Design of an automated solar tracker for teaching astronomy and mechatronic engineering

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Abstract. Astronomy is one of the sciences that attracts a large number of people, because of the celestial bodies and phenomena that can be observed, such as the moon, planets, constellations and the sun during the day. Telescopes, the main observation tool employed for astronomical observation, are often not very accessible for the majority of the population, due to their cost. This problem has been addressed through the design of low-cost three-dimensional printed telescopes or the use of digital cameras and cell phones with filters suitable for this purpose. This work describes the components and building of an automatized light tracker that can be coupled to a digital camera, protected by a white light filter, to emulate a low-cost solar telescope. The resulting device can also be operated manually, serving as a teaching tool for astronomy that illustrates how mechatronics and programming can be employed for scientific outreach. Aided by a digital camera, the robotic solar tracker was used by students to observe and record the 2019's Mercury transit.

1. Introduction
The dissemination of science is essential as a tool for training scientists and engineers [1]. Furthermore, astronomy is an effective field to induce people’s interest in science and technology due to the depth of its implications about the origin of the Universe and the relationship between space phenomena and those occurring on our planet [2]. It is in this aspect that those spaces in which people have access to an astronomical observatory are of great value for the training of new scientists and engineers, through the dissemination of many of their technological and scientific aspects [3].

In Mexico, there are 12 digital planetariums and 18 with astronomical equipment and instruments dedicated to the teaching of astronomy. These facilities have sidereal telescopes for observing the moon, Mars, and some stars [4]. Specifically, solar telescopes are used to know the physical characteristics of the solar surface such as storms, spots, and filaments which affect the telecommunication signals of the Earth. While magnetic activity, which also affects telecommunications, it has been reported that, when the sun is at its minimum activity, the Earth’s climate also reaches its minimum; that is, the formation of glaciations [5].

The observation of planetary transits, which are phenomena that occur when a body passes in front of a larger one, is one of the most famous uses for telescopes [6]. From our planet, it is possible to observe the transits of Mercury and Venus, when these planets pass between the Earth and the Sun. These transits occur with a frequency of 3, 7, 10, and 10 years for Mercury
and 105.5, 8, 121.5, and 8 years for Venus [7]. Therefore, it is important to have adequate equipment for its monitoring and, as far as possible, to facilitate the access of telescopes to increase the number of observers. Because of the rarity of astronomical transits (separated from a few years to centuries), their observation usually attracts a large number of watchers; however, the available number of solar telescopes is very limited, relative to the number of attendees. This problem was identified during the 60s: It was solved by providing visitors with white light filters so that people could observe without damaging their vision [8]. Subsequently, this strategy evolved with the manufacture of filters that could be placed on the lens of optical devices (including telescopes, digital cameras, and cell phones). However, the quality, focus, and squaring of the images obtained are often compromised by the skill of the user [9].

Although, the proposal for the use of digital devices partially solves the need for the acquisition of telescopes; the experience of manipulating a telescope and making observations allows people to enter into this exact science or, later, to acquire the skill for proposing solutions to problems related to natural phenomena [10]. Recently, González in [11] proposed the design and construction of low-cost parts and controlled solar tracking device with an Arduino processor to follow the solar trajectory. Although this proposal showed high performance, this observation system is not capable of acquiring, collecting, and storing images.

Therefore, this work proposes the conceptualization, design, and development of a robotic solar telescope, which allows the capture of images of its photosphere. The objective of this device is to provide an image record for the dissemination of science and scientific research. Additionally, this project aims to show how systems engineering and mechatronics can be used within the context of physics and astronomy for the development of prototypes that increase the collection of spaces such as local museums and people interested in solar astronomy.

2. Methodology
This work developed a solar tracker to facilitate access to a solar observation system, instead of acquiring a solar telescope that costs around 600 to 800 US dollars [12]. This proposal replicates the elements of solar telescopes whose operation is based on carrying out a pre-assigned tracking of the sun through the movement of servomotors. While for the observation, the eyepiece is replaced by a camera for the acquisition, transmission, and storage of the images to a computer for their analysis [13]. Figure 1 shows the elements that make up the robotic solar tracker; Figure 2(a), a side view of the solar tracker, shows the gears used for helping the motor that produces the polar rotation and Figure 2(b), a frontal view, shows the position of the photoresistors that send the signal to the Arduino processor when aligned with a luminous source. The elements of the solar tracker are described below:

- **Supports:** The supports were designed in Solidworks, a program that mechatronics students use during their academic training. The printing was done by using Createbot 3d printer employing a poly acetic acid filament (PLA), a common material used to print devices such as [14], heliodons [15] and robotic telescopes [11]. There are two kinds of supports: The first type is connected to the base of the prototype, through a small t-shaped piece that holds the first servo motor. Two gears were placed at one side of this support two, to empower the torque of the second servo motor (very useful to aid the rotation of the second stepper motor when the selected camera is heavier than around 300 grams). A top of the first supports there is a, smaller, second pair that holds the digital camera. These upper supports also hold up the photoresistors that aid the tracking of the luminous source.

