B. TECH. PROJECT REPORT

On

Design and Development of Smart Cervical Collar using Shape Memory Alloy

BY

ADITYA GOVIL

DISCIPLINE OF MECHANICAL ENGINEERING

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Design and Development of Smart Cervical Collar using Shape Memory Alloy

A PROJECT REPORT

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Submitted by:

Aditya Govil (130003003)

Guided by:

Dr. I.A.Palani (Associate Professor)

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DECEMBER 2016

CANDIDATE'S DECLARATION

Preface

This report on "**Design and Development of Smart Cervical Neck Collar using Shape Memory Alloy**" is prepared under the guidance of **Dr. I.A. Palani.**

Through this report we have tried to give a detailed design of a Smart Cervical Neck Collar which has been actuated by the help of Shape Memory Alloy and have tried to cover every aspect of the new design, if the design is technically and economically sound and feasible.

We have tried to the best of our abilities and knowledge to explain the content in a lucid manner. We have also added 3-D models and figures to make it more illustrative.

Aditya Govil

B.Tech. IV Year

Discipline of Mechanical Engineering

IIT Indore

Acknowledgements

I wish to thank **Dr. I.A. Palani** for his kind support and valuable guidance. This work has been done in framework of the IIT Indore project that is funded by the **PRIUS** (Promotion of Research & Innovation for Undergraduate Student). I would like to acknowledge Mr. Karthick Subramaniam, Mechatronics & Instrumentation lab, Industrial Engineering Research lab and Central Workshop of IIT Indore for providing their sincere cooperation and guidance to carry out this research.

It is their help and support, due to which we were able to complete the design and technical report. Without their support this report would not have been possible.

Aditya Govil

B.Tech. IV Year

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Abstract

In this report I aim to elaborate on the design and development of a Cervical Collar using Shape Memory Alloy. The Smart Collar works with the help of the Shape Memory Alloy spring. SMA has been chosen as the preferred mode for producing actuation as it has many considerable advantages over other available methods, biocompatibility being one of these. The creation is the smart cervical collar for the patients having cervical spondolysis or any other neck pain or neck injury (may be accidental or because of aging) incorporating **SHAPE MEMORY ALLOY** in it. The collar facilitates extreme comfort to the patients along with its basic functions of immobilization, comfort to surrounding muscles and speed recovery.

Shape Memory Alloy changes its shape as one changes the temperature of the alloy. This property of the SMA has been exploited in the fabrication and working mechanism of the Cervical Neck Collar. The Collar has been incorporated with a **FLEX SENSOR** which provides input to the SMA, which in turn actuates to adjust to the user's needs.

In this, I have tried to develop a Neck Collar and devise a relation between the input to the sensor and the displacement of the belt, or the displacement of the belt w.r.t. the neck movements of the user.

In this report, I am going to discuss the design, working mechanism, fabrication, experimentation and validation of the device.

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Fig. 18. Final Prototype – Smart Neck Collar Belt

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Chapter 1. INTRODUCTION

1.1 Motivation

Persons suffering from cervical spondolysis and victims of whiplash injuries are advised to wear Hard Collar belts for the purpose of healing the affected cervical area. In this process, many patients experience discomfort and develop soreness in the muscles, callous in the occipital area, weakness in the clavicle and shoulders, crease in the trapezius etc. They also face other problems like immobility of the neck and surrounding areas, manual tightening and loosening of the neck collar belt. The Smart Cervical Belt aims to relieve the patients from these problems as far as possible. To create a more comfortable product for such patients is a major source of motivation for taking up this project and developing a prototype of the same.

Figure 1. Currently Available Hard Collar Belts

1.2 What is a Shape Memory Alloy (SMA)?

An SMA, smart material, memory metal, memory alloy, muscle wire, smart alloy is an alloy that "remembers" its original shape and that when deformed returns to its pre-deformed shape when heated. This material is a lightweight, solid state alternative to conventional actuators such as hydraulic, pneumatic, and motor-based systems. Shape-memory alloys have applications in industries including automotive, aerospace, and biomedical and robotics.

The two main types of shape-memory alloys are copper-aluminium-nickel, and nickel-titanium (NiTi) alloys but SMAs can also be created by alloying zinc, copper, gold and iron. NiTi alloys change from austenite to martensite upon cooling; M_f is the temperature at which the transition to martensite completes upon cooling. Accordingly, during heating A_s and A_f are the temperatures at which the transformation from martensite to austenite starts and finishes.

Repeated use of the shape-memory effect may lead to a shift of the characteristic transformation temperatures (this effect is known as functional fatigue, as it is closely related with a change of microstructural and functional properties of the material).

The maximum temperature at which SMAs can no longer be stress induced is called M_d, where the SMAs are permanently deformed. The transition from the martensite phase to the austenite phase is only dependent on temperature and stress, not time, as most phase changes are, as there is no diffusion involved.

Similarly, the austenite structure receives its name from steel alloys of a similar structure. It is the reversible diffusion less transition between these two phases that results in special properties. While martensite can be formed from austenite by rapidly cooling carbon-steel, this process is not reversible, so steel does not have shape-memory properties.

1.3 Shape Memory effect

“Shape Memory" describes the effect of restoring the original shape of a plastically deformed sample by heating it. This phenomenon results from a crystalline phase change known as “Thermo elastic martensitic transformation. At temperatures below the transformation temperature. Shape memory alloys are martensitic, in this condition their microstructure is characterized by "selfaccommodating twins ", the manensite is soft and can be deformed quite easily by de-twinning. Heating above the transformation temperature recovers the original shape and converts the material to its high strength austenitic condition.

a. One-way memory effect-

When a shape-memory alloy is in its cold state (below A_s), the metal can be bent or stretched and will hold those shapes until heated above the transition temperature. Upon heating, the shape changes to its original. When the metal cools again it will remain in the hot shape, until deformed again. With the one-way effect, cooling from high temperatures does not cause a macroscopic shape change. A deformation is necessary to create the low temperature shape. On heating, transformation starts at A_s and is completed at A_f (typically 2 to 20 °C or hotter, depending on the alloy or the loading conditions). As is determined by the alloy type and composition and can vary between −150 °C and 200 °C.

b. Two-way memory effect-

The two-way shape-memory effect is the effect that the material remembers two different shapes: one at low temperatures, and one at the high-temperature shape. A material that shows a shape-memory effect during both heating and cooling is called two-way shape memory. This can also be obtained without the application of an external force (intrinsic two way effect). The reason the material behaves so differently in these situations lies in training. Training implies that a shape memory can "learn" to behave in a certain way. Under normal circumstances, a shape-memory alloy "remembers" its low-temperature shape, but upon heating to recover the high temperature shape, immediately "forgets" the low-temperature shape. However, it can be "trained" to "remember" to leave some reminders of the deformed low temperature condition in the high-temperature phases. There are several ways of doing this. A shaped, trained object heated beyond a certain point will lose the two-way memory effect, this is known as "amnesia".

1.4 Engineering Aspects and applications of the SMA

The shape memory effect can be used to generate motion or force, while super elasticity can store deformation energy. The function of the difference can be explained in simple terms using the example of a straight tensile wire. The wire is fixed at one end. Stretching it at room temperature generates an elongation after unloading. The wire remains in the stretched condition until it is heated above the transformation temperature of this particular alloy. It will then shrink to its original length As no load is applied, this is called free recovery. Subsequent cooling below the transformation temperature does not cause a macroscopic shape change. If, after stretching at room temperature, the wire is prevented from returning to its original length, length. If constrained to the extended length upon heating above the transformation temperature, it can generate a considerable force. This so-called constrained recovery is the basis of many successful applications.

