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(Research Article)

Design of an optical sensor system for robots inspired by the human eye

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Abstract

The development of autonomous motion capability by robotic systems, particularly in dynamic environments, is strongly related to the sensor systems installed in the robot. An important feature of these sensors should be their ability to detect the world in the same way as humans do. This paper focuses on the design of a prototype of a robotic eye, or optical sensor, which has functional characteristics similar to those of the human eye and complies with two Degrees of Freedom (DOF) in its movement. In addition to this, the entire design process of the parts is documented with computer-aided design (CAD) support, the manipulation software, and the programming structure used to control it. The performance tests performed and the analysis of the results obtained demonstrate the total fulfillment of the proposed objectives, which were even surpassed.

Keywords: Human Eye; Ocular Movement; Optical Sensor; Prototype; Robotic Eye; Visual Identification

1. Introduction

The most important sense for the human being is sight. It is mainly related to the environment and is a key element in the design of any artificial system [1]. Therefore, when developing an artificial system, such as a robot, that will interact with the human being in human environments, it must have a sensor equivalent to the human eye [2]. In robotics, the actions of the robot are based on the identification of the states of the environment, which are measured by sensors, and are the ones that inform and allow to establish behavioral actions [3, 4].

In the advance of the systems that incorporate a camera in its structure, different interests have been generated, achieving considerable progress in many fields [5]. This shows people's interest in covering different problems that concentrate on electronic components, this has generated great advances at the research level. In general, a particular goal is sought, demonstrated in a diversity of branches, among them medicine for example, contributing several ideas in systems, innovating in instruments, and entering more deeply into the field of bio-medicine [6, 7, 8].

It is important the contribution in services to people and security, where a robot is recreated for the integration in a familiar environment, giving confidence in the home [9]. This same trend is also reflected in technological sectors, building and incorporating new ideas in the improvement of human quality. This is observed in systems such as those present in automobiles, among others [10]. In the great variety of cases in which a camera with a set of mechanisms has been included, and a specific purpose is pursued, considerable performance increases have been achieved [11]. This is how research in robotics is developing, creating, and aggregating several functions that humans have and perform by default.

The human eye's capacity for movement has been evolutionarily decanted over millions of years [12]. The environments designed by the human being contemplate among other aspects this functionality. The approach sought in the prototype

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aims to replicate some of these capabilities, in particular, evaluated through optical tracking. In [13] a similar system is developed, where the movement of the prototype feeds back to the control software, this allows to produce of the movement of the robot in real-time concerning the image to be followed [14]. Problems related to image disturbance and high-speed motion are not initially considered in this research, focusing the efforts of this first stage on the functional problem (mechanical structure) [15].

Thus, like other research used as a basis, the idea was to build a prototype of a robotic eye, starting from the concept of basic movements (such as horizontal and vertical), which represent two degrees of freedom (DOF) [16, 17]. In addition, the coupling of the two movements to generate a circular movement [18]. Lightweight materials are considered in the construction to maximize performance and save costs [19]. It is also designed criterion size, looking for a small archetype in coherence with the sizes of other prototypes developed by the research group, but using standard parts and materials on the market [20].

Since the mechanisms and structures suitable for the functional duplication of eye movements possess capabilities superior to those of the biological model, the design proposal never ruled out the idea of a prototype with superior movement capability to that of the human eye [20, 21]. In this sense, improvements are proposed in the speed of response of the eye, as well as in the angles of movement, allowing an improvement both in dimensions and in the purpose of having the vision system incorporated in a reduced space, and with excellent interaction with the human being [20, 8].

The article is organized as follows. Section 2 presents some preliminary concepts, the functional profile of the prototype, and some other design considerations. Section 3 fully details the design of the robotic eye structure, including selection criteria and adopted final specifications. Section 4 presents the evaluation of the prototype’s performance using a functional model that considers the response speed, operating possibilities, and movement capacity of the prototype. Finally, Section 5 concludes the article.

