів, опис функціонування системи, та система збору даних.

ABSTRACT

The explanatory note of the qualification work has: 78 pages, 40 figures, 17 tables, 2 appendices, 48 sources.

LASERS, AMPLIFIERS, OPTICAL SYSTEMS, VISUAL DATA, URBAN ENVIRONMENT, INTERFERENCE

The object of study - the scanning system.

Subject of research - photo sensory amplification systems.

The purpose of the qualification work - development of an amplification system for optoelectronic signals received by the photosensor in the scanning aperture of the third prototype of the Technical Vision System (TVS3) using a transimpedance amplifier.

Research methods - theoretical analysis, numerical calculations, mathematical modeling, statistical data processing, geometry analysis, review of the principles of triangulation.

This paper reviews the light and magnetic spectrum, reflections and photoelectric effects, analyzes the use of photo sensors and amplifiers, develops an interface to control the positioning of motors and lasers, describes the operation of the system and data collection system.

LIST OF CONDITIONAL ABBREVIATIONS

FOV - field of view;

TVS - technical vision system;

ASCII - American standard code for Information interchange;

FPGA - field programmable gate array;

OpAmp - operational amplifier;

TIA - transimpedance amplifiers;

PIN - positive-intrinsic-negative diode;

SOIC - small outline integrated circuit;

DIP - dual in-line package;

PLD - programmable logic device;

DC - direct current;

GUI - graphical user interface;

PCB - printed circuit board;

CAD - computer aided design;

LiDAR - light detection and ranging;

TV - technical vision;

ADC - analog-to-digital converter;

UDP - user datagram protocol;

SA - scanning aperture.

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INTRODUCTION

In the sphere of artificial vision, the systems of laser scanning are widely used in the works such as robotics, building, and geodesy. This kind of technology can be used for both manufacturing needs and scientific research. Both of the aforementioned require 3D coordinates of the surroundings they're working with.

The laser pointer is pointed towards a certain point of view where it is being reflected from a surface to the scanning diaphragm that would scan our reflected signal. This scanning device is constantly moving trying to find our laser in our order to determine the surface. This setup makes dynamic triangulation our method of choice because it's not limited to the size of the device itself unlike in static triangulation where the size of the receiver is connected with the light that it receives. Using these elements that output a gaussian curve which gives us the information on how the energy of our scanned object was distributed on top of the info about the angles by which our scanning equipment is positioned we can use simple trigonometry to determine the points in space where our object is positioned [1].

In previous research projects TVS was used in a new, a bit different way. Using laser scanning to determine the biological parameters certain methods were developed. These methods would use photoscanners as photoresist and a voltage comparator to determine whether an object in the scanning area even exists and then by calculating the impulses the system would determine the angles as well as the distance to the said object.

Various prototypes before TVS3 would use stepper motors and a gear-like system to position the laser scanner as well as the scanning diaphragm. Using a discrete FOV makes it limiting or straight up impossible to scan smaller objects due to the stepper nature of the motors. Also because of this the distance can become a problem as well.

In order to improve the TVS the number of steps was drastically increased by using current motors which were used as servo motors by adding the spinning

detectors. This way the separation capacity was greatly increased which resulted in a pretty much uninterrupted FOV.

This master's research is based on the exclusive usage of the TVS prototype, developed in UABC for the practical application of the principles of dynamic triangulation. Using this prototype with addition of different photosensors for used to detect visible light, we tested certain possible upgrades described later in this work:

To conclude, considering the level of today's technology we can see that the transimpedance amplifiers have a wide variety of uses and great potential to be used not only in the devices mentioned above but many others. On top of that we can conclude that the speed at which these amplifiers are capable of working should be more than enough to take care of the object which our scanning system is going to be used on. One of the biggest parts of this whole research is testing the effectiveness of the devices aforementioned and hopefully building those 3D clouds we talked about earlier using the data collected.

1 ANALYSIS OF EXISTING DEVICES AND SCANNING SYSTEMS IN 3D MONITORING TASKS

1.1 Theoretical analysis of the problem

1.1.1 Overview of the features of the light and magnetic spectrum

Visible light is part of the electromagnetic spectrum, which ranges from microwave ovens to gamma rays. Electromagnetic waves, as their name suggests, are oscillations of electric and magnetic fields that can transfer energy from one place to another. Electromagnetic radiation can also be described as a flux of photons or particles that, while charged with energy, have no mass. Each of them has wave-like properties and operates with the speed of light. When traveling as a wave, light can be identified by its wavelength and frequency. Those are the properties that indicate the amount of energy carried by each photon. As can be seen in the figure 4.1, visible light, on the other hand, is no different from other parts of the electromagnetic spectrum, except that the human eye can detect it using chemical photodetectors on the retina. These photoreceptors convert visible light into electrochemical energy, which is then processed by the brain.

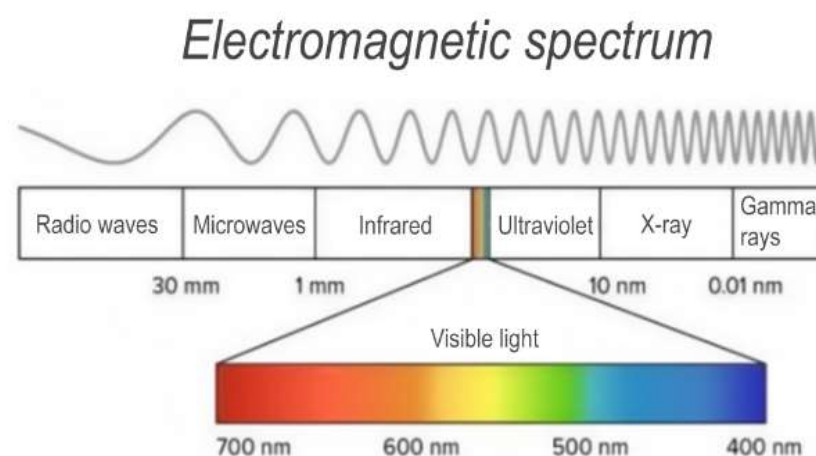


Figure 1.1 - Representation of the electromagnetic spectrum

1.1.2 Overview of the features of reflection and photoelectric effect

The law of reflection says that when light comes into contact with the surface, it is reflected in a certain way (depending on the surface itself). In the case of a mirror image, the angle at which the light meets the surface is called the angle of incidence. It is always equal to the angle reflected from the surface which is called the angle of reflection. This basically means that light falling in one direction can only be directed in one direction.

The photoelectric effect is a phenomenon in which light particles, called photons, affect electrons in a metal, separating them from atoms, as shown in Figure 1.2.

There are two types of photo effects - internal and external. In the case of an external photoelectric effect, free electrons are emitted from the surface by absorbing energy photons. This is usually observed with metals inside the vacuum housing (case), and its efficiency is usually less than 50%.

In the case of the internal photoelectric effect, it is mainly observed in semiconductors, whose less opacity causes the main effect at a certain depth, where very few electrons can actually fly to the surface. The process consists of absorbing an energetic photon, which creates a pair, an electron and a hole.

When the photon energy exceeds the material's range of empty conduction bands, the charge carriers can move freely in the conduction band. The electron moves during this process, causing an electric current.

This phenomenon is used in factories that use solar panels which implement an internal photovoltaic effect. It then basically receives light energy from the sun, converting it into electricity.

Around 1887 Heinrich Hertz discovered this effect by irradiating the metal surface with short-wavelength light. As a result, it could produce electron radiation.

It is called the photoelectric effect because light and electricity are involved in this phenomenon. Pretty simple [22].

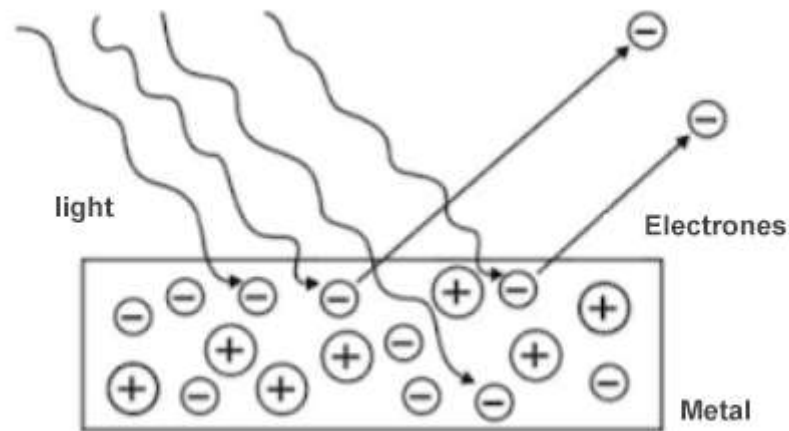


Figure 1.2 - Representation of the electromagnetic spectrum

1.1.3 Analysis of photoconductivity features

Photoconductivity is defined as the change in the electrical conductivity of a material due to the action of incident radiation.

The first report on photoconductivity was made in 1873 by W. Smith, who noted that the resistivity of selenium can be decreased due to solar radiation. The basic principle on which photoconductivity is based:

- When an energy photon greater than or equal to the gap in the material enters the semiconductor, it can be absorbed by the material, transferring the electron to the conduction band, leaving a hole (vacuum) in the valence band; These two carriers increase the conductivity of the material. In this case, the conductivity is called internal [24].
- In the case of materials with defects, impurities or any type of distortion, there might be in instance where the absorbed photon is less than the gap of the material, and the electrons pass into the conduction band, or alternatively holes are formed in the valence band, in which case only one type of carrier increases.

This process generates external photoconductivity [25].

1.1.4 Photo sensors

A photo sensor is an electronic component that detects the presence of visible light, infrared and/or ultraviolet light. Most photosensors consist of a semiconductor with photoconductive properties, in which the electrical conductivity varies depending on the intensity of the radiation reaching the material.

The most common types of photosensors are photodiodes, phototransistors and photofet. These devices are essentially the same common diodes, bipolar transistors and field-effect transistors, except that their cases have transparent windows that allow light to reach the transitions between the semiconductor materials inside. Bipolar transistors and field-effect transistors further enhance sensitive capabilities of photosensors [26].

1.1.5 Conditioning and signal reception

Signal conditioning to put it simply is the process by which an input signal, whether electrical or mechanical, can be converted into an output signal. Signal compatible with the control process, which can be interpreted by another system, and can be processed or used to perform calculations or to obtain more accurate measurements and thus have a more accurate idea of the behavior of the object under study. One of the specifics of a is that it may, for example, be too small to measure, and/or have interference due to signals from other processes.

1.1.6 Signal conversion

The main function of signal conditioning is to obtain a signal measured in the form of heat, current, light intensity or other types, and convert it into an electrical

signal compatible with the process. Due to the large number of processes, industrial applications, types of sensors for measurements, the signals received from these sensors may be incompatible with the control system, and may require conversion. Although almost every real system has nonlinear characteristics, (i.e. the input-output ratio cannot be represented by a linear differential equation), many systems can be reasonably described by linear models in at least certain operating ranges. Some signal conditioners can linearize the output signal (in other words, if the signals supplied by the sensor do not correspond linearly to the physical value, the conditioner performs the signal interpretation process). This method is used for greater accuracy due to not all sensors being completely linear.

In order for the signal to be properly conditioned it needs to be amplified accordingly. Two methods are available for amplification: increasing the resolution of the input signal or increasing the signal-to-noise ratio. On the other hand, contrary to the gain, signal attenuation is required when the measured voltages are outside the possible range of the selected driver. This form of signal conditioning reduces the amplitude of the input signal so that the conditional signal is within the allowable range of the controller.

1.1.7 Signal filtering

Filtering is a very important function when it comes to signal conditioning. Filtering consists of filtering the frequency spectrum of the signal, preserving only the useful frequencies, and separating the useful signal from the noise or blocking all the noise. Filters can consist of passive, active components or a digital algorithm. The passive filter uses only capacitors, resistors and inductors with the maximum gain, while, on the other hand, the active filter uses passive components in combination with active components such as operational amplifiers, resistors and transistors that use external power supplies and thus can amplify the input signal. There are also digital filters; mathematical filters used to manipulate the signal using logic

components such as program-specific integrated circuits (ASICs) or programmable gate arrays (FPGAs).

1.1.8 Data collection

Data collection is the process by which phenomena or physical conditions in real life are transformed into data that can be understood by a computer.

Figure 1.3 shows a block diagram depicting this process.