Some Applications of the SMA:

• Medical: Orthodontic wire, Biliary stent, Regional-chemotherapy, Endoscopic guide wire.

• Aerospace Engineering: Cryofit, Frangibolt, Pin puller.

• Automobiles and Trains: Oil controller, Steam tap.

• Construction: Underground ventilation, Static rock breaker

1.5 Limitations on the use of the SMA

• Heat dissipation is slow. External cooling is required for fast applications.

• Range of motion is limited to shape change of the material.

• **Stiffness/Flexibility:** Stiffness increases at low (room) temperature.

• Relatively expensive to manufacture and machine compared to other materials such as steel and aluminium.

• Most SMA's have poor fatigue properties; this means that while under the same loading conditions (i.e. twisting, bending, compressing) a steel component may survive for more than one hundred times more cycles than an SMA element.

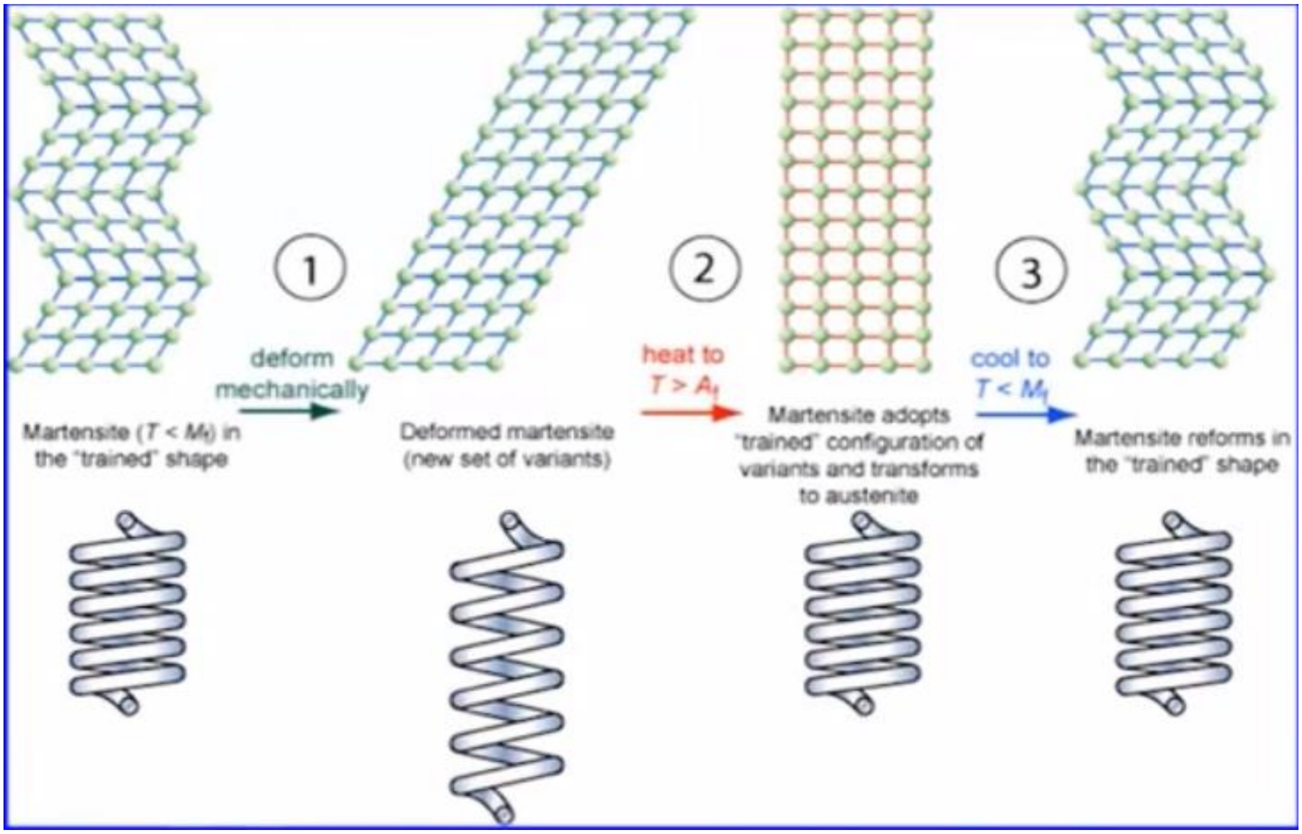


Figure 2. Phase Transformation of SMA

1.6 Literature Review

[1] Matthew Fonte, Matthew Palmer [Appl. No.: 13/936,866; Filed: Jul. 8, 2013]

This patent outlines the use of SMA actuated SHOE for the athletes. This introduced me to the use of SMA in biomedical engineering and its various applications.

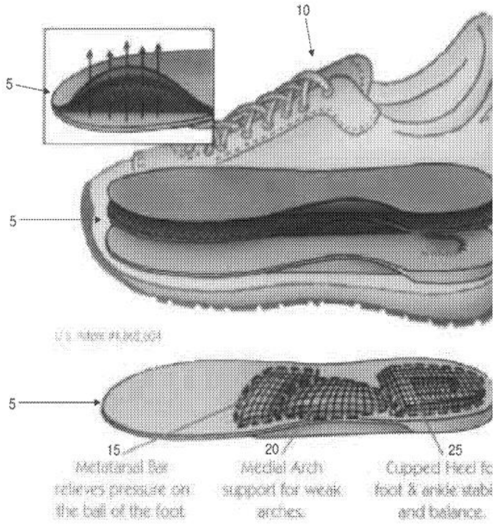


Figure 3. Shoe Insole Patent

[2] Matthew Palmer, Matthew Fonte [App1.No.: 13/843,656; Filed: Mar. 15, 2013]

This patent helped in understanding the current practice of IMPLANTS in the cases of injuries when movements may be restricted as opposed to the mechanism developed by me.

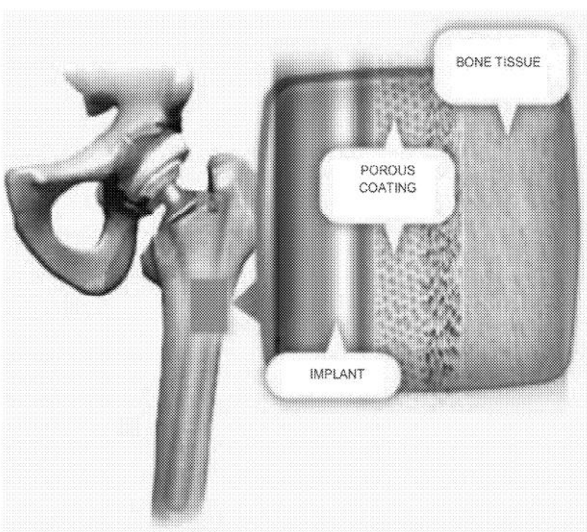


Figure 4. Implant Technology

[3] Russell A. Houser, James G. Whayne [Appl. No.: 09/965,542; Filed: Sep. 27, 2001]

This patent delves in the area of wearable technology by using solid brackets for controlling the movements of the affected areas.

