USE OF STRETCH SENSORS TO DETECT THE FORMATION OF AN ENDOSCOPIC LOOP

Fritzpatrick Roque
fritzpatrick_1989@yahoo.com

Aidan Murphy
crevice@verizon.net

Bijan Bayat Mokhtari
bijibijmak@yahoo.com

Joseph Kim
joseph.kim@mail.citytech.cuny.edu

Alex Barbaran
darklor7@gmail.com

Andy S. Zhang
azhang@citytech.cuny.edu

Farrukh Zia
fzia@citytech.cuny.edu

New York City College of Technology
186 Jay Street, Brooklyn NY 11201

Abstract: When a doctor performs an endoscopic procedure, it is possible that a loop may be formed by the endoscopic tubing inside the patient's body. This condition may potentially harm the patient seriously if the doctor who performs the procedure is unaware of the situation. This paper presents a technique on how to detect the formation of an endoscopic loop using stretch sensors. A custom-made loop detecting device using the stretch sensors was developed. Upon bending, sections of the endoscope will elongate while other sections will be compressed. The changes in dimension of the stretch sensor result in changes in resistances that are ultimately read as changes in voltage by the microcontroller. Utilizing a stretch sensing material, the onset of a loop during an endoscopic procedure was accurately determined. The effectiveness of each configuration in detecting the formation of a loop is studied.

This loop detecting device was designed in a way that it can be attached to an endoscope without significantly increasing the diameter of the endoscopic tubing. Once a loop is formed, the device will send a warning signal so the doctor who performs the endoscopic procedure can adjust his or her operation to avoid harming the patient.

Keywords: Endoscopic loop detection, medical device design, undergraduate research projects.

1. Introduction

Endoscopy is a medical procedure used for the purposes of diagnosing or treating many complications within the human body. The endoscopic procedure is an out-patient procedure that usually does not require the patient stay overnight. As with all medical procedures though, a certain amount of risk is associated with the practice. An endoscopic procedure runs the risk of tearing tissue such as the lining of the stomach or the inside of the colon causing internal bleeding, inflammation or infection. The most common cause of these risks is due to looping of the endoscope within the body. Although the endoscopic procedure is carried out by a team of health care professionals, due to the limitations of the endoscope itself, loops occur within the endoscope that further increase the probability of risk. Currently, many of the Doctors administering the endoscopic examination rely on intuition to detect if a loop has formed. For the purposes of detecting these loops in a more accurate and dependable way, a reliable yet simple, inexpensive yet sophisticated, user-friendly sensing device with an emphasis on optimal efficiency and patient comfort was developed.

The device, which is called Loop-O-Scope the by team, revolves around a stretch sensing material installed onto an endoscope for the purpose of detecting loops. The method of detection relies upon the mechanical behavior of the endoscope while it undergoes a bend. Upon bending, sections of the endoscope will elongate while other sections will be compressed. These changes in length are then picked up by the sensing material and interpreted by a microcontroller. Should the microcontroller detect the onset of a loop, the system will alert the healthcare professional administering the endoscopic examination.

2. Objective

The main objective of this research project was to develop a loop detector prototype endoscope to help doctor to avoid harming the patient when performing the endoscopic procedure. While developing the loop detecting device, the team has to pay attention to followings:

- Loop detection concept must be as simple as possible.
- Medical technicians must easily grasp the theory behind the device in order to quickly troubleshoot and fix problems in case the instrument malfunctions.
- Device must be simple to use so that end users with not have to take classes on how to operate the device.
- Must not produce false loop forming signal.
- Must be versatile.
- Must provide optimum comfort and avoid stress to the patient and possibility of injuring the patient.

3. Design Principle

The device was designed around the mechanical principle of bending or flexure. The principle of bending states that when an object undergoes bending, the top fibers of the object will be stretched while the lower fibers will be compressed. The loop detector takes advantage of this principle simply because whenever any type of endoscopic loop forms, as shown in Figures 1 and 2, the fibers of the endoscope will behave as the principle of bending suggests. By placing a sensor that is sensitive to these changes in dimension, we have a reliable way to detect loops as they are beginning to form.

