UNIVERSITY "POLITEHNICA" of BUCHAREST
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DOCTORAL THESIS

Studiul şi perfecţionarea unui sistem optomecatronic de măsurare şi testare oculară
Research and Development of an Optomechatronic System for Eye Measurement and Testing

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1.INTRODUCTION. THESIS OBJECTIVES.

Ophthalmic Optometry is the science that deals with investigating the functioning of the human visual system. It analyzes the results, highlights the problems, and recommends methods and means to improve the visual system's functioning to obtain comfort in relation to the subject's needs, but without medical treatment, if possible.

Functional Optometry is a new orientation of ophthalmic optometry that considers the individual as an integral part of the environment in which he lives and systematizes from this point of view the analysis of performances and the synthesis of visual problems. [1]

The technology in the ophthalmology field is constantly developing and besides the laser operations performed on the eyeball, special constructions of personalized progressive lenses have been developed, created especially according to the measurements of the individual parameters of the patient. To perform these measurements, which are necessary for people with major facial asymmetries, measuring devices, stationary units and mobile units are built, that by capturing images and processing them, lead to very accurate measurement results.

The main objective of the thesis is the conception and realization of a mechatronic system for testing the visual function, which will have the function of placing in the workspace a tablet that measures and calculates the individual optometric parameters of the patient.

With this device, the pupil projections of the patient will be determined and measured for three specific working distances - reading, working on the laptop, respectively monitor (350 mm, 450 mm, 650 mm), with the patient sitting on the chair and capturing images in his position activity. The measurements of pupillary projections will be determined according to the patient's position and his gaze through the lens. ***This system will be able to be used in the field of optometry,*** and in medical offices, ***to facilitate and improve the measurements performed to determine the parameters*** necessary to process the raw material to ***manufacture personalized progressive lenses.***

1.1.Statistical studies on vision defects incidence in various categories of population

The frequency of eye diseases has a high growth rate nowadays. Humans will experience at least one eye condition in their lifetime. Around the globe, almost 2.3 billion people have visual impairments, of which 1 billion, near or far, the impairments can be prevented if they are detected early.

1.2.Visual impairments – existing ametropias and their development among the population, mainly due to digitalization

According to a WHO study, the prevalence of myopia in 2020 was 33.0% globally, which is expected to increase to 52.0% by 2050.

1.3.The importance of measuring individual optometric parameters, anatomical-physiological particularities with impact in optometry and the justification of the need to know the patient's physiognomy

The maximum visual performance achieved by a patient is due to the methods and means of measuring the optometric parameters. In recent years, more and more emphasis has been placed on the exact measurements of individual parameters depending on the predominant activity performed by the patient in a working day. All these asymmetries, which are frequently found in the physiognomy of patients, must be taken into account to build a pair of glasses suitable for their needs.

1.4.The complexity of the optometric act, the evolution of the lens and test method

The optometrist is the one who measures the patient's refraction to prescribe the appropriate lenses and the doctor is the one who deals with the pathology. Patient requirements are increasingly demanding and the desire for a clear view at all working distances is very important. The demands of eyeglass wearers have changed and eyeglass lens manufacturers support this change by developing methods and visual solutions that are adapted to the modern patient.

1.5.Thesis objectives

The main objective pursued in the thesis is to make the ***most accurate measurements of the client's optometric parameters.*** For this, the next ***objective*** was the ***design and construction of an optomechatronic device for positioning a tablet in space, to capture images of the patient.*** These parameters help in the construction of custom, high-performance progressive lenses. ***High accuracy and repeatability of the measurement results***, when using the optomechatronic device that positions the tablet to capture images, at fixed working distances, were followed and demonstrated in the experiments performed. The "seated" position is a real working position at the laptop and monitor, and the optomechatronic device is a real help, precisely determining the positions of the patient's pupils, under specific working conditions**.**

1.6.Brief description of the thesis chapters content

The thesis consists of seven chapters, a bibliography, and appendices. **The first chapter** of the thesis brings to attention the increasing incidence of vision problems among the population, which appear from an ever younger age. In recent years, due to the pandemic, the population has been forced to work more with digital devices, forcing vision due to short working distances. In the **second chapter** of the thesis, the optometric parameters of the patient are described, which are determined by processing his image with a software, for example EyeFit, to be introduced in the construction of the progressive lens, more precisely in the calculation of power deposition on the surface of the lens. Practical tests show that the most problematic situations of blurred vision with the progressive lens are in the near and semi-distance area. The practice has revealed the fact that the correct position of the patient is essential when capturing the close-up images, to construct the progressive lenses - namely the "chair" position, used in a very large proportion (90% of cases), in office work.

Chapter three demonstrates the need for devices to measure the patient's optometric parameters. The current devices for measurements are fixed or mobile units (the tablet), which include a software for calculating and processing the captured images, which have excellent results for distance vision, but numerous shortcomings for near and semi-distance, generated by "hand-held" handling ” of the tablet, specific to both mobile and fixed units. As such, the solution proposed in the thesis is the development of an optomechatronic device for positioning the tablet at well-defined working distances, in relation to the patient, to improve the measurement results. The design and construction of the optomechatronic device are described in the **fourth chapter** of the thesis. It ensures the positioning of the tablet, which has three degrees of freedom, through a horizontal translation movement, a vertical translation movement, and a rotation movement, which tilts the tablet to specific angles for reading, working on the laptop and monitor. The coordinates of the working positions are personalized, in relation to the height of the patient, respecting the ergonomic recommendations for the three activities, which involve near and semi-distance vision. In the **fifth chapter**, the procedures for measuring the optometric parameters with the current method and the additional actions of the proposed method are presented, to expand the capabilities of the EYE FIT system, for determining the optometric parameters for semi-distance and near, with the use of the optomechatronic device made. In the absence of knowledge about the algorithms used in the EYE FIT program (registered trademark), a mathematical model was developed, based on the calibration of the tablet's front camera, equivalent to an infinitely thin optical system. This model gave satisfaction, being tested with the author's optometric data. **Chapter six** presents the experimentation of the device, through measurements performed with and without it on several patients, including the author, respectively with several different devices located in optical offices (Zeiss, Essilor, Hoya). The results of personal measurements varied, which is why another instrument was used for their determination (ruler, roulette, caliper, digital pupil dismeter). I tested the optomechatronic device to correctly determine the working distances and checked on the mannequin (mannequin head on which markers were glued at distances measured with the caliper) their correctness. The comparison of the results showed the effectiveness and superiority of the optomechatronic device through its repeatability. Several patients were tested and the results were analyzed, the differences are obvious. The optomechatronic device positions the tablet more correctly to capture the patient's images, the tables in which the obtained values are introduced highlight this thing.

In chapter seven the conclusions are clear, the optomechatronic device for positioning the tablet in space makes the captured images more correct, the software processes more precisely and the result is superior to the measurements made without the device.

2. PREREQUISITE REQUIREMENTS FOR MEASURING PATIENT PARAMETERS

The individual parameters of the patient (figure 2.1) must be measured for good positioning of the optical centers of the lens, so that the movements of the eyeballs are perfectly correlated with them - for clear vision.

The new eye and frame system must be adjusted so that the patient has maximum comfort and clarity of the viewed image. For people who have facial asymmetries outside the "standard" area, adjustments must be made to both the glasses frame and the lens construction. All these individual parameters are used in the construction of the progressive lens to customize it:

2.1. Pupillary distance

Pupillary distance or interpupillary distance, measured in millimeters, is the distance between the centers of the pupils of the eyes and is used in the prescription of glasses.

2.2. Vertex distance

The vertex distance is known as the distance between the cornea and the back surface of the lens and is the parameter needed to determine the movement of the eyes behind the lens and optimize the areas with adequate power for a clear image.

2.3. Convergence

Convergence, a very important parameter of each person, is described by the movement of the eyeball around its center of rotation. This movement of the eyeball occurs when the gaze descends from infinity to near. When we read or work at a short distance, the convergence is maximum, the pupils come closer to the nose.

2.4. Spectacle frame parameters

The frame is very important and is part of the patient's visual system. The frame will have to be chosen according to the physiognomy, the material from which it is made, and according to the lens that will be fixed in the mount. In the construction of personalized progressive lenses, these constructive parameters are taken into account, as well as the following parameters for the final positioning of the frame:

2.4.1. Pantoscopic Angle

The pantoscopic angle is the angle determined by the plane of the lens, perpendicular to the optical axis of the view at infinity. This angle has a standard size of 8 degrees.

2.4.2. The frame curvature angle

This angle is described by the radius of curvature of the two annuaries of the frame. In the predominantly used eyeglass frames, this angle has a small value, between 0 - 15 degrees.

2.5. Patient visual problem

It is characteristic of visual reception that the eye has a visual sensation only for a limited spectral range, namely, approximately, for radiation with a wavelength of 400 nm - 700 nm. Only that part of the radiant energy received by the eye is called visible energy, or light (in the usual sense of the word).

2.5.1. Emmetrope eye (normal eye)

2.5.2. Ametropic eye

A). Myopia; B). Hypermetropia; C). Astigmatism; D). Presbytism

2.5.3. Compensation of spherical ametropia

For the ametropic, myopic, or hyperopic eye to clearly see an object point from infinity without accommodation, it must use an aerial compensatory or contact lens.

A). Myopia compensation;

B). Hypermetropia compensation;

C). Astigmatism compensation.

2.6. The problem of adapting the patient to the progressive lens

The progressive lens is the most performing lens, it offers the possibility of clear vision at all distances and can be built with the individual parameters of the patient, determined from images captured and processed with software like Eye Fit. The height of the progression channel is built according to the movement of the eyeball, varying from the distance vision axis to the near vision axis. This channel is built in 1 mm increments, starting from 12 mm

to 19 mm. To see clearly at a distance ($8000 - 10000\ mm$), one must look through the upper part of the lens, where the necessary power is built, through the middle area of the lens one can clearly see objects at half distance and through the lower area of the lens can clearly distinguish close objects ($300 - 400\ mm$)[30],[31].

A). Peripheral vision - Perception of movement

B). Binocular vision - Fusion motor - Sensorial fusion

C). Foveal vision - Eye accommodation, posture and movement - Eye and head movement - Visual acuity

2.7. Specific optical requirements of a progressive lens

The optical characteristics of a progressive lens are defined by the physiology and postural behavior of the user, as determined by clinical experiments. They can be divided into two categories:

- characteristics that must respect the strictly determined values;
- characteristics that should be kept below the given limits;

A). The requirements of the progressive power

B). Visual perception requirements - Custom progressive lenses

Due to the small deviations accepted when fitting progressive lenses compared to the rest of the lenses, a precise measurement is indispensable for fitting this type of glasses [45].

Progressive glasses for the near and semi-distance area are used in more than 90% of cases in the "chair" position:

- Accounting - works in the office - position "on the chair"
- Administration – General Directorate of Local Taxes, City Hall, Taxes and Fees, etc. - position "on the chair"
- Education - works at the desk - position "on the chair"
- IT - works on the computer - position "on the chair"
- Library / Registry office - reading/writing - position "on the chair"

The near area of progressive glasses is mainly used while sitting on a chair at the following distances:

- For reading and writing $\sim 350\ mm$
- For laptop use $\sim 500\ mm$
- For computer use $\sim 650\ mm$

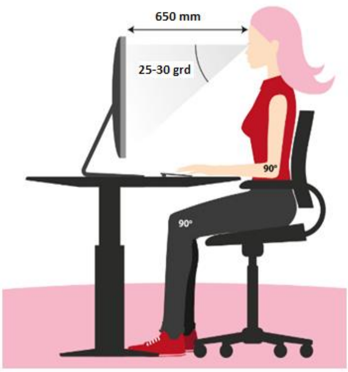


Fig.2.28. Correct posture and distance for office work [46]

The effort to view the monitor, when it is placed incorrectly in relation to the operator's position, results in postural discomfort, possibly accompanied by pain. The correctness of the working position is determined by two factors: the viewing angle and the viewing distance. Viewing distance refers to the space between the operator's eyes and the screen, according to figure 2.28 [48]. The existing guidelines and recommendations, both regarding the viewing angle and, in particular, the viewing distance differ, sometimes significantly, depending on the device being worked on (laptop - smaller distance $\sim 450\ mm$ or monitor - larger distance $\sim 650\ mm$). Researchers agree that, at rest, the eyes naturally assume a direct and downward line of sight, which subtends, according to experimental determinations, an angle varying from about 15^o to nearly 30^o. Accommodation and convergence are the two main functions that govern the viewing of objects at closer distances. The eyes have a default distance of accommodation called the Rest Point of Accommodation (RPA) and a default Rest Point of Vergence (RPV). In practical terms, at distances greater than RPA and RPV, neither accommodation nor convergence is needed. Under these conditions, people with perfect vision $(20/20)$ or those with properly corrected vision are not likely to suffer from eye strain (assuming they take adequate "rest breaks" to focus on the screen) [49],[50]

The numerical values of RPA, about $76\ cm\ (\sim 30\ inches)$ and RPV about $81\ cm\ (\sim 32\ inches)$ are close, which makes it quite simple to establish the correct viewing distance. The viewing range from $40\ cm$ to $70\ cm$ (approximately $15 - 27\ inches$) provides visual comfort for most computer users, both laptop and monitor.

3. METHODS AND DEVICES FOR MEASURING AND EVALUATING PATIENT PARAMETERS

In the course of time, we wanted the measurements of the patient's antopometric parameters to be as accurate as possible. This means a very precise construction of the glasses and of course maximum comfort for the wearer.

The newest and most accurate methods of measuring individual parameters are those that use the image processing method for their determination.

Fixed systems, such as e-COLUMN in figure 3.14 and i.Terminal 2 in figure 3.15, offer a much better measurement precision because they eliminate errors due to improper positioning of the patient in relation to the camera that will take the picture of his face.

By using these systems, all the parameters necessary for the construction of glasses with progressive lenses can be measured, with a precision of a tenth of a millimeter and a calculation time of only 20 seconds. On average, this method is up to 60% faster than manual measurement procedures and 84% more accurate [57].

Fig.3.14. Fixed measuring device e-COLUMN that uses image processing [57]

The fixed system offered by Zeiss has the following advantages [58]:

- allows to measure the parameters of patients with high ametropia;
- can be used with any type of frame;
- good automatic focus, which reduces errors due to improper positioning of the patient in relation to the system;
- height adjustment of the system so that it can be positioned according to the height of the patient.

Fig.3.15. Fixed measurement system - i.Terminal 2 [58]

The fixed measurement systems use to capture the image of the patient up close, a tablet connected with a USB cable to the fixed unit. A test text appears on it, to fix the gaze and produce the convergence of the patient's eyes.

Another measurement system is the one developed by Hoya under the name of VisuReal (figure 3.17), which is located on a mobile device (tablet). The tablet is easier to handle by the optician in the office and makes precise measurements and faster calculations.

Fig.3.17. VisuReal portable system [59]

Thus, due to the increased computing power of the processors built into tablets, these measurements can be made just as accurately with a tablet on which dedicated software is installed. The first measurement is made from 65 cm in front of the patient, with the tablet placed parallel to him, after which a few more images are acquired, in order to determine all the individual parameters.

3.1. Signal acquisition and processing systems

Grouping signals from various measurement sources and digitizing them so that they can be analyzed, stored and presented on a computer, means data acquisition (DAQ). Researchers and engineers can choose from a variety of PCI, PXI, PCMCIA, USB, IEEE 1394, PCI Express, PXI Express, serial ports, parallel ports for data acquisition in automation, test and measurement applications [47]. There are five components to consider when building a basic DAQ system: ***Transducer; DAQ hardware; the Software; Corresponding driver applications; Programming***

3.2. The existing solution, subject of the proposed improvement

For images acquisitions to be processed, EYE FIT program was used, developed in the JAVA language, which only works on tablets with ANDROID operating system. It is installed on a SAMSUNG Galaxy Note SM-P600 tablet (figure 3.23) with the following characteristics:

- Screen diagonal: 25.6 cm (10.1"); screen resolution: 2560 x 1600 $pixels$;
- Internal storage capacity: 16 GB; processor frequency: 1.9 GHz, RAM memory: 3 GB;
- Main camera resolution (digital): 8 MP; rear camera type: single camera, (3264 x 2448 pixels).
- Front camera resolution (digital): 2 MP, front camera type: single camera.
- Highest Wi-Fi standard: Wi-Fi 5 (802.11ac), assisted GPS (A-GPS).
- Integrated card reader; weight: 540 g.
- Installed operating system: Android.

Fig.3.23. Samsung Galaxy Note SM – P600 tablet with Eye Fit software.

The lens of the camera attached to the tablet is the first element through which the light rays pass to capture and form the image on the photosensitive sensor matrix, in order to process it with the Eye Fit software. Being a constructive element of the optical subassembly, assimilated with a lens, it is considered to be bathed in air, regardless of its situation in the subassembly of which it is a part, because it will be processed and checked in air.

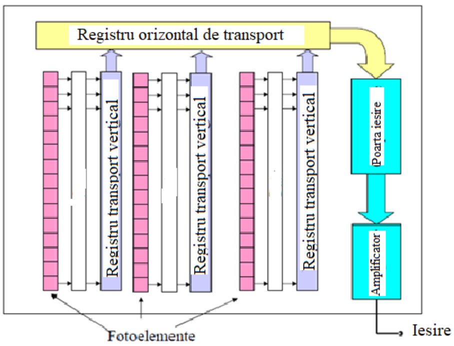


Fig.3.27. CCD sensor [64]

The CCD (Charge Coupled Device) is the most widespread image sensor, being present in almost all imaging devices. It is made two-dimensionally, from a constructive point of view, being made up of cells that can accumulate electric charges, proportional to the duration and intensity of the light radiation.