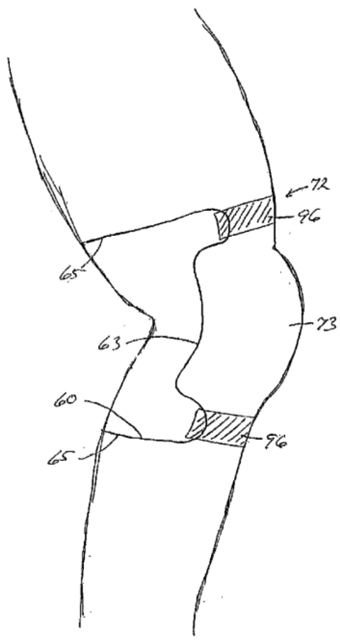


Figure 5. Knee Braces Patent

[4] Ehsan Tarkesh Esfahani; The University of Toledo

Developing an active ankle foot orthosis based on shape memory alloys- This paper reflected the way SMA was being used in the field of Foot Orthosis, yet another area of biomedical application of the SMA.

[5] Diego Mantovani

This paper basically outlines the properties of the SMA and its possible uses in the field of biomedical engineering.

1.7 Problems in the existing neck collars

- **Soreness in the muscles, callous in the occipital area, weakness in the clavicle and shoulders, crease in the trapezius**

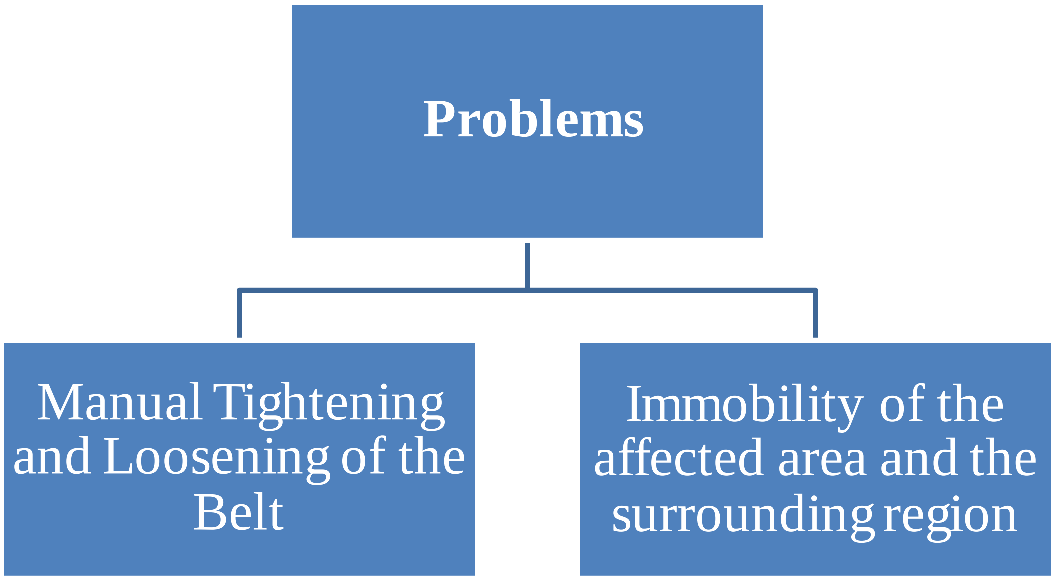
  The user can adjust the required pressure as per one's comfort along with maintaining the gap between the vertebrae and thus avoiding unwanted and painful effects like soreness in the muscles, callous in the occciputal area, weakness in the clavicle and shoulders, crease in the trapezius.

- **Immobility of the neck and surrounding areas**

  As per the comfort required by the user (whenever he is required to change the pressure), one can control the variation in the pressure by using the switch provided with the collar. When the SMAs are actuated, the pressure between the collar and the body part can be adjusted by providing a slight variation in the area of the collar near that part.

- **Manual tightening and loosening of the neck collar belt**

  With the advent of this product, during processes like eating, speaking etc. a person would no longer need to manually control the belt, instead it will only be a click away. It will automatically adjust according to the size and shape of the user.



1.8 Objectives of the product

- **Provide relief to patients**

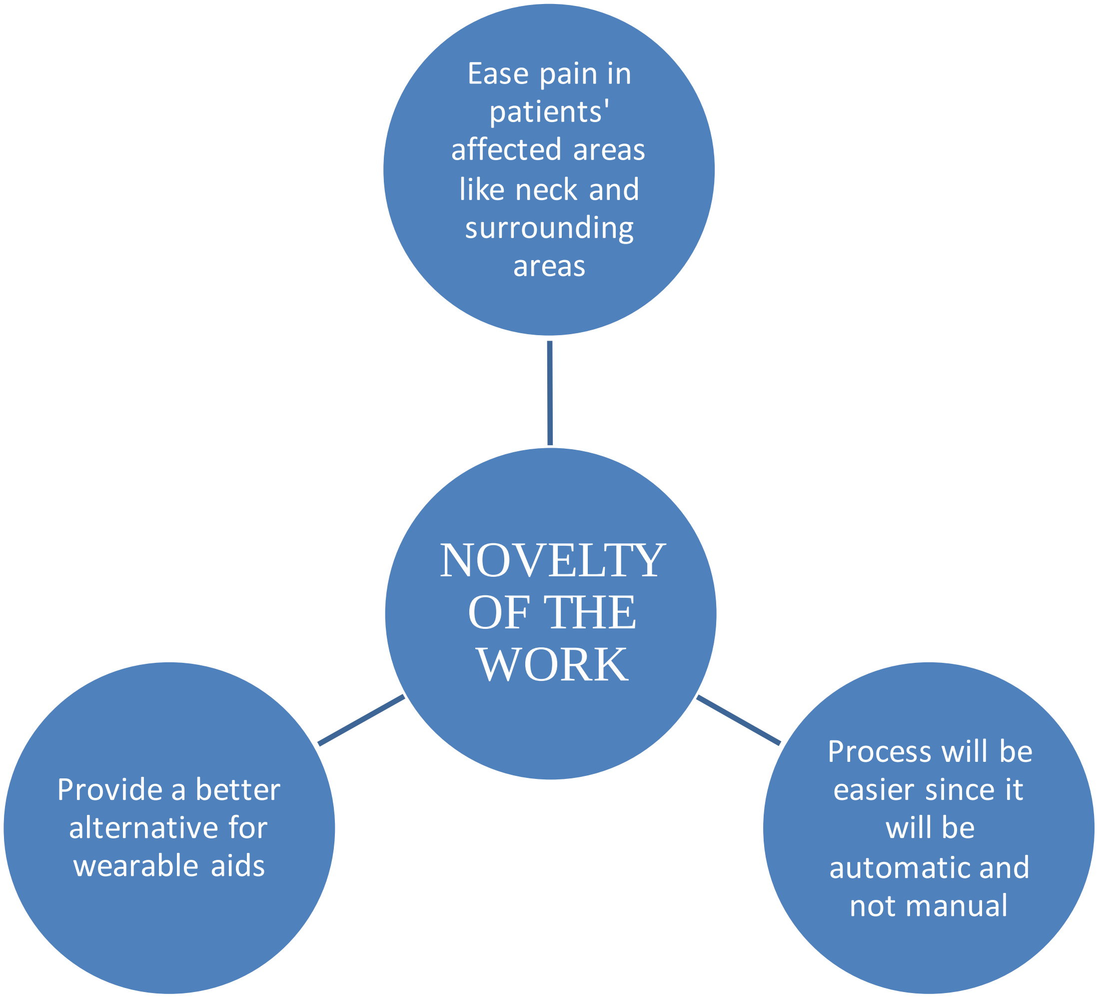
  The collar facilitates extreme comfort to the patients along with its basic functions of reduction of skin injury and irritation and speedy recovery. The constant irritation, pain and uneasiness experienced by the patient is a major cause of discomfort. The immediate and first observable impact will be the lessening of this discomfort to the patients.