The stretch sensor, whose properties are shown in Table 1, is made of a silicone material. Its' resistive value changes as it is stretched. A change in length of the sensor translates to a change in resistance value of the sensor. The sensing wire itself has an intrinsic resistance value and is pre-stretched during fabrication which is used as the standard value for an undisturbed endoscope. The Loop-O-Scope system uses the sensing material as a conducting wire and in conjunction with a 5-volt power supply, measures the change in voltage. As the endoscope is manipulated, the change in resistance value was interpreted by the microcontroller and should the values indicate the presence of a loop, a visual signal will alert the health care professional.

The changes in dimension of the stretch sensor result in changes in resistances that are ultimately read as changes in voltage by the microcontroller. This is achieved by using the electrical principle of Ohm's Law. Ohm's Law states that a relationship exists between voltage, current, and resistance in an electrical circuit. A simple diagram, as shown in Figure 3, is commonly used to explain this relationship.

For the loop detecting system, a constant 5 volt supply was provided to energize the sensing wires. During a no-bend or zero deflection state of the endoscope, a constant baseline value for the voltage was first obtained. By keeping the current constant at all times, one can apply the Equation 1 shown in Figure 3 that shows how a change in resistance leads to a change in voltage. Voltage and resistance in this case are directly proportional to one another. Therefore, an increase in resistance would lead to an increase in voltage and vice versa. The microcontroller is programmed to detect these changes and interpret them as bends or loops.

The functioning of the loop detection system is very similar to the way a multimeter, or to be more precise, similar to that of an Ohm meter. Ohm meters work by supplying a known voltage at known amperage through a circuit. On the return side of the multimeter, the positive leads read the level of voltage that has returned and interprets that as a resistance value. In fact, as many who have used Ohm meters would know, without a power source such as a battery, the device will not read any values at all. It would cease to function. Collecting and interpreting the values that the sensor receives is handled by an Arduino microcontroller. During normal operation, the endoscope will naturally bend and flex, a program was developed that can decide whether the endoscope is functioning normally or not. To detect loops in all direction, the sensing wire is arranged in a four-way configuration. The program itself is intuitive enough to detect in which direction – up, down, left, right – the endoscope is bending. The logic behind the program is shown in the flow chart in Figure 4.

4. Alternative Methods

During the early stages of development for the loop detection system, the team investigated several alternative methods that could potentially detect the bending and looping of an endoscope.

One of the more popular methods for detecting bends is through the use of a standalone flex sensor as shown in Figure 5.

Flex sensors are composed of thin layers of a variable resistive material sandwiched between two thin plates of conductive materials. Current is allowed to flow from one conductive layer to the other but is forced to pass through the layer of resistive material. Upon bending, the thickness of the resistive layer is decreased, bringing the conductive layers closer together. As the distance between the plates decrease, the resistance of the flex sensor decreases as well. While this method seemed extremely promising, the team encountered many problems with the flex sensor during early design stages. The problems related to the use of the flex sensor are:

• Since the flex sensor is flat, its design only allows for bending about a single axis. This means it can only bend longitudinally (up and down) but not laterally (side to side). As already noted, an endoscope may bend in any of four directions. If mounted onto an endoscope, the flex sensor would not be able to detect loops in all these directions.

• If the flex sensor is somehow mounted onto an endoscope in a four-way configuration such that it can detect loops in all directions, the flex sensor would be subjected to repeated lateral deflection. It has been found that this repeated deflection will cause the flex sensor to tear due to tensile stresses.

The next method that the team investigated was the use of a stretchable cloth-like conductive material as shown in Figure 6. The cloth is composed of silver plated nylon and elastic fiber fabrics. Depending on the direction in which the fabric is stretched, the conductivity either increases or decreases. Similar to the silicone stretch sensing material currently used in the Loop-O-Scope system, the electrical value of the conductive cloth changes as it is stretched. While this too seemed promising, several problems with this material occurred as follows:

• Unlike the silicone stretch sensing material, which can stretch several times its original length, the total amount of deformation the conductive fabric material may undergo is very limited.