2. Problem formulation

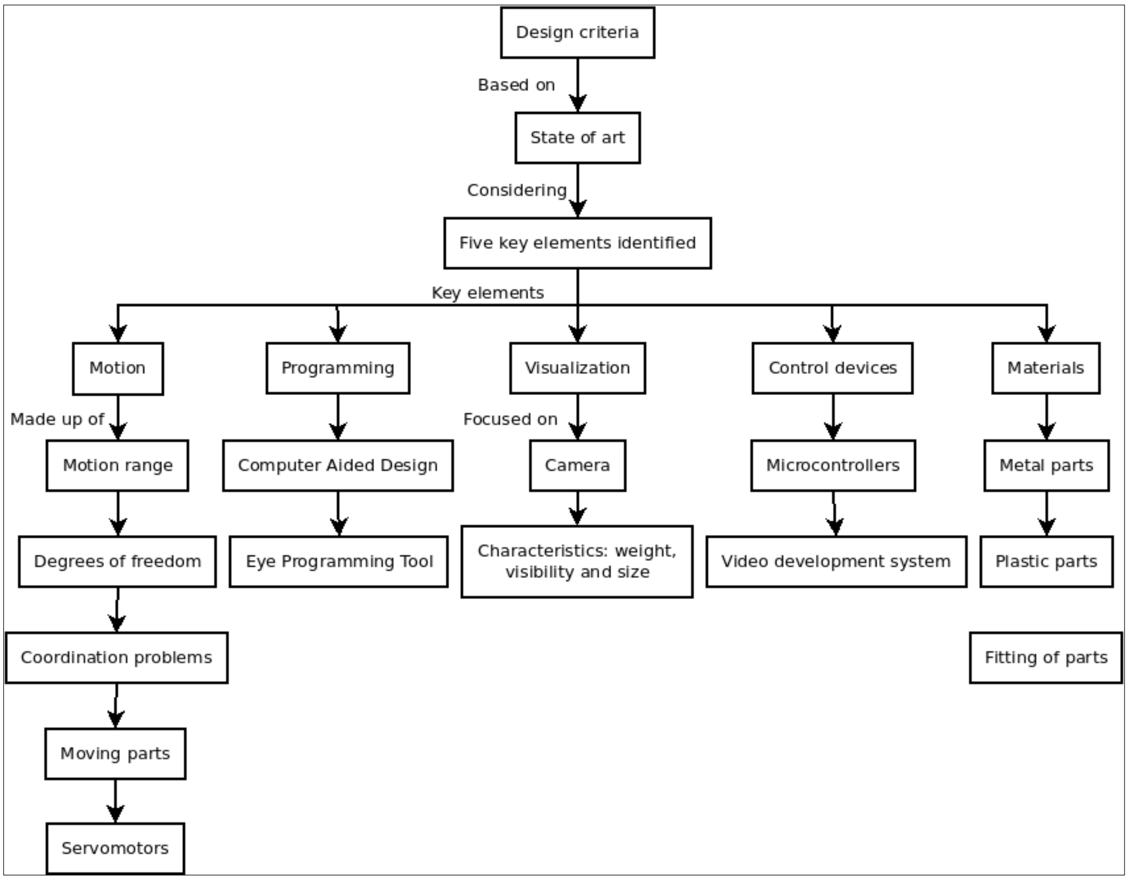

Figure 1 Conceptual map of design criteria

The project aims to develop an artificial eye prototype with a movement capacity similar to that of the human eye, which can be integrated into small robotic platforms as an optical sensor. Among the sensory capabilities, we need to be able to detect video in real-time and can process basic information (detection of colors, motion, and shapes).

In the previous study, the necessary information was collected to determine the best way to carry out the prototype design. In general, functional, availability and cost aspects were considered. This conceptualization structure of the design is summarized in Fig. 1.

According to the requirements that are needed for the prototype (two DOF, Fig. 2), we made use of different models emphasized in the movement of a camera, in which it was evident the use of mechanisms to be able to make horizontal and vertical displacements, and the set of both. By taking into account the various forms of the designs documented in relevant research, we took the main parts and recreated a design.

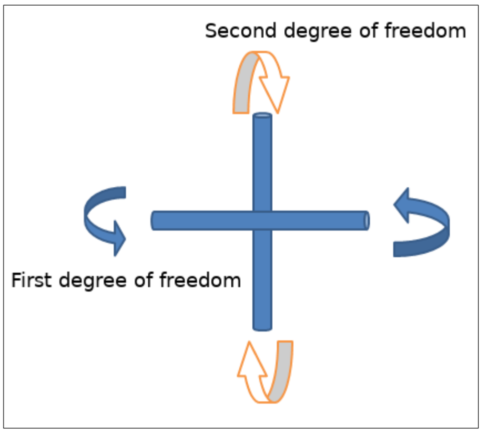

Figure 2 Visual recreation of degrees of freedom

To increase human/robotic eye interaction we considered the use of powerful and simple programming software. At the same time, we took into account the control devices that allowed programming to be easy to interact with. For these reasons, we selected the programming language C for the development of the libraries and the programming of the prototype.