- **Mobility to the wearer**

  The hard collar belts, currently available restrict the wearer's chin movements and make it difficult for him/her to perform certain actions for example talking, eating etc. without first, manually adjusting the belt. This product aims to eliminate this aspect.

- **Provide a cushioning effect to neck and surrounding areas**

  This SMA actuated belt aims to serve its basic purpose ie. provide comfort to the affected area, mostly neck and the surrounding areas, the basic need of the belt, to help the patient with the neck injury. This shall help in relieving pain in the affected region of the neck.


Ease pain in patients' affected areas like neck and surrounding areas
NOVELTY OF THE WORK
Provide a better alternative for wearable aids
Process will be easier since it will be automatic and not manual

Chapter 2. DESIGN

2.1 Choice of SMA Component

SMA springs were used for obtaining the actuation in the sheet. We conducted experiments on two of the available SMA products, namely SMA springs and SMA wires. Experiments were done on both and the former came out as the preferred choice. Since the actuation in the wire was too miniscule to have even a considerable effect, the SMA springs, on the other hand, proved to be the better alternative.

Property	SMA Wire	**SMA Spring**
Actuation (Relative Displacement)	Very Small	**Adjustable** (as per requirements)
Restoring Force Required	Low	**Very Low**
Implementation in design	Clumsy	**Easy**

Table 1. Choice of SMA Component

Hence, the obvious choice was to work with SMA Springs.

2.2 Conceptual Model Design

After the above step, a Solidworks 2-D model of the proposed neck collar was designed.

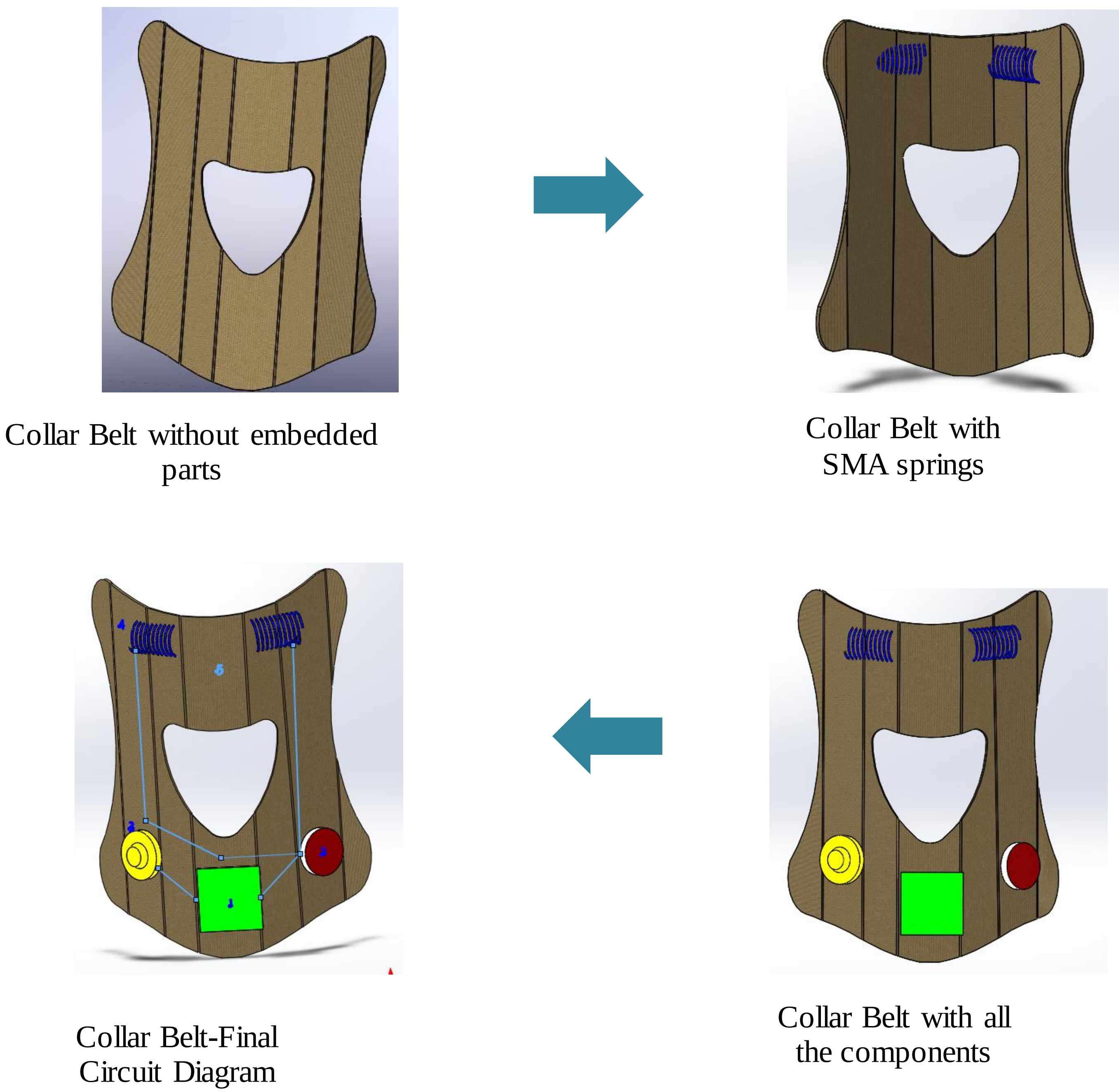


Figure 6. Neck Collar Design 2-D

The above illustrated design of the neck collar belt has the following enumerated parts used in it as labelled in the diagram

1. Controller (Arduino, in our case)

2. Controller Knob (later, Flex Sensor takes its place)

3. Battery (12V)

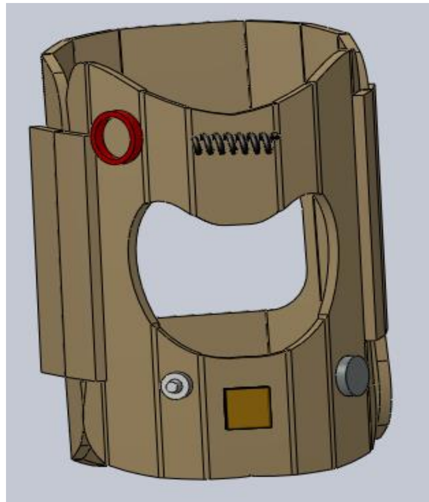
4. SMA Springs

5. Foam Sheet (acts as the neck collar belt)

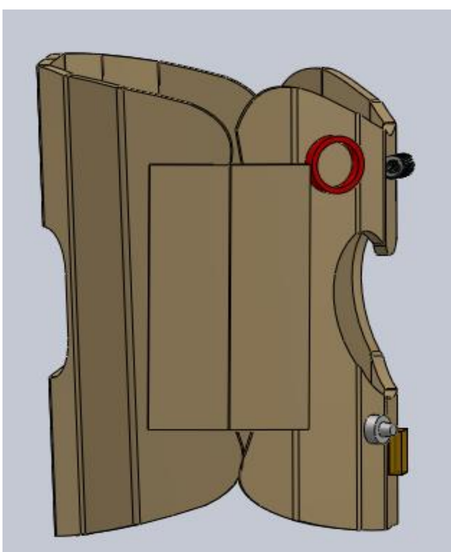
The length of the SMA spring chosen was 13.86 mm keeping in mind the length of the foam sheet which had to be actuated. Rest of the parameters are as follows-