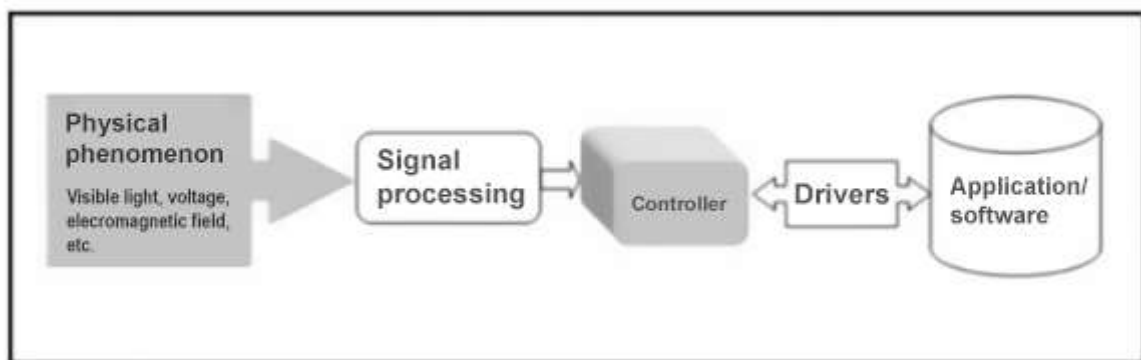


Figure 1.3 - Data collection

Then the signals must be transmitted from the sensors to the system control via interfaces. The simplest interfaces can be considered as a wire through which an analog signal is transmitted, while the most complex interfaces may include a number of applications, such as remote transmission by electromagnetic waves or digitally over a network. There are analog and digital interfaces. Typical analog interfaces are voltage or current signals, these signals vary continuously between the upper and lower limits. The main advantage of these systems is the use of the signal-to-noise ratio of the device. Digital signals, on the other hand, use well-differentiated electrical variables that alternate over time, thus transmitting code. Each electrical level is 1 or 0.

1.1.9 Operational amplifier

An operational amplifier (OpAmp) is fundamental to many types of signal conditioning. OpAmp is a high-gain DC amplifier with differential inputs and usually with one output.

In this configuration, OpAmp produces a potential output that is usually thousands of times greater than the potential difference between its terminals. One of the most common applications of OpAmp is that a non-inverting amplifier (shown in the diagram in Figure 1.4 has an input signal connected to its non-inverting input, so its input has an infinite resistance. The OpAmp then directs the current to the R_F until the negative input is at the same level as the V_{in} . Then you can use the voltage divider rule to calculate V_{out} .

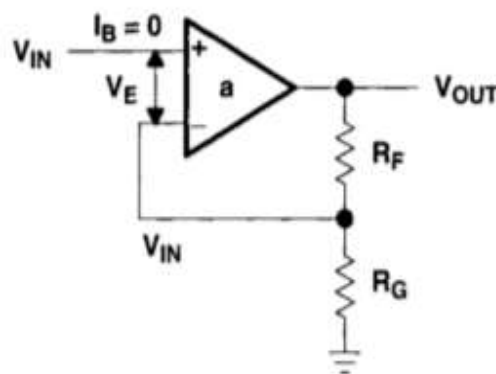


Figure 1.4 - Non-inverting amplifier

1.1.10 Transimpedance amplifier

More specific uses of OpAmp are transimpedance amplifiers (Transimpedance Amplifiers - TIA, shown as a diagram in Figure 1.5, which, unlike non-inverting amplifiers, are devices that use a current signal and convert it into a voltage signal, supporting a certain signal amplification. This is extremely important for many applications of optics, because the means for detecting the light signal are photodetectors, because in general these photodetectors receive a signal of light

intensity and generate a current signal that, when properly operated, is proportional to the specified intensity. However, many measuring devices (such as oscilloscopes, analog-to-digital converters, spectrum analyzers, etc.) process voltage signals, and they also have a certain dynamic range. On the other hand, depending on the use of photodetectors and their technical characteristics, the currents they produce can be significantly low (in the case of photodiodes used in this work, in the order of microamperes). That is why, in addition to converting the current signal into voltage, it must be amplified.

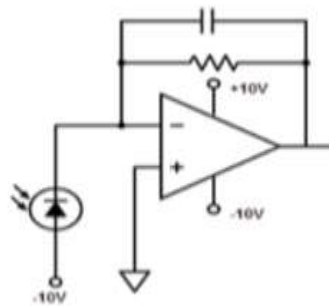


Figure 1.5 - Transimpedance amplifier

1.2 Analysis of the possibilities of using photosensors

Photodiodes are the main semiconductor devices that convert light into electricity, they are similar in operation to conventional diodes, and they're mainly used in light sensors. Current occurs when a photon is absorbed by a photodiode. Photodiodes are divided into 4 main types; PN, PIN, Avalanche and Schottky. On the other hand, a phototransistor is a semiconductor device capable of detecting light levels and varying the current flowing between its emitter and collector according to the level of illumination it receives. Both phototransistors and photodiodes can be used to detect light, but a phototransistor is more sensitive than a photodiode due to the gain provided by a bipolar transistor. The efficiency of different light sensors is compared taking into account the speed at which measurements can be made and the range of visible light that these detectors can detect. When we compared the options available to us it was decided to reduce the choice to 2 remaining sensors that met the

characteristics of the project. The results were compared using an experiment designed to measure the possible gain of both sensors in combination with two different amplifiers. The following sensors fit our criteria.

- Photodiode BPW21R, VISHAY
- Phototransistor TEPT5600, VISHAY

1.3 Analysis of the possibilities of using amplifiers

In addition to the photosensors, two amplifiers were selected to be used in similar experiments. The following amplifiers:

- Amplifier OPA656, with a good design for optical projects and low input noise. One of the disadvantages would be the use of SOIC packaging.
- The LM324N amplifier which has an advantage of being easy to use as well as being commercial. It, having DIP packaging, makes it easier to perform experiments with.

1.4 Analysis of technical vision systems (TVS)

The TVS system was developed to use the method of dynamic triangulation in UABC, details of each of the developed prototypes are given below.

1.4.1 Analysis of TVS1

Developed in the UABC Laboratory of Optical Electronics and Automatic Measurements, this TV consists mainly of a dynamic triangulation system that uses stepper motors to position the scanning aperture as well as the laser positioner.. The laser pointer is directed to a specific area of it's FOV, where it is reflected on the surface of the object and then "captured" by a scanning aperture that rotates on a DC motor in search of this reflection of the laser.

This makes dynamic triangulation, which uses non-fixed angles for transmitter and receiver, to have a measuring range regardless of the size of the sensor used to detect. Although this prototype has been replaced by TVS2 and TVS3 and is no longer used, the principle of operation of prototypes 2 and 3 is the same.

1.4.2 Analysis of TVS2

The predecessor of the current prototype system, prototype 2 or TVS2, consists of two main mechanical parts - a laser positioner and a scanning diaphragm.

Using the principle of dynamic triangulation, this system has advantages over traditional systems based on cameras. The mechanical parts are controlled by stepper motors, which creates a discrete field of view. The use of discrete fields of view makes it impossible to scan smaller objects at its resolution, which is the main disadvantage of the system. As mentioned in [1], this example of the field of view can be seen in Figure 1.6, the distance between the points p increases with increasing scanning distance d .

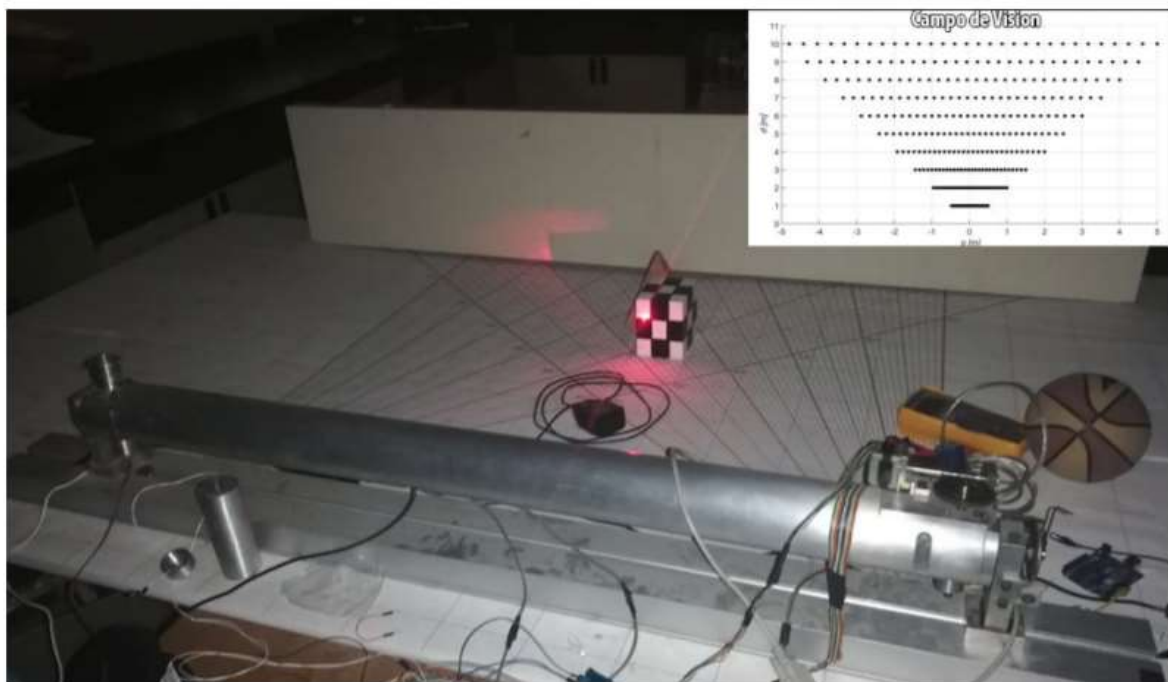


Figure 1.6 - TVS2 discrete field of view

1.4.3 Analysis of TVS3

The current TVS prototype, or TVS3, on the other hand, uses a continuous field of view to replace the stepper motors used in the TVS 2 prototype with DC motors which are used as servo motors by adding rotary encoders. Thus, the resolution of the system was significantly increased, obtaining a continuous FOV, as shown in Figure 1.7. In addition, a previous study resulted in developing a control system for these servo motors for their accurate positioning, which, among other things, made it possible to more accurately scan objects [4].

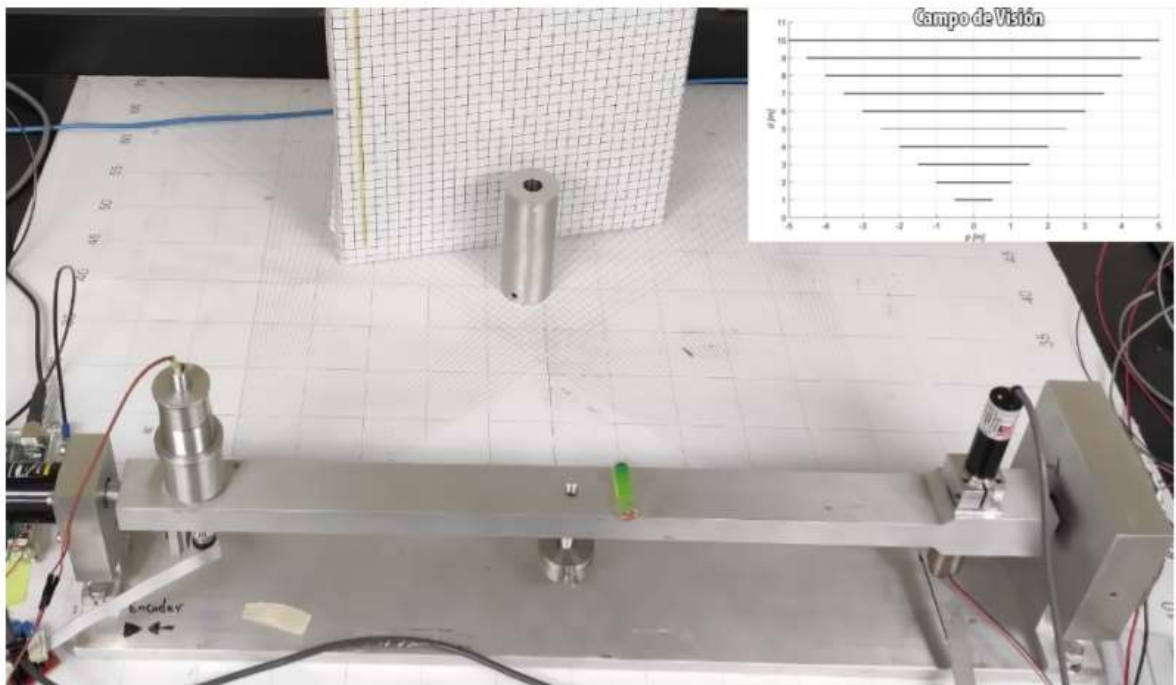


Figure 1.7 - Continuous field of view of TVS 3

2 ANALYSIS OF PROBLEMS OF SYSTEM USE OF TECHNICAL VISION IN THE TASKS OF 3D-MONITORING

2.1 Use of laser scanning systems in the field of artificial vision

In the sphere of artificial vision, the systems of laser scanning are widely used in the works such as robotics, building, and geodesy. This kind of technology can be used for both manufacturing needs and scientific research. Both of the aforementioned require 3D coordinates of the surroundings they're working with. That's where the triangulation comes in. Triangulation is a part of geodesy which is using mathematical methods for calculating different types of surfaces. The kind of triangulation we would need here is called dynamic triangulation which is basically two elements constantly moving and changing angles. The elements here are a laser pointer and a positioner which make an angle γ .