- **Mechanical components:** Two 28BYJ48 stepper motors allow the azimuthal and polar movement of the supports of the prototype. The motors are strong enough to allow the rotation, even if heavier digital cameras (up to 1 Kilogram) are placed at the top of the upper supports. Also, the stepper motors offer high precision at positioning thanks to its
standard pitch angle of 5.6 degrees with the possibility of fine-tuning it down to 0.08 degrees with the help of an integrated internal reducer (1/64). Two types of power sources can be wired to the stepper motors: either a 9-volt squared battery or a 9-volt power adapter, that can be plugged to a standard 110-volt power socket. To ensure the functionality of the tracker in any location; A matrix keyboard was attached where any of the following options are typed to activate the various operating modes, these are: key A for automatic mode, key B for search mode, and key C for manual mode. Whereas, to control the movement of the solar tracker in manual mode; An Arduino XY joystick was incorporated to allow the user to control the prototype (moving the lever from left to right tarts the polar rotation while moving it in the top-bottom direction activates the azimuthal rotation).

- Electronics: All the orders that control the prototype were programming by using an Arduino-IDE. Two operating modes were designed: automated and manual tracking. Automated tracking depends on the reading of the photoresistors. Each photoresistor communicates a specific light intensity, depending on its alignment to the light source. The tracking function was programmed so that the azimuthal and polar rotations of the supports are activated in the direction in which the photoresistors send its largest readings. The movement only stops when the readings of the photoresistors are equal. In the manual mode, the user controls the movement by using a joystick. Moving the joystick in the left-right direction activates the stepper motor controlling the polar movement, while the up-down movement activates azimuthal rotations. The program including both movement modes was loaded onto an Arduino Mega board, that converts the binary signal into voltage variations that start the motors to position the camera, atop the upper support, in the directions in which either the photoresistors or the user identify the highest light intensity. The mechanical, electrical components and the power supply were interconnected with a breadboard which is powered directly from the Arduino through its 5-volt power output, enough for the operation of the components used, while the Arduino can be powered by connecting it to a laptop using the USB port or using the Arduino's external power jack.

A website was set up (http://astroteccolima.000webhostapp.com/) to promote the dissemination of the science involved with this project. This site will also be added to the portal of the Museum of Science and Technology “Xoloitzcuintle” in the city of Colima, México.

Figure 1. Side view of the solar tracker, without camera, (a) and (b) frontal view of the camera support, showing the photoresistors.
3. Results
While the three-dimensional (3D) printed of the solar tracker was being carried out (taking around 70 to 80 hours), the mechanical components were interconnected to the breadboard and power source. On the other hand, the programming of the code on the Arduino board was developed so that the photoresistors could carry out the solar tracking, as well as the search criteria; finally, the matrix keyboard was incorporated to verify its functionality. At the end of printing; The printed, mechanical and electronic components were assembled and some field tests were carried out to evaluate the functionality and the device in automated and manual mode (using the joystick).

Figure 2(a) shows the device assembled to a semi-professional digital camera, where the gears that facilitate polar rotation, the support system for the camera, the motors and the box containing the electronics are shown enclosed by the rectangles numbered from 1 to 4. Automated tracking was tested by evaluating the correct movement of the prototype while tracking the Sun. Each photoresistor was covered with a clipping of a standard white light astronomical filter for shielding them from receiving signals from luminous sources other than the Sun. Figure 2(b) shows the typical values registered by the Arduino processor when the photoresistors at the front of the solar tracker are aligned with the Sun. When the tracker was aligned to the Sun, the typical readings of the Arduino processor of the analog to digital signal were between 450 and 400 while at its worst alignment these values were below 20. Also, the centering of the images was check by mounting a semi-professional camera, programmed to take a picture every 15 minutes, and protected by a white light filter to avoid damage by burning [16].

![Figure 2](image_url)

Figure 2. (a) Semi-professional camera with a white light filter coupled to the proposed technological design (b) typical reading shown by the Arduino processor for the analog signal sent by the photoresistors shielded by the white-light filter.

A field test for the solar tracker was made possible during the mercury transit occurred last November 11 2019. The solar tracker at the configuration shown in Figure 2(a) was put in automatic mode while the professional camera was programmed to take a picture every 20 minutes minutes. Figure 3 shows two of the resulting images at the beginning and end of the transit.
Figure 3. Photographs of the transit of Mercury taken by the prototype coupled with a semi-professional camera at 216X zoom at (a) 10:00 hours and (b) 12:15 hours.

4. Conclusions
This work reports the conceptualization, construction, and evaluation of a low cost automated solar tracker. Unlike solar telescopes. This device has an approximate cost of $35 US dollars, lower than the $50 US dollars necessary for the construction of the telescope; this technological proposal replaces the observation lens with a digital camera or smartphone, even the design and construction of this prototype allow us to attach and use a camera or telephone as a substitute for the lens, while the previous proposal is limited to the use of a bird observation lens with specific dimensions.

Regarding the mechanical and electrical components; they can be purchased in electronics stores and/or web portals, allowing interested persons to increase solar observation systems. Additionally, a web portal was built where general dissemination of the activities carried out in the Xoloitzcuintle Museum regarding solar observation is made, a step-by-step guide is offered on how to develop a solar tracker prototype, a collection of images captured by the telescope home solar and information on possible courses or workshops to be taught to the public.

Future work will couple the prototype to a solar panel, to take advantage of its extended exposition to sunlight to access a self-sustaining energy source. Also, the creation of remote monitoring of the solar tracker from this platform will be developed.

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