Automatic Diopter-Adjustable Spectacle for Presbyopia Correction

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Abstract— A large number of the population suffer from presbyopia. Presbyopia is an ophthalmic disease in which the person is not able to focus on near objects due to the hardening of the natural lens. In this paper, I have demonstrated an electromechanical spectacle which changes the diopter power as per the sight distance. The spectacle contains lead screw sliding mechanism and a pair of a concave and convex lens. When the wearer changes the sight, a distance sensor mounted on the spectacle measures a new sight distance and micro-stepper motor moves as per the algorithm and as a result, effective diopter power changes. The presented spectacle design can be used as an alternative for multifocal and progressive lenses.

Keywords: Presbyopia, Spectacle, Diopter, Multifocal, Lens

I. Introduction

Presbyopia is an ophthalmic disease that occurs naturally due to the hardening of the natural eye lens. Usually, over the age of 40, the elasticity of the crystalline lens gets reduced. As a result of this, the person suffering from presbyopia is unable to focus on near objects or scenario such as reading where near sight is required [6]. A lens with fixed optical power of negative and positive can solve the problem of myopia or hypermetropia respectively. But in the case of presbyopia, as the elasticity gets reduced, a fixed optical power cannot be a feasible solution. Therefore, one has to use a spectacle with multiple powers such as bifocal, trifocal or progressive lenses for presbyopia [4]. In multifocal lenses, the whole aperture of a lens is divided into multiple sections and each section has different optical power. Hence the field of view gets restricted [1]. In multifocal lenses abrupt change in optical power is noticeable and that can confuse the wearer while looking through that sharp line. This problem is more noticeable when going down the stairs. A more reliable solution to this problem is the use of progressive lenses. The progressive lens has no sharp boundary where two optical lens areas having different power meet. The progressive lens has a large number of different optical power areas between two edges. The change in optical power is gradual therefore wearer usually does not suffer from noticeable boundaries. At first, the wearer might get suffer from distortion know as swim effect due to viewing from different optical powers at different time.

To overcome the problems related to eyeglasses for presbyopia it is quite clear that, the wearer needs eyeglasses that have an ability to change its optical power either by manually or automatically. There are certain methods, like electronically and mechanically changing the equivalent optical power of a lens. In this prototype, the change in optical power is achieved by mechanical movement of two lenses. The prototype comprised of a lead screwed micro stepper motor. The spectacle has two frames from which one is stationary and the other is sliding. It has an ultrasonic distance measurement sensor which measures the distance of sight from the user and returns the distance value to the microcontroller. As per the algorithm, the stepper motor moves to change the distance between the stationary and sliding frame. When the distance between the two lenses changes, an equivalent optical power changes.

II. Literature Survey

There are different methods to achieve change in optical power of an optical system. Primarily the methods are divided into two types - a mechanical and an electronic. In order to vary the optical power of a system, one needs to vary some systems parameters like changing the refractive index, changing the separation between two lenses.

In the method of changing the optical power mechanically, a lens-shaped hollow glass container is used. By the use of a syringe a liquid is injected in the hollow portion of the lens, as a result, the refractive index gets changed and it starts to work as a lens. The amount of liquid in the gap between two walls determines the effective power of the lens. In this type, the user has to inject and remove the liquid manually. A driving mechanism for syringe could be used to get it done automatically. Another mechanical type is Alvarez and Lohmann refractive lenses. It is an optical design used to change the optical power of a spectacle. It comprises two air separated optical elements. When the two elements are moved in the opposite direction horizontally, effective optical varies from negative to positive. At one particular point, the equivalent optical power is zero. These elements are mounted on some sliding mechanism and the movement is done by mechanical motion [2].

Another way of changing the optical power is by using electronic components. Liquid crystal layers are embedded in a spectacle glass. When an electric field is applied to the liquid crystals the modulation of light happens and hence the refractive index of light happens. Apart from these two methods, a lens combination can be used to change the effective optical power. It is found that when two thin lenses are combined, their equivalent optical power is inversely proportional to the distance of separation between them [2,3].