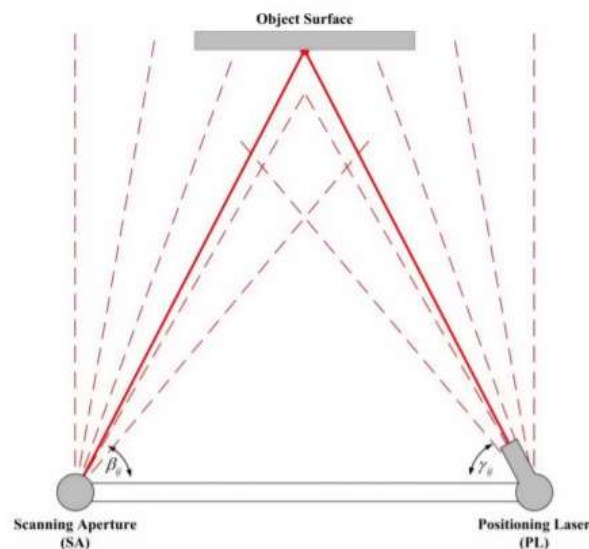


Figure 2.1 - Dynamic triangulation

The laser pointer is pointed towards a certain point of view where it is being reflected from a surface to the scanning diaphragm that would scan our reflected signal. This scanning device is constantly moving trying to find our laser in our order

to determine the surface. This setup makes dynamic triangulation our method of choice because it's not limited to the size of the device itself unlike in static triangulation where the size of the receiver is connected with the light that it receives. Using these elements that output a gaussian curve which gives us the information on how the energy of our scanned object was distributed on top of the info about the angles by which our scanning equipment is positioned we can use simple trigonometry to determine the points in space where our object is positioned [1].

In previous research projects TVS was used in a new, a bit different way. Using laser scanning to determine the biological parameters certain methods were developed. These methods would use photoscaners as photoresist and a voltage comparator to determine whether an object in the scanning area even exists and then by calculating the impulses the system would determine the angles as well as the distance to the said object.

Various prototypes before TVS3 would use stepper motors and a gear-like system to position the laser scanner as well as the scanning diaphragm. Using a discrete FOV makes it limiting or straight up impossible to scan smaller objects due to the stepper nature of the motors. Also because of this the distance can become a problem as well. Example of such a FOV is shown in Figure 2.2.

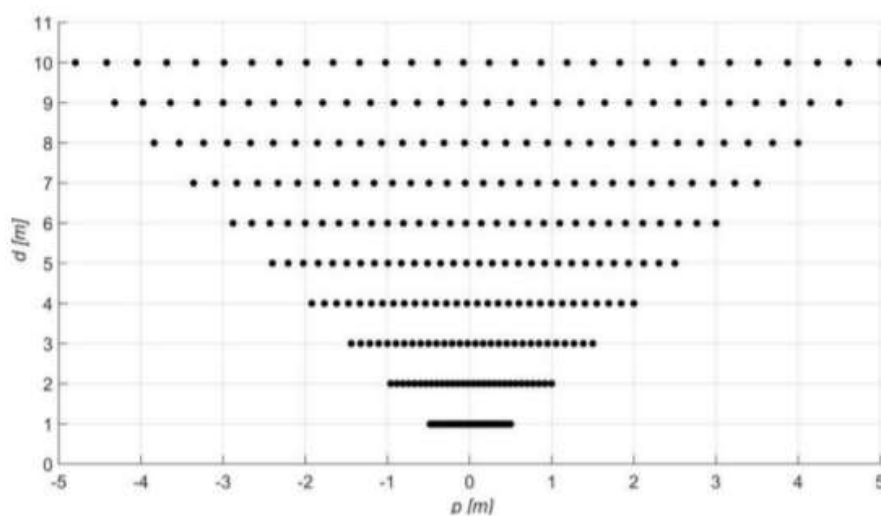


Figure 2.2 - Discrete field of view

In order to improve the TVS the number of steps was drastically increased by using current motors which were used as servo motors by adding the spinning detectors. This way the separation capacity was greatly increased which resulted in a pretty much uninterrupted FOV. Figure 2.3

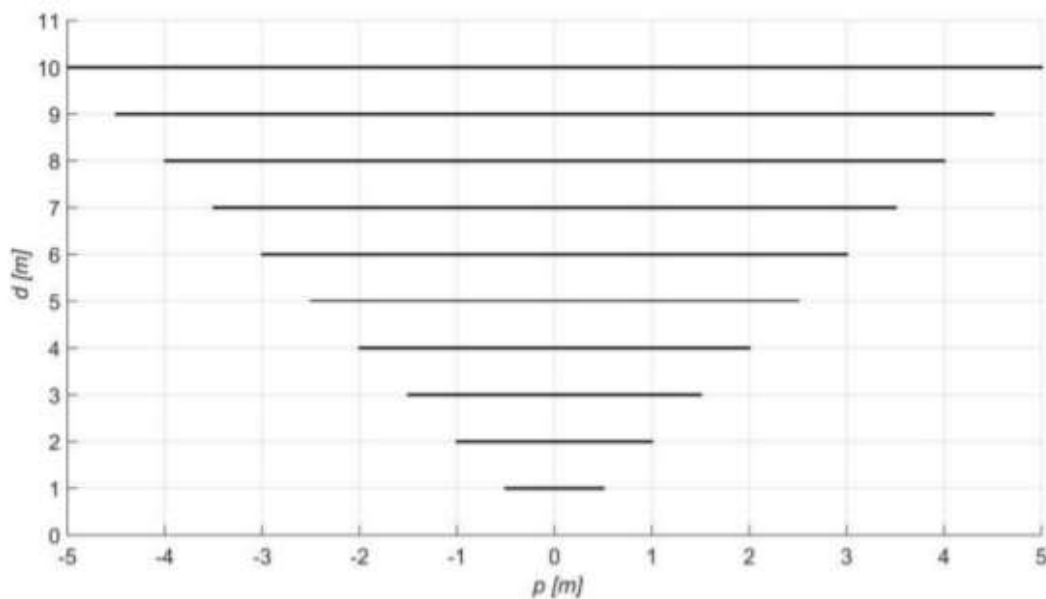


Figure 2.3 - Continuous FOV

Not only that but there was a special control system built specifically for those servo motors that would allow and open new possibilities for more detailed scans of the objects that are not only smaller but also way more distant from the scanners. To improve the prototype even further and allow the ability to scan smaller objects from further distances was decided to give the prototype a transimpedance amplifier. Such an amplifier can the amplitude of the optical-electric signal received with the help of the scanning diaphragm. Those kinds of amplifiers are widely used in other tech that takes very low current as an input signal.

This master's research is based on the exclusive usage of the TVS prototype, developed in UABC for the practical application of the principles of dynamic

triangulation. Using this prototype with addition of different photosensors for used to detect visible light, we tested certain possible upgrades described below:

- In order to automate the process of positioning the laser on the scanned object and scanning process itself without a significant loss in scanning data we changed the software that was in control of the motors to suit the current motors and their uninterrupted nature. The change from stepper motors required more precise commands in order to position our scanning equipment correctly.
- The commands that are being sent between the software and the hardware consist of the angle and/or coordinates that would determine whether or not the laser has reached its full range of motion and/or if there are any errors/obstacles in the process.
- The interface that is based on C was programmed to control the laser in order to give it a path to follow to scan an object.
 1. In this interface you're able to tell the laser whether or not it should use its full FOV or for example the number of degrees that would make one step.
 2. After inputting the needed info, the software will do its part and will tell the laser how to position itself at each and every step.
 3. The information received as the result of this scanning process will then be stored on the drive:
- Capturing the distribution of the energy which is being seen as the Gauss signal will allow us to analyze such characteristics as: color, type of material, and the angles at which our object is positioned.
- These characteristics as well as the angles and the distance are being determined with the help of the aforementioned transimpedance amplifier. It's important to remember that the response time of the amplifier will determine the speed at which the whole system is going to perform. This is because the amount of amplification will have its effect on the response time.

After we successfully harvest the scanning data we can use an additional piece of software to determine the signal peaks or we can use a completely different method

that will be mentioned later to determine the energy center of the Gauss signal. More specifically the β angle. Using all the aforementioned we're able to triangulate each and every point determined during our scanning process. These points will allow us to compile them into a 3D 'cloud' that would later become a 3D model. It's important to notice that even though in his studies this master does mention these 3D modeling capabilities he didn't actually dive deep enough to provide a thorough study on the topic. That being said, the quality and quantity of the scanned area has been drastically improved which naturally would result in better 3D models of the objects scanned.

Some of the examples of using the aforementioned transimpedance amplifiers in highspeed programs will be mentioned later. There in order to set up a connection between two PLDs we used an OPA656 amplifier to provide fast enough switching capability.

To conclude, considering the level of today's technology we can see that the transimpedance amplifiers have a wide variety of uses and great potential to be used not only in the devices mentioned above but many others. On top of that we can conclude that the speed at which these amplifiers are capable of working should be more than enough to take care of the object which our scanning system is going to be used on. One of the biggest parts of this whole research is testing the effectiveness of the devices aforementioned and hopefully building those 3D clouds we talked about earlier using the data collected.

The third prototype of laser scanning equipment that was used to acquire the 3D coordinates of certain objects by reflecting the laser and calculating the angles by «Dynamic Triangulation» was created in the engineering institute UABC. This system was called «Prototype TVS 3». TVS 3 allowed the setting of the 3 scanning parts (the moving frame, the laser pointer and a scanning diaphragm) with the help of the current motors and spin detectors instead of the stepper motors that were used previously. This was used to move away from gear like nature and somewhat limiting steps of the stepper motors towards way less interrupted FOV that was provided by the current motors. The system uses the light reflection and its intensity to determine

the angle by which the object is being scanned by the diaphragm. Then using the fixed distance between the diaphragm and the laser + angles we get the distance between our scanning equipment and the object being scanned. This is all thanks to triangulation which allows us to calculate these variables.

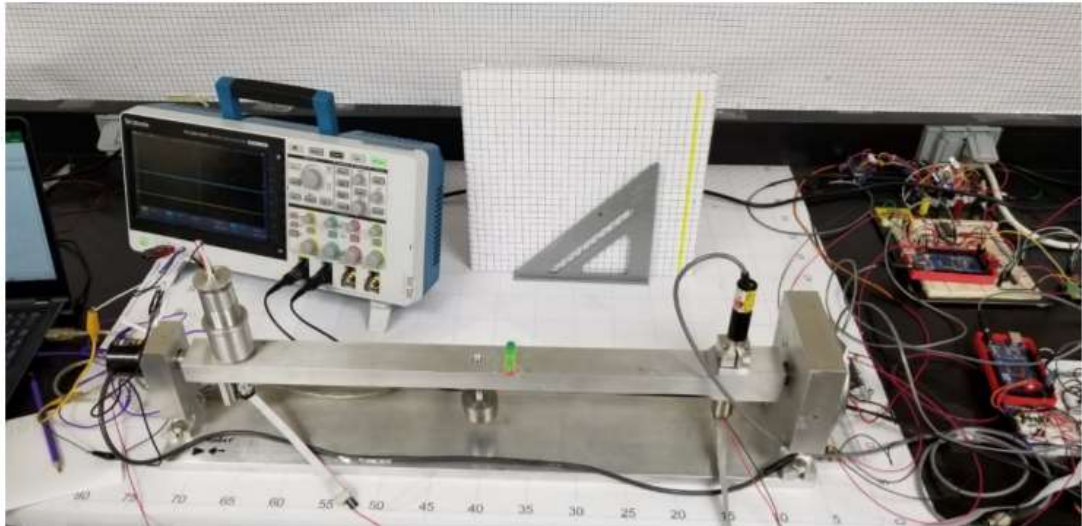


Figure 2.4 - shows the prototype (center) and position controllers (right)

The positioning of the motors is done by the consecutive connection with the central microcontroller Arduino MEGA, which sends the instructions regarding the positioning in real time using the algorithm that allows to constantly control the location as well the speed of the motors. With closed control with rotary encoders and a precise LM629 controller, DC motors and servomechanisms are controlled by four-step adjustment of the step position, which allows precise control of the motor position.

