

The LM741C Integrated Circuit As A Voltage Comparator Building The Electronic Exercise Apparatus

INTRODUCTION:

In this experiment, we attempt to build and monitor an electronic exercise apparatus. The circuit was built using a LM741 operation amplifier as a voltage comparator and two voltage dividers. A voltage comparator is an analog circuit that monitors the input voltage (V_{in}) and the reference voltage (V_{ref}). When V_{in} rises above or below the V_{ref} , the output voltage changes from negative to positive value and back. A light emitting diode (LED) is used and it lights when certain physical conditions of the apparatus is present.

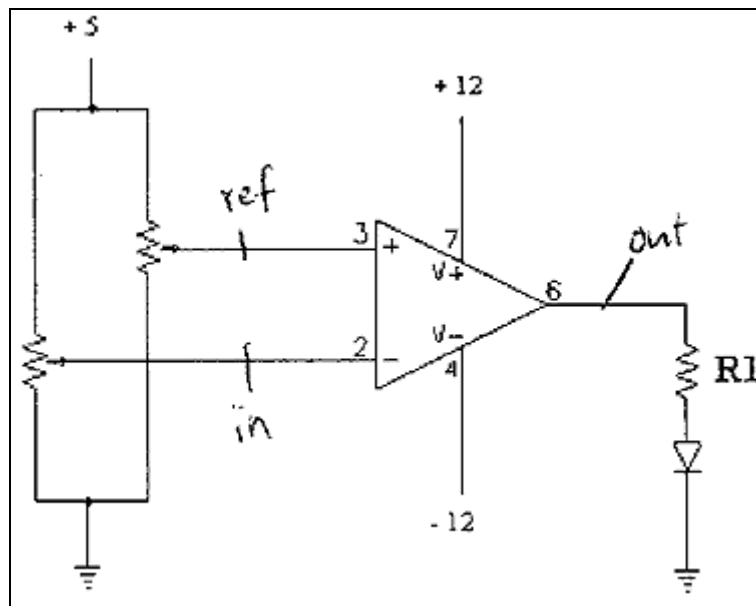
Use of such circuits can be used to monitor the physical condition of a patient suffering from such injuries as muscular or skeletal injury that requires that the patient not extend his movements beyond a certain point or angle. The diode can be used as a signal when that limit has exceeded.

METHODS & MATERIALS:

- Solderless breadboard
- Wire, electronic parts, wire strippers
- Voltage divider (potentiometer glued to two rulers)
- DC power supply
- 3 voltmeters
- 470 Ω resistor
- 2 – LEDs
- 100K potentiometer (variable resistor)
- LM741C operational amplifier

The analog circuit was built according to the schematic shown in Figure 1 below:

Figure 1:



As shown in the schematic, a 100K potentiometer was connected in line with pin 3 of the LM741 operational amplifier. The voltage divider was connected in line with pin 2. A 470 Ω resistor was connected in line with pin 6. A voltmeter was connected in line to pin 3 and ground. The reading on this voltmeter corresponds to the reference voltage (V_{ref}). Another voltmeter was connected in line to pin 2 and ground; its reading corresponded to the input voltage (V_{in}). Finally a third voltmeter was connected in line to pin 6 and ground; its reading corresponded to the output voltage (V_{out}).

The apparatus (potentiometer glued to two rulers) was taped to the lab bench to facilitate taking angle measurements. At 0° , V_{ref} was adjusted to 1.99V by adjusting the notch in the variable resistor. Starting at 0° , the untaped ruler of the apparatus was rotated in a clockwise fashion until the LED lit. The LED lit when $V_{out} = V_{ref}$. The angle at which the LED lit was measured. Voltages at three angles greater than and three angles less than the angle at which the LED lit were recorded (the angles corresponding to each voltage were also measured). The angles were measured at irregular intervals and the maximum angle measured was 180° . Next, V_{ref} was adjusted to 1.00V. Again, starting at 0° , the untaped ruler was rotated clockwise until the LED lit at $V_{out} = V_{ref}$. A total of seven voltages were recorded, each corresponding to a