- No. of Turns:18
- Wire Diameter: 0.77 mm
- Mean Diameter: 5.69 mm
- Power Supply: 12V
- Size of the foam sheet: 30 cm * 20 cm

FRONT VIEW



SIDE VIEW



TOP VIEW

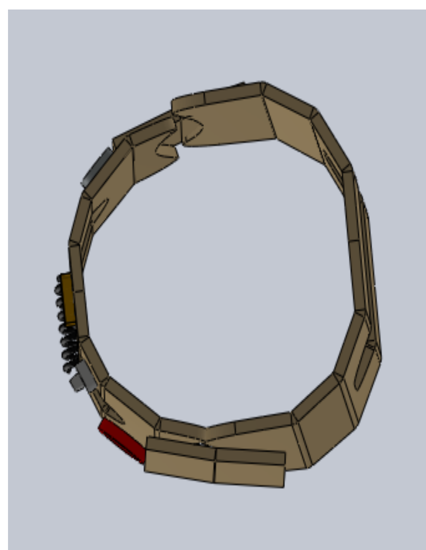


Figure 7. Neck Collar Design 3-D

2.3 The Flex Sensor

After having designed the outline of the prototype, the next step was to incorporate the pressure sensing device in the collar which would give the input to the spring for actuation to take place.

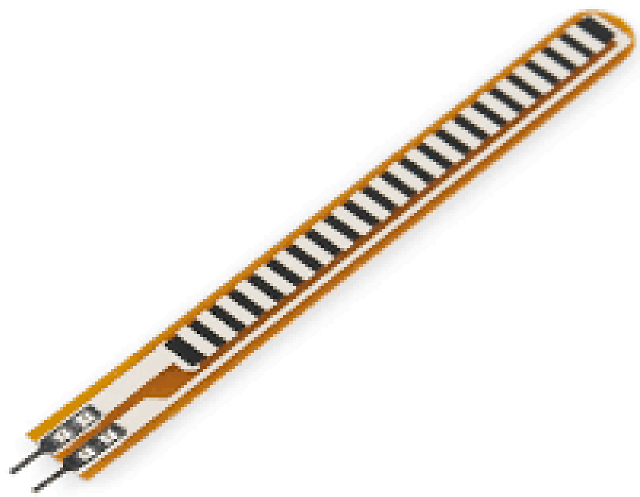


Figure 8. Flex Sensor

The basic principle of the flex sensor is that its resistance changes as its bend angle changes. The sensor has a minimum resistance when it is in a neutral position. As we bend it on either side, its resistance changes which causes a change in the current flowing through the circuit. This property of the Flex Sensor has been used in the actuation of the SMA spring.

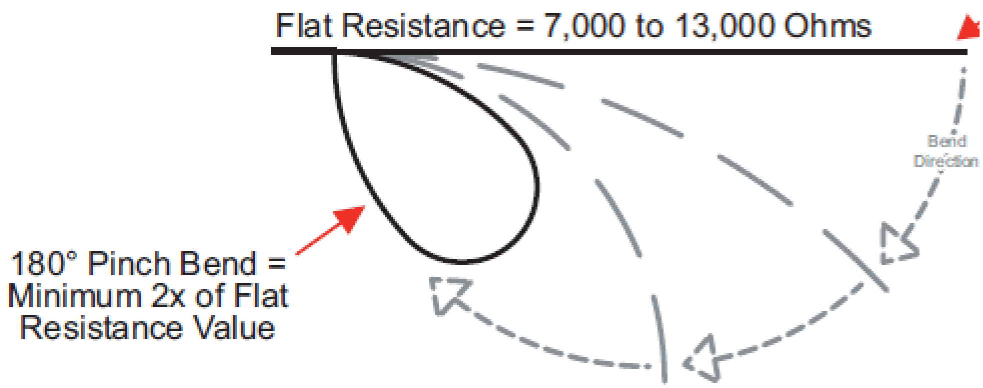


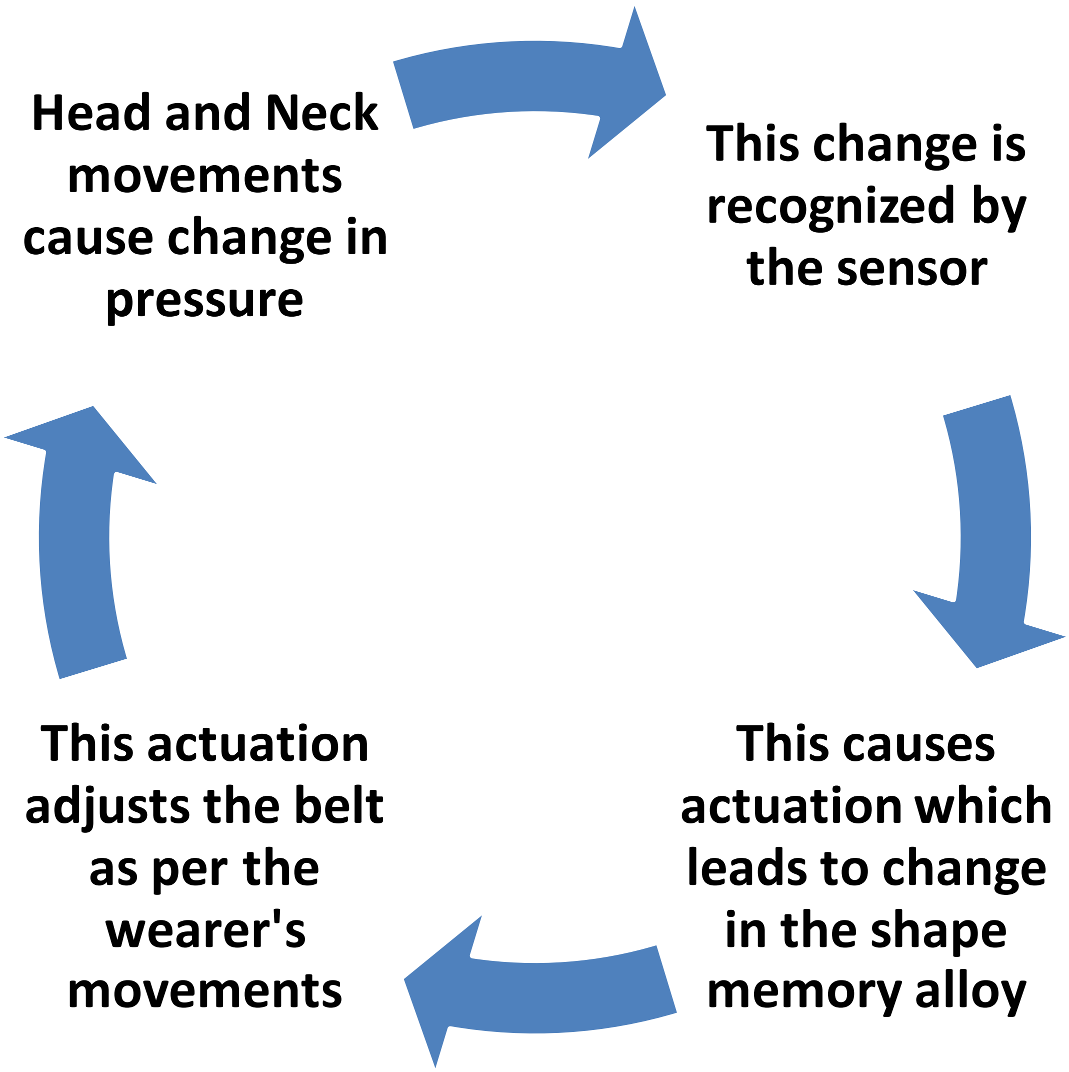
Figure 9. Working of a Flex Sensor

The basic specifications of the Flex Sensor as obtained from the datasheet of the specific sensor are as folows-