3.3. Image analysis and processing software

For the correct determination of the measurement results, the image capture on which the processing is to be performed must be extremely clear. The measurement of the parameters is carried out by converting the pixels that make up the image into units of length [mm]. Captured images cannot be perfect due to external factors that influence their clarity, namely lighting, incorrect positioning, patient cooperation, device camera, etc.

To avoid this problem, the captured images are sometimes processed (converted), using image filters according to the purpose of using the images.

The fully filtered image is obtained by repeating this algorithm for each pixel of the CCD array [64].

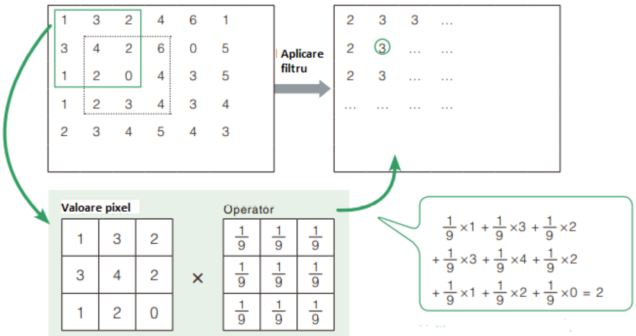


Fig.3.29. Applying a filter to the image to gain clarity [64]

Sampling consists in measuring and retaining the signal values at certain moments of time, separated by a constant interval called the sampling period, T, as in figure 3.30. The resulting discrete values must allow the reconstruction of the analog signal with a minimum error.

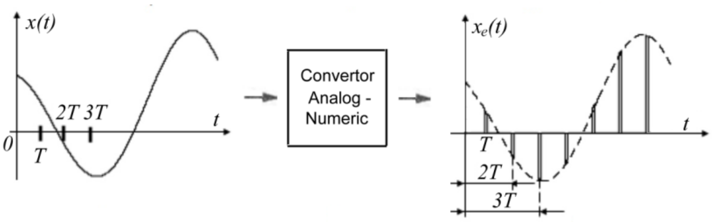


Fig. 3.30. Signal sampling

Quantization is defined as the process of converting the amplitude of an analog signal into a digital representation, which is performed by an analog-digital converter. Figure 3.34 shows the quantization mode of the signal represented on 4 $bits$, the quantity q being $1/24$ of the range of variation of the information-carrying physical quantity.

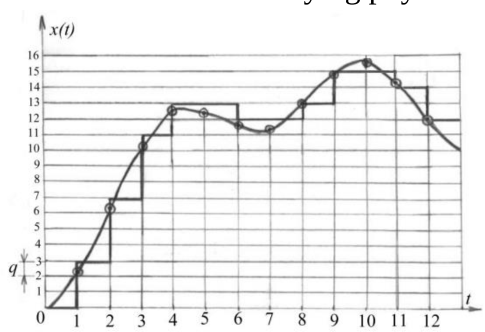


Fig.3.34. Quantizing a signal in 4-bit representation

Digital images can be stored in the memory or disk of an image processing and analysis system, in the form of files, for viewing or further processing. Files can be of several types, depending on the format in which the data representing images is organized: BMP, JPEG, GIF, TIFF, etc.

Laplace operator

Laplacian is a second-order differential operator, which applied to the image function highlights discontinuities in its gray level and serves to delimit regions with different gray levels. There are two ways to apply this filter on the image: Positive Laplacian, which subtracts the resulting image from the original one, respectively negative, which adds the resulting image to the original image, to obtain a clear image [67].

Prewitt Operator

Calculates the gradient of the possible transition from light (open) to dark (dark), showing whether the image change is steep or smooth at each point, for edge detection and their orientation.

Sobel Operator

It is very similar to the Prewitt operator, consisting of an "isotropic" numerical derivation algorithm, for both directions, based on the convolution of this filter with the light intensity function, in each point of the image. The result of applying the Sobel operator is also edge detection [65],[66].

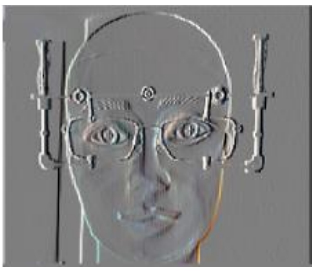


Fig.3.38. The result of applying the Sobel H operator [67]

Similar results to the application of the Sobel filter are obtained with the Prewitt operator filter, as in fig. 3.40.

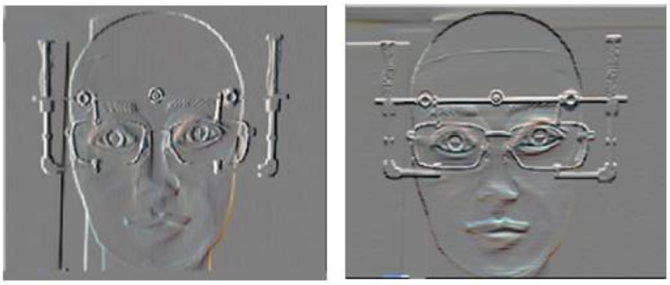


Fig.3.40. The results of applying the Prewitt H and Prewitt V operators [67]

4. THE MECHATRONIC SYSTEM FOR POSITIONING THE TABLET IN RELATION TO THE PATIENT

For the tablet that acquires the images necessary to determine the anthropometric parameters of the patient to be positioned with high precision (repeatability), a mechatronic system was designed and made, which positions it in three directions relative to it (fig. 4.1).

4.1. System kinematics - degrees of freedom, work area

The optomechatronic system has three degrees of freedom, moving the tablet, through translation in the vertical and horizontal directions, respectively ensuring a rotational movement of the tablet with an angle between 0 and 90 degrees.

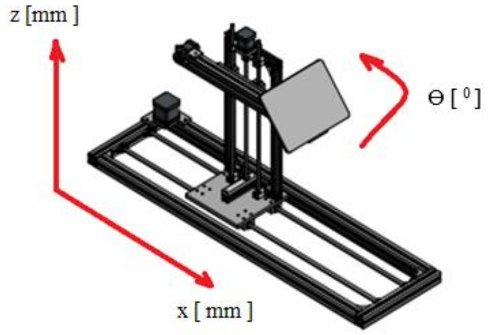


Fig.4.1. Optomechatronic positioning system with three degrees of freedom.

The positioned tablet contains the Eye Fit software for measuring individual parameters in fixed positions, up close and at semi-distance. The patient is seated in the chair, at the desk, in front of the device and three clear reference distances are considered (fig. 4.2). For position 1, "reading", the tablet is placed by the device at a distance of $350\,mm$ from the patient's eyes, under an angle of 50^o with the vertical plane, to acquire the image used to determine the position of the pupils through the lenses. In position number 2, "laptop activity", the tablet is placed by the device $450\,mm$ from the patient's eyes, rotated by 30^o from the vertical, so that he looks into the tablet, as if he were working on the laptop. By taking the picture and processing it, the position of the pupillary projections at this distance is determined. In position number 3, "computer activity", the tablet is placed at a distance of $650\,mm$ from the patient's eyes, raised vertically by a distance that depends on the patient's height and inclined by 15^o to the vertical plane, so that the patient looks as if how it would work on the monitor, determining the positions of the pupil projections for this distance. The positioning of the tablet both horizontally, vertically and at a certain angle is achieved with the help of three stepper motors and mechanisms for transmitting and transforming the rotational movement.

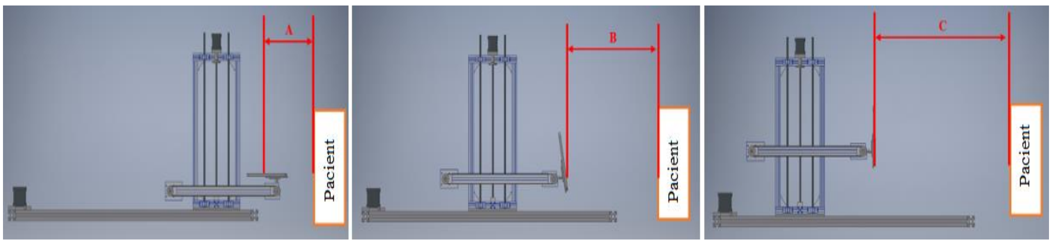


Fig.4.2. Fixed working positions (A - reading, B - laptop, C - monitor)

4.2. System structure

The positioning system for measuring visual parameters consists of a mechanical and an electrical/electronic subassembly. The mechanical part includes: the skeleton of the assembly made of aluminum alloy profiles, joined with the help of specific corners; the cylindrical guides, on which the two translations are made, together with their fixing elements on the support frame; the trapezoidal movement screw, together with its nuts; elastic couplings between motors and driven mechanisms, rolling bearings made with ball bearings; the supporting and fixing elements of the engines; ball slides with recirculation; the support frame of the vertical assembly; toothed belt drives; tablet holder; screws and nuts necessary for the dismountable assembly of the parts. The electrical/electronic part consists of the tablet, electric stepper motors, two Arduino Uno microcontrollers, amplifiers (drivers) for the stepper motors and a bluetooth signal transmission and reception module. The constructive dimensions of the device are: $1060\ mm$ long, $300\ mm$ wide, $560\ mm$ high and a length of the arm that slides together with the tablet of $520\ mm$.

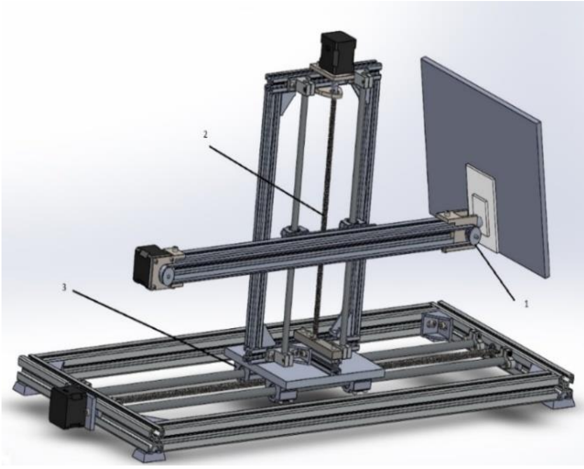


Fig.4.3. Realized positioning system

Figure 4.3 shows the main sub-assemblies of the system, which serve to obtain the three degrees of freedom necessary to position the tablet:

1- the subassembly with which the rotation of the tablet is obtained;

2- the subassembly with which the translation movement of subassembly 1 is obtained, vertically;

3- the subassembly that serves to translate subassemblies 1 and 2 on the horizontal axis.

4.3. Verification of the horizontal cylindrical guides

Determining the loading of these guides is facilitated by the Solidworks environment, through the Mass Properties command (figure 4.8, figure 4.9). The mass of the 4 ball slides on the vertical axis was extracted from the manufacturer's catalog sheet.

According to figure 4.8, the mass of subassemblies 1 and 2, selected in blue color, is:

$$m_{ans} = 4103{,}68\ g = 4{,}104\ kg$$

To this is added the mass of the support plate, which is part of subassembly 3, but loads the guides of the same subassembly.

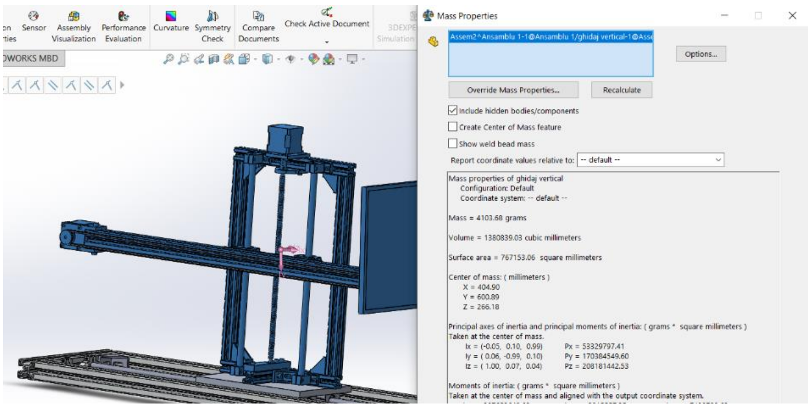


Fig.4.8. Mass of subassemblies 1 and 2, calculated in SolidWorks

$$m_1 = 791{,}03\ g = 0{,}791\ kg$$

From the catalog of the ball slide manufacturer (figure 4.10), the mass of one is extracted:

$$m_2 = 92\ g = 0{,}092\ kg$$

Result: $$m_{total} = m_{ans} + m_1 + 4m_2 = 5{,}262\ kg \quad (4.1)$$

and $$G_{total} = m_{total} \cdot g = 51{,}79\ N \quad (4.2)$$

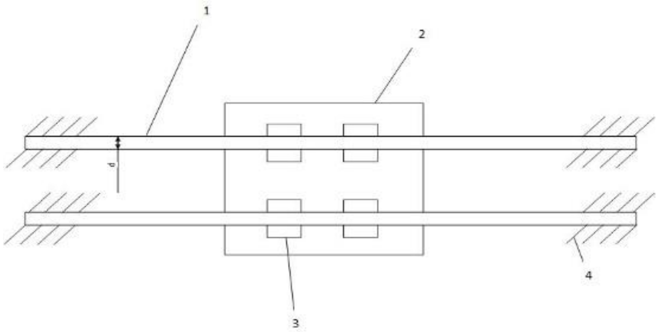


Fig. 4.11. The diagram of subassembly 3 (1- guide, 2- plate, 3- slide with balls, 4 - fitting)

From figure 4.11 it can be seen that the total load is distributed in 4 contact points, between each slide and the corresponding cylindrical guide. The position of the center of mass of subassemblies 1, 2 and plate 2 is in a vertical plane, parallel to the guides, but it moves in this plane so that the maximum bending moment is expected to occur when plate 2 is in a position symmetrical to the recessed ends of the guides. As the position of the center of mass of subassemblies 1, 2 and plate 2, in the horizontal direction, has not been determined, the approximate symmetry of subassemblies 1 and 2 justifies the quasi-equal distribution of the load on the two guides. Due to the embedment at the ends, a guide bar, required by the loads, is an indeterminate static system.

The third positioning direction of the tablet is also affected by the rotation implied by the transverse deformation of the guide, basically, the angle being added or subtracted to the angular position of the tablet, depending on the range of the x coordinate of the subassembly that moves horizontally. Therefore, the error introduced by the bending of the guide is about 4.5 times smaller than the angular positioning resolution of the tablet is not significant and cannot be corrected.

4.4. The screw-nut transmission

From a kinematic point of view, the chosen screw-nut assembly must ensure a certain positioning resolution, with a good transmission efficiency, requirements that are contradictory.

However, with a trapezoidal screw (figure 4.14) having the nominal diameter $d = 8\ mm$, the apparent pitch $p = 2\ mm$; the height of the spiral $H_1 = 0{,}5p$ and $n = 4$ beginnings, an advance of 8 mm is made for one rotation.

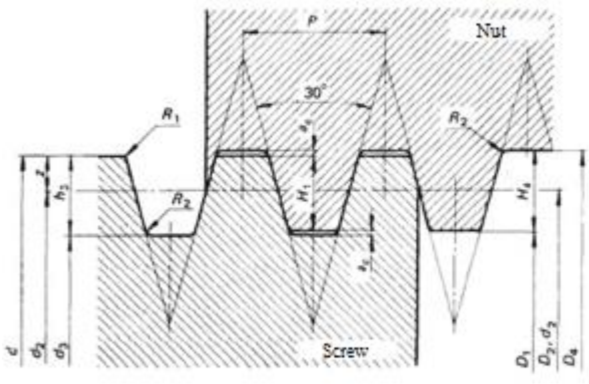


Fig.4.14. Trapezoidal thread [71]

If the stepper motor driving the screw has *200 steps/revolution (1,8°/step)*, the linear displacement corresponding to one step has a theoretical value of 0.04 mm, which is a very good resolution in the vertical direction and can be used for correction of z-axis errors. The transformation of the rotational movement of the screw into a translation of the nut is done according to the relationship:

$$s = \frac{np}{2\pi}\varphi \tag{4.21}$$

where: s – nut linear movement; φ – screw rotation angle.
To calculate the efficiency of the transmission, it is necessary to determine the pitch angle of the propeller, in the area of the middle cylinder, of diameter d_2. This results from the figure 4.14:

$$d_2 = d - H_1 = d - 0{,}5p = 7\ mm \tag{4.22}$$

The pitch angle of the propeller is:

$$\alpha = arctg\frac{np}{\pi d_2} = 20° \tag{4.23}$$

To determine the friction angle, the usual friction coefficient for the steel-bronze material couple is used, $\mu = 0{,}15$ and the angle of inclination of the trapezoidal sides, $\beta = 15°$.
The friction angle is:

$$\gamma' = arctg\frac{\mu}{cos\beta} = 8{,}83° \tag{4.24}$$

With these data, the transmission efficiency is:

$$\eta = \frac{tg\alpha}{tg(\alpha+\gamma')} = 0{,}661 \tag{4.25}$$

The mass of the tablet and its support were determined by weighing, having the value $m_t = 0{,}65\ kg$. From the SolidWorks program, the Mass Properties function, results in the total mass of the mobile subassembly components (frame, shafts, bearings, belt transmissions, ball slides, nut), $m_p = 0{,}478\ kg,$ and the mass of the stepper motor is provided by the manufacturer $m_m = 0{,}38\ kg$. The total mobile table mass, is:

$$m_{tot} = m_t + m_p + m_m = 1{,}508\ kg \tag{4.26}$$

4.5. The angular position of the tablet

The tablet positioning subassembly is shown in figure 4.17. It is observed that its weight develops a resistant moment, with the maximum value, when the tablet is in a vertical position:

$$M_r = m_t \cdot g \cdot l = 0{,}286\ Nm \tag{4.37}$$

where $l = 45mm$ is the distance between the median plane of the tablet and the axis of the 3' shaft (figure 4.17).