• While the conductive cloth does stretch, it is not elastic. The fabric itself will not recover from any deformation it undergoes meaning that once the fabric has been stretched, it will never return to its original length. We concluded that this material will never stand up to the repeated action of flexing that an endoscope undergoes during normal operations.

• The cost per inch of the fabric also exceeds that of the stretch sensor material. At $29.95 per foot, the conductive fabric would have been an expensive alternative to the silicone stretch sensor.

Finally, the team investigated the use of an inductor to detect endoscopic loops. The inductor is made of very thin 40 gauge copper wire as shown in Figure 7. As electricity flows through the copper wire, a magnetic field will build around the wire. Sensors placed anywhere near the inductor will then pick the magnetic flux emanating from the copper wire. With this method, the actual sensing can be done away from the endoscope. However, the team encountered several problems when using this method:

• The magnetic sensors needed for this method to work have to be placed throughout the examination room. The sensors would also have to be extremely sensitive to pick up the low levels of magnetic flux from the endoscope. However, this level of sensitivity would then be able to pick up even the minutest of magnetism. Any electrical equipment in the examination room would therefore interfere with the ability of sensors to detect an endoscopic loop.

• The complexity of the proposed inductance based loop detector would be well outside the scope of knowledge of medical professionals. One of the objectives of this project was to make the system easily graspable so that medical technicians can quickly troubleshoot and fix problems in case the instrument malfunctions.

5. Computer Model

As part of the design process, the team has reproduced an endoscope using the Autodesk Inventor 3D solid modeling program. The 3D computer model of the endoscope helped team members visualize not only the endoscope and its constituent parts, but how the sensor itself will be attached to the endoscope. Shown below is the finalized concept of the stretch sensor along with a detailed view of the sensor attachment as well as a section view of the guide rings.

6. Test Results

Testing of the loop detecting system was done many times at lab. During repeated testing of the loop detector however, the team encountered several issues with the system. The biggest issue is that the test results would vary greatly between an endoscope sheathed with the PVC sleeve and a bare endoscope with exposed loop sensors. The bare un-sheathed endoscope produced steadier values and proved to be more reliable. However, once the endoscope was covered, pressure from the sheathing would be exerted onto the sensing wires and lead to mixed results. The values of bending would fluctuate randomly between wide ranges of values. While this can be adjusted for, the complexity and frequency of adjustment would be outside the scope of a health care professional.

Alternative means of sheathing the endoscope were investigated and included using non-conductive electrical tape, partially covering the endoscope only along the guide rings, and using a heat-shrinkable fabric. While each alternative allowed the loop detector to function normally for the first few bends, repeated bending would lead to the same problems as stated in the preceding paragraph.

A single aspect from all the repeated testing did however prove promising. If the endoscope and subsequently the loop detector are allowed to relax between tests, the values would stabilize and not fluctuate as much. A proposed solution, one that is a combination of a mechanical and programming fix, was then conceived. By only partially covering the endoscope along the brass guide rings, the team relieved the sensor of some of the pressure from the heat-shrinking. Also, to account for the relaxation time, the program has been altered so as to dynamically change its threshold value based on the state of the sensor at any given time. With the alterations done to the endoscope, performance of the loop detector improved. On the test rig, the improvements proved to help the endoscope detect the loops more reliably and accurately.

A stretch sensor circuit was constructed to detect the changes in voltage. Figure 10 and 11 shows the procedure to find the correct reference resistor.

After some calculations as shown below and calibrations, the stretch sensor circuit was developed as shown in Figure 12.

a) Average Resistance

$$R_{need} = \frac{R_{max} + R_{min}}{2}$$

This results:

$$R_{need} = \frac{50k\Omega + 19k\Omega}{2} = 34.5k\Omega \approx 35k\Omega$$

b) Minimum and Maximum Voltage

Minimum Voltage:

$$V_{out(min)} = \left(\frac{R_{need}}{R_{max} + R_{need}}\right) V_{cc}$$

This gives:

$$V_{out(min)} = \left(\frac{35k\Omega}{50k\Omega + 35k\Omega}\right) 5V$$
$$= 2.1V$$

Maximum Voltage:

$$V_{out(max)} = \left(\frac{R_{need}}{R_{min} + R_{need}}\right) V_{cc}$$

This gives:

$$V_{out(max)} = \left(\frac{35k\Omega}{19k\Omega + 35k\Omega}\right) 5V$$
$$= 3.2V$$

7. Conclusion

The team developed a low cost but effective way to detect the formation of loop. The loop detector alerts medical personal to the presence of a loop through two LED lights, one red and one green, mounted externally and away from the device. By changing the color of the fiber optic light between red and green during the insertion process, medical professionals would instantly be alerted to the presence of a loop. The final model can be seen in Figure 13.