III. Proposed Methodology

There are many ways to achieve variable optical power of an optical combination by means of electronically or mechanically. In the presented prototype, a combination of both the techniques is used to achieve variable optical power spectacle. When two lenses having the focal lengths of f1 and f2 are planed on the same optical axis and separated by a distance d, the equivalent optical power is given by the formula [8],

$$P_D = \frac{f_1 + f_2 - d}{f1 \times f2}$$

Where,
P_D is the effective optical power in diopter
f_1 is the focal length of 1^{st} lens in meter
f_2 is the focal length of 2^{nd} lens in meter

d is the distance between two lenses in meter

Here, optical power is a function of the distance of separation between two lenses. As the distance increases the effective optical power increases.

To implement this technique in a spectacle, a mechanical sliding mechanism is necessary in order to change the distance between lenses. There are many possible mechanisms like rack and pinion, lead screw slider, etc. to move a lens in one direction. Amongst them, the lead screw sliding mechanism is more suitable for the miniaturized sliding purpose. Lead screw shaft micro-stepper motor is used to implement this in the prototype. As the motor shaft itself is a lead screw there is no need to attach any further coupling here. The slider is designed in such a way that, slider's teeth should match the lead screw. Therefore direction sliding block can be decided by direction of the stepper motor rotation.

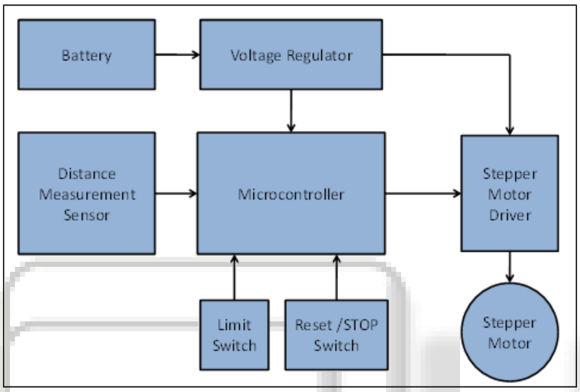

Fig. 1: System block diagram

In order to make a system automatic, feedback to the controlling unit is essential. Here the term feedback refers to the distance between wearer and sight. Many techniques like ultrasonic distance measurement, infrared reflective distance measurement, inductive proximity distance measurement, etc. are used. Amongst them, the ultrasonic distance measurement technique is more feasible as far as the size, and accuracy for relatively small distance are concerned. Hence an ultrasonic module is used in the prototype for distance measuring purpose. This work as feedback to the system and as per the feedback output is reflected by means of the stepper motor. A microcontroller is installed in the system for controlling system components and making decisions regarding stepper motor rotation and hence changing the optical power of the spectacle.