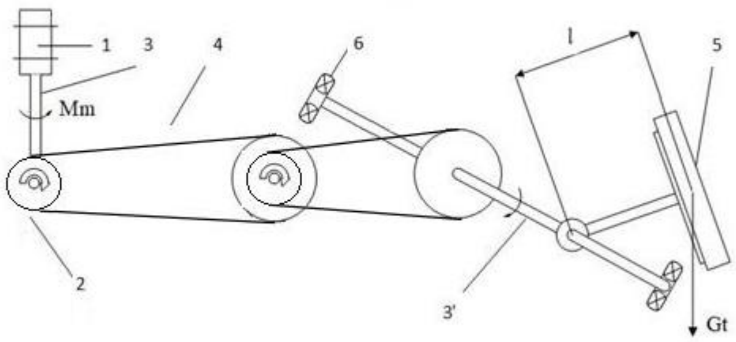


Fig.4.17. The tablet rotation mechanism (1 - stepper motor; 2 – belt pulley; 3, 3' – shafts; 4 – toothed belt; 5 – tablet and its support; 6 – bearing)

At the same time, the acceleration during the positioning of the tablet introduces an inertial load, in which the moment of inertia of the tablet relative to the axis of the shaft that rotates its support, intervenes. The tablet can be considered a board having the length $a = 240\ mm$ and the width $b = 185\ mm$, which has the moment of inertia around the longitudinal axis of symmetry:

$$J_y = \frac{m_t b^2}{3} = 7{,}42 \cdot 10^{-3}\ kgm^2 \qquad (4.38)$$

Applying Steiner's theorem, the moment of inertia of the tablet in relation to the axis of rotation, i.e. the axis of the shaft, is:

$$J_t = J_y + m_t \cdot l^2 = 7{,}475 \cdot 10^{-3}\ kgm^2 \qquad (4.39)$$

As stated in the analysis of the errors caused by the elastic deformations of the horizontal guides, the rotation of the tablet is driven by a step-by-step motor, by means of two reduction steps with toothed belts, having the total transmission ratio:

$$i = \frac{z_2}{z_1} \cdot \frac{z_4}{z_3} = 5{,}325 \qquad (4.40)$$

where: $z_1 = z_3 = 26$ and $z_2 = z_4 = 60$ - the numbers of teeth of the pulleys wheels.
The maximum frequency (steps/s) at which the motor should operate is:

$$f = \frac{\omega_r}{\varphi_p} = 42{,}27\ steps/s \qquad (4.45)$$

The equation of motion of the tablet, reduced to the motor shaft becomes:

$$M_m = (J_m + J_{te})\varepsilon + M_{rm} = 0{,}059\ Nm \qquad (4.46)$$

where: M_m – the motor moment required to accelerate the mobile subassembly that rotates the tablet; J_m – the moment of inertia of the motor rotor; $J_m = 12 \cdot 10^{-6}\ kgm^2$ – moment of inertia of the Plusivo motor rotor 17HS8401S (from the catalog); $J_{te} = 0{,}264 \cdot 10^{-6}\ kgm^2$ – reduced moment of inertia of the tablet [73],[74].

4.6. Positioning the tablet on horizontal direction

In paragraph 4.2, the tablet positioning device was described, stating that the horizontal movement of subassemblies 1 and 2 is ensured by a toothed belt mechanism with a transmission ratio of 1, the drive wheel is driven by a stepper motor, and the translation is obtained by connecting the mobile system to a rectilinear area of the belt. The kinematic scheme of the training is presented in figure 4.18.

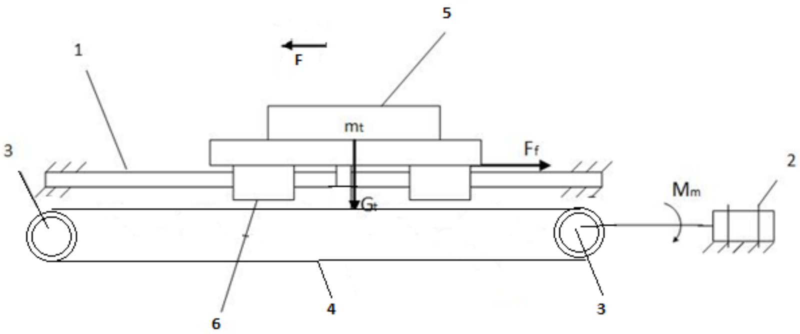


Fig. 4.18. The kinematic diagram of subassembly 3 (1 – cylindrical guide; 2 – stepper motor; 3 – toothed wheel; 4 – toothed belt; 5 – vertical subassembly; slide with balls)

The timing belt pulleys have the same number of teeth, $z = 26$, and the belt has an ISO profile, with the step $p = 2{,}5\ mm$. The primitive diameter of the wheels is:

$$d_p = \frac{pz}{\pi} + q = 20{,}74\ mm \tag{4.48}$$

where: $q = 0{,}054\ mm$ is a correction applied due to the polygonal winding of the belt on the wheel. The value is extracted from table 5.111 of the work [69], for $z = 26$ and $p = 2{,}5\ mm$. The transmission ratio between the linear speed of the belt, therefore also of subassembly 3, and the angular speed of the motor is:

$$\frac{v_r}{\omega} = \frac{d_p}{2} = 10{,}37\ mm \tag{4.49}$$

The mass of mobile subsystem 3 is the largest and will create important inertial forces during its acceleration, but also frictional forces between slides and guides. Their calculation, in the case of rolling guides, takes into account the size of the load, the existence of a pretension in order to reduce the clearances and lubrication. An estimation of these forces can be obtained with the relation:

$$F_f = \mu \cdot P + f \tag{4.50}$$

where: μ - the dynamic friction coefficient, with recommended values in figure 4.19; P – calculated workload*;* f - sliding friction force, generated by seals (if any).
This corresponds to the resisting moment of the motor shaft:

$$M_{rm} = F_r \cdot \frac{d_p}{2} = 1{,}45\ Nmm = 0{,}0145\ Nm \tag{4.53}$$

The equation of the tablet motion, reduced to the motor shaft becomes:

$$M_m = (J_m + J_{te})\varepsilon + M_{rm} = 0{,}017\ Nm \tag{4.58}$$

where: M_m – the motor moment required for the acceleration of the mobile subassembly that realizes the positioning on the direction x; J_m – the moment of inertia of the motor rotor; $J_m = 2{,}943 \cdot 10^{-4}\ kgm^2$ – the moment of inertia of the Plusivo motor rotor 23HS5628; $J_{te} = 5{,}659 \cdot 10^{-4}\ kgm^2$ – reduced moment of inertia of the mobile subassembly.
The maximum power transmitted by the belt is achieved at the end of the acceleration period, when the regime speed is reached, but the inertial load is still manifested. Taking into consideration the value of the moment corrected with the safety coefficient 2, this is:

$$P_{max} = M_s \cdot \omega_r = 0{,}29\ W \tag{4.60}$$

and the speed $$n = \frac{30\omega_r}{\pi} = 81\ rev/min$$

The theoretical resolution of the horizontal movement is the distance traveled in the horizontal direction when the motor rotor moves by one step:

$$\delta_p = \frac{d_p}{2} \cdot \frac{\pi}{200} = \frac{20{,}74 \cdot \pi}{400} = 0{,}164\ mm \qquad (4.62)$$

4.7. Calculation of the positioning coordinates of the tablet

In order to achieve the image acquisition positions corresponding to the determination of the patient's particular anthropometric parameters, for near (reading) and semi-distance (laptop and monitor) vision, the positioning device was diagrammed as in figure 4.20.

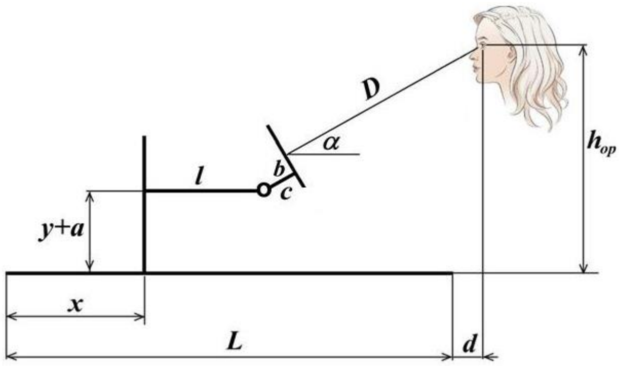


Fig.4.20. Th diagram for determining the position of the tablet

This scheme allows the determination of the x and y coordinates of the tablet positioning device, in the horizontal and vertical direction respectively, under the conditions in which the value of the angle α, of its inclination, is imposed for ergonomic reasons. In the figure, $L = 830\ mm$ is the distance between the initialization position of the x coordinate and the right edge of the device support, and $d = 200\ mm$ is the distance between this edge and the plane of the special frame with markers. Also in the horizontal direction is the support arm of the tablet, length $l = 235\ mm$, $c = 45\ mm$ is the length of the rotating segment of this arm and $b = 70\ mm$ is the distance from the center of the tablet to the fixing point. In its continuation, the distance D takes the values considered optimal for reading ($350\ mm$), laptop ($450\ mm$) and monitor ($650\ mm$). In the vertical direction, the positioning height of the patient's eyes is measured from the level of the table on which he is seated the device support, and the y coordinate represents the stroke of the nut to bring the center of the tablet from the initial position to the required one, knowing that $a = 38\ mm$ (the distance from the table to the bottom limit of the nut). The projection of the contour on the x respectively y direction, leads to the equations:

$$x = L + d - l - (c + D)cos\alpha - bsin\alpha \qquad (4.63)$$

$$y + a = h_{op} - (c + D)sin\alpha - bcos\alpha \qquad (4.64)$$

or

$$x = 795 - (D + 45)cos\alpha - 70sin\alpha \qquad (4.63^*)$$

$$y = h_{op} - (D + 45)sin\alpha - 70cos\alpha - 38 \qquad (4.64^*)$$

It is observed that the movements in the horizontal direction are made in 3 fixed positions, corresponding to the activities that involve reading, working on the laptop, respectively observing the monitor, while in the y direction a correction is necessary related to the height at which the patient's eyes are located. Thus:

- for near (reading) angle $\alpha = 50°$, distance $D = 350\ mm$ and x =487,4 mm;
- for semi-distance (laptop) angle $\alpha = 30°$, distance $D = 450\ mm$ and x =331,3 mm;
- for semi-distance (monitor) angle $\alpha = 15°$, distance $D = 650\ mm$ and x =105,6 mm.

In number of motor steps, these distances are covered like this:

- for near (reading): $n_1 = \frac{x_1}{\delta_p} = 2972\ steps$;
- for semi-distance (laptop): $n_2 = \frac{x_2}{\delta_p} = 2020\ steps$;
- for semi-distance (monitor): $n_3 = \frac{x_3}{\delta_p} = 644\ steps$.

Considering that the intended working positions are with the back straight and forearms placed on the desk, it follows that $\boldsymbol{h_{op}}$ is the difference between the height of the eyes and that of the elbow:

$$\boldsymbol{h_{op} = 0,936H - 0,630H = 0,306H} \tag{4.65}$$

where H is the height of the patient. Equation (4.64*) becomes:

$$\boldsymbol{y = 0,306H - (D + 45)sin\alpha\text{-}70cos\alpha - 38} \tag{4.64**}$$

Based on the equation (4.64**), the necessary positions for subjects with a height of 1500 - 2000 mm were evaluated, in the 3 test cases (reading, laptop and monitor).

It is observed, from equation (4.64**), that the variation of the required position, y, with the height of the patient, H, is linear and is calculated with:

$$\Delta y = 0,306 \cdot \Delta H \tag{4.66}$$

Table 4.1 presents the values of the coordinate y, depending on the height of the patient, calculated for $\Delta H = 10\ mm$, to which it corresponds $\Delta y = 3,02\ mm$.

	READ	**LAPTOP**	**MONITOR**
H [mm]	***y* [*mm*]**		
1600	103,6	143,1	203,7
1610	106,62	146,12	206,72
1620	109,64	149,14	209,74
1630	112,66	152,16	212,76
1640	115,68	155,18	215,78
1650	118,7	158,2	218,8
1660	121,72	151,22	221,82
1670	124,74	164,24	223,84
1680	127,76	167,26	227,86
1690	130,78	170,28	230.88
1700	133,8	173,3	233,9
1710	136,82	176,32	236,92
1720	139,84	179,34	239,94
1730	142,86	182,36	242,96
1740	145,88	185,38	245,98
1750	148,9	188,4	249
1760	151,92	191,42	252,02
1770	154,94	194,44	255,04
1780	157,96	197,46	258,06
1790	160,98	200,48	261,08
1800	164	203,5	264,1

Tabel 4.1. The values of the y coordinate, for positioning the tablet, depending on the activity and the height of the patient

4.8. Device structure verification regarding the precision of the realization

A complex assembly of parts, some of which have long lengths, such as the built device, can accumulate their individual errors in a position of the effector (tablet), difficult to estimate. In the present case, a laser level was used to control the perpendicularity of the vertical and horizontal positioning directions (figure 4.22).

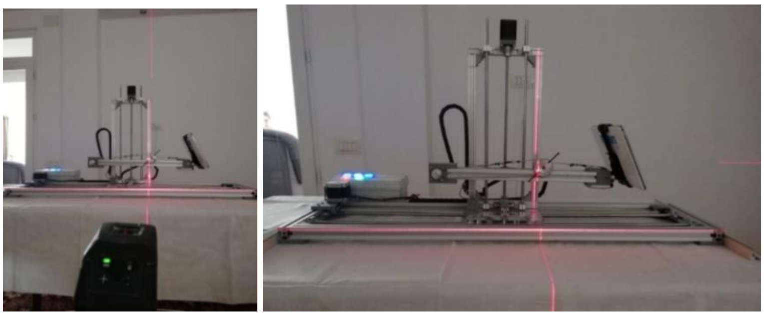


Fig.4.22. The perpendicularity verification of the vertical and horizontal positioning directions

4.9. Device control

For the control of the entire optomechatronic system, an Arduino UNO development board was chosen, and for the positioning movements of the tablet, a second Arduino UNO board is used, to which a "CNC Shield" is connected. The main Arduino microcontroller communicates directly with the console with buttons of the optomechatronic device and can communicate, via bluetooth, with the tablet, on which a "remote control" integrated into the Eye Fit program is built, at the execution position of the near and semi-distance picture. The remote control implemented on the tablet serves to fine-tune its position in the vertical and angular direction, in order to center the reticles generated by the Eye Fit program on the markers of the auxiliary frame. The control programs, implemented in Arduino, are written in C++ language and are detailed in Appendix 8.2. The voltage source of the system provides, for the motors, a constant voltage of 12 V, at a maximum current of 3.4A, being powered from the mains (220V). The same source supplies the electronic circuits, through step-down modules.

From an electrical point of view, the device is composed of the following elements:
2 Arduino UNO development boards; 5 Buttons with lamp (green, red and 3 blue); 1 Bluetooth module; 1 CNC Shield extension board; 3 amplifiers (drivers) for stepper motors, A4988; 3 Stepper motors; 3 Limit switches, normally open, which determine the initial, reference position of the mobile system of the optomechatronic device.
The connection diagram of the electrical assembly is presented in fig. 4.24.

ARDUINO is one of the easiest to use microcontroller platforms. It is, in fact, a microcomputer (it has the computing power of an ordinary computer from 15 years ago), being able to gather information from the environment and react to it. Around the microcontroller of the Arduino board (ATMEGA 328P-PU) there is an assembly of compatible devices, very well developed, which contains ready-to-interface sensors, "shield" type boards that solve hardware problems of communication and interface with the desired application.

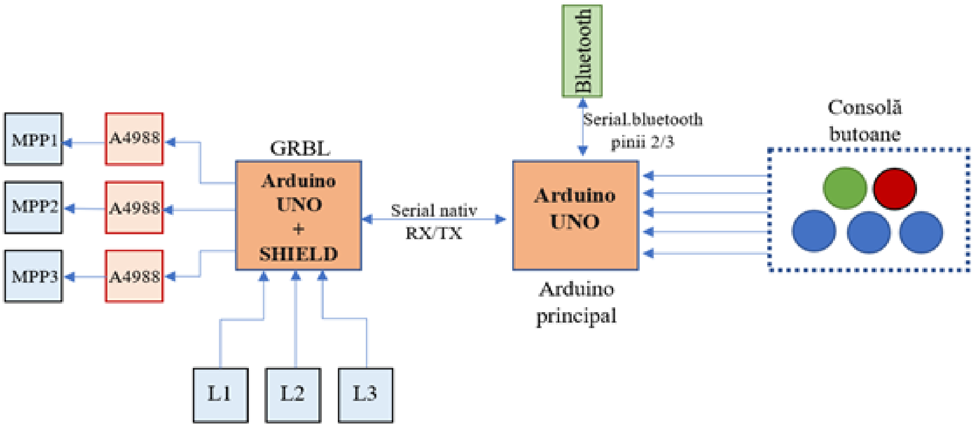


Fig.4.24. Connection diagram [80]

The HC-06 Bluetooth module is used for serial communication through Bluetooth technology, between Arduino and other devices located at a distance. This Bluetooth module has two constructive variants: master and slave.

The Bluetooth operating module can communicate with the other Bluetooth device, in serial mode, if two conditions are met [78],[79]:

The modules, which enter into communication, are one master and the other slave; Communication is carried out through serial signals RX and TX, wirelessly at 2.4 GHz, and with a correct password.