The visualization is a fundamental component in the prototype since it generates the field of action allowing one to see in an image the movements of the design. This was achieved by selecting a camera of size, weight, and visibility with the characteristics according to the system. Within the elements defined in the profile, we need the camera to have a small size, with the ability to display good performance, in addition to being able to obtain information quickly. That is why we chose a small color camera for analog security systems (CCTV camera, 520 TV lines, with CMOS sensor, 0.008 Lux, NTSC system, and wide viewing angle).

The control unit focuses on a small development board with a microcontroller (ATmega328P). It handles components such as servomotors and expansion cards for video processing. This means that the robotic eye will have its decentralized control system, which will interact with the central control unit of the robot on which it is implemented.

As far as the selection of materials is concerned, we have chosen those with mechanical characteristics suitable for the handling of the prototype. It is also a key element of the selection the ease of molding, and the mechanical strength necessary to withstand sudden movements without deformation. Another important factor was availability, bearing in mind that these were easy to acquire at a low budget. Under these conditions, we opted for the use of ABS (Acrylonitrile Butadiene Styrene), a very impact-resistant plastic (amorphous thermoplastic) used especially in the automotive industry.

3. Material and methods

The design of the prototype takes into account two fundamental and integrated parts that follow the design principles of CyberPhysical Systems (CPS), and make sense in all practical design: one part hardware and one part software. The hardware design was developed with support from SolidWorks. This tool allowed to interact with the design to evaluate its capacity of movement and mechanical resistance. Before considering a design, the designer must be clear about what elements must be incorporated to generate motion. In that aspect, the idea of recreating the movement utilizing three servomotors was outlined. Although the two degrees of freedom can be generated with two servo motors, one more was added to facilitate the coupling of the set.

Another fundamental element of the system is the sensor in charge of capturing and processing video. Here was incorporated a small analog CCTV camera that provided a wide field of view for capture and digitization. This camera was included in the three-dimensional designs as well as the control unit. The control unit is a small development board with little processing capacity, only handles the servomotors, and serves as a support for the video processing board. Nootropic Design's Video Experimenter shield was selected for the latter. This module together with the microcontroller allows the primary processing. This will eventually increase the response speed of the robot using the sensor.

The construction of the pieces is made from the horizontal and vertical movements that the prototype must-have. As a supporting principle, a triangular base (three support points) was selected with support at one of its internal points for open rotation. With the help of SolidWorks, we recreate the parts taking into account the servomotors, the control card, and the camera. All parts are coupled in a single design, simulating movements to perceive mechanical errors. In principle, the servomotors were coupled in such a way that they complied with the movement of the two degrees of freedom, this allowed us to see the best coupling for the servomotors. Fig. 3 shows the three-dimensional detail designed for the optical sensor prototype.

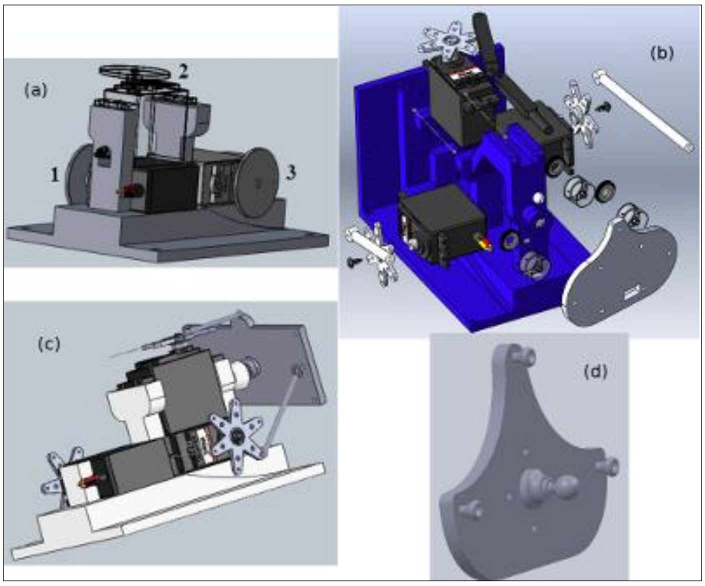

Figure 3 Different views of the three-dimensional design of the prototype. (a) Assembly of the three servomotors. (b) Uncoupling of the three servomotors. (c) First prototype of camera support base. (d) Detail of the final design of the camera support base

In the final design, we printed eight pieces on ABS. These pieces were assembled with the control card, the Video Experimenter shield card, the camera, and the three servomotors to conform to the system, which counts a total of fourteen pieces.