It is suggested that a hydrophobic polymer material [3] be used to coat the entire endoscope to protect the sensors. Many medical devices already make use of hydrophobic materials because they protect medical equipment from bodily fluids, moisture, and corrosion [4, 5]. Further research needs to be done in order to find a way for endoscope loop detection.

Acknowledgement

References

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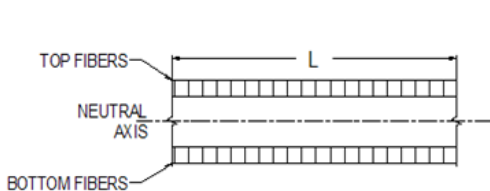
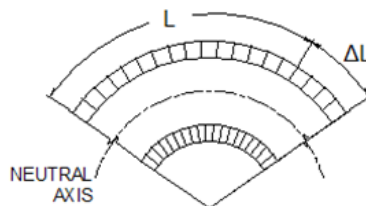Figure 1: Straight Endoscope
Top fibers at original length, L

Figure 2: Bent Endoscope
Top fibers elongated, DL has occurred

Table 1: Stretch Sensor Material Properties [1]	
Material	EA60 Polysiloxane
Color	Black
Operational Temp. (continuous)	-50 to 180°C (-60 to 360°F)
Operational Temp. (intermittent)	-60 to 230°C (-80 to 450°F)
Tensile Strength (psi)	870
Tear Strength (ppi)	80
Elongation (%)	250
Specific Gravity	1.15
Resistivity (Ω*cm)	7
Contact Information	imagesco.com

V = Voltage (V)
I = Current (A)
R = Resistance (Ω)

$V = I \times R$ (eq. 1)	$I = V/R$ (eq. 2)	$R = V / I$ (eq. 3)
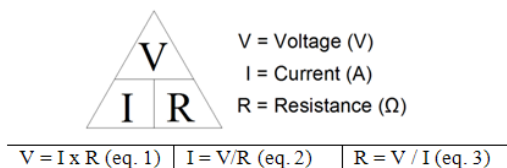
Figure 3: Ohm's Law
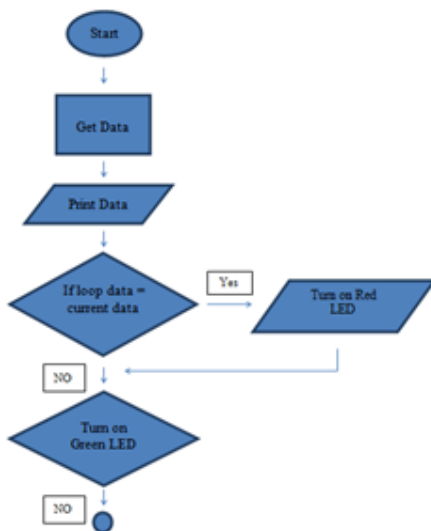
Figure 4: Logical Flow Chart
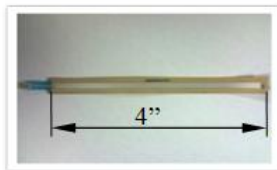
Figure 5: Flex Sensor

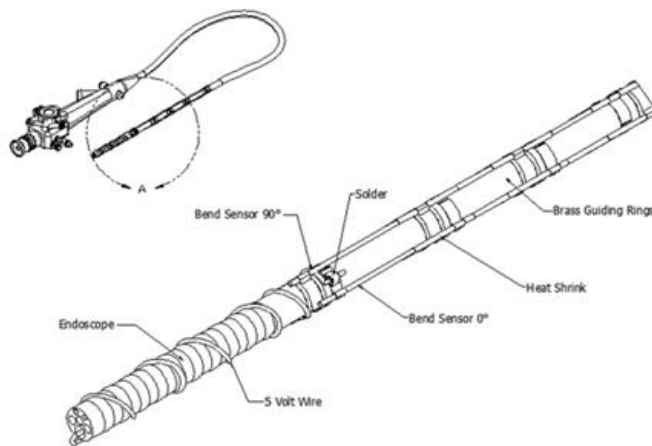Figure 6: Conductive Fabric [2]   Figure 7: Copper Wire Inductor