The technical characteristics of the HC-06 module are: VCC: +5 / v RXD: Arduino Serial (3.3V HIGH level) / TXD: Arduino Serial / GND: Arduino Minus.

To start and initialize the stand, hold down the green button. In the initial stage, the system will move to the initial position (zero position), which is set by the limit switches. After initialization, the system is controlled by two methods: from the console with buttons, for quick movement in the 3 working positions, the most suitable for those suitable for the test (reading, laptop, monitor) and respectively the height of the patient from the tablet placed on the support (Bluetooth communication), for fine adjustments of the vertical and angular position.

There are 5 buttons available for control from the console: Start (green button), Stop (red button) and three blue buttons, for positioning the stand in the 3 reading areas. The buttons are connected to digital pins 4-9.

The positioning of the tablet is handled by the second Arduino UNO, on which the CNC shield is mounted (figure 4.27.). It communicates with the first Arduino (the main one), through the native (hardware) serial port, whose connection is established by digital pins 0 and 1. Depending on the desired position, it receives a GCODE line of code on the serial.

Fig.4.27. Arduino Uno + CNC Shield + A4988 assembly [81]

After the positioning command has been received and interpreted by the second Arduino UNO, it sends a train of electrical pulses to the A4988 amplifiers, representing the number of steps the stepper motors must take to move the system to the desired position.

These positions are determined by calculation, in coordinates (x, y, α,), as in figure 4.20, measured from the initialization position, considered the origin of the coordinate system. If on the x and α, directions the values corresponding to the 3 working positions are unique, the y coordinate depends on the height of the patient and requires a fine adjustment to center the reticle generated by Eye Fit on the image of the marker captured by its camera.

To move the entire device vertically and bring it to elbow level, it sits on an electrically adjustable height table, such as the TT-1060, from the Tomey optometric office equipment catalog (figure 4.28).

Fig.4.28. The height-adjustable table - TT-1060 [87]

It supports loads up to 65 kg, has an adjustable height in the range of $661 - 911\ mm$, by electric actuation and the tabletop dimensions of 1060 x 600 mm.

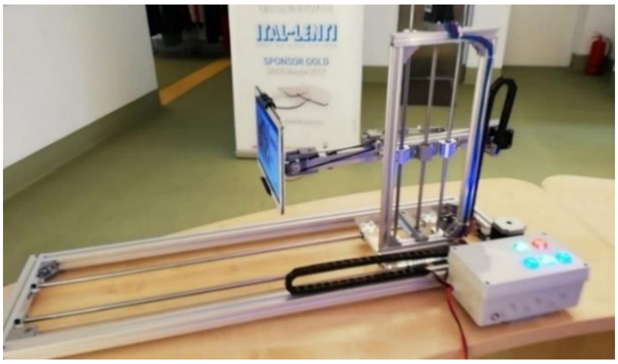


Fig.4.29. The constructed optomechatronic device

To turn on the device and initialize the tablet position, the green (ON) button must be pressed and held. Following this command, the mobile system moves to the initial position (system origin), established by the travel limiters (L1, L2, L3). For manual control there are 5 buttons connected to the Arduino UNO, considered the Master Controller: ON (green button), OFF (red button) and three blue buttons for rough positioning of the tablet, in the 3 test positions, according to paragraphs A), B) and C). The mechatronic positioning system and the manual control console are shown in figure 4.29.

The fine adjustment of the vertical position and the tilt of the tablet is controlled from the Eye Fit program, which can increase or decrease the value of the y coordinate by $0.2mm$ (5 steps) and the angle value by $\pm 1{,}014°$ (3 steps).

After achieving the centering, by overlapping the reticle with the corresponding marker, the command is given to capture the image of the patient's eyes, from the local console, by pressing and holding the green button for two seconds. After capturing the images needed to measure the interpupillary distance at the three locations, the system can be turned off by holding down the red button (which will return it to its initial position) or receive another command to test a new patient.

5. TABLET CALIBRATION AND THE MATHEMATICAL MODEL OF OBJECT SPACE CORRELATION WITH THE IMAGE PLANE

The optomechatronic system designed and made includes the mechatronic positioning device presented in chapter 4 and the positioning tablet, on which the EYE FIT program, developed in the Java language, is loaded. It runs on a mobile device, such as a 'SAMSUNG' tablet with Android 5.0 or latest operating system.

5.1. The current method of measurement and testing

Testing a patient with the EYE FIT tablet begins with positioning him in an area of the office with very good natural light to acquire quality images. The measurement of the patient's parameters at "infinity" does not require the use of the tablet positioning device, so that he will be able to stand in the "standing" position, looking into the main chamber of the tablet, at a distance of $800\ mm$ from it, after the frame with markers was mounted over the spectacle frame chosen by the patient (figure 5.1).

The measurements are based on the processing of the images acquired by the tablet, with the help of the EYE FIT program (figure 5.2). Generic, it evaluates the distances between the points of interest of the image, by comparison with the known distances between the markers, the dimensional transformation ratio being equal to that of the pixel numbers of the measured dimension and that of the known distance between the markers.

Fig.5.2. EYE FIT mobile device for determining individual parameters

The frame with markers is very important to obtain correct measurement results. The positioning is done taking into account that the marker in the center is exactly on the vertical line that divides the face and the chosen frame, in two halves (figure 5.3).

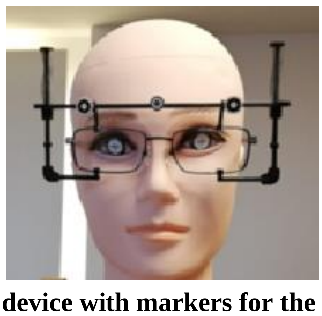


Fig.5.3. Frame device with markers for the current method

The first image of the patient is acquired from the front, looking into the main camera of the tablet, in order to be able to calculate the pupillary distance to infinity, for each distance interval. This also results in the mounting height of the lens, the dimensions of the glasses frame and the size of the bridge of the nose.

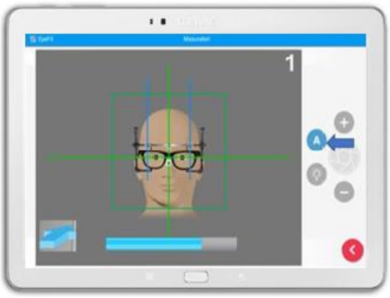


Fig.5.4. The main image of the patient.

Two images are then acquired, with the patient looking at infinity, which serves to determine the pantoscopic angle of the frame, the curvature of the frame and the vertex distance for each eye (figure 5.5).

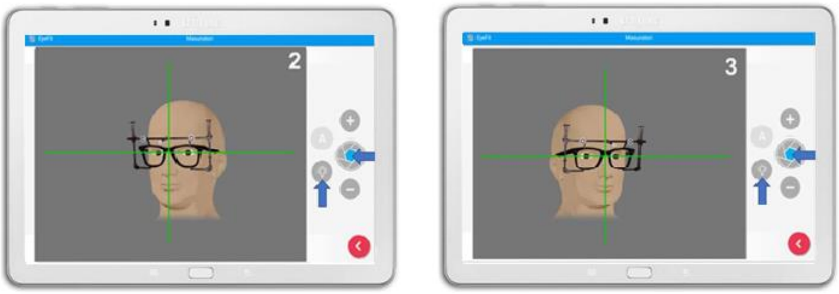


Fig.5.5. Profile images of the patient.

In the current procedure, the last image acquisition is performed with the patient looking closely into the frontal camera of the tablet, to measure the following parameters: the convergence on each eye and the reading position through the lens. This last image of the patient is given by the position of the arms, because the patient has a frame with "demo-lenses" (flat lenses) on his face and cannot read. This position is "standing", it is not comfortable nor relevant for the correct reading position. In addition, the camera is changed, which has a different resolution and an eccentric placement, 20 mm from the vertical line of symmetry of the tablet. It should be stated that the EYE-FIT program restricts the positions from which the tablet is taken, by requiring it to be positioned so that the reticles generated by it are superimposed on the centers of the markers (figure 5.6).

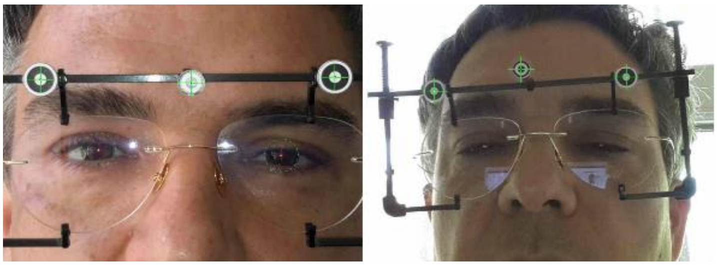
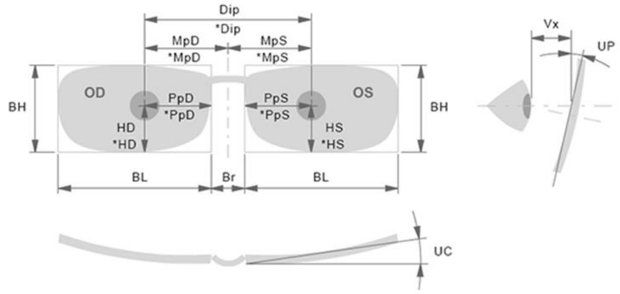


Fig.5.6. Image capture of the patient with Eye Fit.

After the patient has been photographed, the EYE FIT program runs the acquired data and displays the results of all measurements of the patient's parameters and the chosen frame, to build a personalized progressive lens. The result is presented in the form (figure 5.7):



						Dimensions for near vision		
Dip:	70.7	mm	BH:	42.5	mm	*Dip:	*68.3	mm
MpD:	34.9	mm	BL:	55.1	mm	*MpD:	*33.9	mm
MpS:	35.8	mm	Br:	17.7	mm	*MpS:	*34.4	mm
PpD:	25.7	mm	Vx:	22.15	mm	*PpD:	*23.1	mm
PpS:	26.8	mm	VxOD:	22.7	mm	*PpS:	*23.5	mm
HD:	30.8	mm	VxOS:	21.6	mm	*HD:	*24.2	mm
HS:	28.4	mm	UP:	5.4	°	*HS:	*22.4	mm
			UC:	4.6	°	Reading distance *36.5 cm		

Fig.5.7. The result of the measurement of individual optometric parameters.

Legend : Dip=interpupillary distance; MpD=pupillary distance for the right eye; MpS=pupillary distance for left eye; Vx = vertex distance (from the cornea to the lens); HD, HS = mounting height; BH = frame height; BL = frame length; Br = nasal bridge; UP = pantoscopic angle; UC = frame curvature angle

As can be seen from the table attached to Figure 5.7, the patient has asymmetry between the two eyes. In the vertical plane, the difference between the pupil centers is $2.4\ mm$ and in the horizontal plane it is a difference of $1.1\ mm$. Also, the patient's eyes do not converge equally, the difference between them being $1.2\ mm$. The positioning of the optical centers of lenses constructed for the patient must take these results into account. For the near area, as can be seen in the image, the relative position of the patient's head to the tablet has an angular deviation to the right, and the deviation from perpendicularity to the tablet generates measurement errors. For the reading distance, which is measured at $365\ mm$, it is observed that the differences between the centers of the two pupils do not remain constant in relation to the movements of the eyeballs and there are differences in the vertical plane of 2.2 mm and in the horizontal plane of $2.1\ mm$. The construction of the personalized progressive lens requires a tenth-of-a-millimeter accuracy positioning of the optical centers, in relation to the patient's pupillary centers.

5.2. The proposed measurement and testing method

With the built optomechatronic device, the proposed methodology for measuring the patient's individual parameters comes into operation after his images have been acquired to determine the constructive parameters specific to the distance zone, i.e. one picture from the front and two from the side.

For the near and semi-distance areas, the optomechatronic device (including the tablet), placed on the TT-1060 table, is positioned in the horizontal (lateral) direction, with the help of the vertical line of the reticle generated by the tablet, which overlaps the center line of the central markers and then in the vertical direction, with the help of its horizontal line. In order to position the device horizontally, a marker was added on the special frame (figure 5.8), in the plane of symmetry of the glasses frame, above the central one. The horizontal centering of the device is considered successful when the vertical line of the reticle generated by the tablet is centered on the two vertical markers (figure 5.9).

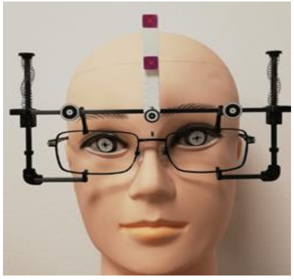


Fig.5.8. Frame device with markers for the proposed method

The vertical position of the tablet is achieved with successive movements, by manual command, according to the method presented in subchapter 4.7, in relation to the height of the patient.

The standard correct distance for reading is $350\ mm$ at an angle of 50°, for a laptop is $450\ mm$ from the patient at an angle of 30°, and that for a monitor is $650\ mm$ at an angle of 15° . The correction of the patient's position and gaze must be continuously managed by the optometrist. The processing of captured images provides specific data on the position of the patient's pupils, of all optometric parameters, ensuring a correct deposition of power on the surface of the lens, so that the gaze through it is exactly through the reference areas, which confers maximum clarity and rapid accommodation with progressive lenses..

Vertical centering is obtained by fine-tuning the position of the tablet in height, being achieved when the horizontal line of the reticle overlaps the centers of the markers placed in horizontal lines on the special frame.

5.3. Calibration of the tablet front camera

Since the patient's images, which serve to determine the interpupillary distance and convergence associated with near and semi-distance vision, in the three cases tested, are acquired with the front camera of the tablet, the values, in millimeters, of the distances between the image points were determined, to determine the optical magnification values in the vertical and horizontal direction, for points where the distances in the (real) object space are known.

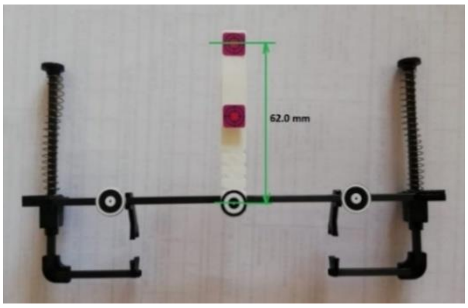


Fig.5.11. Additional marker added vertically to the central one, 62 mm above

For this purpose, a marker (figure 5.11) was added in the vertical direction of the central one, $62\ mm$ above, in addition to the markers required by the EYE FIT system. This marker is placed in the same plane as the lateral ones, unlike the central one, located $40\ mm$ in front of the plane of the glasses frame. The images acquired with the front camera of the tablet, placed vertically (parallel to the plane of the markers), at the working distance for the monitor ($649\ mm$), by capturing the screen, were processed with the "open source" program ImageJ, which allows measuring the distance, in pixels, between two points of the image (figure

5.12). Placing the tablet without the specific tilt of the view at the monitor serves to determine the transverse magnification in the vertical direction.

Initially, the dimensions of the screen are measured, which are in the ratio 16/10, having the values: $a = 217{,}5$ mm and $b = 136\ mm$, whose product verifies the specified screen area $\sim 295{,}8\ \text{cm}^2$. Thus the screen resolution is 2560×1600 pixels, the pixel density per mm, in the horizontal and vertical direction is:

- Horizontal $\rightarrow \frac{2560}{217{,}5} = 11{,}77\ pixels/mm$; - Vertical $\rightarrow \frac{1600}{136} = 11{,}77\ pixels/mm$.

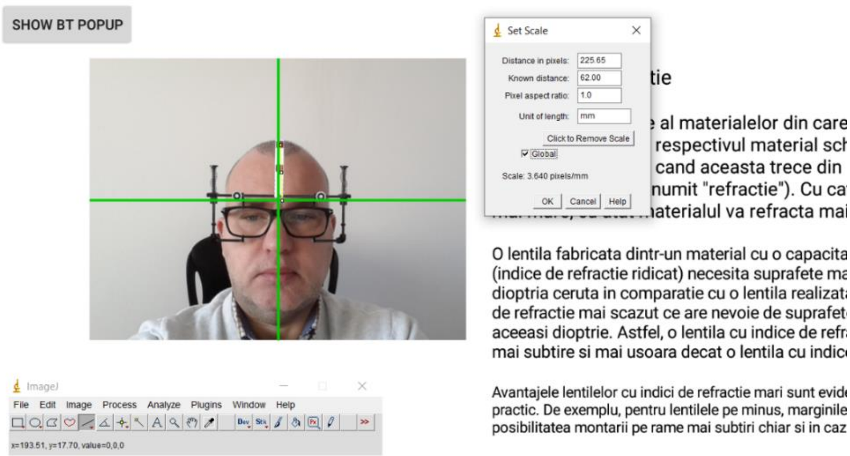


Fig.5.12. Determining the number of pixels between the central (vertical) markers, using ImageJ, for the viewing distance to the screen

According to figure 5.12, for the distance of $62\ mm$, vertically, between the central markers, the ImageJ program evaluated $225.65\ pixels$. It results that the image of the distance between the two markers has the size $225.65 : 11.77 = 19.17\ mm$. If this value is related to the real distance, it results in the transversal enlargement of the optoelectronic system, in the y direction:

$$\beta_y = \frac{19{,}17}{-62} = -0{,}3092 \tag{5.1}$$

The lateral markers in figure 5.8 are located in the plane of the patient's frame, symmetrical to its middle and have a distance of $100\ mm$ between them.