This is all done with the help of a GUI which was programmed in LabView, where all the important information as well as the parameters of each and every controlled are being controlled.

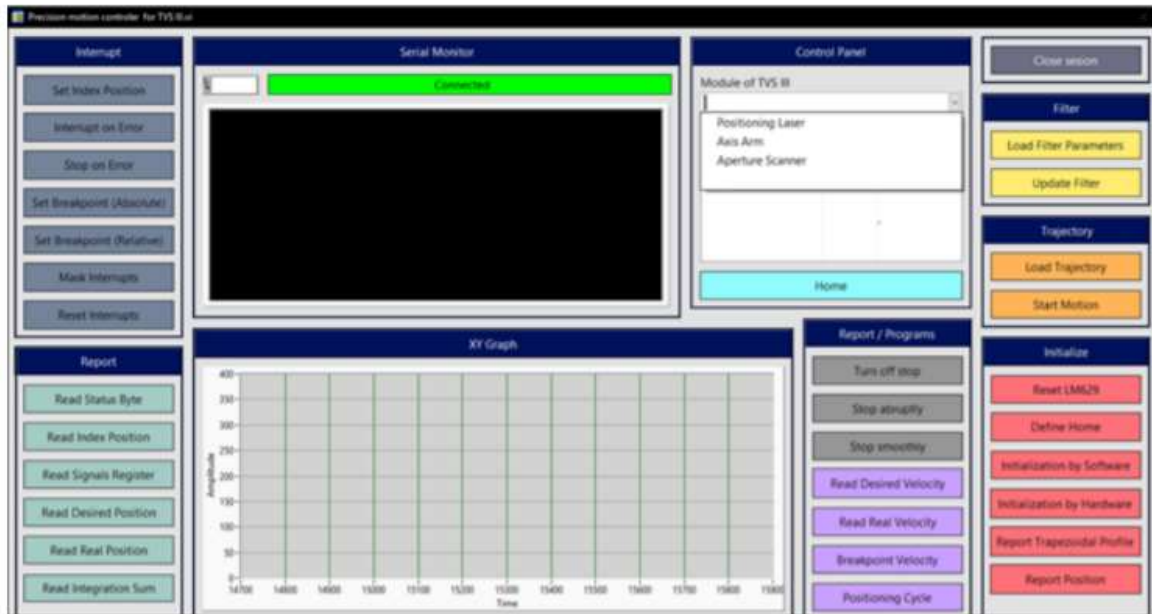


Figure 2.5 - Shows a screenshot of the interface with the positioning system DC motors.

This interface has the ability to control the positioning as well as the speed on top of which it can also start and stop the movement of the motors. In order to connect the interface with the controllers we use certain libs that were specifically created to send all sorts of commands, which the LM629 controller then receives or sends through its output ports.

The system has a reference of each and every controller used for each and every positioning motor. These controllers have specific libs created by using C to connect with the user interface and control the positioning, speed and the constant correction of the coordinates. This process is being done thanks to using the algorithm that calculates the trajectory and gives commands to LM629 .

It is considered to be possible to determine the reflection of the concentrated light (such as laser) from a wall using the phototransistor as a detector as shown in figure 2.6. However there are certain limitations which are caused by the factors such as the sensitivity of the detector and the surface from which the light is being reflected. Because of that it's advised to choose the best combination of the photo detectors (e.g.

photodiode, phototransistor and an operational amplifier to calculate the intensity of the light that is being reflected from the test objects)

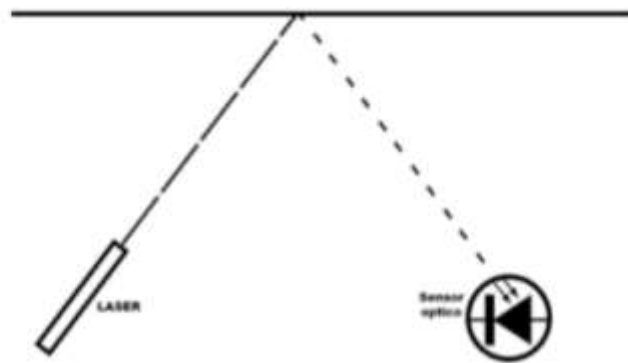


Figure 2.6 - Surface reflected laser

2.1.1 Theoretical review of triangulation methods

A triangle is used in many different working spheres, starting from navigation and ending with civil buildings because it presents us with very precise coordinates. Some examples include: positioning of a ship or a direction in which a tunnel or a road needs to be built. That being said, there are a lot of cases where the objects need to be scanned from a distance. This is all based on basic trigonometry, which uses at least one side and two available angles to calculate the remaining two sides and the remaining angle. In Figure 2.7 you can see how these angles are shown, followed by the equations that represent the equality of angles and the Law of sines.

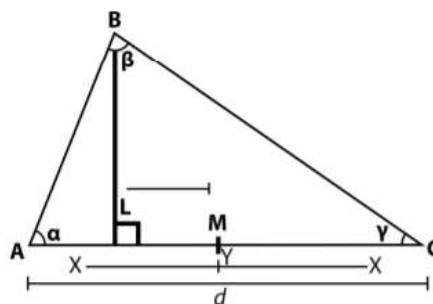


Figure 2.7 - Triangulation of objects

First we need to determine the missing angle. Knowing that:

$$\alpha + \beta + \gamma = 180^\circ \quad (2.1)$$

$$\beta = 180 - \alpha - \gamma \quad (2.2)$$

And by using the Law of sines, then:

$$\frac{b \cdot \sin\beta}{a \cdot \sin\alpha} \quad (2.3)$$

$$a = \frac{1}{\left(\frac{\sin\beta}{\sin\alpha \cdot b}\right)} \quad (2.4)$$

$$c = a \cdot \frac{\sin\gamma}{\sin\alpha} \quad (2.5)$$

While the points B and C are being held at a constant and available to us distance from the center we know that:

$$d = d_1 + d_2 \quad (2.6)$$

And provided that the values of α and γ can be measured, the tangent of each angle in one of the right triangles formed between the center of both dimensions is the ratio between the length of the opposite side and the length of the adjacent side, then: Knowing that:

$$L = d \cdot \frac{\sin(\alpha) \cdot \sin(\gamma)}{\sin(\alpha + \gamma)} \quad (2.7)$$

In mean time to calculate the distance from A to C and B to C we use:

$$AC = AB \cdot \frac{\sin(\gamma)}{\sin(\alpha+\gamma)} \quad (2.8)$$

$$BC = AB \cdot \frac{\sin(\alpha)}{\sin(\alpha+\gamma)} \quad (2.9)$$

And then the distance from M to L:

$$ML = \frac{AB}{2} - BC \cdot \cos(\gamma) \quad (10)$$

Where abscissa is X which is the distance from M to A or C, and the ordinate is Y which equals distance L, while point B is equal to the coordinate of the scanned point.

2.1.2 Review of the method of static triangulation

If every surface can reflect at least a fraction of the light pointed towards it, it means that theoretically you can make the light from a laser to be pointed towards a surface and reflect that reflection by your detector making a triangle knowing the angles that would form it on top of the distance using Triangulation. Demonstration of the process is shown in figure 2.8.

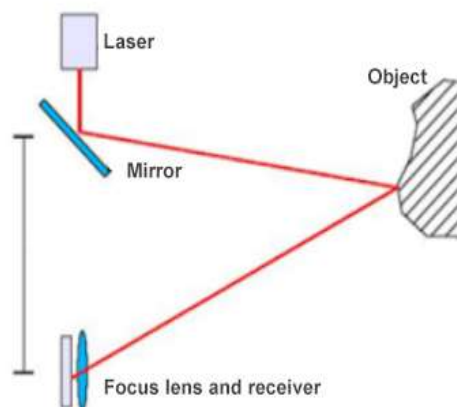


Figure 2.8 - laser triangulation

2.1.3 Review of the method of dynamic triangulation

Triangulation of the objects in the laser scanning systems can be dynamic or static. Dynamic method allows us to change the angle of the laser pointed in accordance with FOV of our laser scanner.

2.2 Description of the problem

Even though other TVS prototypes have previously proven to be quite successful there's a growing need in the range of scanning/calculation. Therefore the purpose of this research is to develop a transimpedance amplifier as well as a way to adapt it to TVS 3 in order to get readable data in the form of Gauss signal. After that we would need to compile this signal into in order to get a 3d info regarding the object being scanned. Other than that we will need to improve the range of our calculations and see how precise our prototype is using practical tests.

2.3 Rationale for the use of theoretical methods

We get the 3D positioning points which use the dynamic triangulation by using certain methods to calculate impulses in addition to the usage of a basic detection system which uses optical detectors and relatively high voltage to make it easier to detect slight changes in the reflected signals. Even though all of the aforementioned systems have proven to work they have some notable disadvantages. The kind of data that you get and it's quality can be questionable and measuring the voltage changes can give some unclear numbers due to noise problems. That's why this work is focused more on implementing a transimpedance amplifier to the TVS 3 and collecting the appropriate data. The reason is this method in particular allows us to directly transform low current that we get from reflections meaning that we can discrete it easier. On top of that it would allow us to get more info of the object we're

scanning by examining its signal's form. Info like shape, color, material which would normally be way harder to obtain due to previous limitations. This way we're able to greatly increase the range of our studies, the amount and the quality of the data we get which would later be displayed as a collection of 3D coordinates.

As was discussed earlier, calculating the coordinates using dynamic triangulation gives us a bigger picture about the objects we scan, especially when we take into account the amplification part. It's said that: «The use of a transimpedance amplifier in the prototype TVS 3 is possible with a currently installed laser, which will improve the maximum possible distance from which the object can be scanned, and the signal received from the amplifier can be used to improve the accuracy of the energy center».

This chapter will further explain general and more specific goals of our research.

The general goal of this research is the development of the amplification systems for optoelectronic signals received by photodetectors in the scanning aperture of TVS with the use of transimpedance amplifiers which will give us more detailed data about the energy distribution in the signal reflected from our scanned objects on top of a bigger scanning distance compared to previous prototypes.

On top of our general goals we have more specific milestones which are:

1. Research on the up to date amplifiers, photosensors and processing methods.
2. Determining the right combination of the sensor and optimal transimpedance amplifier scheme for the COHERENT laser model STR-520-10-AHR-D01m 520 nm which are used in TVS 3.
3. Increasing the scanning range set by previous prototypes (~70 cm) with the help of the transimpedance amplifier.
4. Design and manufacturing of the PCBs.
5. Design and implementation of the data storage system for 3D points received from scans, which would use current motor moving algorithms as a base.

6. Development of a filter program that would determine the signal peaks and the signal itself.

7. Development of the program for dynamic triangulation and visualisation of the 3D coordinates.

3 ANALYSIS OF PHOTSENSOR AMPLIFIER DESIGN METHODS FOR LASER SIGNAL SCANNING OPTICAL SIGNAL MATCHING IN 3D MONITORING TASKS

3.1 Analysis of the surface measurement system in the study area for accurate measuring the geometry of the surface of objects.

Nowadays there are a lot of uses for the systems that scan surfaces. These systems basically operate by calculating a set of points on a surface from which we can build an image using dynamic triangulation. Then accurate geometric measurements are used to create three-dimensional computational models for various applications, such as autonomous navigation in robotic tasks, during surveying to accurately determine the position of the surface at points, distances and angles using leveling devices, to monitor the structural condition to obtain a complete database structure and obtaining a complete diagnosis of assembly, and mainly in the manufacturing industry, it is used in the creation of computer-aided design (CAD) for the design or reconstruction of parts that would otherwise be impossible. These measuring systems usually work with careful processes, especially in autonomous navigation, to detect obstacles and avoid collisions, or when the designed parts must fit into the existing equipment, minimizing the possibility of errors in geometric measurements. Surface measurement systems usually have contact measurement methods such as micrometers or coordinate measuring machines, but sometimes the object of interest may not be in direct contact with the tools that obtain geometric information due to various factors.: its size, distance or type (nature) of the material. For these types of tasks, there are many non-contact surface measurement methods that are able to accurately measure surface geometry. One way to measure these objects is with camera scanners and laser scanners, which are used to obtain information about the surface or coordinates of these objects.