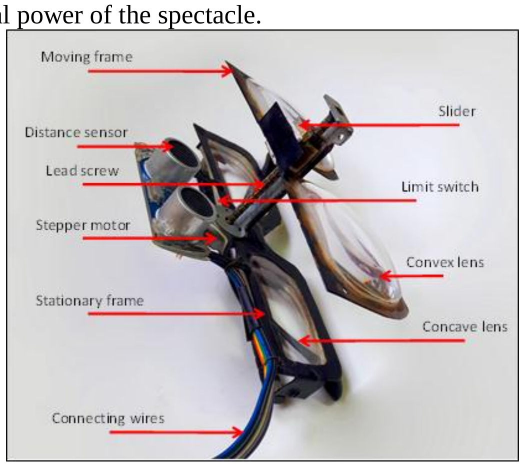

Fig. 2: Prototype

A. Algorithm

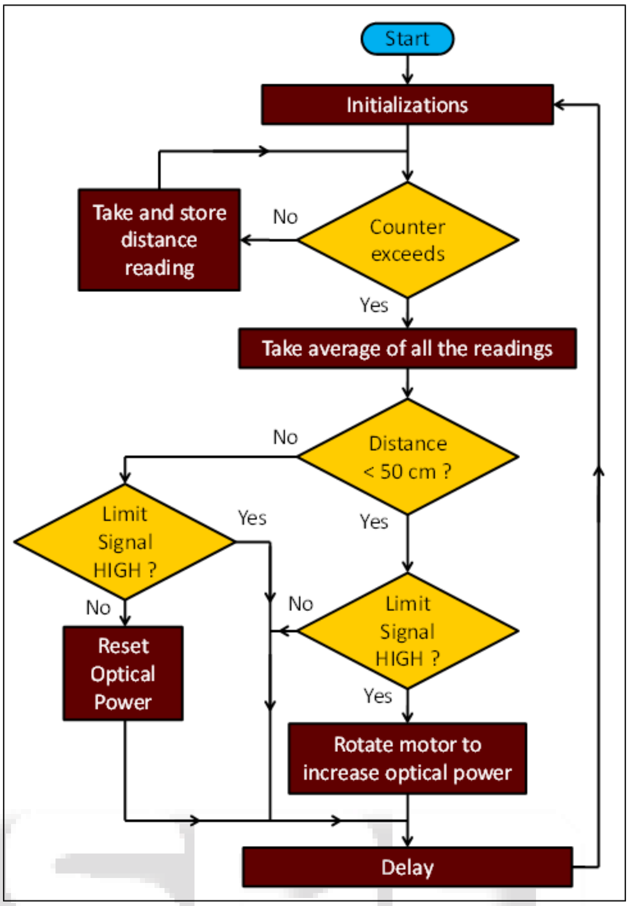

Fig. 3: Algorithm flowchart

Initialize the microcontroller, do necessary operations like pin assignment, defining the directions, etc.

Average of 5 successive readings need to be taken into consideration in order to avoid malfunctioning and false decision and make the system more stable. Hence the average of 5 readings is made.

There are two components which are required to take the decision. Those are measured distance and limit switch status. Four possibilities and their respective actions are given below in a tabular form.

Status		Action to be performed
Distance < 50cm	Limit switch pressed	
No	No	Rotate motor anticlockwise (Decrease the optical power)
No	Yes	No movement
Yes	No	No movement
Yes	Yes	Rotate motor anticlockwise (Increase the optical power)

Table 1: Conditions and decisions in the algorithm

Some finite delay is required to settle the motor and to avoid malfunctioning due to a fast sampling rate

B. Optical Details Considerations

Usually optical power required for presbyopia varies between 0 to 3 diopter (it may be greater than 3 diopters also). Hence in optical design, it is considered that at maximum separation the optical power should be greater than +2.5 diopter. There are multiple combinations by which the desired power can be achieved. The main problem here is that the lead screw slider can only travel around 50mm. Therefore it is necessary to choose the optical elements in such a way that, maximum required power should be achievable by separation less than 50mm.

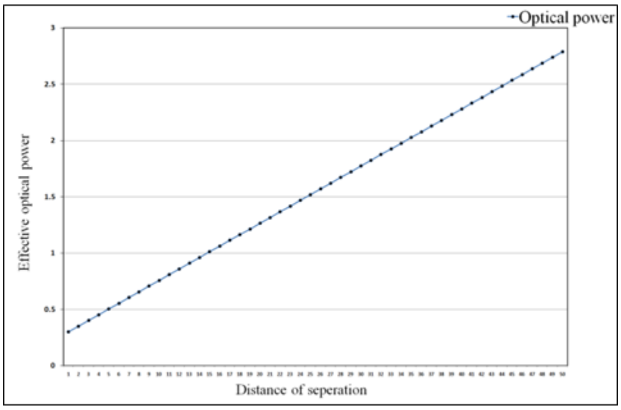

Fig. 4: Distance of separation vs. effective optical power

As the power of the lens increases its sagitta also increases and hence the weight of the lens increases. Hence it is necessary to do a tradeoff between optical power, the required distance of separation and weight of the lens. The parameter weight can be neglected by using lenses made up of fiber or CR rather than glass. The optical combination of +7.25 diopters and -7.0 diopters is found to be reliable to meet the required maximum power.