According to figure 5.13, for the distance of $100\ mm$, in the horizontal direction, between the extreme markers, the ImageJ program evaluated $364\ pixels$. It results that the image of the distance between the two markers has the size $364 : 11.77 = 30.93\ mm$.
If this value is related to the real distance, it results in the transverse increase in the x direction, for the patient's working distance to the monitor:

$$\beta_{xm} = \frac{30{,}93}{-100} = -0{,}3093 \tag{5.2}$$

It is observed that the transversal magnification is practically the same in both directions of the image, it should be noted that this value includes both the optical contribution of the camera that focuses the light beam on the miniature CMOS, as well as the digital electronic amplification, which determines the image displayed on the screen.

The transversal magnification value resulting from relations (5.1) and (5.2) corresponds to the patient-monitor distance, for the other positions, respectively laptop and reading, specific calibrations are required. In paragraph 5.3 it is demonstrated that the magnification is not influenced by the angular position of the tablet in relation to the x axis, but only by the patient-tablet distance.

According to the figure, the distance between the image points of the extreme markers is $371.23\, pixels$, which corresponds to a dimension in mm: $371.23: 11.77 = 31.54\, mm$. If this value is related to the real distance, it results in the transverse magnification in the x direction, in the case of laptop viewing:

$$\beta_{xl} = \frac{31{,}54}{-100} = -0{,}3154 \quad (5.3)$$

For the reading distance (figure 5.15), due to the proximity of the patient to the camera, the transversal magnification is higher. Using ImageJ, it was determined that the image of the distance between the markers has a length of $375.61\, pixels$, which translates into $31.91\, mm$. The result is a transversal increase in the reading distance:

$$\beta_{xc} = \frac{31{,}91}{-100} = -0{,}3191 \quad (5.4)$$

5.4. The associated mathematical model

The programs for determining the optometric parameters of patients, such as EYE FIT, identify the positions of some key points in the captured image of a patient's face, which they deliver in the form of specific dimensions, after transforming the image unit - pixel, into the measurement unit of dimensions - millimeter. For this purpose, a trial frame with four markers is used, mounted over the patient's frame. The horizontal markers are positioned at fixed intervals of $50\, mm$, and the fourth marker is located, in the same plane as the horizontal ones, on the vertical of the central marker, $62\, mm$ above it (figure 5.8). The plane of the 3 markers is located $10\, mm$ in front of that of the glasses frame. For the success of the determinations, the captured image must be very clear and acquired in conditions of maximum brightness and resolution.

The arrangement of the markers is defined in relation to two main planes, which intervene in the calculation of individual optometric parameters: the first plane, [α], is the plane of the extreme markers, and the plane [β] is the plane of the lenses, i.e. the plane of the trial frame clamps. A third main plane, perpendicular to the first ones, is the plane $[\pi]$ of symmetry of the patient's head (figure 5.16).

As the use of the ImageJ program to determine the distances between the key points of the image is not very productive, an extension of the capabilities of EYE FIT, for the near and semi-distance area, using the test method and device, together with the processing algorithm for the near area, is expected.

Under these conditions, the only possible approach is to equate the tablet's camera and display system with a virtual optical system, which would produce, on a screen the size of the tablet, the same image. The position of point A is determined by the formula that relates the object-image distance (denoted by C) to the transverse magnification, denoted by β[63]. In Gaussian coordinates, the object abscissa of the optical system is given by the formula:

$$A(C, \beta) = \frac{C}{\beta - 1} \quad (5.5)$$

An observation must be made, namely that the electronic image of the tablet is straight and, consequently, the optical image resulting from this scheme is reversed left-right and up-down, compared to the electronic image.

In order to calibrate, for the virtual optical system, the object consists of four markers marked with M_0, M_1, M_2 and M_3, the first and last being the reference for the correct horizontal centering.

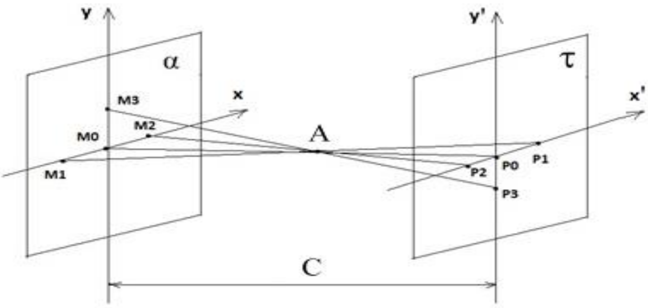


Fig.5.17. Virtual optical system (marker plane and tablet plane)

Markers M_1, M_2 and M_3 are in the same vertical plane [α], and M_0 is the projection of a marker spaced 40 mm in front, used to determine the pantoscopic angle from the distance photos, captured from the side (EYE FIT system). M_0 is the origin of the reference trihedral of the virtual optical system, where the plane [τ] is the image plane (figure 5.17).

According to the figure, the segments in which point A divides the segment M_0P_0 result from the similarity of the triangles:

$$\frac{AP_0}{AM_0} = \frac{P_1P_2}{M_1M_2} = \frac{P_0P_3}{M_0M_3} = |\beta| \quad (5.6)$$

The object distance, AM_0, is obtained from (5.6), by adding the denominator to the numerator:

$$\frac{AP_0+AM_0}{AM_0} = \frac{C}{AM_0} = |\beta| + 1 \quad (5.7)$$

The formula (5.5) was found with a changed sign due to the move of the origin from A to M_0, from which it follows that:

$$AM_0 = \frac{C}{1+|\beta|} \quad \text{și} \quad AP_0 = C - AM_0 = \frac{|\beta|C}{1+|\beta|} \quad (5.8)$$

To solve the inverse problem, i.e. determining the distances in the object space, when those in the image plane are known, the photographs from the front can only be used to determine those points that belong to parallel planes or rotated only around the x or x' axis.

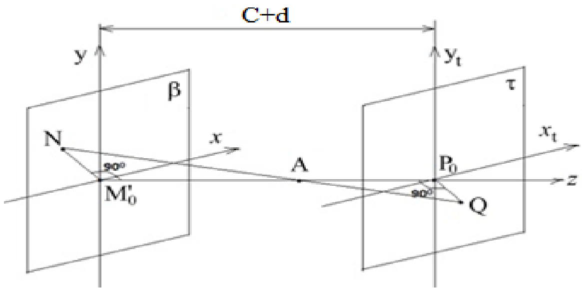


Fig.5.18. The virtual optical system (the object plane, different from that of the markers and that of the tablet)

The situation in figure 5.18 involves parallel planes, in which the object point is $N(x_N, y_N, z_N)$, from the plan [β] of the glasses frame or the one tangent to the eyes again $Q(x_Q, y_Q, z_Q)$ is the image point in the plane of the tablet, τ. If the origin of the reference system is at the point M_0', from the object plane, the equations of the two planes are:

Object plane: $z = 0$ (5.9)

Image plane: $z = C + d$ (5.10)

where d is the distance between the plane of the markers and that of the frame (in the case of the glasses frame, $d = 10\ mm$.

The line (virtual ray) that joins the object point with the image point in space passes through points A and Q, having the equation in canonical form:

$$\frac{x-x_A}{x_Q-x_A} = \frac{y-y_A}{y_Q-y_A} = \frac{z-z_A}{z_Q-z_A} \tag{5.11}$$

Point A has the coordinates $x_A = y_A = 0$ and $z_A = AM'_0 = AM_0 + d = \frac{C}{1+|\beta|} + d$, and $z_Q = C + d$. Point N is at the intersection of the plane $z = 0$ with the AQ line, so that equation (5.11) becomes:

$$\frac{x_N}{x_Q} = \frac{y_N}{y_Q} = -\frac{\frac{C}{1+|\beta|}+d}{\frac{|\beta|C}{1+|\beta|}} = -\frac{C+d(1+|\beta|)}{|\beta|C} \tag{5.12}$$

From relation (5.12) the coordinates of point N, depending on those of its image, Q:

$$x_N = -\frac{C+d(1+|\beta|)}{|\beta|C} \cdot x_Q \tag{5.13}$$

$$y_N = -\frac{C+d(1+|\beta|)}{|\beta|C} \cdot y_Q \tag{5.14}$$

From equations (5.11) and (5.12), it follows that the transversal increases in the x and y directions remain equal:

$$\beta_x = \beta_y = \frac{x_Q}{x_N} = -\frac{|\beta|C}{C+d(1+|\beta|)} \tag{5.15}$$

It is observed that for d=0, the transversal magnification obtained during calibration is found.

The models developed so far considered that the plane of the tablet is parallel to that of the object (frame with markers). In all three cases (monitor, laptop and reading), there are recommended angles for tilting the screen, which are taken into account below.

From the specialized literature, two methods are known for rotating a mobile coordinate system, compared to a fixed coordinate system, which have a common origin. This is done by a rotation matrix, using Euler's or Bryan's angles. The latter are the known angles of rotation around the axes of a reference system attached to the moving body (roll, pitch and yaw), used in (aero) ship dynamics. Next, Bryan angles and homogeneous transformation matrices, known from robotics, are used.

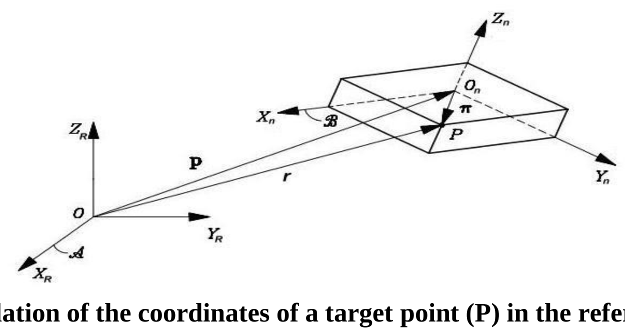


Fig.5.20. The calculation of the coordinates of a target point (P) in the reference system $X_RY_RX_R$ depending on the one attached to the body ($X_nY_nX_n$) belongs to P

In general, the position of the triad $X_nY_nX_n$, *in relation to* $X_RY_RX_R$ *it is the result of some translations combined with elementary rotations, which are mathematically defined, through homogeneous transformation matrices (MTO), the orientation of the mobile trihedral relative to the reference one. The coordinates of point P (figure 5.20), in the reference system, are the result of the matrix product:*

$$\begin{bmatrix} X_R \\ Y_R \\ Z_R \\ 1 \end{bmatrix} = R_{T_n} \cdot \begin{bmatrix} X_n \\ Y_n \\ Z_n \\ 1 \end{bmatrix} \tag{5.16}$$

For example, mobile system translation, $x_1y_1z_1$ *with the distance z, along the z-axis of the system xyz has the matrix:*

$$xyz_{T_{x_1y_1z_1}} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5.17}$$

A rotation of the mobile system, $x_1y_1z_1$ *around the x-axis of the system xyz has the matrix:*

$$x_1y_1z_{1_{T_{x_2y_2z_2}}} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos\alpha & -sin\alpha & 0 \\ 0 & sin\alpha & cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5.18}$$

The general displacement of the mobile system results from the combination of the elementary ones, by multiplying the related matrices:

$$R_{T_n} = \prod_{m=1}^{n}(m-1)_{T_m} = 0_{T_1} \cdot 1_{T_2} \cdot 2_{T_3} \dots \tag{5.19}$$

Customizing the coordinate $z_{Qt} = 0$, *equations (5.22) become:*

$$\begin{aligned} x_{QR} &= x_{Qt} \\ y_{QR} &= y_{Qt}cos\alpha \\ z_{QR} &= y_{Qt}sin\alpha + C + d \end{aligned} \tag{5.22*}$$

Equations (5.22*) show that rotating the tablet around the x-axis does not influence the horizontal dimensions of the image ($x_{QR} = x_{Qt}$), *instead, it amplifies the vertical dimensions by the factor* $(cos\alpha)^{-1}$. *This does not influence the parameters monitored in the near and semi-distance tests, i.e. interpupillary distance and convergence.*

Completely different is the situation of rotating the tablet around the z axis, which can occur when the tablet is held in the hand. In this case, equation (5.21) becomes:

$$\begin{bmatrix} x_{QR} \\ y_{QR} \\ z_{QR} \\ 1 \end{bmatrix} = \begin{bmatrix} cos\gamma & -sin\gamma & 0 & 0 \\ sin\gamma & cos\gamma & 0 & 0 \\ 0 & 0 & 1 & C+d \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{Qt} \\ y_{Qt} \\ z_{Qt} \\ 1 \end{bmatrix} \tag{5.23}$$

After multiplying the matrices from (5.23), it results:

$$\begin{aligned} x_{QR} &= x_{Qt}cos\gamma - y_{Qt}sin\gamma \\ y_{QR} &= x_{Qt}\,sin\gamma + y_{Qt}cos\gamma \end{aligned} \tag{5.24}$$

$$z_{QR} = z_{Qt} + C + d$$

The result shows that ensuring the horizontal position of the tablet is essential and that it must be checked and adjusted including on the optomechatronic device, before making determinations. In the case of the current method, this angular deviation is difficult to observe with the naked eye, the tablet being held in the patient's hand, which prevents an adequate incidence of the optometrist's gaze.

At a rotation with 3°, are obtained $|\Delta x| = 1{,}56\ mm, respectively\ |\Delta y| = 1{,}83\ mm\ and\ \Delta_3 = 2{,}4\ mm.$

This deviation is impossible when using the device and unlikely even when capturing the image "from the hand", because the difference in height of the corners of the tablet, on the opposite sides, is visible, having a value of 12.7 mm.

To determine the interpupillary distance in the 3 use positions of the device, the photos are analyzed, determining the number of pixels of the segment between the patient's pupils and the line of vertical symmetry (figure 5.21).

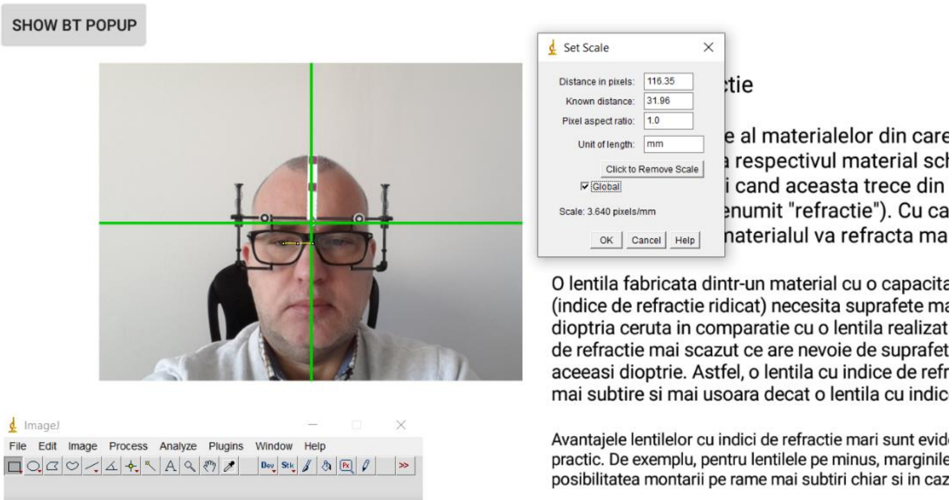


Fig.5.21. Pupillary distance, in pixels, measured in ImageJ, in the right eye (monitor)

In the image plane, the measured right pupillary distance (MPD) is:

$$MpD\ image = 116{,}35 pixels/11{,}77\ pixels/mm = 9{,}88\ \text{mm}.$$

In relation to the object points in figure 5.18, the patient's pupils are located in a plane parallel to that of the markers, behind it, at the distance *d' =10+Vx* (*Vx*- vertex distance of the patient). Since the distance between the monitor and the patient's glasses is 649 mm, the distance between the screen and the plane of the markers is C= 639 mm. Knowing that the patient has vertex distance *Vx=12,5* mm and *d'=22,5* mm, the transverse magnification of the segment measured in the image plane is given by the relation (5.15):

$$\beta_m = -\frac{|\beta| C}{C + d'(1 + |\beta|)} = 0{,}302$$

where: $|\beta| = 0{,}3092$ (monitor). It results that the pupil-object distance of the right eye is:

$$MpD\ object = MpD\ image/\beta_x = 9{,}88/0{,}302 = 32{,}71\ mm$$

In the image plane, the measured left pupillary distance (MpS) is:

$$MpS\ image = 108{,}98 pixels/11{,}77\ pixels/mm = 9{,}26\ mm$$

It results that the pupil-object distance of the right eye is:

$$MpS\ object = MpS\ image/\beta_x = 9{,}26/0{,}302 = 30{,}66\ mm$$

The total interpupillary distance is: $DIP = MpD + MpS = 63{,}37\ mm$, a value very close to the one known by the patient for distance vision, *DIP=63 mm*.

To determine the convergence angle, use the diagram in figure 5.23. Due to the facial asymmetry, frequently encountered when anthropometric measurements are taken the contribution of each eye to the convergence angle is different and requires the measurement of the pupil distance - axis of symmetry of the nose, both for the left eye (MpS) and for the right eye (MpD).