The robotic eye management libraries are written in C. In total five basic functions can be customized or improved by adding more functionality. These are designed by cases, allowing the user to select which task he wants the prototype to execute. The cases are as follows:

3.1. Case 1

Vertical movement. This is executed from top to bottom, and in the opposite direction, starting from any point on the vertical axis (Fig. 4).

Figure 4 Vertical movement

3.2. Case 2

Horizontal movement. Case in charge of executing the second degree of freedom, the horizontal. It works the whole horizontal axis from left to right, and in the opposite direction, starting from a previously specified point (Fig. 5).

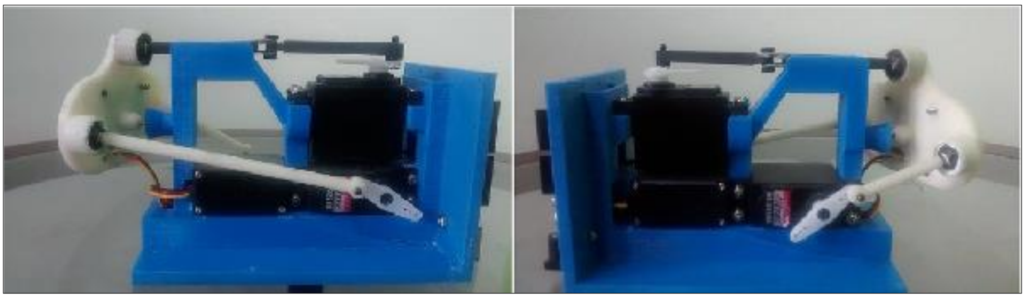

Figure 5 Horizontal movement

3.3. Case 3

Set of horizontal and vertical movements. This is the union of cases one and two, taking into account that all the characteristics of each case are executed. The two degrees of freedom of the prototype are observed (Fig. 6).

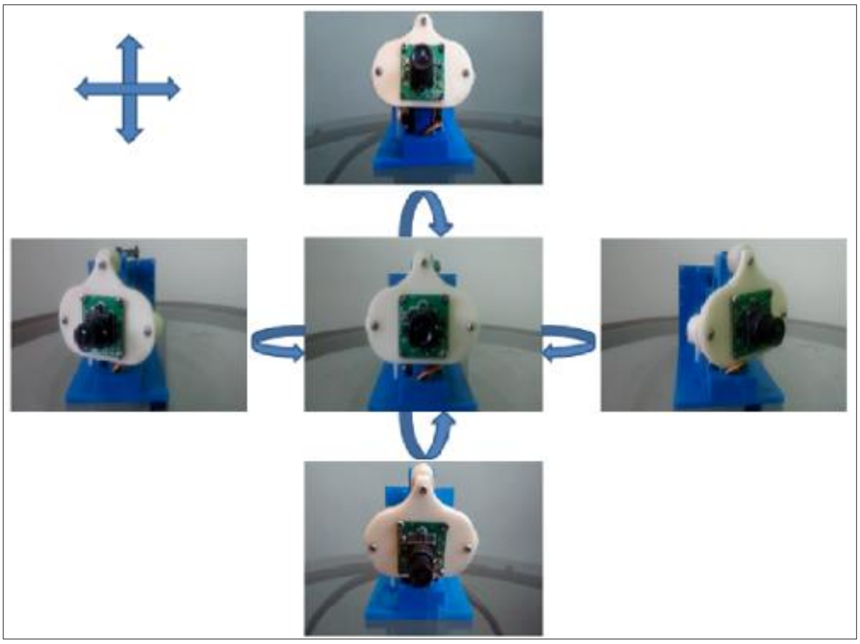

Figure 6 Set of horizontal and vertical movements

3.4. Case 4

Set of horizontal, vertical, circular, and diagonal movements. In principle it has the same programming characteristics as case three, the two degrees of freedom of the prototype can be observed, but with the difference that the horizontal and vertical movements are combined to generate the circular and diagonal movements of the robotic eye (Fig. 7).

