Scalable Long-Stroke Linear Variable Displacement Sensor Using Inexpensive Components and 3D Printing

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***Abstract*—Displacement sensors measure the change in position of a physical object attached to the sensor[1], [2]. Instruments, such as linear slide potentiometers, are inexpensive and robust when such a physical connection is not a problem or even an advantage. However, the currently manufactured slide potentiometers offer only a limited number of size and range choices. Driven by the need to allow arbitrary ranges of displacements and to scale to larger and smaller displacements, we experimented with a simple, inexpensive approach using LEDs and light sensors in a 3D printed chamber. The measured analog light intensity is not linear with distance, but in a modern system where it is likely to be digitized into a microcontroller, it is easily calibrated. The resulting system seems a practical, inexpensive approach to producing displacements sensors of scales both significantly larger than and smaller than 10 cm. However, it is not clear that it offers any advantage over recently developed time-of-flight distance sensors enclosed in a similar housing. A YouTube video[3] explains and demonstrates this work https://www.youtube.com/watch?v=mArdBpymk8I.**

Keywords–linear variable displacement sensor, 3D printing, LED.

I. Introduction

A. Motivation

This research grew out of our need to make small sensors of specific sizes which we were unable to easily source. We are in fact building a robot as a network or framework of actuators–rods which can change their length. Our controller for this larger robot is a puppet or waldo constructed from linear variable displacement sensors in the same geometry. The resulting waldo can be manipulated by hand to cause a corresponding, isomorphic change in the larger robot.

Ideally, we would be able to construct this waldo out of sliding rods that can change their length in any size that we desire. Since we combine the joints using a special joint, the Kwon-Song-Kim joint, that can only be created by 3D printing, it is natural for us to seek a 3D printable solution, even though of course in a perfect world one might order a sensor of any size that could be manufactured with a wide variety of techniques.

B. Mechanism

In open space, the intensity of light falling on a sensor is inversely proportional to the square of the distance travelled between the source and sensor. When encased in a tube, some fraction of the light is reflected off the walls of the tube. Since much of this light occurs at the a low grazaing angle, the reflectance will be high no matter what material is used for the tube. The light reaching the sensor is does not have a simple mathematical relationship with displacement. However, it is monotone—the light intensity decreases smoothly with increasing displacement, even if the rate of decrease is not easily predictable. Since we always intended to read our sensor value with a microcontroller such as an Arduino, it is simple to perform calibration in software. By using a simple light-and-sensor mechanism in a sliding cylinder with a reflective piston, we construct a displacement sensor with few limits on scaling up or scaling down. By putting the sensor and the light at the same end, we simplify the wiring, although this requires a reflection of the light. If the light were reflected from a mirror to a sensor near the light source in free space (not contained within a tube), the intensity would be proportional to the inverse of the fourth power of the distance.

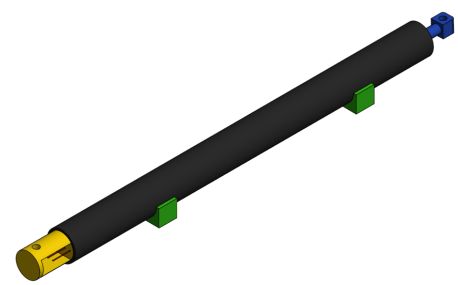

Figure 1. Isometric View

Figure 2. Contracted View

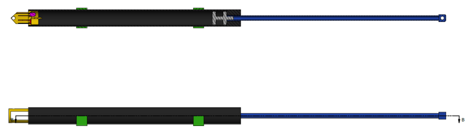

Figure 3. Expanded View

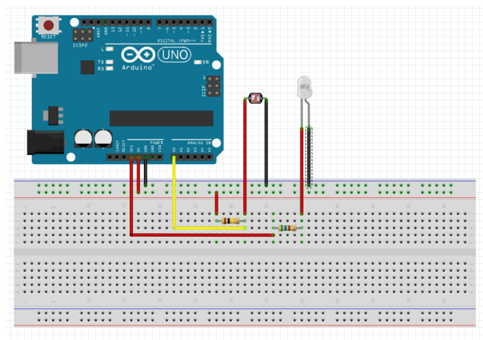

Figure 4. Basic Arduino Experimental Setup

II. Construction of the Sensor

We used basic materials that came with the Arduino Experimenters Kit (ARDX) from Adafruit[4]: an Arduino Uno microcontroller (which has an analog to digital converter), an LED as a light source, and a CdS cell for light detection. We physically measured the LED and CdS cell and created them in AutoDesk Inventor. Then a housing unit was created for the LED and CdS cell with a baffle to separate them so that the LED did not directly shine on the CdS cell. A piston and cylinder (as separate pieces) were created to for the housing. Tolerances were checked for the CAD model and then the models were 3D printed. We powered the CdS at 5V and the LED at 3.3V using the Arduino Uno. A resistor was added to the LED circuit to prevent it burning out. The CdS cell voltage was read and digitized by the analog input of the Uno. This procedure was repeated for a smaller version of the sensor as well. In theory the cylinder size can be parametrically controlled to a large number of physical lengths and even diameters.

III. Electrical Performance

The charts below show the measured voltage at the CdS cell based on physical change in the displacement of the piston within the cylinder. Initially, we performed a regression analysis, but it soon became clear that digital calibration would be preferred. There was in all cases a smooth monotone relationship between output signal voltage and the position of the piston as seen in the diagrams below.