Knowing the two pupillary distances, for the left and the right eye, according to figure 5.23, the convergence angles of each eye are:

$$\theta_S = arctg\frac{MpS}{C+d\prime} = 2{,}65° \tag{5.27}$$

$$\theta_D = arctg\frac{MpD}{C+d\prime} = 2{,}83° \tag{5.28}$$

The total convergence angle is:

$$\theta = \theta_S + \theta_D = 5{,}48° \tag{5.29}$$

In the case of laptop activity, the image was acquired from 450 mm, determining the distances between the right pupil (figure 5.24), respectively the left (figure 5.25) and the vertical line of symmetry, in pixels.
In the image plane, the measured right pupillary distance (MPD) is:

$$MpD\ image = 115{,}06 pixels/11{,}77\ pixels/mm = 9{,}78\ mm.$$

The transversal magnification of the segment measured in the image plane is given by the relation:

$$\beta_l = -\frac{|\beta|C}{C + d'(1 + |\beta|)} = 0{,}304$$

where: $|\beta| = 0{,}3154$ (laptop). It results that the pupil-object distance of the right eye is:

$$MpD\ object = MpD\ image/\beta_x = 9{,}78/0{,}304 = 32{,}16\ mm$$

In the image plane, the measured left pupillary distance (MpS) is:

$$MpS\ image = 107{,}34 pixels/11{,}77\ pixels/mm = 9{,}12\ \text{mm}$$

It results that the pupil-object distance of the left eye is:

$$MpS\ object = MpS\ image/\beta_x = 9{,}12/0{,}304 = 30\ mm$$

The total interpupillary distance is: $DIP = MpD + MpS = 62{,}16\ mm.$
The convergence associated with the transition from the distance of the monitor to that of the laptop is:

- For the right eye: $\boldsymbol{MpD_{mon} - MpD_{lap} = 32,61 - 32,16 = 0,45\ mm}$
- For the left eye: $\boldsymbol{MpS_{mon} - MpS_{lap} = 30,56 - 30 = 0,56\ mm}$

In the case of reading and the laptop position, the image was acquired from $350\ mm$ and $450\ mm$, determining the distances between the right and left pupils and the vertical line of symmetry, in pixels. The pupillary distances for reading and laptop were determined as in the example of the monitor position.

6. EXPERIMENTAL TESTING OF THE PROPOSED DEVICE AND METHOD. COMPARISON WITH OTHER METHODS AND MEANS

6.1. Measurement procedure with the EYE FIT tablet, held in the hand

The existing solution is based on EYE FIT, an image acquisition and processing software, installed on a tablet-type mobile unit, which is manually operated, easy to use by the optician in the optical and optometry offices, and performs the measurement of the patient's individual parameters. The user of the tablet, the optician, must position himself correctly in relation to the patient in order to capture clear images for the measurements. The position of the optician and the patient influences the accuracy of the measurements made. The standard distance from which the patient is posed is $800\ mm$, with the tablet held parallel to him and perpendicular to the ground. Following are two pictures from the profile, taken of the patient at an angle of approximately $25\ degrees$, with the specification that he must look forward (toward infinity), without moving his head. The three captured images serve to determine the remote parameters of the patient.

The picture for close-up measurements is taken standing, with the tablet held by the patient at the patient's reading distance, approximately $350\ mm$. This solution, although easy to use and positioned manually, must be improved by capturing the near and semi-distance image, at different working distances, because it is limited to determining the optometric parameters for distance and near vision. In fact, in the near view, the acquisition of the patient's image is achieved by questionable positioning, in the patient's hands, while standing, which caused a considerable number of complaints (about 27%).

However, the EYE FIT system without a device is limited to the far and near positions, because it is impossible to position the tablet by supporting it with the arms, at least at the monitor distance and possibly for many patients, at the laptop distance.

6.2. Measurement procedure with the EYE FIT tablet, mounted in the device

To more accurately perform close-up measurements at different working distances, the optomechatronic tablet positioning device was built, which ensures the repeatability and stability of the relative position between the patient and the tablet, in three standard working situations: monitor view, laptop and reading The advantage of such a system comes from the elimination of human positioning errors, due to the optometrist or the patient during measurements, because by using this positioning system there is no longer a need to manually handle the tablet, but it will be done automatically with precision. At the same time, errors due to the distance from the patient to the tablet camera are also eliminated because during the measurements the patient will sit in a fixed position in relation to it.

For the stages of determinations required for near and semi-distance vision, the patient is seated on the special chair, with the possibility of height adjustment, and made to look at the tablet mounted in the special support, attached to the arm of the positioning device (figure 6.1). The device is placed on the TT-1060 table (or a fixed one), which has the possibility of adjusting the position vertically.

Fig.6.1. The tablet mounted in the special support, attached to the arm of the device

The position of the tablet must be adjusted in relation to the height of the patient so that the camera is centered on the marker in the center of the patient's frame. Bearing in mind what was demonstrated in chapter 5, regarding the influence of a possible tilt of the tablet through a rotation in its plane, its horizontality is checked as in figure 6.2.

Fig.6.2. Horizontality verification of the tablet

The device is started by pressing the green button (figure 6.3), and it adjusts itself to the start position. The close working distance is chosen after the discussion with the patient and the tablet is positioned according to the patient's distance and height (from the three blue buttons and with the arrows on the tablet screen, for fine-tuning), as shown in the chapter 4, which shows the operation of the device. The close-up picture of the patient is taken (holding down the green button) in the working position mainly used during a day of activity and with all the captured images, the calculations of the individual parameters are carried out.

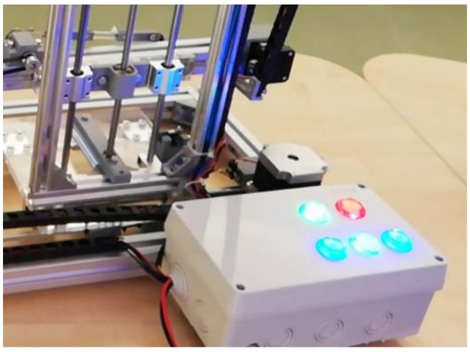


Fig.6.3. Device control panel

The device moves in the three determined working positions in relation to the height of the patient. For the image captured in the write/read position, the device moves the tablet 350 mm from the patient with an inclination of 40 degrees to the horizontal plane. For the image captured in the laptop position, the device moves the tablet 450 mm from the patient with a height calculated according to table 4.1 and an angle of 60 degrees to the horizontal plane of the desk. For the image captured at the monitor position, which is the farthest position from the patient, the device moves the tablet 650 mm away from him with a height also calculated in table 4.1 and with the tablet tilted 75 $degrees$ to the desk.

6.3. Comparison between the results of the measurements made with the EYE-FIT software, with and without the mechatronic system made

For a necessary comparison, which demonstrates the effectiveness of the correct positioning of the powers on the lenses, when using the mechatronic device, a test with several measurements was made for two patients, with the EYE FIT software, in the two measurement postures with the tablet: "in the hand" and "mounted in the device". Holding the tablet in the hand, both by the optometrist, for the distance image, and by the patient, for the close-up image, forces them to capture the images while standing. The near position is not the usual one for activities associated with near vision, i.e. writing/reading, computer work.

It was decided to process the data with the tablet through the EYE FIT program, to be able to draw conclusions regarding the accuracy of the results in the two cases, through the degree of their repeatability.

The tablet and EYE FIT were used to capture the close-up image of the patient in the "hand-held, standing" position, as the measurement is currently performed, and on the same patient, the close-up image was captured using the built-in mechatronic device, in the position "seated" (figure 6.4).

To calibrate the device equipped with the EYE FIT tablet, a mannequin, ruler, and caliper were used to measure the working dimensions (Figures 6.5, 6.6, and 6.7). Pupils were glued to the mannequin to be able to accurately measure distances, and a frame of glasses and pictures were taken to determine the parameters [67]

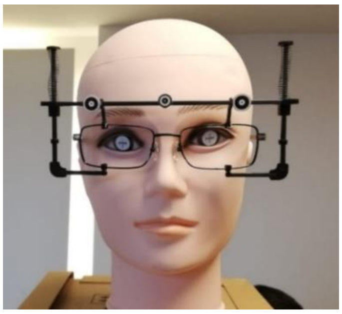


Fig.6.5. Mannequin with pupils, spectacle frame and frame with markers [67]

Fig.6.6. Caliper measurement of mannquin pupillary distance (64.77 mm) [67]

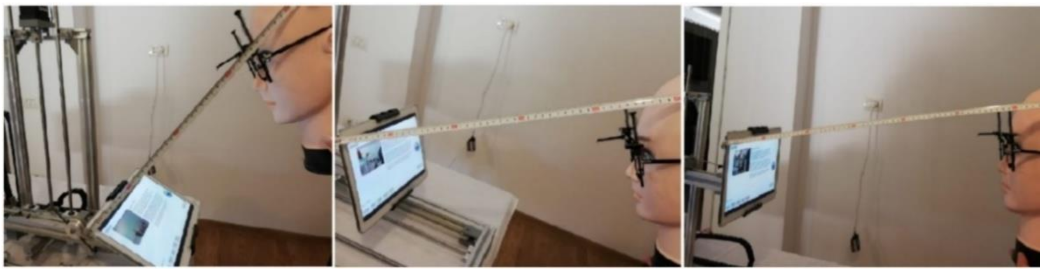


Fig.6.7. Măsurarea cu ruleta a celor trei poziții pentru aproape (350mm/450mm/650mm) a manechinului

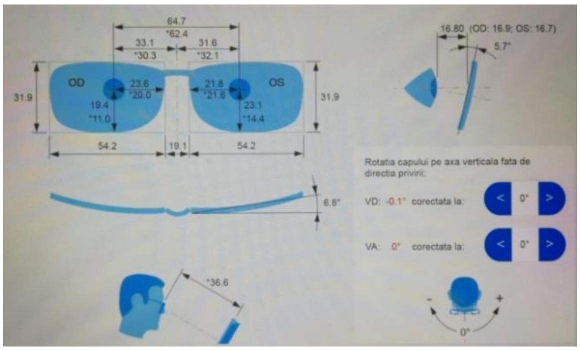
The corresponding results for measuring the dimensions of the mannequin are presented in table 6.1.

PARAMETERS	MEASUREMENTS [mm]
Pupillary Distance[PD]	**64.77**
Vertex Distance	**OD: 17 / OS: 16.8**
Reading distance	**36.5**
Nasal bridge	**19.16**

Tabel 6.1. The results of the mannequin parameters measurements with caliper and roulette[67]

The images of the mannequin were acquired with the tablet in the device (figure 6.7) and processed with the Eye Fit program, according to the algorithms implemented by the software developer - Centwins SRL - Bucharest. Initial testing of the software was done in their labs on mannequins as well as human subjects, without the mechatronic positioning device. The program's algorithms process images, and isolate key points related to markers, the position of the patient's pupils, and the chosen frame, managing to count the number of pixels and convert it into distances measured in millimeters, as a way of measuring the necessary parameters. The measurements for the mannequin were made with the caliper and the roulette, and for the human subjects, mechanical and electronic rulers and pupil dismeters were used, for comparison with the results of the image processing. A series of eyeglass frames were also measured and taken into account for the accuracy of the results.

After performing measurements with Eye Fit, for the mannequin, the following dimensions of optometric parameters resulted in values very close to those measured mechanically (table 6.2).



						* Dimensions for near vision		
Dip:	64.7	mm	BH:	31.9	mm	*Dip:	62.4	mm
MpD:	33.1	mm	BL:	54.2	mm	*MpD:	30.3	mm
MpS:	31.6	mm	Br:	19.1	mm	*MpS:	32.1	mm
PpD:	23.6	mm	Vx:	16.8	mm	*PpD:	20.0	mm
PpS:	21.8	mm	VxOD:	16.9	mm	*PpS:	21.0	mm
HD:	19.4	mm	VxOS:	16.7	mm	*HD:	11.0	mm
HS:	23.1	mm	UP:	5.7	°	*HS:	14.4	mm
			UC:	6.8	°	Reading distance:	*36.5 cm	

Tabel.6.2. Measurements results with Eye Fit [67]

The experiments with patients started with a comparison of how the two support the tablet for the reading/writing position, if they are standing. As can be seen from figure 6.8, for the two patients, the position of the tablet has variations in the eye-tablet distance and the tilt angle, depending on the patient's posture, which creates a variation in the height of the progression channel and convergence on each eye.

In conclusion, the fixed position adopted by the patient when using the device is more correct vis-à-vis the use of the lens, and the power distribution on the surface of the lens is built according to the movements of the eyeball for these working distances.

For comparison, some 20 determinations were made for each patient, for near vision, in the current version, with the tablet held in the hand, respectively mounted in the device (figures 6.9 and 6.10). The results of these determinations are presented in tables 6.2 and 6.3.

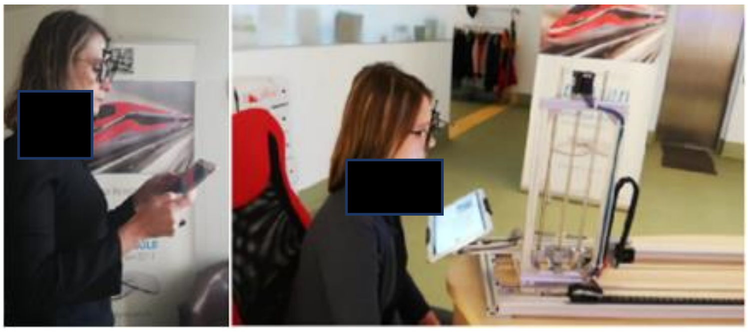


Fig.6.9. The first patient: the reading distance without and with the optomechatronic device

No.	Reading distance (mm)	Progression channel height OD / OS (mm)	Convergence OD / OS (mm)
1	349	15.6/14.9	1.5/1.2
2	350	15.4/14.6	1.3/1.0
3	343	16.8/16.1	2.0/1.7
4	348	17.5/17.2	1.6/1.3
5	347	17.2/16.7	1.6/1.4
6	350	15.8/15.1	1.5/1.3
7	345	16.3/15.8	1.8/1.5
8	352	15.5/14.8	1.3/1.0
9	346	17.5/16.8	1.9/1.6
10	350	16.1/15.6	1.6/1.4
11	349	15.9/15.4	1.7/1.5
12	351	15.1/14.7	1.4/1.0
13	344	17.0/16.5	1.9/1.6
14	344	17.1/16.7	2.0/1.7
15	348	17.9/17.2	1.8/1.4
16	347	17.8/17.3	1.8/1.6
17	349	16.1/15.8	1.8/1.4
18	350	16.3/16.0	1.7/1.5
19	346	17.0/16.6	2.0/1.7
20	349	16.1/15.9	1.9/1.6

a) without device

No.	Reading distance (mm)	Progression channel height OD / OS (mm)	Convergence OD / OS (mm)
1	342	15.9/15.2	1.9/1.5
2	348	15.3/14.7	1.5/1.2
3	346	15.5/15.0	1.7/1.4
4	340	16.0/15.4	2.0/1.6
5	346	15.5/15.0	1.7/1.4
6	348	15.3/14.7	1.5/1.2
7	342	15.9/15.2	1.9/1.5
8	346	15.5/15.0	1.7/1.4
9	348	15.3/14.7	1.5/1.2
10	346	15.5/15.0	1.7/1.4
11	350	15.1/14.3	1.4/1.1
12	348	15.3/14.7	1.5/1.2
13	348	15.3/14.7	1.5/1.2
14	346	15.5/15.0	1.7/1.4
15	348	15.3/14.7	1.5/1.2
16	342	15.9/15.2	1.9/1.5
17	348	15.3/14.7	1.5/1.2
18	346	15.5/15.0	1.7/1.4
19	350	15.1/14.3	1.4/1.1
20	348	15.3/14.7	1.5/1.2

b) with the device

Tabel 6.2. Measurements results with the tablet for the first patient: a) without device and b) with the device

The conditions and the results of the measurements performed show greater variations in the version without the device (standing), than in the one with the device: a) a $22\,mm$ variation in the reading distance; $1.6\,mm$ for the height of the progression channel; $0.7\,mm$ convergence difference; b) a variation of $8\,mm$ in the reading distance; 0.8 mm for the height of the progression channel; $0.5\,mm$ difference in convergence.

It is noted the lack of repeatability of the results in case a), where the data obtained at the distance of $349\,mm$ are 4 times different, while in case of b), all 8 results for the distance of $348\,mm$ are identical.

In the following, the results of the measurements for the individual parameters of the near and semi-distance zone, for the patient George Baboianu, obtained with the optomechatronic device built for this purpose (figures 6.11, 6.12 and 6.13) are presented.