The advantage of cameras is that they resemble how human vision works, which facilitates the implementation of algorithms for detecting different scenarios or objects in an unknown environment. In addition, the scan results do not depend on surface properties of the object when using cameras. However, cameras are not recommended for measuring coordinates or distances, as they generate large amounts of data and due to their dependence on weather conditions and the presence of visible light. On the contrary, laser scanning systems are suitable for accurate coordinate measurements on objects at long distances regardless of ambient lighting. They also have the advantage of fast measurements and simple optical installation with inexpensive elements. On the other hand, it should be noted that for laser scanning systems, the measurement values depend on the scanning area, and that post-processing is required due to the large sets of 3D data with high resolution.

Laser scanners can be classified according to design principles and measurement methods, which are briefly described in the following two sections.

3.1.1 Principles of designing a photosensor amplifier for matching the optical signal of a laser scanning system in 3D monitoring tasks

Design principles describe the characteristics of a laser scanner and determine its design. There are three basic design principles for laser scanners:

- Portable laser scanners.
- Mobile laser scanners.
- Stationary laser scanners.

Portable laser scanners are small and compact devices found in a growing number of applications, where flexibility and mobility play a central role in determining coordinates. Unlike stationary laser scanners, they have a smaller scanning range.

Portable laser scanners are often used as barcode readers or portable coordinate measuring devices. In stationary laser scanners (also called terrestrial laser scanners),

the surface geometry of objects is recorded digitally. This creates a set of discrete sampling points called a point cloud.

This cloud of points is then transformed into user data by post-processing using mathematical methods. Stationary laser scanners, just like cameras, operate on tripods and are usually installed in buildings or facilities for monitoring and control purposes.

3.2 Using measurement methods to create a laser scanning system in 3D monitoring tasks

3.2.1 Review of the method of measuring time

The flight time is made of a source of laser radiation, two photodetectors and a signal processing unit. This method uses time, amplitude or frequency as a variable to calculate the distance between the laser source and its reflection on the surface.

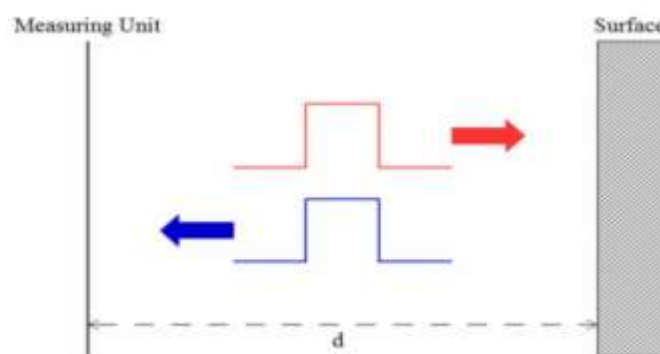


Figure 3.1 - Flight time

The laser scanner measures the absolute flight time t of the emitted and received laser pulse. Thus, the laser pulse must arrive and reflect perpendicular to the measured surface so that the transmitter and receiver can be combined in one unit. The advantage of these methods is the high response rate, and their main disadvantage is the high cost, because they require high resolution. One of the examples can be seen in the LiDAR system which uses 32 different sensors.

3.2.2 Review of the method of measuring phases

For the phase measurement method, we send a harmonic laser signal which then «lays» on top of its reflected signal.

The main advantage of this method is its ability to achieve high resolution, and its main disadvantage is the small distance when scanning objects. The distance between the unit of measurement and the measured surface is determined by the phase shift between the emitted (red) and reflected (blue) laser circuit, as shown in Figure 3.2.

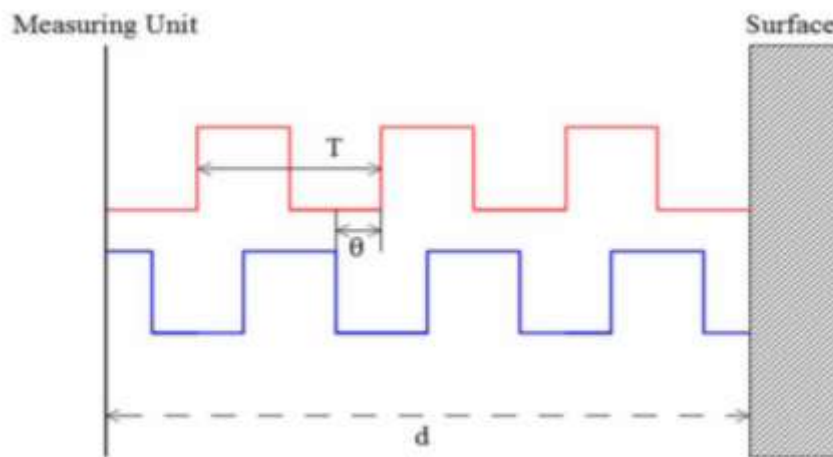


Figure 3.2 - Phase measurement

3.2.3 Review of the method of triangulation

As was mentioned previously, triangulation is a classic topography method in the field of geodesy and which is basically dividing and measuring the area using triangles. From these triangles, the coordinates of the vertex of the triangle are determined by the opposite side of this vertex and the two adjacent angles of this side. Laser scanners that use triangulation usually consist of a transmitter and a receiver.

The transmitter sends a constant or pulsed laser beam and places it in the field of view of the laser scanner. The laser beam (full or diffuse) is reflected on the surface

of the object and is measured by the receiving unit. The use of the triangulation method in laser scanner systems can be static or dynamic.

Trigonometric functions are used to calculate 3D coordinates in Space. The main advantage of this method is its good cost-benefit ratio, while its main disadvantage is the inconsistent behavior on different materials and surfaces.

4 EXPERIMENTAL STUDIES

The following section describes the methodology for developing experiments conducted to identify the optimal components for the amplification scheme and subsequent collection of scan data.

4.1 Description of the experiments

A later experiment was to collect data to verify the performance of a TVS3 scanning aperture equipped with a transimpedance amplifier in different gain configurations in accordance with the calculated distance that is supposed to be measured. After the sensors, transimpedance amplifier and the equations were characterized there was a comparison made with other proposed amplifiers. The components were characterized using photosensors, directly measuring the reflection of laser light from a cylindrical object and checking the results. Once this was done, we began to verify these results by installing sensors inside the scan aperture and making new measurements from the amplifier. Then the sensor with the highest efficiency was selected. Factors taken into account during the scanning aperture experiment are the level of illumination in the laboratory (measured with a lux meter, for example, 1076 lux), the voltage in the used photo sensor, the resistance used for the transimpedance amplifier (which is directly related to the magnification), the speed of rotation of the scanning aperture and the distance at which the object was scanned. Table 4.1 shows the factors that were taken into account during the experiment.

Table 4.1 - Factors used in experimentation

Table of experimentation factors		
Measured effect	Way of measurement	Change Δ in factor
Light in laboratory	Turning the light off and on	
Voltage in photosensor	5V to 7V	1 V
Resistance for the amplifier	1 M Ohm to 1M Ohm	1 M Ohm
Opening speed scanning	300 rpm 6500 rpm	
Distance from scanned object	10 to 50 cm	5 cm

4.2 Justification of the choice of components for the experiment

To amplify the laser signal reflected by the object when it is captured by the scanning aperture, and taking into account the characteristics defined as the wavelength of light 518 nm emitted by the laser positioner, and the environment where the measurements will be made, the following limitations were identified:

- Attenuation of light reflected by the object due to the environment.
- Reflection in different directions when the surface on which the light is reflected is not flat or textured.
- Random detection of ambient light by means of a scanning aperture with the help of a photodetector in the same range of detection as laser light.
- Optoelectronic signals obtained by scanning aperture with very low amplitude.

For the initial tests, two different light sensors were selected. These sensors were chosen because of their high sensitivity to the electromagnetic spectrum used by the laser, while the laser light has a size of 518 nm, and the sensors have a peak sensitivity of about 560 nm. These sensors are a phototransistor TEPT5600 from the manufacturer VISHAY and a photodiode BPW21R from VISHAY. There were a total of 2 amplifiers used to test the aforementioned sensors to compare the results in the amplification methods. The following amplifiers were selected for comparison:

- Transimpedance amplifier (using LM358 chip)

- Non-inverting voltage amplifier (using LM358 chip)

To do this, when the laboratory light was off, the sensitivity of each sensor was checked by a round of laser light reflection measurements from a metal object directly, using 5 V in each of the sensors outside the scan aperture, as shown in Figure 4.1 to have baseline measurements.

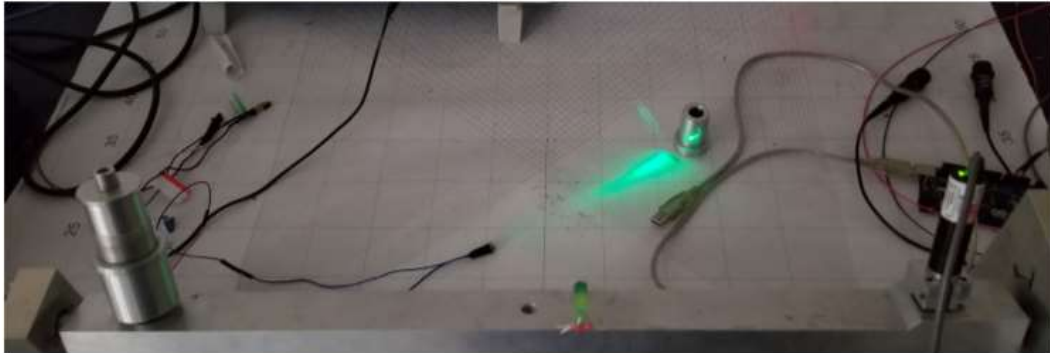


Figure 4.1 - Direct laser light reflection measurement

Table 4.2 - Evaluation of the TEPT5600 phototransistor without amplifier

Sensor TEPT5600 measured without amplifier	
Condition	Maximum measurement (metal cylinder)
Received optoelectronic signal by reflection	1.622V
Environmental noise	0.01V

Table 4.3 - Evaluation of the BPW21R photodiode without amplifier

Sensor BPW21R measured without amplifier	
Condition	Maximum measurement (metal cylinder)
Received optoelectronic signal by reflection	0.759V
Environmental noise	0.014V

After that, the behavior of these sensors was evaluated when they were installed inside the scanning aperture (SA). For this purpose, a cylindrical metal object was used 30 cm in front of the system (as shown in Figure 4.2), simultaneously pointing to the scanning diaphragm mirror and the laser positioner to the object. On top of that the two amplification schemes were implemented for comparison, the results of which are shown in Tables 4.4 and 4.5:



Figure 4.2 - Reflection measurement in scan aperture

Table 4.4 - Evaluation of sensors receiving ambient noise at scanning aperture
(1 M Ohm resistance transimpedance amplifier)

Measurement of ambient noise		
Sensor	Maximum measurement	Used amplifier
BPW21R	0.013V	Transimpedance amplifier
BPW21R	0.013V	30x non-inverting amplifier
TEPT5600	0.349V	Transimpedance amplifier
TEPT5600	0.014V	30x non-inverting amplifier

Table 4.5 - Evaluation of sensors receiving optoelectronic signal in scanning aperture (1 M Ohm resistance transimpedance amplifier)

Measurement of ambient noise		
Sensor	Maximum measurement	Used amplifier
BPW21R	0.104V	Transimpedance amplifier
BPW21R	0.015V	30x non-inverting amplifier
TEPT5600	2.960V	Transimpedance amplifier
TEPT5600	0.459V	30x non-inverting amplifier

Based on the above data, it was agreed to use the voltage gain sensor obtained by TEPT5600. In addition, a comparison with a non-inverting amplifier determined that although it is possible to obtain a response, it was determined that the response curve to the photocurrent of the sensor is linear, while the voltage characteristic is not, so it is impossible to amplify the current using this amplifier.

4.3 Characteristics of the sensor and emitter

After selecting the sensor TEPT5600, an experiment was developed in which we checked the amplification power of the optoelectronic signal received in the scan aperture, the range of the constructed circuit and the characteristics of the scan aperture

To make these measurements, it was decided to use factors such as distance in combination with ambient lighting to measure with an amplifier and put the system's motors to rest, using the principle of static triangulation directed towards the reflective object.

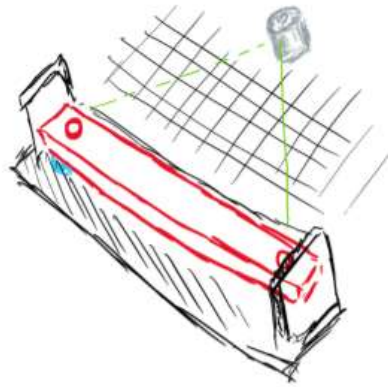


Figure 4.3 - Experimentation in a static triangulation configuration

Measurements were taken every 50 cm with the laboratory lighting on and off, using both a metal cylinder and a wall as a detection object (note that the wall was white). The mirrors and the scanning aperture were aligned to perform the measurements by directing the laser directly at the scanning aperture mirror and making sure that the light beam was completely in the center of the mirror. Measurements were performed by aligning the object in the center of the TV, directing the laser to the center of the object. This was adopted as a profile for measuring objects with the same configuration each time.