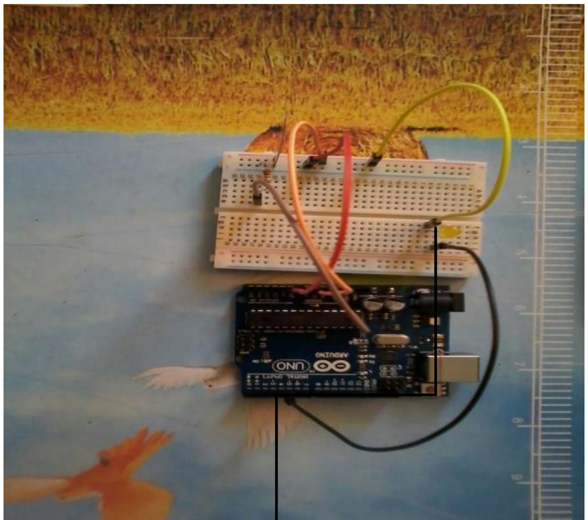
1. Flat Resistance: 10K Ohms
2. Resistance Tolerance: ±30%
3. Bend Resistance Range: 10 kΩ to 20kΩ
4. Power Rating : 0.50 Watts continuous. 1 Watt Peak
5. Temperature Range: -35°C to +80°C

2.4 Working Mechanism

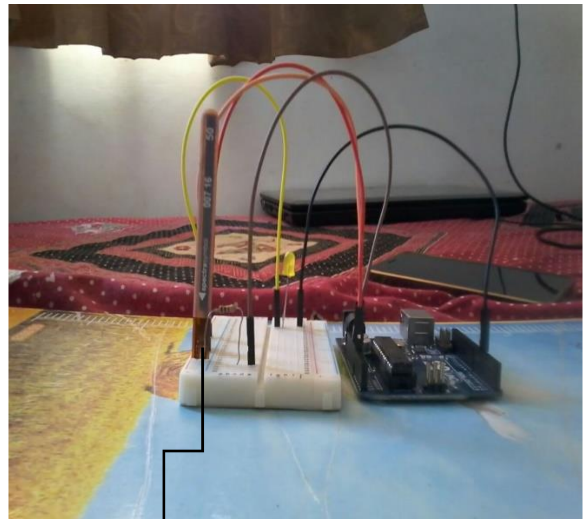
Now, that we have finalized the design and sensor, the following diagram shows the working mechanism of the system-



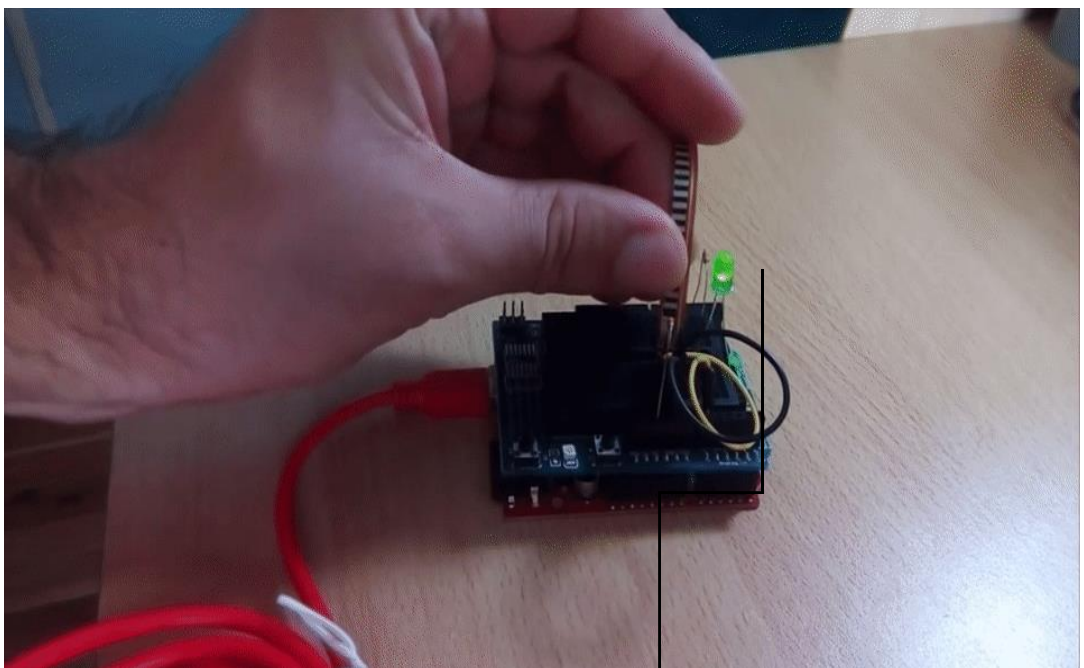
The first analysis was done using Arduino Uno as controller and LED in place of SMA spring to test the working of the setup at a low current input (since Arduino can give only a limited amount of current).



LED BULB



FLEX SENSOR



LED BULB

Figure 10. Fluctuation of LED Bulb using Flex Sensor

The working mechanism of the neck collar or the Closed Loop Control System which is responsible for the working of the belt is shown below.