Fig.6.11. The parameters measured in the "writing/reading" position

Fig.6.12. The parameters measured in the "laptop" position

Fig.6.13. The measured parameters in the "monitor" position

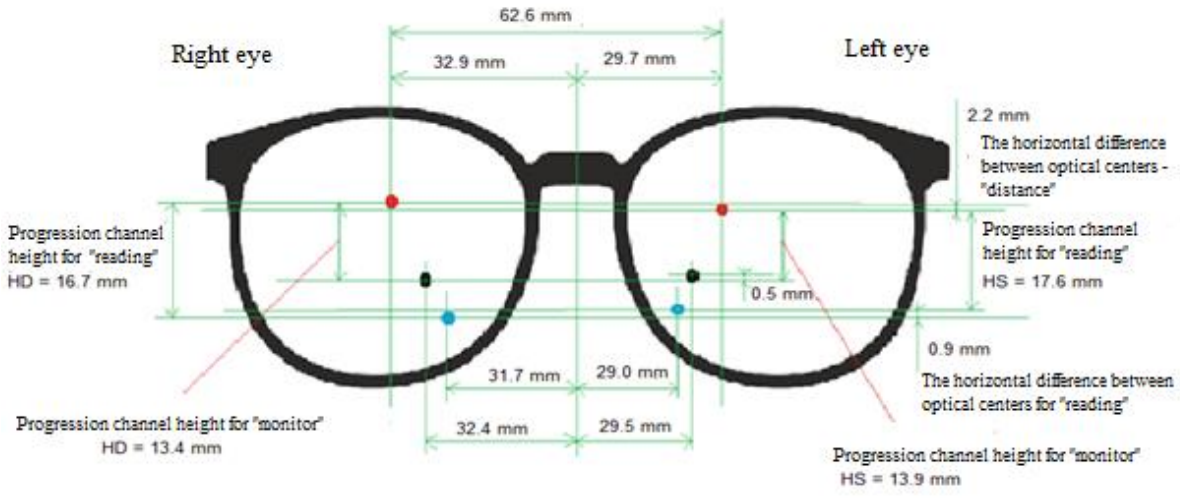


Fig.6.14. The positioning of the optometric parameters in the construction of the personalized progressive lens – patient George Baboianu

To complete the specific determinations of the patient G. Baboianu, the capabilities of the EYE FIT program were used, to position the specific optometric parameters for the construction of the personalized progressive lens (figures 6.14, 6.15 and 6.16). Their comparative values are summarized in table 6.4. It should be noted that, until this research, EYE FIT did not provide data regarding vision at laptop and monitor distances**.**

DIP infinite	DIP read EyeFit	DIP read-device	DIP laptop-device	DIP monitor-device
62.6 mm	**60.7 mm**	**60.2 mm**	**61.2 mm**	**61.9 mm**
OD 32.9 OS 29.7	**OD 31.7 mm OS 29.0 mm**	**OD 31.3 mm OS 28.9 mm**	**OD 32.0 mm OS 29.2 mm**	**OD 32.4 mm OS 29.5 mm**
Working distance	**372 mm**	**356 mm**	**451 mm**	**649 mm**
Progression channel height	**OD 16.7 mm OS 17.6 mm**	**OD 16.9 mm OS 17.8 mm**	**OD 15.3 mm OS 16.0 mm**	**OD 13.4 mm OS 13.9 mm**

Tabel.6.4. The parameters measured for close up in the three working positions – George Baboianu

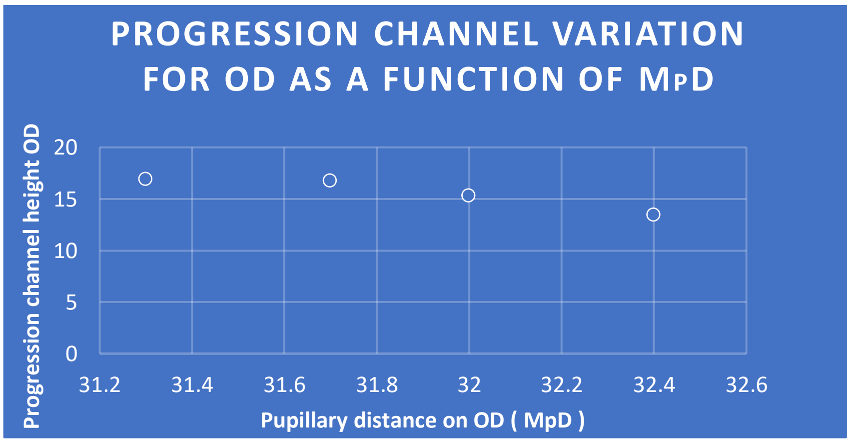


Fig.6.15. Height variation of the progression channel according to the MPD, for OD (right eye)

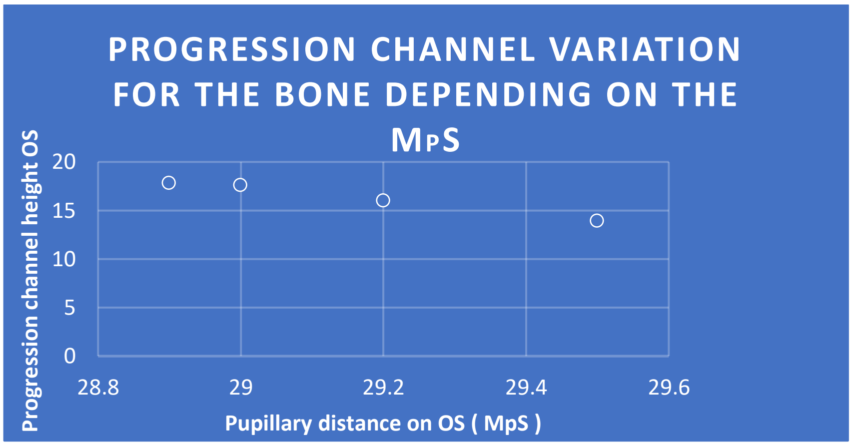


Fig.6.16. Height variation of the progression channel according to MpS, for OS (left eye)

From the measurement results for the patient George Baboianu, a variation of the DIP interpupillary distance is observed, depending on the eye-tablet distance and the measurement method:

1. Eye Fit, without device (standing position) - "the reading" distance $= 60.7\ mm$
2. Eye Fit, with device - "the reading" distance $= 60.2\ mm$
3. Eye Fit, with device - "laptop" distance $= 61.2\ mm$
4. Eye Fit, with device - "monitor" distance $= 61.9\ mm$

The DIP variation between the "reading" position measured with the hand-held tablet and the "reading" position measured with the optomechatronic device, both through the Eye Fit program, is $0.5\ mm$, which logically shows the importance of the device. In addition, this is the only alternative to evaluate these parameters for the "laptop" and "monitor" positions. Thus, the DIP variation between the "read" and "monitor" positions can be measured by using the optomechatronic device, which is $1.2\ mm$.

Another important conclusion is that the height of the progression channel varies according to the working distance of the patient, thus:

1. Eye Fit, without device - "the reading" distance - OD $= 16.7\ mm/$OS $= 17.6\ mm$
2. Eye Fit with device - "the reading" distance - OD $= 16.9\ mm/$ OS $= 17.8\ mm$
3. Eye Fit with device - "laptop" distance - OD $= 15.3\ mm/$ OS $= 16.0\ mm$
4. Eye Fit with device - "laptop" distance - OD $= 15.3\ mm/$ OS $= 16.0\ mm$

The variation of the height of the progression channel between the "reading" position measured with Eye Fit and the "reading" position measured with the optomechatronic device is for OD $= 0.2\ mm$ and OS $= 0.2\ mm$.

Another piece of information, unavailable until the device was made, is the variation in the height of the progression channel between the "reading" and the "monitor" position, measured with the optomechatronic device, having the values for OD $= 3.3\ mm$ and OS $= 3.7\ mm$.

The experiment involved measurements on approximatively 30 people, primarily by taking the close-up picture from the "standing" position, as is currently done to measure the patient's close-up parameters. Then, for each person, the built device was used, to be able to take the measurements from the "seated" position, with the positioning of the tablet in the three established working positions. Next, the measured values for three subjects are presented, which have larger asymmetries and require custom progressive lens construction.

The results of the measurements, which were presented, as well as those that did not signal important asymmetries, highlighted the need for the optomechatronic device designed for the correct achievement of the optical power progression of the progressive lens, in the "near" and semi-distance vision areas.

6.4. Results verification by measurements made with other devices for evaluating individual parameters

The Eye Fit tablet was used to test a number of approximately 30 people of different ages and work activities observing differences in the positioning of the pupillary projection, when changing the working distance in the near area.

To begin with, the subject of testing individual parameters was the author of the thesis, using several existing computing and image processing systems – Essilor, Zeiss, Hoya, and of course EYE FIT. It started with the measurement of interpupillary distance (IDP) at infinity with a digital pupil dismeter, which can measure both right-eye and left-eye ranges.

Fig.6.26 Interpupillary distance measured with the electronic pupildismeter (George Baboianu)

As can be seen from figure 6.26, the interpupillary distance of the subject is $63\ mm$, with the specification that the interval of the right eye measures $33\ mm$, and the interval of the left eye is $30\ mm$. These values define an important asymmetry, of about 5%, so that, when determining the rest of the individual parameters, special attention must be paid.

Using the Zeiss tablet, only two pictures were taken, one from the front with the tablet held parallel to the patient at about $800\ mm$ and the second from the side at a $90 - degree\ angle$. No close-up picture was taken. Progression canal height and convergence are not measured with this device. As can be seen in figure 6.27, only the parameters for the distance and the dimensions of the spectacle frame are measured. A lens marked with the circle to be read is positioned on the captured picture and by fitting it into the frame of the glasses, the height of the progression channel of the lens to be ordered is determined (fig. 6.28).

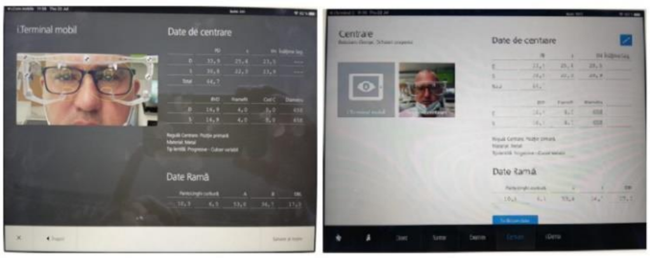


Fig.6.27 The parameters measured with Zeiss tablet

With the tablet from Hoya, two pictures were taken, front and profile (figure 6.30). The associated software evaluates the individual parameters at a distance, and the height of the progression channel is chosen according to the size of the frame, the dioptric power of the patient, the addition, and what height of the progression channel he previously wore is taken into account.

Fig.6.30 Parameters measured with Hoya tablet

For comparison, the fourth measurement of the author's parameters was made with the Eye Fit tablet from the Nova Lenti company, that is, the one used by the author in his current activity. The measurements were made in the medical office, by a qualified person. He acquired the first image from the front, from a distance of about 800 mm, two images from the profile, left and right, and one close-up with the tablet held in his hand, in the standing position. The Eye Fit tablet calculates all the individual parameters for distance, near and spectacle frames. The measurements made with this are the most comprehensive for building highly customized progressive lenses (figure 6.31).

						Dimension for near vision		
Dip:	62.6	mm	BH:	36.0	mm	*Dip:	*60.7	mm
MpD:	32.9	mm	BL:	52.3	mm	*MpD:	*31.7	mm
MpS:	29.7	mm	Br:	17.7	mm	*MpS:	*29.0	mm
PpD:	24.1	mm	Vx:	13.65	mm	*PpD:	*21.8	mm
PpS:	20.5	mm	VxOD:	15.3	mm	*PpS:	*19.2	mm
HD:	19.9	mm	VxOS:	12.0	mm	*HD:	* 3.2	mm
HS:	22.1	mm	UP:	9.8	°	*HS:	* 4.5	mm
			UC:	7.1	°	Reading distance *	37.2 cm	

Fig.6.31 The parameters measured with Eye Fit tablet

Legend: Dip = interpupillary distance; MpD = interpupillary distance for the right eye; MpS = interpupillary distance for the left eye; Vx = vertex distance (cornea to lens); HD, HS = mounting height; BH = frame height; BL = frame length; Br = nasal bridge; UP = pantoscopic angle; UC = curvature angle of the frame

INDIVIDUAL PARAMETERS	MEASUREMENTS [mm] ZEISS	MEASUREMENTS [mm] ESSILOR	MEASUREMENTS [mm] HOYA	MEASUREMENTS [mm] EYE FIT/ Nova Lenti
Interpupillary distance [DIP]	**64,7**	**65,4**	**63,8**	**62,6**
Pupillary distance [MpD/MpS]	**OD: 33,9 / OS: 30,8**	**OD: 33,5 / OS: 31,9**	**OD: 34,3 / OS: 29,5**	**OD: 32,9 / OS: 29,7**

Mounting height	**OD: 25,4 / OS: 22,3**	**OD: 20,8 / OS: 21,3**	**OD: 23,3 / OS: 24,3**	**OD: 19,9 / OS: 22,1**
Nasal bridge	**17.3**	**17.2**	**16.5**	**17.7**
Anou lenght	**53.0**	**52.9**	**53.9**	**52.3**
Anou height	**36.7**	**36.9**	**36.6**	**36.0**
Pantoscopic angle	**10.3 grd**	**7 grd**	**9.3 grd**	**9.8 grd**
Frame curvature radius	**6.5 grd**	**4 grd**	**6.1 grd**	**7.1 grd**

Tabel 6.12 The results comparison of of the measurements made with the four tablets

From the analysis of the parameters presented in table 6.12, measured with the four devices, it can be seen which measurement is closer to the one performed with the pupil dismeter, the device with which the interpupillary distance is most accurately determined, respectively the Eye Fit tablet. Each tablet has its peculiarities, for the calculation of the parameters, each tablet captures several pictures from various positions of the patient, corresponding to the algorithms on which the own software is based, to determine the individual parameters that serve to construct personalized progressive lenses, for patients who they have facial asymmetries and cannot wear a standard lens.

7. CONCLUSIONS. ACHIEVEMENT OF OBJECTIVES. FUTURE RESEARCH DIRECTIONS

Daily activities, with a high rate of evolution, accentuated digitization and technological development, make the wearer of glasses a demanding person, with performance claims regarding the lenses and the treatments applied to their surfaces, for protection. It should be specified that many people have facial asymmetries outside the standard area, needing glasses with specially constructed lenses, corresponding to anatomical parameters, so that wearing glasses brings visual benefits.

Specialists in optics perform the act of consultation to high standards, with the help of advanced digital devices, for a correct solution to the personalized behavioral optometry of the patient. The agreed solutions are consistent with the predominant activities and the measured optometric parameters.

Digital measuring and control devices are in continuous development, testing, and research, reaching performances that guarantee a tenth of an millimeter. Lens suppliers in the optical market develop different testing solutions for maximum results. For a clear image and a correct perception of the viewed objects, the optical centers of the progressive lenses must be built perfectly on the pupillary projections of the eyes. Any deviation of the parameters in the construction of the lens produces a blurred image for the patient and discomfort in wearing the glasses. The most well-known aberration, formed on the surface of the lens, is a prismatic aberration, which makes the image of the viewed object diffuse, causing dizziness and pain felt in the eyeballs. This aberration occurs when the optometric parameters are incorrectly positioned in the construction of the glasses, it being imperative to correctly fit the lenses, in the patient's pupillary projections with strict observance of the DP and the height of the progression channel.

To have precise results of the lenses constructive parameters, the companies providing optical products have developed numerous measuring devices. The best-performing devices can also be found in optical offices in Romania, these being static devices - fixed, or mobile devices - tablets, which include special software for measuring the patient's optometric parameters. The images captured by these devices are processed, and each pixel is evaluated and transformed into a unit of $length - mm$. One of the situations that pose measurement problems for the devices would be the patient's position for near and semi-distance work activities. In the framework of the thesis, it was demonstrated that the existing devices do not include such positioning of the patient for the near and semi-distance zone, with clear working distances ($350\ mm, 450\ mm, 650\ mm$) – reading, laptop, monitor. The devices at the lens suppliers have, for the most part, the facility of performing a single measurement performed in the "standing" position of the patient, which, from the point of view of similarity, the conditions of use during a working day, has an infinitesimal probability, in office work. Therefore, the determination of the parameters for the construction of progressive glasses, in conditions different from those of the activity, can lead to measurement deviations that exceed a tenth of an mm. Individual parameters are introduced in the processing and deposition of power on the surface of the progressive lens, and the deviation of several tenths of mm creates discomfort for the wearer. This situation requires accurate measurement for a clear view.

Glasses with progressive lenses, according to statistics, are used in more than 90% of cases, sitting in the "sitting" position. During the construction of the optomechatronic device, these aspects were taken into account, and the coverage of a niche not solved by the current systems, measuring the individual parameters of the patient, for the three working distances (reading, laptop, monitor) with precision and repeatability.

It has been proven that testing the patient in the "seated" position in front of the optomechatronic device, at fixed working distances, helps capture images with more precision, implicitly the pupil positions for a correct construction of progressive lenses. From the image captures performed on test subjects, it has been observed that the repeatability and accuracy of measurements are clearly superior when using the optomechatronic device.

In conclusion, the constructed optomechatronic device helps to perform more accurate measurements for near and mid-distance, vis-à-vis the posture of the patient sitting at a fixed distance, specific to the office work position.

7.1. Achieved objectives

The optomechatronic device is designed and made, operating within the proposed parameters, namely three degrees of freedom for positioning the tablet depending on the patient's height, at predetermined distances, depending on the patient's work activity - reading, laptop, monitor (350 mm, 450 mm, 650mm).

The necessity of the device was demonstrated by repeated measurements on several subjects, **that there are differences** in the positioning of the optical centers on the progressive lens, which create accommodation problems when they are not taken into account or are not measured correctly. **Measurements** of optometric parameters help to make a personalized progressive lens for the patient with facial asymmetries and close work activity, where they have to cover more distances. If a good positioning of the optical centers of the lens is not obtained, prismatic aberrations are formed on its surface, with consequences regarding the clarity of the image. Aberrations due to inaccurate measurements are greater on the surface of the lens the higher the diopter the patient wears. **The tests made on different**

subjects showed a constancy of the working distances, as well as the results of measuring the optometric parameters. The measured dimensions are of the order of tenths of a millimeter, correct from the point of view of the mounting standards of progressive lenses. In the chapters of the thesis**, it was argued the need to use such a measuring device to more accurately determine the parameters for the construction of a pair of glasses with personalized progressive lenses that confer clarity and comfort**.

The device was mechanically, electrically, and electronically analyzed and dimensioned according to design standards. The controls and electrical actuation work properly, and the device is designed to be used in medical offices to measure the patient's individual parameters, at the recommended working distances, adjustable according to the patient's dimensions.

7.2. Personal contributions and originality

The entire thesis is under the sign of a multidisciplinary approach, in which the quality requirements in the field of optometry are solved with the means of fine mechanics and mechatronics engineering, considering their connection with optometry, through technical optics.

A first personal contribution is a concept of measuring the patient's optometric parameters for near and semi-distance (reading, laptop, monitor), used in the construction of the progressive lens, to obtain comfortable and correctly constructed glasses, without fitting problems.