Figure 4.4 - Configuration of the positioning of the measurement object system in static triangulation

These measurements were obtained using a transimpedance amplifier, which directed two prototype mirrors manually on a metal cylinder and a white wall with a multimeter and with ambient lighting 1076 lux, obtained with a light meter. Tables

5.6 and 5.7 show the difference in measurements on the wall when the light is on and off, while 5.8 shows the measured ambient noise. It should be noted that in the above tables of measurements the increase in amplitude by more than 2 meters is present due to the fact that the scanning aperture is exposed to interference from ambient light at positions on the Z axis greater than 0 degrees.

A graphic example of this can be seen in Figure 4.5. Figures 4.6 and 4.7 graphically show a comparison of scanning aperture voltage measurements when measuring the reflection of two objects with artificial light interference in the laboratory and without interference, using a transimpedance amplifier.

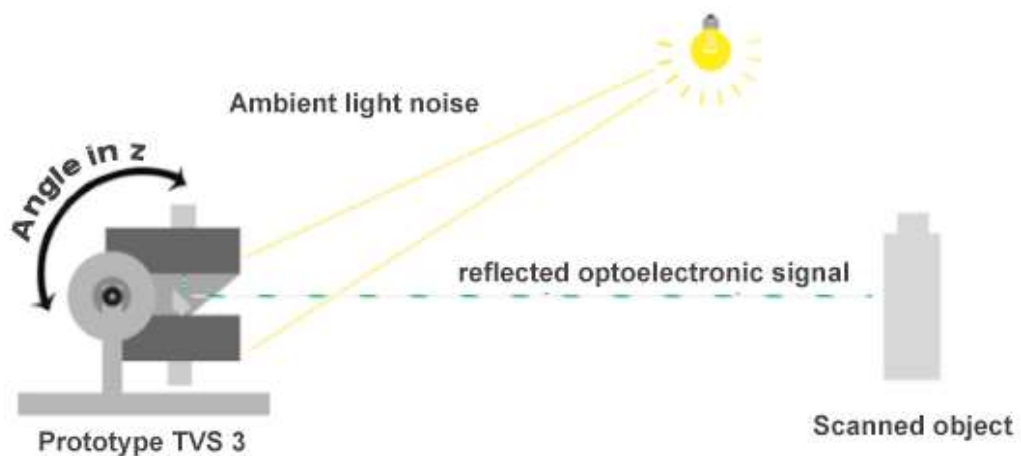


Figure 4.5 - Scan aperture is expanded to ambient light interference

Table 4.6 - Values using transimpedance, lights off

Values using transimpedance amplifier, lights off		
Condition	Maximum measurement (metal cylinder)	Maximum measurement (Wall)
0.5m	2.957V	1.517V
1m	2.804V	1.406V
1.5m	1.850V	1.2017
2m	1.532V	0.960V
2.5m	1.102V	0.975V
3m	0.850V	0.719V

Table 4.7 - Values using transimpedance, lights on

Values using transimpedance amplifier, lights off		
Condition	Maximum measurement (metal cylinder)	Maximum measurement (Wall)
0.5m	3.504V	2.502V
1m	3.523V	2.416V
1.5m	2.950V	2.179V
2m	2.552V	1.970V
2.5m	2.719V	2.857V
3m	2.652V	3.045V

Table 4.8 - Comparison of ambient noise (without laser light) using artificial light in the laboratory

Comparison of ambient noise (without laser light)	
Environmental noise status	Maximum measurement
Lab light on	1.695V
Lab light off	0.350V

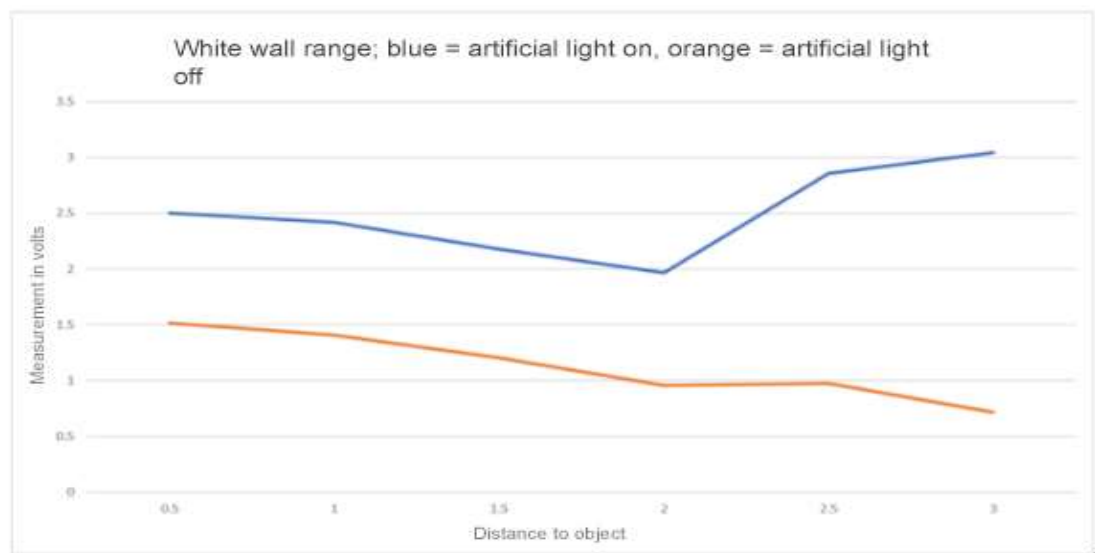


Figure 4.6 - Result comparison of transimpedance amplifier with laser light reflected in metal cylinder when interference laboratory light is on and off as shown in tables

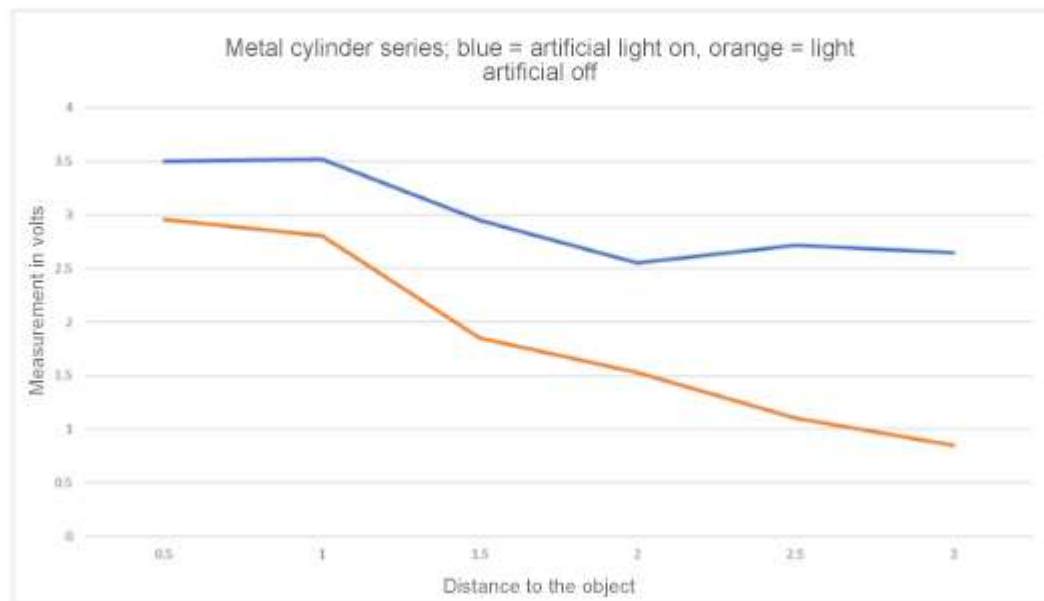


Figure 4.7 - Comparison of the transimpedance amplifier with laser light reflected in a metal cylinder when the interference light is turned on and off, as shown in tables

4.4 Laser scanning and data collection experiment

Scanning an object requires the combined use of two systems. The laser positioner's DC motor control system and the z-axis positioner, to position the laser every number of degrees on the object relative to the TVS laser positioner and to maintain the stability of the z-axis angular position. These signals were captured by an Arduino Mega microcontroller, which is used to control a motor designed to scan aperture at a constant speed by receiving a command from a computer using each new pulse of a rotary encoder to store 200 units of data in an array in memory. Memory, which will later be sent to the computer system (example in Figure 4.8). The data stored is the speed, the angle at which the scan aperture was at that time, and the readings obtained from the sensor using the internal ADC of the microcontroller.

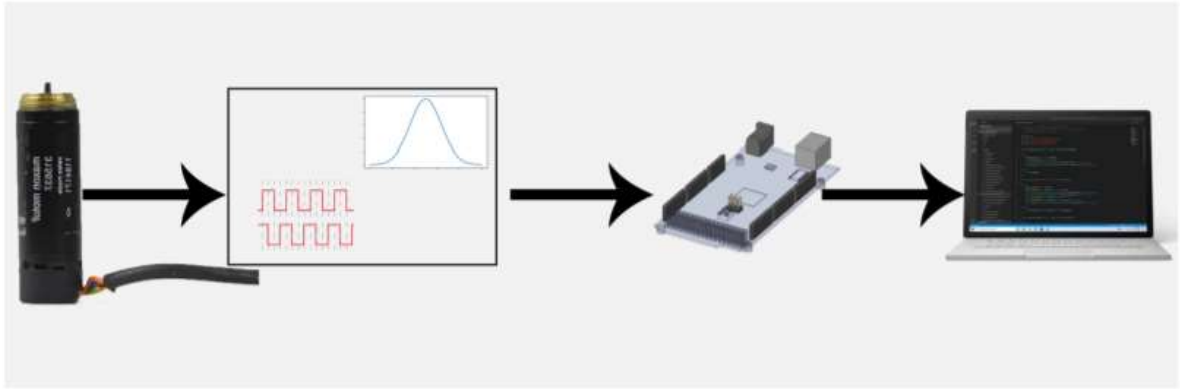


Figure 4.8 - Obtaining Gaussian signal

These measurements are transmitted to the computer equipment via a serial connection at the end of the data collection. Only then to change the angle indicated by the laser positioner and start collecting new data.

The next section shows a series of steps that are involved in collecting data during a scan and how they are stored before processing to obtain the distance and angle to the object being measured.

As mentioned above, the scan aperture must be moved at a constant speed to scan objects. For these purposes, there was an interface program developed that simultaneously collects information from each point for further processing. This tool, programmed in C, uses a client server to send packets over UDP with a series of coordinates to a modified DC motor control interface to obtain as a command a series of angles at which the laser positioner should move. These angles are predefined by the user, as well as the area or scanning section. Once the laser is installed, the angle increases by a predetermined value after receiving confirmation from the motor control interface that the laser positioner has been positioned correctly.

In the following figure 4.9 to figure 4.14, you can see part of the laser path above the object, along with the scanning aperture of the oscilloscope. The signal from the amplifier can be seen in Figure 4.10, while the aperture does not receive an optoelectronic signal due to the position of the laser on the object, as shown in 4.9. The peak signal can be clearly seen in Figure 4.13 and Figure 4.14 when the signal at

the scan aperture does not receive a signal from the laser. Figure 4.12 shows the midpoint of the signal, and 4.13 shows the position of the laser.