Distance of Separation	Effective optical power
~ 1 mm	0.3 D
15 mm	1.01 D
30 mm	1.77 D
50 mm	2.78 D

Table 2: Effective optical power for the selective distance

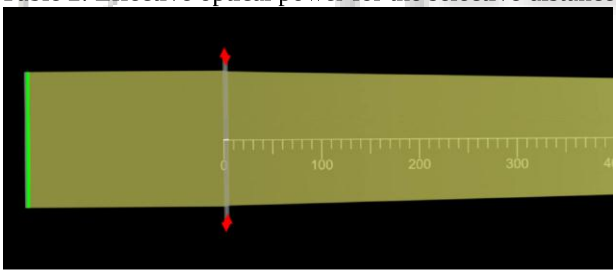

Fig. 5: (A) - Minimum separation between two lenses.

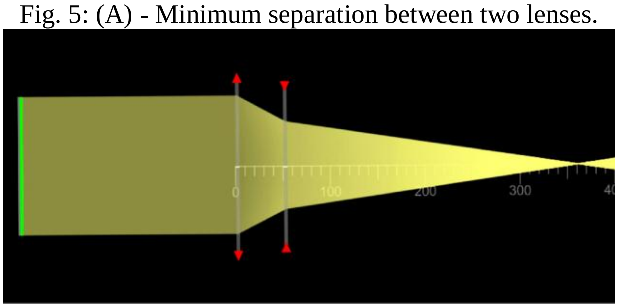

Fig. 5: (B) - Maximum separation between two lenses

C. Mechanical Design

The mechanical design comprises two spectacle frames. The stationary frame and the moving frame both are made up of copper sheet. A lead screw micro stepper motor is installed on the upper end of the nose rest. An ultrasonic distance measurement sensor is installed on the top of the stepper motor with two supports from a stationary frame. The moving frame is fixed on the slider with the help of a bonding element. The optical elements are pasted on the frames with adhesive. If the spectacle weight is 25g, nose-pad area must more than 200mm^2 [5].

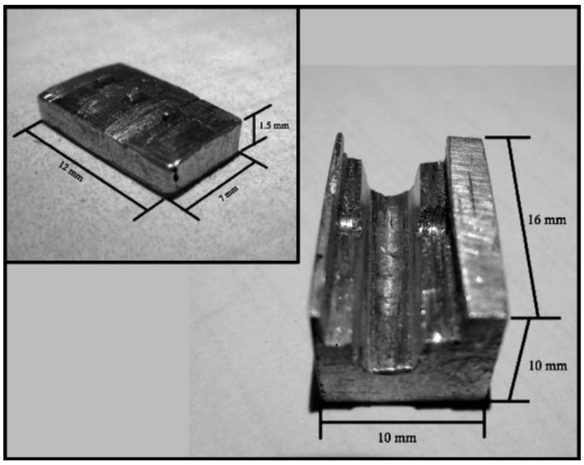

Fig. 6: Slider design

IV. EXPERIMENTAL RESULT

To check the variable power of a spectacle obstacle is placed in front of the ultrasonic distance measurement sensor. This gave two extreme low and high possible powers of the spectacle. Manually stopped stepper motor such that distance of separation would be half of the total sliding length. Photographs have been taken to record the change in the equivalent optical power of a spectacle.

Fig. 7: (A) Effective optical power at minimum separation (~ 1mm)

Fig. 7: (B) Effective optical power at intermediate separation (~ 25mm)

Fig. 7: (C) Effective optical power at maximum separation (~ 50mm)

V. CONCLUSION AND FURTHER WORK

A completely novel approach to variable power spectacle with automatic power changing capability by using the lens combination principle and the electromechanical system. The spectacle is experimentally tested on various scenarios to check the algorithm reliability. The algorithm became more reliable when a method of averaging of multiple distance reading was implemented.

In the presented prototype, the slider needs to travel 50mm to make the effective required optical power. By the use of different optical combinations and aspherical lenses, this sliding distance can be reduced. The weight of the spectacle can be further reduced by using a polymer body and a miniaturized distance sensor. The design will be more reliable if the electronic circuit gets embedded in the spectacle body itself. As optical power is variable in the spectacle, variable power spectacle could be useful even after wearer's optical power changes due to aging [7].

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