specific angle, which was also measured: three angles greater than and three angles less than the angle at which the LED lit. Next, a second LED was wired in the opposite direction of the LED already present in the circuit. V_{ref} was set to 1.00V at 0° once again. Rotating the untaped ruler from 0° in a clockwise direction, the voltage at which the second LED turned off and the original LED lit was recorded and the corresponding angle measured. Once again, seven voltages were recorded and their corresponding angles were measured using the same procedure as the first two trials.

RESULTS:

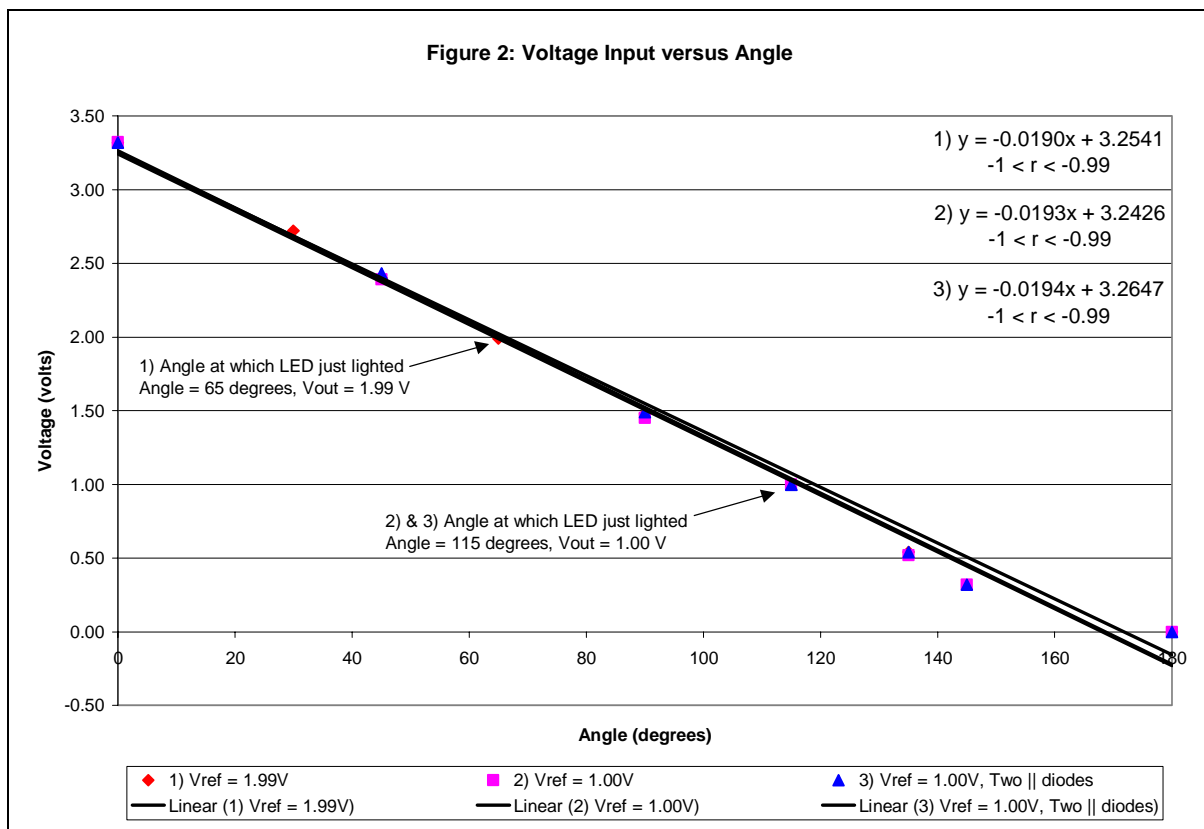


Figure 2 above illustrates the graphs of the input voltage (V_{in}) and the angle of the apparatus for all three experimental setups. All three trends show a near perfect negative linear progression, as evident with the calculated Pearson's coefficients ($-1 < r < -0.99$). When collectively analyzing the data, the Pearson's coefficient is still within the $-1 < r < 0.99$ range which signifies that the relationship between input voltage and angle is independent of the