Figure 4.9 - Angle laser positioner 1

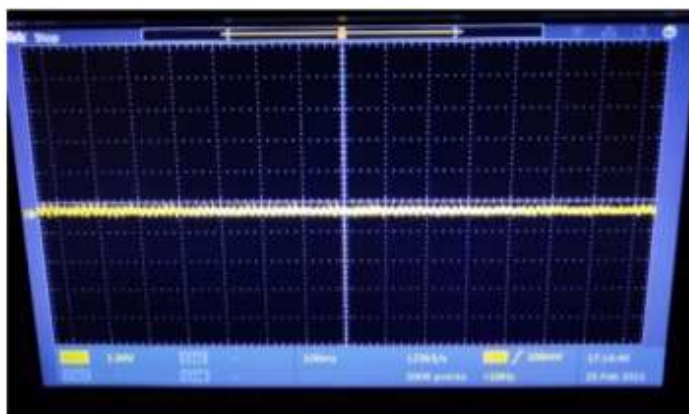


Figure 4.10 - Signal Laser Scan 1



Figure 4.11 - Angle laser positioner 2

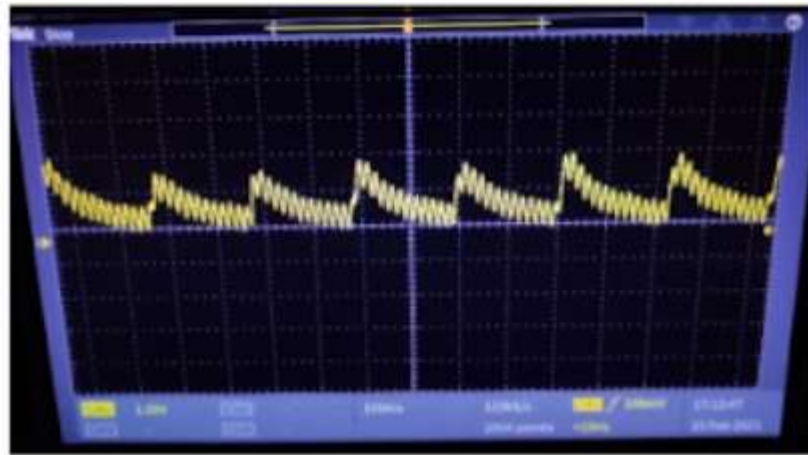


Figure 4.12 - Signal Laser Scan 2



Figure 4.13 - Angle laser positioner 3

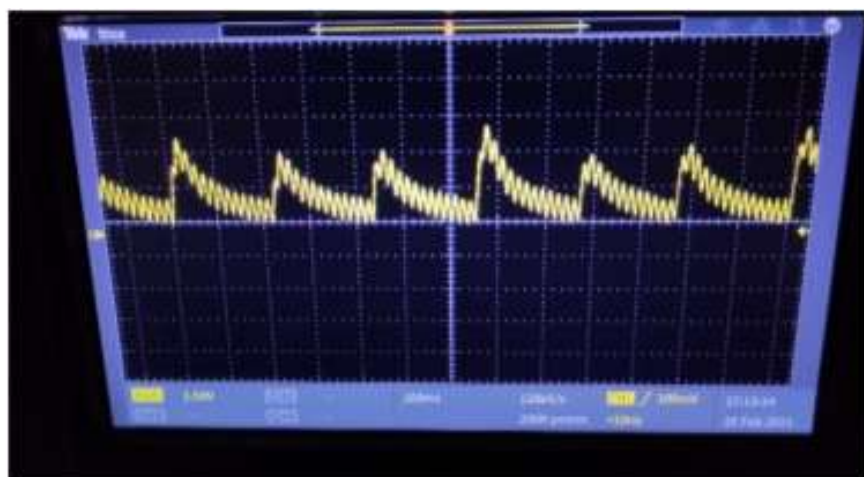


Figure 4.14 - Signal Laser Scan 3

After receiving confirmation from the DC motor control interface, the tool uses commands to automatically ask the microcontroller to save the data. When saving data, the microcontroller responds with a string of characters to then automatically go to the next view or, if desired, when you click next in the control interface. This data is stored using a user-defined prefix together with the current laser positioner angle and other useful data collected, including the scan aperture angle for each measurement, the scan aperture speed, and the ADC measurement. This data is then stored together with the angle information from the laser positioner.

Figure 4.15 shows the configured parameters of the data storage interface, which includes the serial port parameters, the prefix with which the data will be stored, the area in front of the TVS system to be scanned, and the number of degrees the laser positioner must move each time the measurement is completed. For location automation purposes, a coordinate reception section has been added to LabView in the control interface, using the UDP receiver structure and status change signaling.

After receiving new data, the motor controller uses this information to create a new trajectory and initiate movement. Upon successful completion, the motor control path activates the command to stop the motor, and uses the UDP transmitter to send a signal to the storage equipment so that it generates a data scan file at this angle and returns instructions to move the laser to the next scheduled point.

The screenshot shows a software interface with the following elements:

- Prefijo:** cm200pmcada01gradps102cap
- Escanear de:** 52 A 60
- Cada:** 0.05 Grados
- Buttons:** Detener, Empezar
- Serial Port Settings:**
 - Port Name: COM3
 - Baud Rate: 19200
 - Data Bits: 8
 - Parity: None
 - Stop Bits: One
- Grados:** 322.8
- IP:** 192.168.43.199
- Buttons:** Log, Report, Start
- Recibido:** Client:OK#322.800000
- Enviar:** 322.8
- Buttons:** Enviar, Guardar, Next (highlighted)
- Buttons:** Start listening, Stop listening
- Text Area:**

```

value 185 = 755.00
value 186 = 1023.00
value 187 = 813.00
value 188 = 818.00
value 189 = 1023.00
value 190 = 859.00
value 191 = 745.00
value 192 = 873.00
value 193 = 1023.00
value 194 = 1018.00
value 195 = 857.00
value 196 = 766.00
value 197 = 772.00
value 198 = 1023.00
value 199 = 1007.00
speed220.00 PWM: 29.40 Ang: 101.25?? 2483.00

```

Figure 4.15 - Interface options

4.5 Analysis of interference signals in measurements

After receiving the first sets of measurements, it was found that the power and control phase of the motors integrated into the system create interference, so the TVS prototype housing redirects these signals to the light sensor, controllers and the table itself. This causes one of the two signals to oscillate uncontrollably, as shown in Figure 4.16.



Figure 4.16 - Unusable measurement due to noise.

In order to receive a useful signal from the amplifier, physical grounding was added to the main body of the TVS prototype, which also served as a necessary safety measure. When repeating the measurements, we obtained the results that show behavior closer to the expected measurements.

In addition to the amplifier and modifications of the prototype body, we developed a computer program to implement algorithms for additional scan data filtering. One of the filtering algorithms is to use the Savitsky-Goley filter, which is based on the calculation of local polynomial regression (degree k) with at least $k + 1$ points with an interval to determine the new value of each point. The main advantage of this method is its tendency to maintain the characteristics of the initial distribution, such as relative highs and lows, as well as the width of the peaks, which usually disappear with other methods (e.g. shifted average). figure 4.17. The main advantage of this method is its tendency to shift the peak of the signal, as shown in 4.18. Both digits represent data sets filtered using 2 points located between a polynomial of the first degree, against one that's unfiltered.

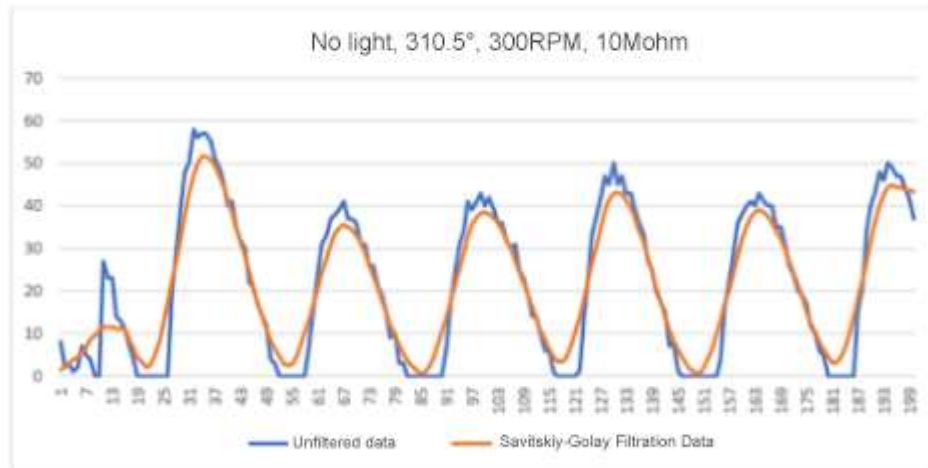


Figure 4.17 - Savitzky-Golay filter. No light, 300 rpm

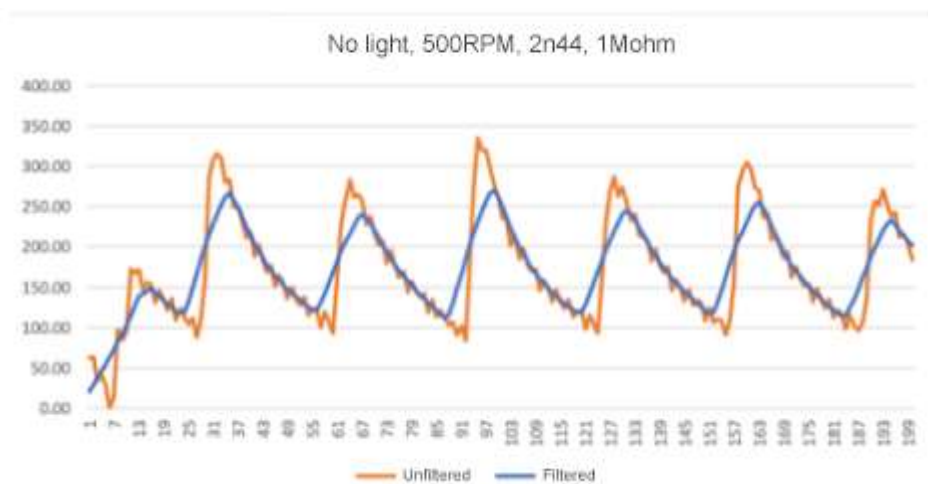


Figure 4.18 - Savitzky-Golay filter. No light, 500 rpm

In addition, a low-pass filter has been built in, which is a filter that allows signals of a certain frequency to be passed, in addition to attenuating signals with a frequency above a given value. It goes without saying that the exact reaction frequency of the filter depends on the specific design of the filter. Figure 4.19 shows the filtering of one of the scan signals using a step frequency of 200 Hz, a sampling frequency of 1000 and a slope of 0.5.

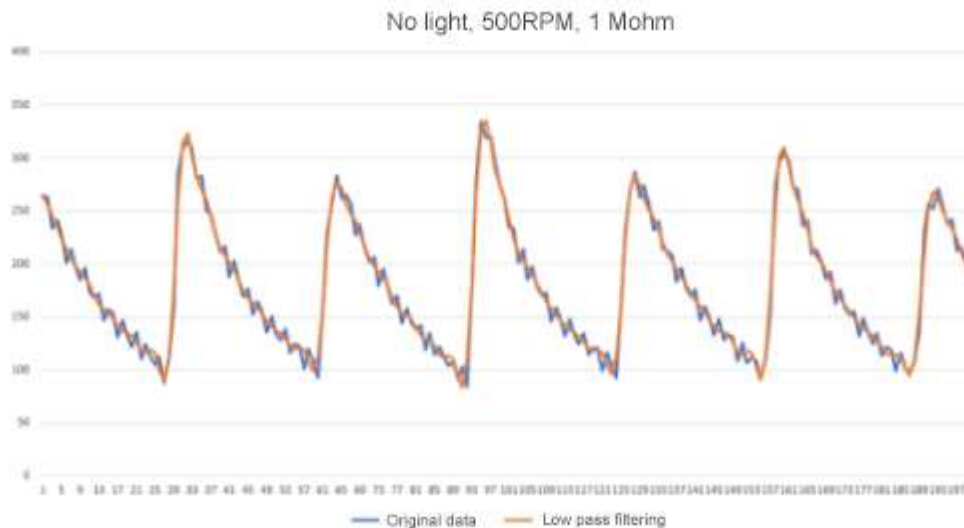


Figure 4.19 - Low pass filter, No light, 500 rpm

After the dataset signal has been filtered, we use scenario C, where the dataset points are compared with the following and previous points, and a list of probable signal peaks is being generated. This process is repeated until the list can't be further reduced. The resulting points are considered signal peaks and are presented as a console output that can be easily adapted to another application for integration with other parts of the triangulation process.

4.6 Triangulation and visualisation of objects

To triangulate and display objects, in particular, you need to use the data obtained in the filter, using points defined as signal peaks, to then obtain the scan aperture angle stored with scan information and the angle of the laser positioner, also stored with information to use triangulation equations and this allows us to find a point in 3D and the distance to the object that will be added to the memory record to build a 3d cloud of points. This section discusses the generation of these 3D points and the measurement of distances to the TVS system, a series of steps performed by an automated program, and the calculation of individual points using triangulation equations.

The following are the results of data collected by automatically scanning the angles of a metal cylindrical object using various factors to change the behavior of the system. Measurements were made from this object every 0.1 degree to create a cloud of dots, while the scanning aperture was rotated clockwise or counterclockwise at 300 rpm or 500 rpm. For verification purposes, we took the point with the highest intensity, and for simplicity in the amount of displayed data, each full cycle or rotation of the scan aperture was divided into 6 shots of 32 spaces out of 200 units of data stored in memory and used in central scanning. This number of samples or reserved memory locations can be changed in the software.