Figure 8: Loop-O-Scope Loop Detector
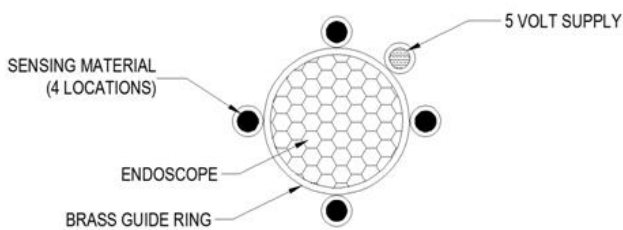Detailed view of loop detector affixed onto an endoscope

Figure 9: Guide Ring Cross Section
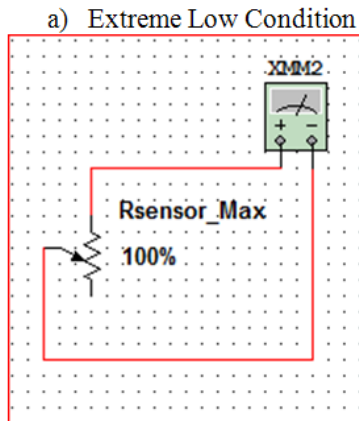Detailed view of loop detector affixed onto an endoscope

a) Extreme Low Condition

b) Extreme High Condition

Figure 10: Measure & Record variable's resistor minimum value (most extreme low condition) R_{min}
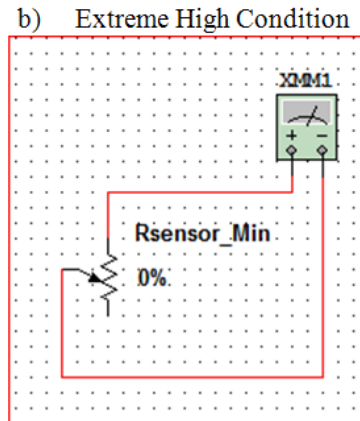
Figure 11: Measure & Record variable's resistor maximum value (most extreme high condition) R_{max}
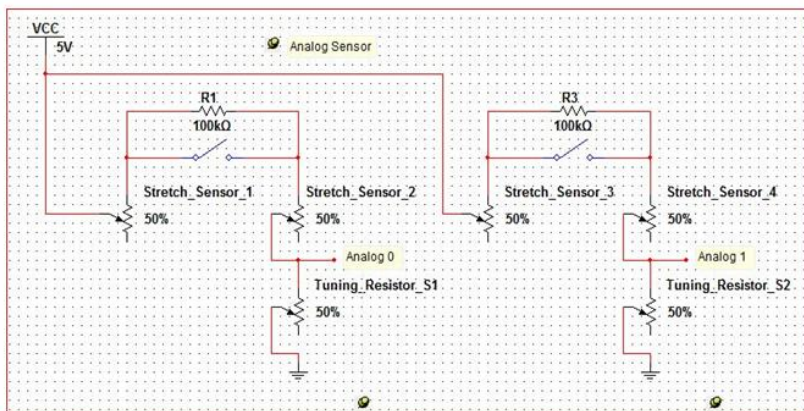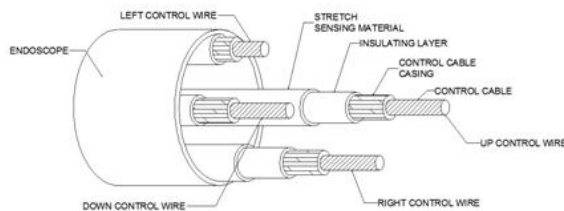

Figure 12: Stretch Sensor Circuit

Figure 13: Proposed Sensor