reference voltage or of the second diode inserted in parallel to the first. The equation of this linear trend is as follows:

$$\text{Input Voltage} = -0.0193 \times \text{Angle} + 3.26$$

For trial 1, the angle at which the LED is initially lit is 65°. For trials 2 and 3, this angle is 115°. It is observed that for this critical angle, the input voltages are identical to the reference voltages. Figure 2 also illustrates this concept. It is also observed that as the angle remained below this critical angle (i.e. as $V_{in} > V_{ref}$), the output voltages remained at a constant negative value. Upon reaching and surpassing this angle (i.e. as $V_{in} \leq V_{ref}$), the output voltages jumped to a constant positive value. This relationship between output voltage and angle is best described as a step function and is graphed in Figure 3 below.

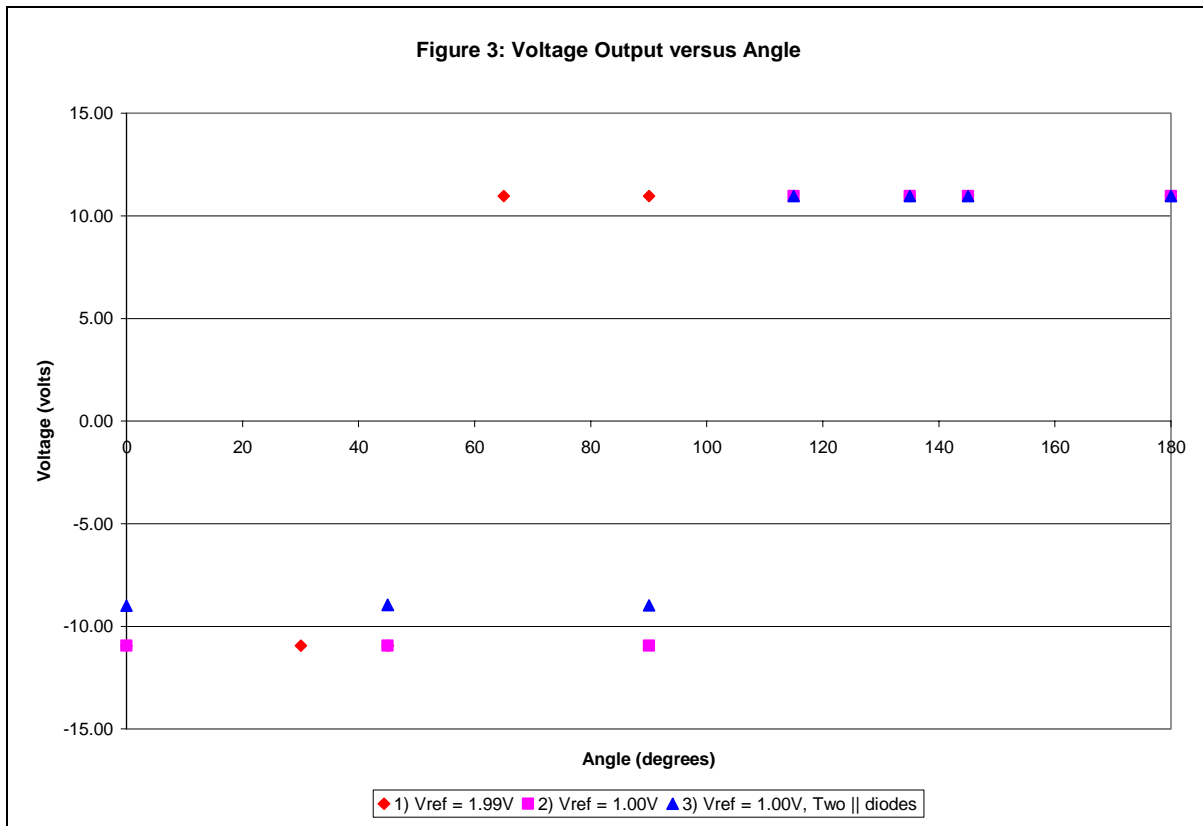


Table 1 below summarizes the output voltages for all three trials. For angles less than the critical angle, the output voltage for trial 3 differs to those for trials 1 and 2 by approximately 2 volts. The difference between trial 3 and the other trials under this condition is that trial 3 had a second LED that was lit.

Table 1: Output voltages		
<i>Trial #</i>	<i>Angles < Critical Angle</i>	<i>Angles ≥ Critical Angle</i>
1	-10.95 V	10.96 V
2	-10.95 V	10.96 V
3	-8.97 V	10.96 V

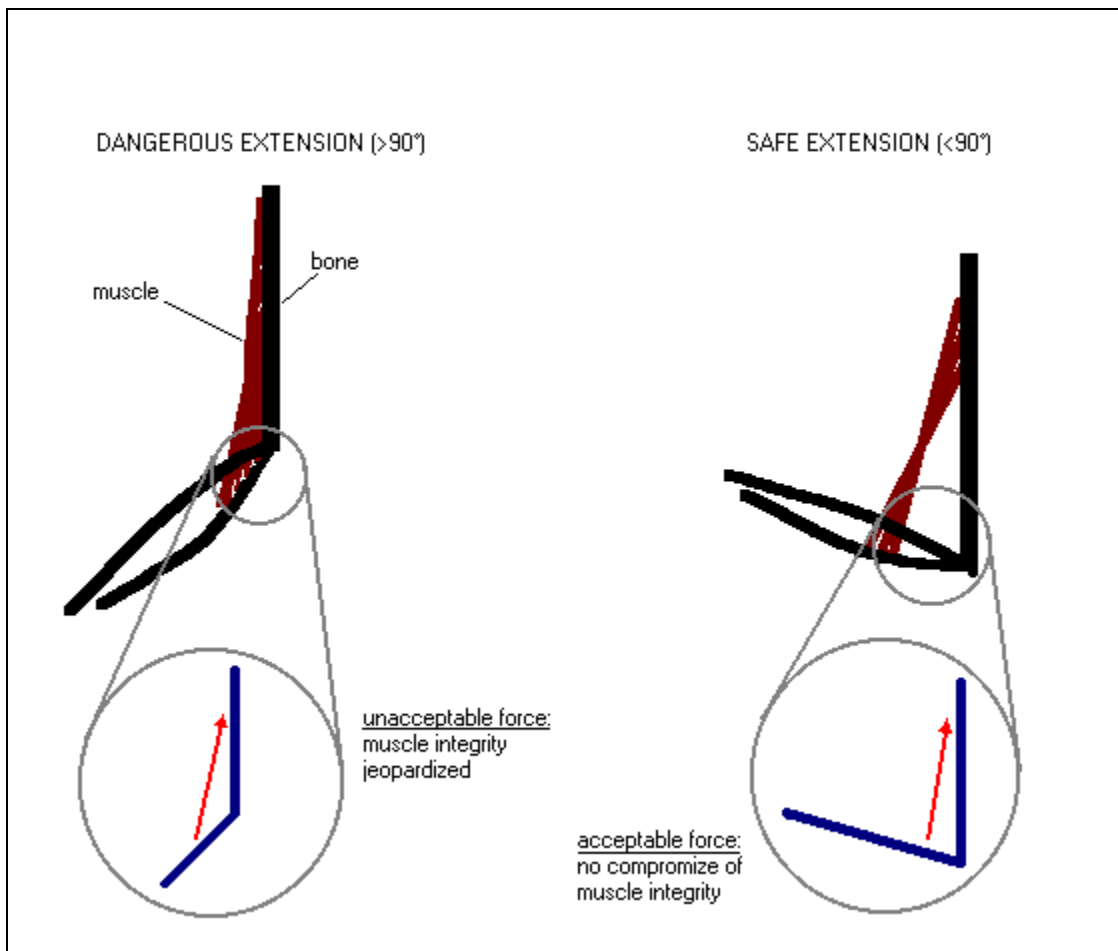
DISCUSSION:

In this circuit, a LM741 operational amplifier was used as a voltage comparator and two variable resistors, otherwise known as voltage dividers, were used. The rotation of the apparatus corresponded to rotating one of the voltage dividers, thus creating a change in voltage inputs, which is compared to the voltage reference with the use of the LM741. The LED lit when the input voltage equaled the reference voltage in all trials. The LED remained lit for all input voltages greater than or equal to the reference voltage and it was not lit at input voltages less than the reference voltage. The voltage at which the LED lit indicated a change in output states. This is evident since the data shows that input voltages less than the reference voltage were negative and input voltages greater than or equal to the reference voltage were positive, but the magnitudes of the input voltages remained constant.

A plot of the input voltage vs. measured angle shows a negative linear relationship between the two (see Figure 2). As the angle increases, the input voltage decreases. When the second LED was connected in parallel to the first, it can be seen that V_{ref} still equals the V_{ref} for a circuit that has only one diode. When $V_{in} = V_{ref}$, the second LED turned off as the first LED lit. The first LED lit at positive output voltage values whereas the second LED lit at negative output voltages. It should also be noted that the magnitude of the output voltages when the second LED lit were approximately 2 volts less than the output voltages corresponding to the lit state of the first LED. This difference is explained by the fact that lighting a LED uses approximately two volts. The lighting of a second LED required two additional volts and thus the output voltages of the second LED were 2 volts less than those of the first LED.

A main feature of the comparator is the signaling of a change in state by means of the lighting of the LED. To this end, the voltage comparator and the analog circuit have biological applications as well. For instance, a modified version of the comparator used in this lab could be used in the rehabilitation of an injured elbow joint. Intuitively it can be seen that the rotational motion of the elbow joint acts similarly to the experimental specimen studied in the lab. Such a device, attached at the joint during rehabilitation exercises, could be calibrated to indicate the safety threshold of rotational extension, thus indicating the maximum possible extension achievable before the integrity of the muscle is compromised. Refer to Figure 4 below for an illustrative explanation.

Figure 4:



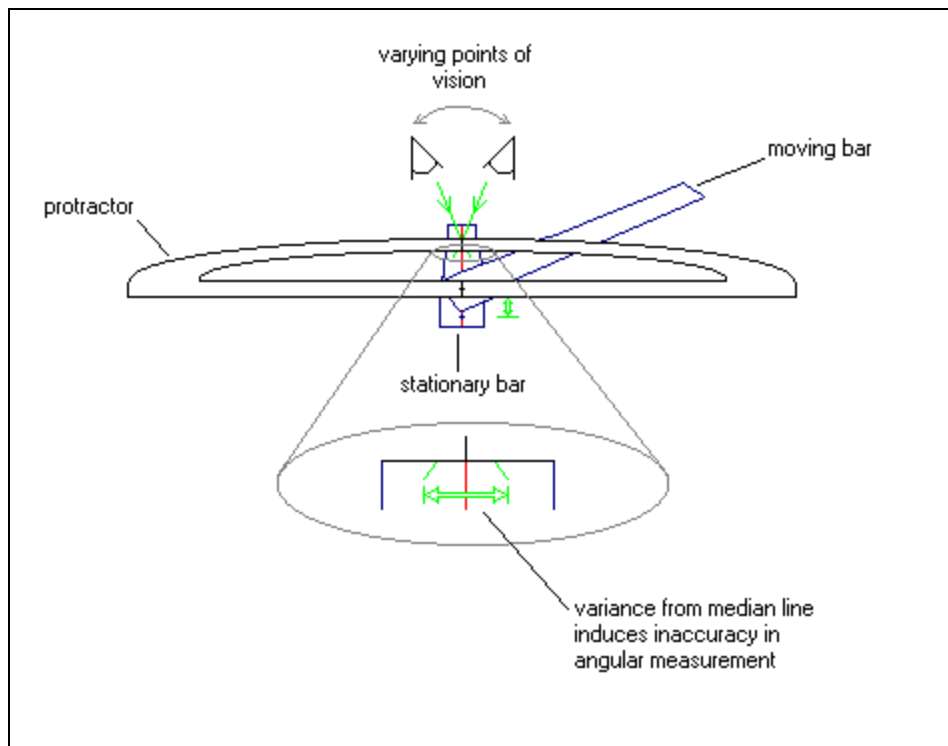
Electronic apparatuses such as the one utilized throughout this experiment accommodate a superior accuracy reading of the angles present within a system relative to simple mechanical

measurements, thus the ability to identify mechanical attribute into electrical resistance is crucial for accurate expression of data. Despite its efficiency, however, angular potentiometer/voltage comparator indicators are by no means perfect, and sources of error are, in fact, inherently more numerous than those exhibited within mechanical experimentation. Perhaps the most prevalent of which is the accumulation of the imperfection of the cables, and voltmeter. The wires utilized to construct the apparatus are not ideal and therefore carry a small amount of resistance; these individually insignificant resistances created by wires, once combined, form a considerable aggregate resistance throughout the system. Furthermore, the lack of perfection of the resistor facilitates a small absorption of current, where an ideal resistor has infinite resistance and therefore absorbs no current. This small loss of current, combined with the resistance throughout the adjoining wires, creates added error within the system. This error is reasoned to be even larger, due to the minute values of current collected by the apparatus; the smaller the current value the larger effect such imperfections have throughout the system. Although this error is assuredly present, it exists only as a diminutive source of deviation. The remaining electrical error is most likely due to a combination of noise and drift, the effects of which were so slight that they played virtually no role in error.

Unquestionably the most definite source of procedural error occurred as a result of the apparatus structure. Due to the thickness of the bars rotated, an accurate physical measure of the angle where V_{in} equaled V_{ref} proved to be an exigent task; the longitudinal median of each bar was first indicated, and the angle between them was then evaluated as accurately as possible. The difficulty resulting was also due in part to the fact that the two bars were separated by a significant distance, thus a shift in point of reference resulted in varying angles. Figure 5 on the following page illustrates these difficulties in accurately measuring the angles.

The final procedural error is also the result of inadequacies in the apparatus. In order to obtain data with greater ease, it was necessary to secure the lower beam to the desk with tape; this theoretically allows angular changes to be solely dependent upon the movement of the upper bar. However the tape gave way to the constant shear forces between it and the lower bar as well as the table. Consequently the lower bar made small shifts, thus decreasing the accuracy of the direct angle measurement.

Figure 5



CONCLUSION:

Usage of the LM741 operational amplifier as a voltage comparable, coupled with the usage of two voltage dividers, allowed for the monitoring of the circuit with the three voltage values: V_{in} , V_{ref} , and V_{out} . The data showed that as the angle changed in the apparatus, the input voltage changed linearly, regardless of the difference in reference voltage. When V_{in} was above V_{ref} , the diode did not lit, and the V_{out} was negative. When V_{in} was less than or equal to V_{ref} , the diode lit, and the output voltage changed from negative to positive. The use of the circuits in this lab allowed for extended applications to the biomedical field in which certain physical conditions must be met and monitored in a patient with injured appendages.