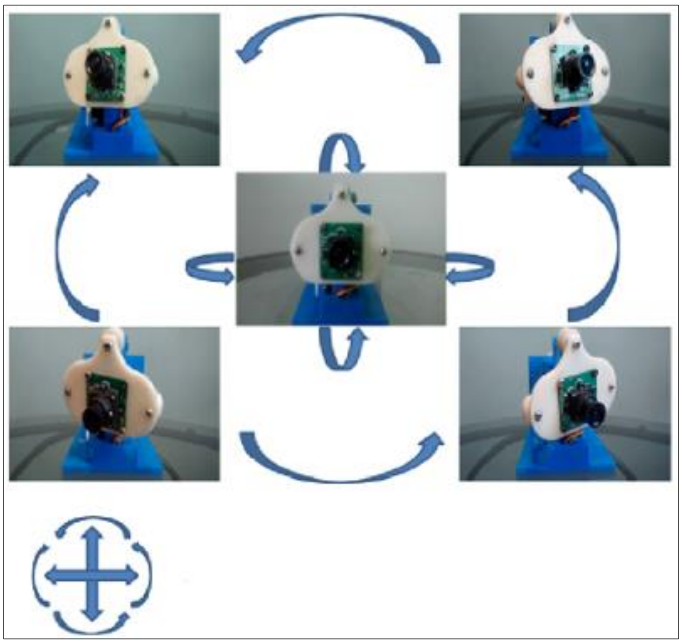

Figure 7 Set of horizontal, vertical, circular and diagonal movements

3.5. Case 5

Manual control. In this case, the movements of the two DOF are carried out with the difference that the programming, instead of having them executed automatically, allows the user to manage in real-time all the movements of the prototype with the help of the peripheral device.

4. Results and discussion

The objective of the prototype performance evaluation was to observe its performance of it and identify design errors both in software (assignment of erroneous functions, tasks that could not be executed by the mechanical part) and hardware (mechanical functionality not detected within the simulation). For this, we designed a strategy consisting of evaluation tests and a base program. The basic program was in charge of generating vertical and horizontal movements activating the two available DOF. In addition to the interaction of both movements, we included the third movement. This new movement corresponds to the joint activation of the two DOF.

Inside the initial tests, it was observed that the pieces of the bars in the union with the base of the camera were of little mechanical resistance. This piece presented a break in the neck between the ball of the bar and the bar. In addition, the parts where the bar is held at the base of the chamber were also damaged (Fig. 8). These pieces were re-designed according to these results. The bar and the base of the camera were modified by adding piece (Fig. 9). This new piece allows the bars to be interlaced with the base, and the junction point of the pieces by adding screws. The bars continue with the same idea of the sphere but are designed separately, achieving that the metal sphere is added after printing.

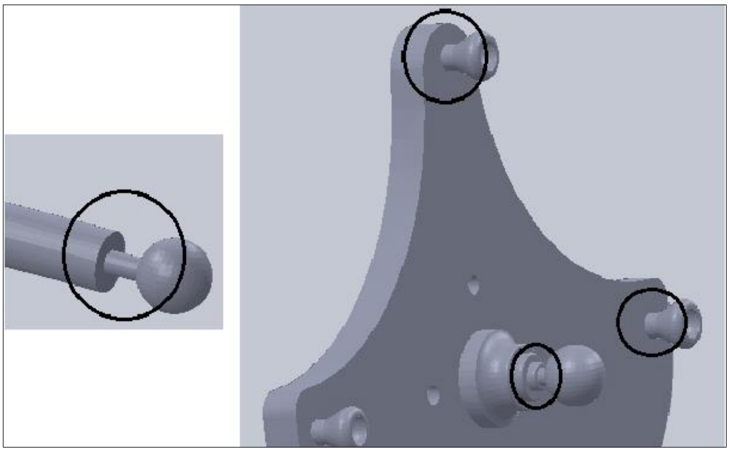

Figure 8 Bar and articulation of the camera support. Parts that were damaged in the initial tests of the robotic eye