This idea is the result of a specialized practice, in which the observation of the negative effects of some incorrectly determined parameters, was fundamented, in the thesis, on a study of the methods and means of measuring these parameters, worldwide**.**

The construction of the optomechatronic device for positioning the tablet in the workspace, with the EYE FIT software for measuring individual parameters, for the near area, where existing devices on the market are deficient, is a new and singular concept in the Romanian optics market. There is currently no measuring device in any optician's office to position the patient "seated" and take images of the near area to process them. The calculation of measurements for the near area, with all measuring devices, is carried out in the "standing" position - incorrect for the use of glasses with progressive lenses.

For the optimal use of the device, the coordinates of the position of the center of the tablet were calculated, depending on the height of the patient, provided in a table, in the range of $150 - 200\ cm$, with a ratio of 10. Due to the linear variation, the vertical positioning coordinates at intermediate values of the patient's height can be quickly calculated by linear interpolation.

Using the built optomechatronic device, it was possible to make clear measurements for the movements of the eyeballs in the working positions, for a more appropriate deposition of power on the surface of the lens, which takes these movements into account. The construction of the lens, in which the powers are correlated with the viewing area of close objects, leads to an easier adaptation with progressive glasses and makes the perception of images very clear.

As an element of originality, this optomechatronic device, the only one in existence at the moment, positions a tablet for the three working distances at the desk and performs the measurements according to them, determining the movements of the eyeballs and the position of the patient's pupillary projections through the lenses, with great accuracy.

For the theoretical confirmation of the results, a geometric model of the object-image correspondence was developed, which includes the global transversal magnification of the tablet, optically and electronically. This model has been verified with a different software than EYE FIT, which confirms its usefulness through the results obtained with the author's optometric data, resulting from images.

The research results were disseminated, during the development of the thesis, through publications:

1. G. Baboianu, C. Nitu, C.D. Comeaga, *Current State of Anthropometric Parameters Measurement with Relevance for Advanced Lens Optometric Compensation*, Proc. of the Intl. Conf. of Mechatronics and Cyber-MixMech., pp. 138-148, September 2018.

2. G. Baboianu, C. Nitu, C.D. Comeaga, *Processing of captured digital images for measuring the optometric parameters required in the construction of ultra-personalized special lenses*, Proc. of the Intl. Conf. of Mechatronics and Cyber-MixMech., September 2019.

3. G. Baboianu, Niță I.E, C.D Comeagă, *Measurement of anthropometric parameters using opto-mechatronic positioning system,* The 12 International Symposium on Advanced Topics in Electrical Engineering – March 25-27, 2021.

7.3. Future research directions

The built optomechatronic device is an experimental model and there are some aspects to improve, especially regarding the dimensions, it is built from aluminum profiles with long lengths, to cover possible unforeseen values of the strokes. Also, a problem to be solved would be the possibility of adjusting the height of the device, with adjustable legs, for easier positioning in front of the patient, if the TT-1060 table is eliminated, which constitutes an additional cost, if does not exist in the cabinet.

The materials from which this device can be built can be more environmentally friendly, and you can also opt for a marketed and ergonomic shape and design specific to medical office equipment.

This device can be built to perform patient pictures for all distances, with high accuracy in measurements and calculations, with the incorporation of motion sensors and detection of the patient's physiognomy, with better-performing cameras for capturing images and last but not least, motors much quieter and more efficient.

The device could be completely detached from the EYE FIT software by researching the applicability of the camera model for distance vision or developing another model.

BIBLIOGRAPHY

1. Dumitrescu N., *Bazele opticii fiziologice*, Ed. Politehnica, Bucureşti, 1991.
2. Flitcroft DI., *The Complex Interactions of Retinal, Optical and Environmental Factors in Myopia Aetiology*. Prog Retin Eye Res 2012;31:622–60.
3. Grupul de experți în pierderea vederii din cadrul studiului Global Burden of Disease. *Cauzele orbirii și deficiențelor de vedere în 2020 și tendințe peste 30 de ani: evaluarea prevalenței orbirii evitabile în raport cu „VIZIUNEA 2020: dreptul la vedere”.* Lancet Global Health 2020. doi.org/10.1016/S2214-109X(20)30489-7.
4. Grupul de experți în pierderea vederii din cadrul studiului Global Burden of Disease. *Tendințe în prevalența orbirii și a tulburărilor de vedere la distanță și aproape de peste*

30 de ani: o analiză pentru Studiul Global Burden of Disease. Lancet Global Health 2020. doi.org/10.1016/S2214-109X(20)30425-3.

5. Fricke, TR, Tahhan N, Resnikoff S, Papas E, Burnett A, Suit MH, Naduvilath T, Naidoo K, *Prevalența globală a prezbiopiei și afectarea vederii din cauza prezbiopiei necorectate*; revizuire sistematică, meta-analiză și modelare, oftalmologie. 9 mai 2018.
6. Grosvenor T., *Primary Care Optometry* 5th ed. Philadelphia: Butterworth Heinemann Elsevier; 2007.
7. https://www.statista.com/statistics/711514/individuals-who-wear-spectacles-in-selected-european-countries/ , Pagină vizitată la data de 03.04.2021
8. Mutti DO, Zadnik K., *Is Computer Use a Risk Factor for Myopia?* J Am Optom Assoc 1996;67:521–30.
9. Ciuffreda KJ, Vasudevan B., *Nearwork-induced Transient Myopia (NITM) and Permanent Myopia—Is There a Link?* Ophthalmic Physiol Opt 2008;28:103–14.
10. Winawer J, Wallman J., *Temporal Constraints on Lens Compensation in Chicks.* Vision Res 2002;42:2651–68.
11. Fowler CW, Sullivan CM. A comparison of three methods for the measurement of progressive addition lenses. Ophthalmic Physiol Opt. 1989;9:81Y85.
12. Fowler CW, Sullivan CM. Automatic measurement of varifocal spectacle lenses. Ophthalmic Physiol Opt. 1990; 10:86Y89.
13. Ting PW, Schmid KL, Lam CS, et al., *Objective real-time measurement of instrument myopia in microscopists under different viewing conditions.* Vision Res. 2006;46: 2354Y2362.
14. T. L. Alvarez, E. H. Kim, and B. Granger-donetti, “Adaptation to Progressive Additive Lenses : Potential Factors to Consider,” no. April, pp. 1–14, 2017.
15. https://www.grandviewresearch.com/industry-analysis/prescription-lens-market/segmentation , Pagină vizitată la data de 04.04.2021
16. https://www.maximizemarketresearch.com/market-report/global-optical-lenses-market/62768/ , Pagină vizitată la data de 04.04.2021
17. https://datareportal.com/reports/digital-2020-romania, Pagină vizitată la data de 04.04.2021
18. Gresset J., *Subjective evaluation of a new multi-design progressive lens.*J Am Optom Assoc 1991;62:691–8.
19. Stengel-Rutkowski S., Schimanek P., (1985), *Chromosomalemed nicht chromosomale dysmorphie syndrome*, Enke Verlag, Stuttgardt
20. Rosenfield M., *Computer Vision Syndrome: A Review of Ocular Causes and Potential Treatments*. Ophthalmic Physiol Opt 2011;31:502–15.
21. Armstrong RA., *When to Use the Bonferroni Correction*. Ophthalmic Physiol Opt 2014;34:502–8.
22. Sullivan CM and Fowler CW. Grating visual acuity testing as a means of psychophysical assessment of progressive addition lenses. Optom Vis Sci 1989;66:565-72.
23. Blehm C, Vishnu S, Khattak A, et al. Computer Vision Syndrome: A Review. Surv Ophthalmol 2005;50:253–62.
24. Gratton I, Piccoli B, Zaniboni A, et al. Change in Visual Function and Viewing Distance during Work with VDTS. Ergonomics 1990;33:1433–41.

25. G. Baboianu, C. Nitu, C.D. Comeaga, *Current State of Anthropometric Parameters Measurement with Relevance for Advanced Lens Optometric Compensation*, Proc. of the Intl. Conf. of Mechatronics and Cyber-MixMech., pp. 138-148, September 2018.
26. Jalie, M. (1977): *The Principles of Ophthalmic Lenses*. 3 Edn. Hazell Watson and Viney Ltd, Aylesbury, Bucks, 512pp.
27. Băcescu D. *Optică Aplicată. Analiza şi sinteza componentelor.* Editura MEDRO Bucureşti 2004.
28. Yeow PT, Taylor SP. *Effects of Short-term VDT Usage on Visual Functions.* Optom Vis Sci 1989;66:459–66.
29. Fannin TE, Grosvenor T. *Clinical Optic.* 2nd ed. Boston, MA: Butterworth-Heinemann; 1996;67Y73, 214Y230.
30. Y. Tang, Q. Wu, L. Qian, and L. Liu, *Design of personalized progressive addition lenses*, Optics and Prec. Eng., vol. 20, pp. 2638-2644, December 2012.
31. Sheedy JE, Buri M, Bailey IL, et al. *Optics of progressive addition lenses.* Am J Optom Physiol Opt 1987;64:90-9.
32. Sullivan CM and Fowler CW. Analysis of a progressive addition lens population. Ophthalmic Physiol Opt 1989;9:163-70.
33. Sullivan CM, Fowler CW. Reading addition analysis of progressive addition lenses. Ophthalmic Physiol Opt. 1991; 11:147Y155.
34. Uemura T, Arai Y, Shimazaki C. *Eye-head coordination during lateral gaze in normal subjects.* Acta Otolaryngol 1980;90:191-8.
35. Selenow A, Bauer EA, Ali SR, et al. *Assessing visual per-formance with progressive addition lenses.* Optom Vis Sci 2002;79:502-5
36. https://www.slideshare.net/GauriSShrestha/progressive-addition-lens1 , Pagină vizitată la data de 04.04.2021
37. J. Forkel, J.L. Reiniger, A. Muschielok, A. Welk, and A. Seidemann, *Personalized Progressive Addition Lenses: Correlation between Performance and Design , Optometry and Vision Science*, vol. 94, issue 2, pp. 208-218, February 2017.
38. Pedrono C, Obrecht G, Stark L. *Eye-head coordination with laterally "modulated" gaze field.* Am J Optom Physiol Opt 1987;64:853-60.
39. A. K. Mok, C. S. Chung, and T. W. Kwok, *A simple clinical test for perception of progressive addition lens peripheral image blur. A pilot study,* vol. 4, no. 1, pp. 30–34, 2011.
40. M. H. Edwards, R. W. Li, C. S. Lam, J. K. Lew, and B. S. Yu, *The Hong Kong Progressive Lens Myopia Control Study : Study Design and Main Findings,* vol. 43, no. 9, pp. 2852–2858, 2002.
41. S. W. F. Hons, *Optometry Progress in the spectacle correction of presbyopia . Part 1 : Design and development of progressive lenses,* pp. 240–250, 2008.
42. Băcescu D. *Metode informatice avansate în optică şi optometrie.* UPB Note de curs2018
43. Imagimi captate din software-ul de comanda lentile Ital-online, software detinut de compania S.C. Nova Lenti S.R.L. – Bucuresti.
44. C. Kee, T. W. Leung, K. Kan, and C. H. Lam, *Effects of Progressive Addition Lens Wear on Digital Work in Pre-presbyopes,* vol. 0, no. 0, pp. 1– 11, 2018.
45. https://opticampus.com/tolerante la montajul lentilelor aeriene, Pagina vizitata in data 05.04.2021

46. https://jysk.ro/blog/pozitia-corecta-la-birou-sfaturi-pentru-o-postura-sanatoasa, Pagina vizitata in data 05.04.2021
47. Benedetto S, Drai-Zerbib V, Pedrotti M, et al. E-readers and Visual Fatigue. PLoS One 2013;8:e83676.
48. Sheedy J and Shaw–McMinn P. Diagnosing and treating computer-related vision problems. Woburn, Mass.: Butterworth–Heinemann, 2002.
49. Piccoli B, Braga M, Zambelli PL, et al. Viewing Distance Variation and Related Ophthalmological Changes in Office Activities with and without VDUS. Ergonomics 1996;39:719–28.
50. Atchison DA. The Glenn A. Fry Award Lecture 2011: Peripheral Optics of the Human Eye. Optom Vis Sci 2012;89:E954–66.
51. Ophtalmi'x Blog Homepage, https://oftalmix.wordpress.com, Pagina vizitata la data 20.05.2021
52. Service book–Autorefractometrul Plusoptix A12 – www.optimed.ro – Optimed SRL, Brasov
53. Mallen EA, Wolffsohn JS, Gilmartin B, et al. *Clinical Evaluation of the Shin-Nippon SRW-5000 Autorefractor in Adults.* Ophthalmic Physiol Opt 2001;21:101–7.
54. Service book–Autorefractometrul RM 800-Top Con – www.optimed.ro – Optimed SRL, Brasov
55. Kimura S, Hasebe S, Ohtsuki H. *Systematic Measurement Errors Involved in Over-refraction Using an Autorefractor (Grand-Seiko WV-500): Is Measurement of Accommodative Lag through Spectacle Lenses Valid?* Ophthalmic Physiol Opt 2007;27:281–6.
56. Mathur A, Atchison DA. *Peripheral Refraction Patterns out to Large Field Angles.* Optom Vis Sci 2013;90:140–7.
57. https://www.opticvideo.com/e-column/, Pagină vizitată la data 27.05.2021
58. https://www.zeiss.com/vision-care/us/for-eye-care-professionals/products/zeiss-instruments-and-systems/i-terminal-2.html, Pagină vizitată la data 27.05.2021
59. https://www.poleoptical.com/verres/technologie-eyecode/, Pagina vizitata la data 28.05.2021
60. https://www.hoyavision.com/en-ca/what-i-need/for-eye-care-professionals/provide-the-ultimate-customer-experience/, Pagină vizitată la data 28.05.2021
61. Paleu V., *Sisteme de achizitie si interfete* – curs pentru studentii Facultatii de Mecanica – Iasi , 2013
62. Bălan T., Şterbeţi C., *Analiză Fourier – Elemente de Teorie şi Probleme,* Ed. Sitech, Craiova, 2001.
63. www.keyence.com – *Image processing Useful Tips – Compilation* – Tutorial, Pagina vizitata la data de 05.07.2021
64. Vertan C., *Prelucrarea si analiza imaginilor,* Editura Printech, Bucuresti, 1999
65. Carlson G.E., *Signal and Linear System Analysis,* Second Edition, John Wiley & Sons, Inc., New York, 1998.
66. Porat B., *A Course in Digital Signal Processings,* John Wiley & Sons, Inc., New York, 1997.
67. G. Baboianu, C. Nitu, C.D. Comeaga, *Processing of captured digital images for measuring the optometric parameters required in the construction of ultra-personalized*

special lenses, Proc. of the Intl. Conf. of Mechatronics and Cyber-MixMech., September 2019.
68. G. Paizi, N. Stere, D. Lazar, *Organe de mașini și mecanisme,* Editura Didactică si Pedagogică București (1980)
69. Demian T, Tudor D, Curiţa I, Niţu C, - *Bazele proiectarii aparatelor de mecanica fina,* Editura Tehnica Bucuresti (1984-1986)
70. Jula A., ş.a., *Mecanisme şurub piuliţă - îndrumar de proiectare*, Braşov, Editura Lux Libris, 2000.
71. Tudor, A., *Frecarea şi uzarea materialelor,* Ed. Bren, Bucureşti, 2002.
72. Pavelescu D., Radulescu, Gh., Gafitanu, M., Gheorghiu, N., *Organe de maşini,* Editura didactică şi pedagogică, Bucureşti, 1985.
73. Klimov K. I. - *Antifrictionnie plasticiniie cmazki* - Moscova, Himiia, 1988.
74. Kragelsky I. V., Alisin,V. V. – *Friction – Wear – Lubrication* - Ed. MIR., Moscova, 1981.
75. Demian, T. – *Elemente constructive de mecanică fină*, Editura Didactică şi Pedagogică, Bucureşti, 1980.
76. https://www.allaboutcircuits.com/technical-articles/understanding-arduino-unohardware-design/ , Pagină vizitată la data 05.07.2021
77. https://i2.wp.com/www.technobyte.org/wp-content/uploads/2016/08/Arduino-Unomultiple-input-management-circuit-op-amp-comparator-min.jpg, Pagină vizitată la data 05.07.2021
78. http://www.ntu.edu.sg/home/ehchua/programming/arduino/arduino.html, Pagină vizitată la data 06.07.2021
79. https://ro.wikipedia.org/wiki/Arduino , Pagină vizitată la data 06.07.2021
80. G. Baboianu, Niță I.E, C.D Comeaga, *Measurement of anthropometric parameters using opto-mechatronic positioning system*, The 12 International Symposium on Advanced Topics in Electrical Engineering – March 25-27, 2021
81. https://components101.com/microcontrollers/arduino-uno , Pagina vizitata la data de 10.03.2022
82. Getting started with Arduino Uno: https://www.youtube.com/watch?v=zusVAX7bgtA , Pagina vizitata la data de 10.03.2022
83. https://electronics.stackexchange.com/questions/61537/what-is-the-cap-for-inarduino-reset-circuit, Pagina vizitata la data de 10.03.2022
84. https://www.mathworks.com/help/vision/ug/measuring-planar-objects-with-a-calibrated-camera.html;jsessionid=c627065c7b49ba5320b6887b93f8, Pagina vizitata la data de 15.03.2022
85. P. Flores, *Concepts and Formulations for Spatial Multibody Dynamics*, SpringerBriefs in Applied Sciences and Technology, DOI 10.1007/978-3-319-16190-7_4, 2015
86. Drillis R, Contini R. Body Segment Parameters. New York, New York: Office of Vocational Rehabilitation; 1966. Report No.: No. 1166-03
87. https://www.tomey.de/products/tt-1060-tt-4060, Pagina vizitata la data de 15.09.2022