The following configuration corresponds to the object in the form of a cylinder made of metallic material and is shown in table 4.9.

Table 4.9 - Factors used in experimentation

Table of experimentation factors.	
Measured effect	Effect status
Light in laboratory	Light off
Voltage in photosensor	5V
Resistor for amplifier	1 M Ohm
Scan aperture speed	300 rpm
Scanned Object Distance	25 cm
Direction of rotation of SA	clockwise

Figure 4.20 shows a graphical representation of the data obtained during this scan (data obtained directly from the ADC of the microcontroller, yellow, data obtained using Savitsky-Goley filtering is blue while the orange shows the angle at which the scan aperture is located at each point scan), and table 5.10 shows the values:

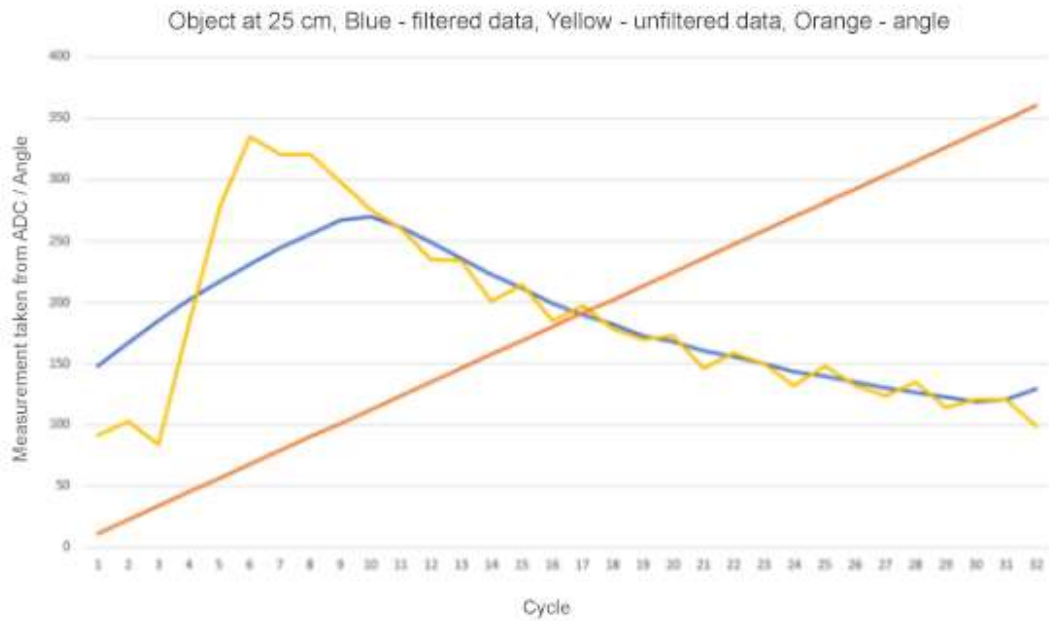


Figure 4.20 - 25 cm object sweep graph.

Table 4.10 - Data table

SA Angle (Degrees)	Measurement (ADC Log)	Speed (rpm)
11.25	91	320
22.5	103	320
33.75	84	320
202.45	181	320
56.25	278	300
67.5	335	300
78.75	320	300
90	320	300
101.25	298	300
112.5	276	300
123.75	261	300
135	235	300
146.25	234	300
157.5	201	300
168.75	214	300

180	185	300
191.25	197	300
202.5	178	300
213.75	170	300
225	173	300
236.25	146	300
247.5	159	300
258.75	150	300
270	132	300
281.25	148	300
292.5	132	300
303.75	124	300
315	135	300
326.25	114	300
337.5	121	300
348.75	121	300
360	99	300

It is determined that the signal peak coincides with 67.5 degrees in SA and 31 degrees in the laser positioner. Next we determined that the distance to the object was 24.05 cm.

The following configuration corresponds to the object in the form of a cylinder made of metallic material and is shown in table 4.11:

Table 4.11 - Factors used in experimentation.

Table of experimentation factors.	
Measured effect	Effect status
Light in laboratory	Light off
Voltage in photosensor	5V
Resistor for amplifier	1 M Ohm
Scan aperture speed	300 rpm
Scanned Object Distance	30 cm
Direction of rotation of SA	clockwise

Figure 4.21 shows a graphical representation of the data obtained in this scan (data obtained directly from the ADC of the microcontroller is blue, and the orange row shows the angle at which the scan aperture is at each point of the scan), and table 4.12 shows the values:

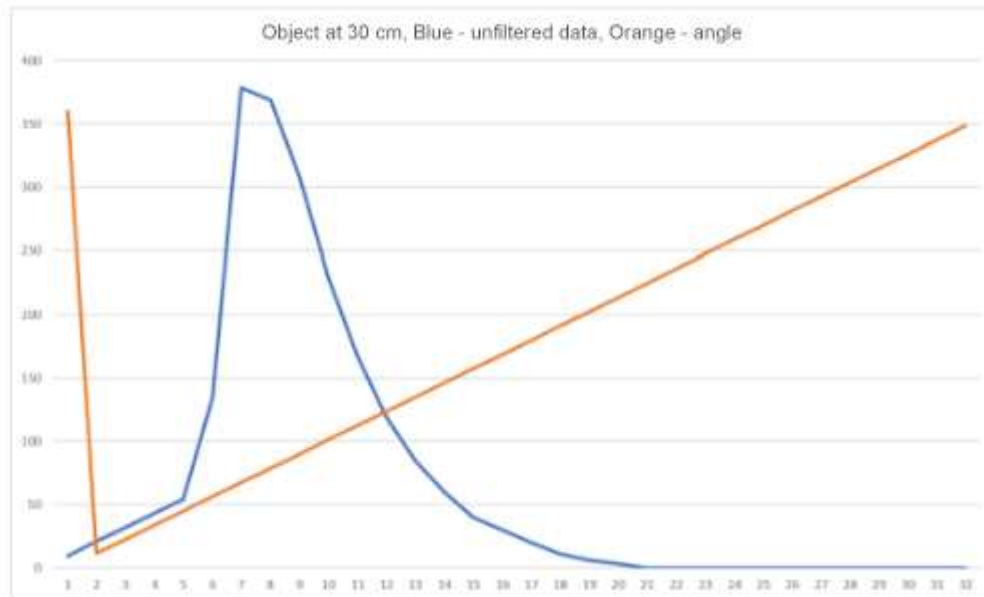


Figure 4.21 - Object sweep graph 30 cm

Table 4.12 - Data table

SA Angle (Degrees)	Measurement (ADC integer)	Speed (rpm)
360	9	260
11.25	21	260
225	32	260
33.75	43	260
45	54	260
56.25	135	260
67.5	379	260
178.75	369	260
90	308	260
101.25	230	260
112.5	167	260
123.75	119	260
135	85	260
146.25	60	260
157.5	40	260
168.75	30	260
180	20	260
191.25	11	260
202.5	6	260
213.75	3	260
225	0	260
236.25	0	260
247.5	0	260
258.75	0	340
270	0	340
281.25	0	340
292.5	0	340

303.75	0	340
315	0	340
326.25	0	340
337.5	0	340
348.7	0	340

It is determined that the signal peak coincides with 67.5 degrees in SA and 40 degrees in the laser positioner. Next, (7) determined that the distance to the object is 31.13 cm.

The following configuration corresponds to the object in the form of a cylinder made of metallic material and is shown in table 4.13:

Table 4.13 - Factors used in experimentation

Table of experimentation factors.	
Measured effect	Effect status
Light in laboratory	Light off
Voltage in photosensor	5V
Resistor for amplifier	1 M Ohm
Scan aperture speed	300 rpm
Scanned Object Distance	10 cm
Direction of rotation of SA	counter-clockwise

Figure 4.22 shows a graphical representation of the data obtained during this scan (data obtained directly from the ADC of the microcontroller are yellow, data obtained by applying Savitsky-Goley filtering is blue, and the orange row shows the angle at which the scan aperture is located.) And table 4.14 shows the values:

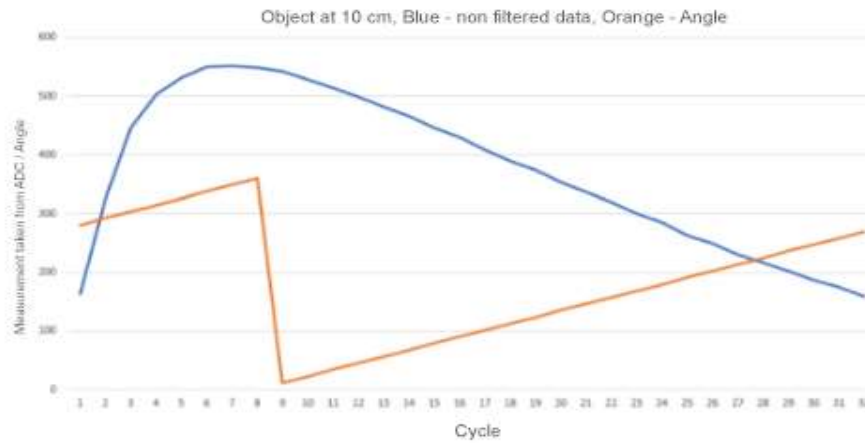


Figure 4.22 - 10 cm object sweep graph

Table 5.14 - Data table

SA Angle (Degrees)	Measurement (ADC integer)	Speed (rpm)
78.75	164	300.00
67.5	323	300.00
56.25	446	300.00
45	103	300.00
33.75	532	300.00
22.5	550	300.00
11.25	552	300.00
348.75	549	280.00
337.5	543	300.00
326.25	529	300.00
315	515	300.00
303.75	499	300.00
292.5	481	300.00
281.25	466	300.00
270	446	300.00
258.75	430	300.00

247.5	408	300.00
236.25	389	300.00
225	374	300.00
213.75	354	300.00
202.5	336	280.00
258.75	319	280.00
191.25	300	280.00
180	285	320.00
168.75	264	320.00
157.5	249	320.00
146.25	231	320.00
135	216	320.00
123.75	203	320.00
112.5	187	320.00
101.25	175	320.00
90	159	320.00

It was determined that the peak of the signal coincides with 11.25 degrees in SA and 70.6 degrees in the laser positioner. Next, we determined that the distance to the object is 9.69 cm.

The following configuration corresponds to the object in the form of a cylinder made of metallic material and is shown in table 4.15:

Table 4.15 - Factors used in experimentation

Table of experimentation factors.	
Measured effect	Effect status
Light in laboratory	Light off
Voltage in photosensor	5V
Resistor for amplifier	10 M Ohm
Scan aperture speed	300 rpm
Scanned Object Distance	65 cm
Direction of rotation of SA	clockwise

Figure 4.23 shows a graphical representation of the data obtained during this scan (data obtained directly from the ADC of the microcontroller are yellow, data of the blue series using Savitsky-Goley filtering and orange series show the angle, under which the scan aperture is located.) and table 4.16 show the values:



Figure 4.23 - 65 cm object sweep graph

Table 4.16 - Data table

SA Angle (Degrees)	Measurement (ADC integer)	Speed (rpm)
22.5	91	280.00

33.75	109	280.00
45	154	280.00
56.25	274	280.00
67.5	296	280.00
78.75	305	280.00
90	297	280.00
101.25	273	280.00
112.5	270	280.00
123.75	236	300.00
135	241	300.00
146.25	200	300.00
157.5	213	300.00
168.75	201	300.00
180	186	300.00
191.25	193	300.00
202.5	163	300.00
213.75	176	300.00
225	160	300.00
236.25	152	300.00
247.5	155	300.00
258.75	132	300.00
270	149	300.00
281.25	136	300.00
292.5	124	300.00
303.75	135	320.00
315	113	320.00
326.25	122	320.00
337.5	118	320.00

348.75	99	320.00
360	116	320.00
11.25	102	300.00

It was determined that the peak of the signal coincides with 78.75 degrees in SA and 59.4 degrees in the laser positioner. Next it was determined that the distance to the object is 4.26 cm

CONCLUSIONS

In addition to the above, the use of a transimpedance amplifier had an effect on the sensitivity range of the system in the prototype, where it was used to significantly expand compared to previous prototypes. Using a low-level program can be recommended for subjects who need a quick scan of their faces, while a scan that lasts longer can be used in situations where an additional sensitivity range is important. A novelty used in this field with a transimpedance amplifier is the acquired ability to obtain information about the energy distribution of scanned objects, it is clear that the study of this new information can be branched into several studies. Possibilities for future work may include analyzing this energy distribution information, which can provide information such as the texture of the object, the material from which it is made, and the color of its surface, as well as advanced methods for detecting energy centers and signal peaks.

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