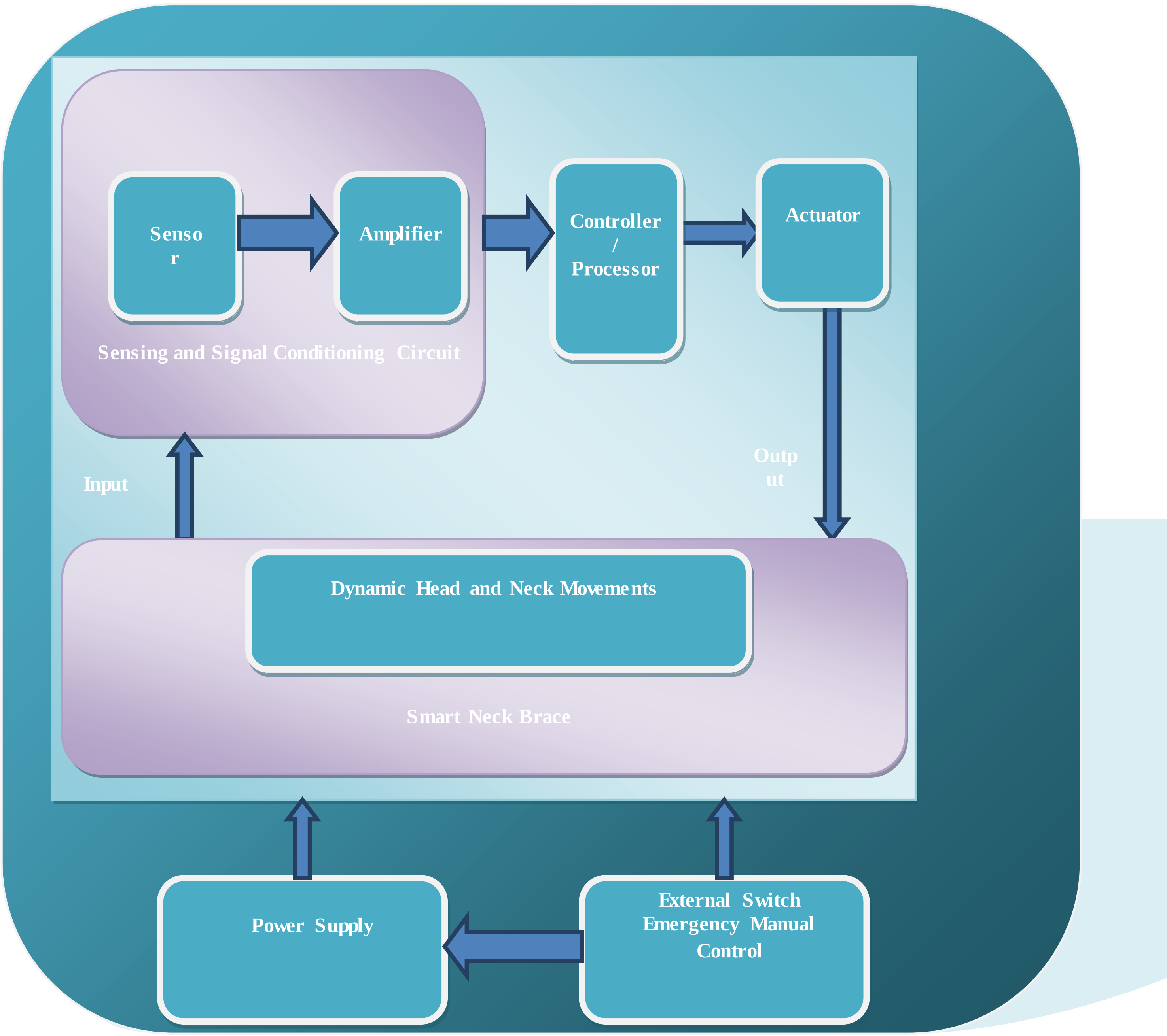


Figure 11. Closed Loop Control System with Feedback Mechanism

2.5 Actuation in the SMA Spring

Once the fluctuation in the LED bulb was observed, the next step was to actuate the spring with input from the sensor. The major hurdle that we came across was the actuation of the SMA spring. Since the spring is such that it actuates at a minimum current flow of 1A across it and the Arduino Uno, by the virtue of its inherent property, can give an output of a maximum of 100mA (in the current setup) as it is constrained to give an output voltage of only 5V. This posed a major problem.

This issue was resolved using a MOSFET (**Metal Oxide Semiconductor Field Effect Transistor**) and a **L293D** Integrated Circuit. The MOSFET and the IC together help resolve the shortcoming of the Arduino Uno, ie. they amplify the current flowing through the SMA spring, hence actuating the spring corresponding to the input from the Flex Sensor.

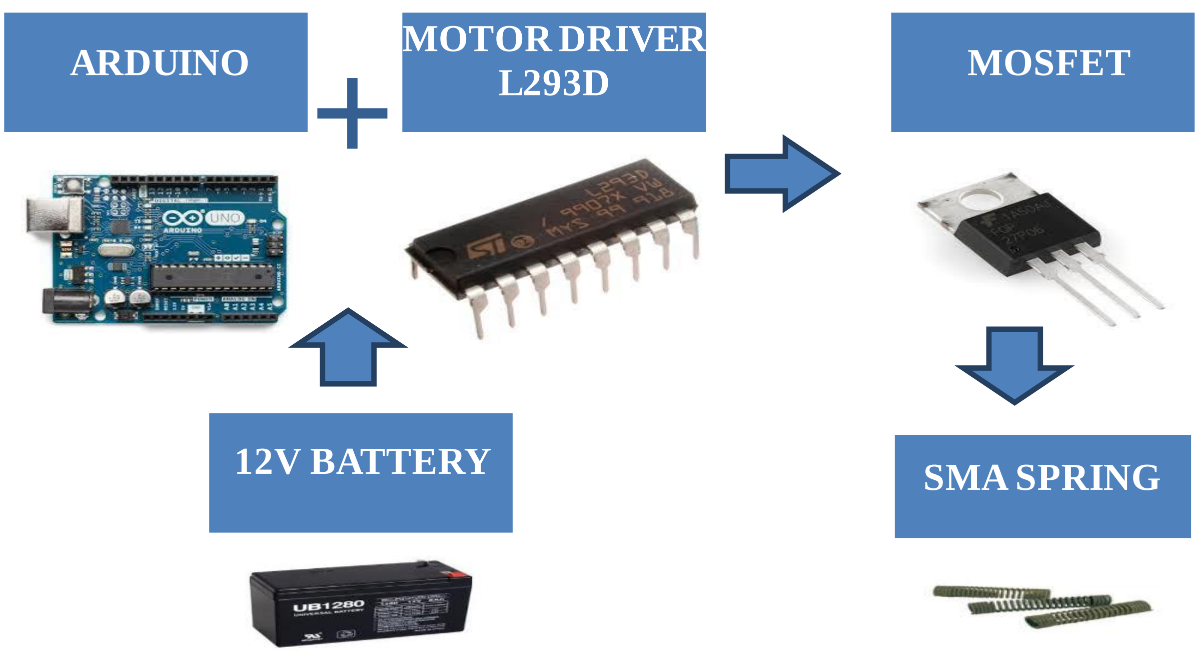
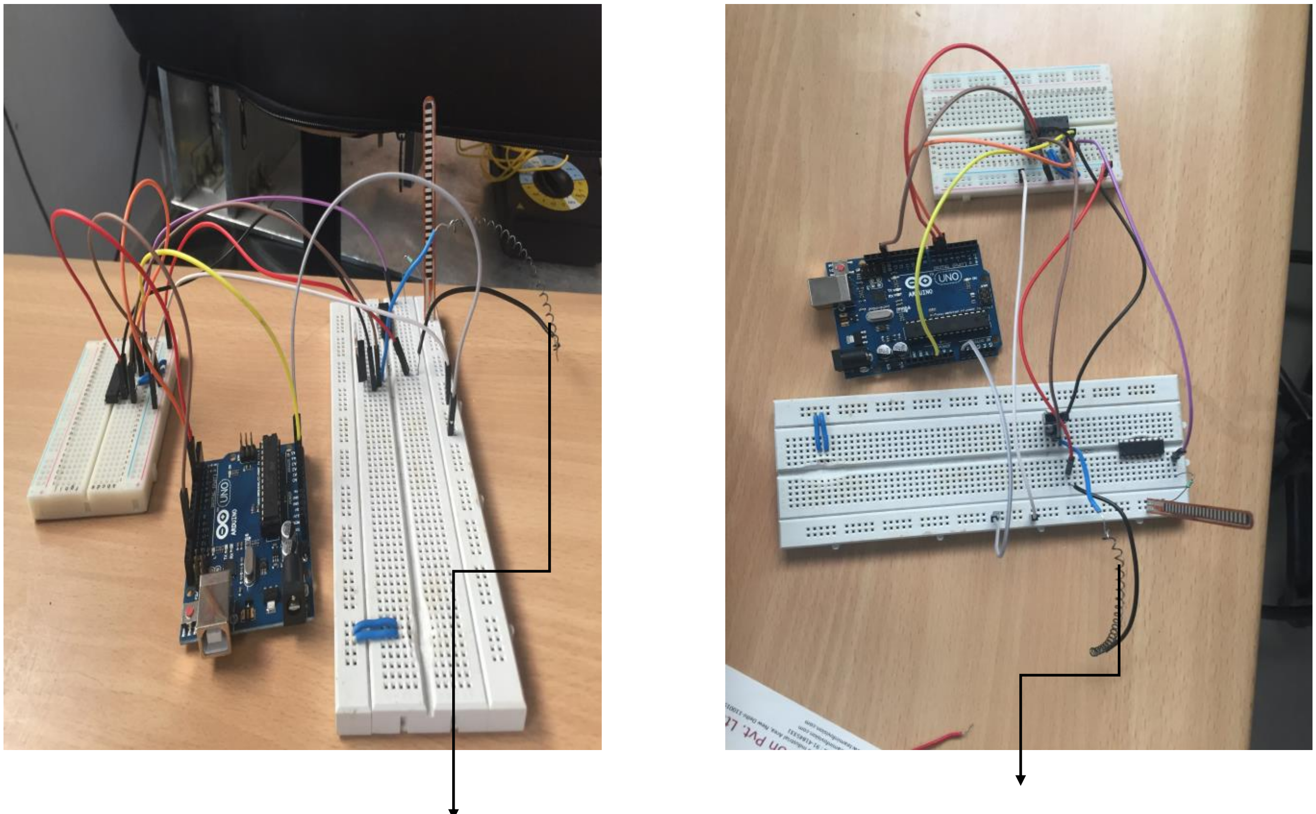