Each plot plots the linear displacement as the vertical (Y) axis. In the large sensor this is measured in centimeters. The horizontal line is the digital read of the analog input returned by the Uno, on a scale of 0 to 1023, which is in fact proportional to the voltage via the formula: V = (input * 1000 milivolts)/ 5 = input * 200 millivolts. An digital read of 1000 corresponds to 5V. In the case of the smaller sensor, the scale of displacement is measured in mm.

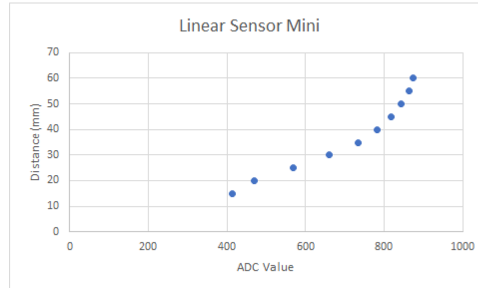

Figure 5. Mini Sensor White Tip Distance vs. Digital Range (note units of Vertical Axis are mm)

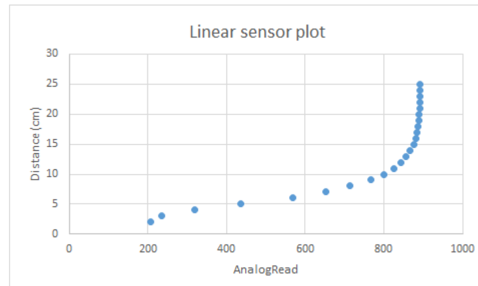

Figure 6. Large Sensor White Tip Distance vs. Digital Range

Observe that using a aluminum foil as the reflector in the large model linearized the curve and allowed better separation of values at large displacements of 15 cm or more.

Note that the voltage depends on the bore diameter, the reflectance of the piston head, the kind of LED and CDS cell, as well as the input voltages.

IV. Digital Calibration

Because the voltage produced by the optical linear sensor is in the common ranges of 0-5V, it is easy to digitize the signal with a standard Analog-to-Digital converter or common hobbyist microcontrollers, such as the Arduino. Although some sensors are carefully designed to allow a directly meaningful voltage level to be output, we assumed that in most cases our sensors would be used by a microcontroller anyway.

The procedure was to wire the LED, photocell, and resistor to the Arduino. A simple Arduino script was used to sample the photocells voltage divider once every second. The ADC value from the serial output of the Arduino was recorded for every 1 centimeter from 0 cm to 26 cm.

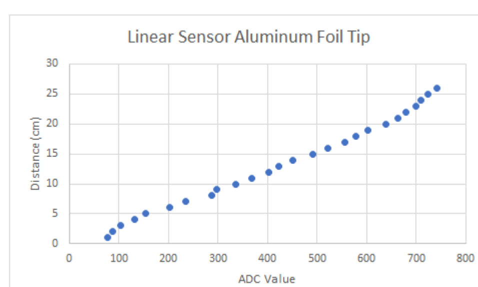

Figure 7. Large Sensor Aluminum Tip Distance vs. Digital Range

The results of the experiment were recorded in an excel sheet. Since the Arduino uses a 12 bit ADC, the output of the serial reading range from 0 to 1023.

We have produced Arduino code that performs a simple linear interpolation of data points recorded by hand. The code is available in our GitHub repohttps://github.com/PubInv/optical-linear-sensor[5] under the GNU Public License.

V. Future Work

This paper explains how to make a calibratable displacement sensor using light intensity as its fundamental mechanism.

This work provides a solution similar to time-of-flight[6] sensors enclosed in a tube. The highest priority for future work is to determine if there are any circumstances where the light intensity solution is better than a time-of-flight solution. Although the system described here is slightly less expensive, this cost would only be important in a situation where many sensors are being deployed. Possibly the light intensity system could work with smaller systems that the time-of-flight system can support.

From this baseline concept of having light as a means of detecting distance, many directions can be taken to improve upon or modify the design for future iterations of the sensor. For instance, in order to decrease the overall footprint of the device, fiber optics could be used to transmit light into a smaller tube rather than having the led taking up space in the tube itself. This would make the circumference of the tube smaller, potentially opening the device to other applications.

We believe the most interesting idea is to attempt to create a digital displacement by creating a digital geometry inside the cylinder. Instead of having a hollow tube, chambers and cavities could be made to catch the light at a precise distance. This would carry on for multiple intervals and in theory when the light hits one of the cavities there would be a sharp drop in reflectivity and the photocell would be able to detect the change in intensity and distance.

There are many more directions that could be taken with the optical linear sensor concept and with each modification, a different use for the device could be discovered.

VI. Conclusion

This paper describes a means of constructing linear position sensors of widely-varying (human-scale) size with 3D printing and cheap electronics components. This invention is released under a Creative Commons license. Because it does not use physical contact as in most pressure sensors or linear potentiometers, it may have advantages in reliability. Because it utilizes only inexpensive electronic components, it may be constructed for a custom length easily via 3D printing or custom cylinder construction by anyone with hobby-level skills. It remains an open question, however, if there is any situation in which a light-intenstiy sensor is better than a time-of-flight sensor. Additionally, we invite other researchers to improve upon this design, as outlined in Future Work.

References

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