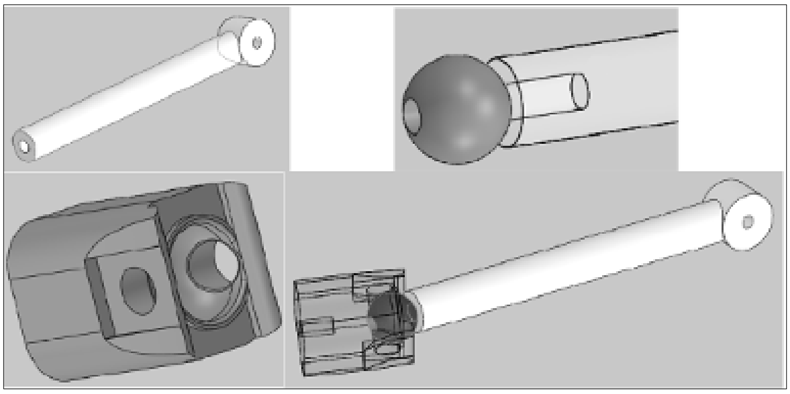

Figure 9 Bar and articulation of the camera support. New parts re-designed to withstand mechanical stresses

During tests with horizontal and vertical movements, we determine the mechanical limits of the prototype. These values (Fig. 10) are the maximum limits of mechanical work, which is why they are limited by code to avoid mechanical damage to the prototype.

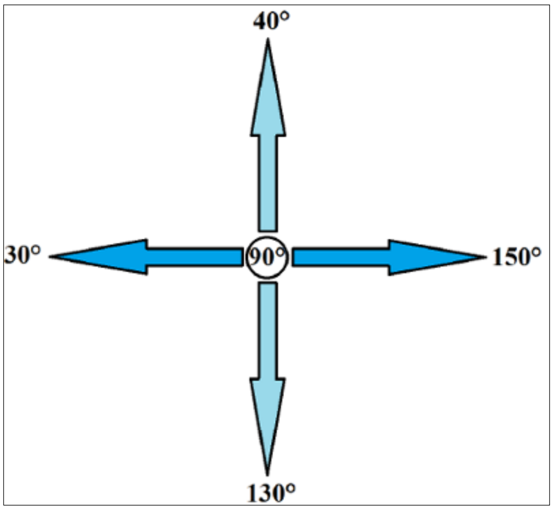

Figure 10 Mechanical turning limits of the robotic eye

In summary, the movement of the bars produced by the servomotors, and observed at the base of the camera, was the greatest challenge of the project. There we looked for the least friction of these parts so that the movement generated by the servos would be transferred in its entirety to the base of the camera. Fig. 11 shows the final fully assembled prototype.

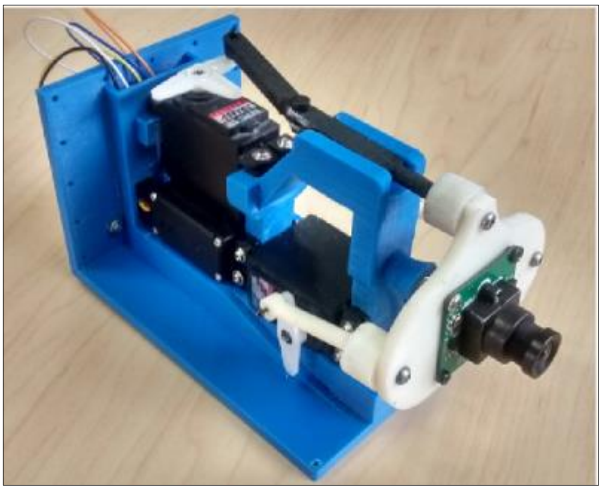

Figure 11 Robotic eye prototype

5. Conclusion

This paper documents the development of a robotic eye designed as an optical sensor for small mobile robots. We are currently developing an autonomous navigation strategy for robots in indoor environments. These environments are expected to assist robotic applications. These environments are characterized by being observable and dynamic, and full of human elements. These elements are visually characterized by the human being, which is why we want an optical sensor with capabilities similar to those of the human eye. These capacities are fundamentally related to the movement of the eye, but they are also important to own capacities of detection of colors, movement, and geometric forms. The developed eye was put to laboratory tests, thanks to which a robust and completely open final design was achieved for its integration into robotic platforms.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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