Figure 12. Method of actuating SMA spring using MOSFET & Motor Driver IC

The final circuit diagram with the inclusion of the above described components is as follows-



SMA Spring Before Actuation

SMA Spring After Actuation

Figure 13. Experimental Setup of Actuating SMA Spring MOSFET

The motor driver L293D IC was used as it has a range of 0.5A to around 50A of current output which was desired in our experiment. The MOSFET was used a switch which would either switch on or off the current flowing through the spring as it detects a change in the input by the Flex Sensor.

As can be seen in the images above, the SMA spring actuates when the sensor gives an input which is set (by us initially, during experimentation). As the sensor output values go beyond the range, which have set in the Arduino code, the spring stops actuating. The exact code has been shown below in the next sub part.

2.6 Arduino Code – Flex Sensor

The final code which was used to actuate the spring is shown below. The code specifies a bend angle value of the senor and ensures that only when the value of the bend angle is less than a specified angle, will the spring actuate. Whereas, in those scenarios where the value of the bend angle is more than the specified value, the spring doesn’t actuate.

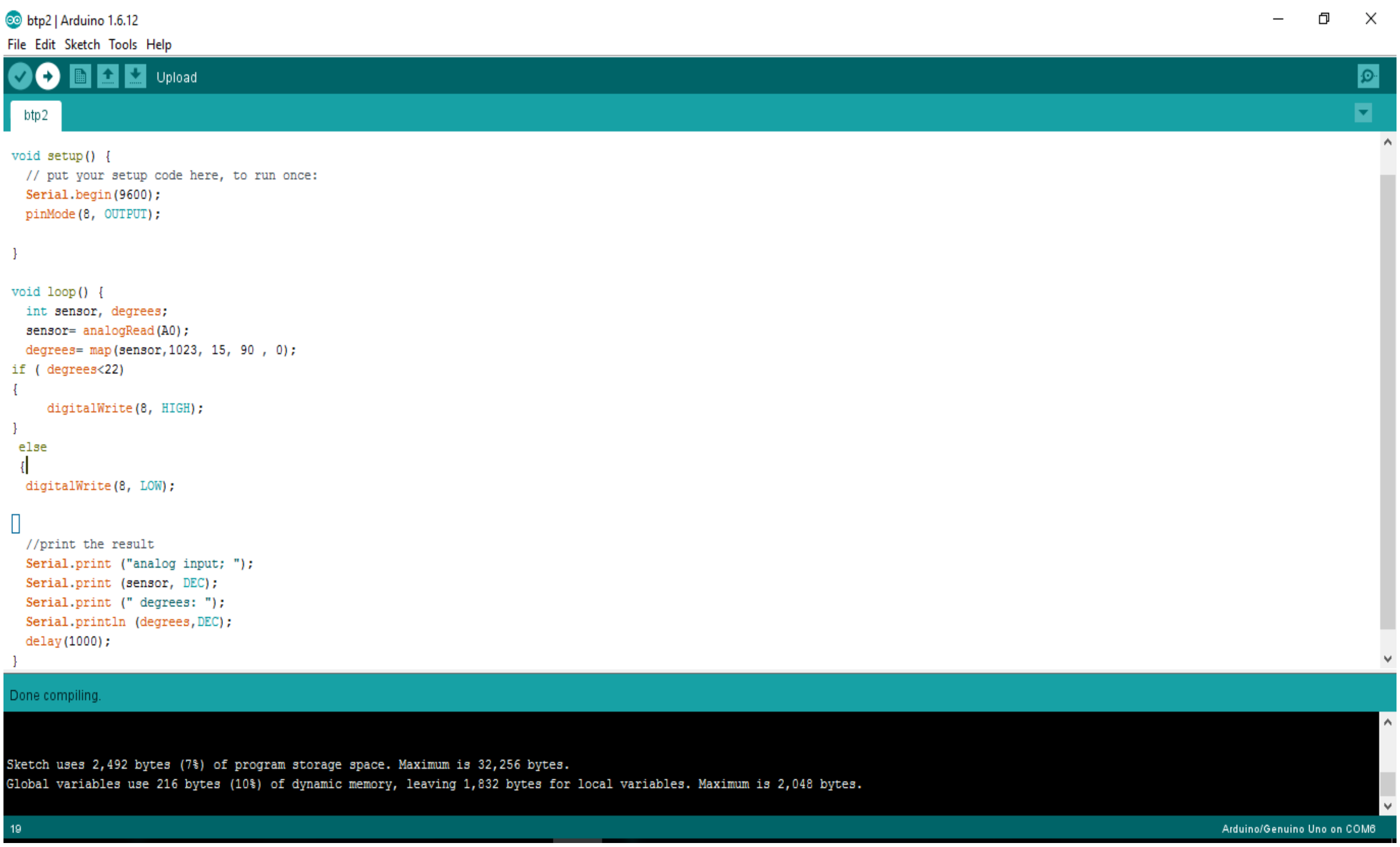


Figure 14. Arduino Code for Variable Sensor Value inputs

Chapter 3. EXPERIMENTATION

3.1 Experimental Setup

The task to find out the displacement of the foam sheet (neck collar belt) when it actuates (the spring does, actually) is performed next. This task is completed using the Laser Displacement Sensor kept in the Mechatronics Lab. The Compact Laser Displacement Sensor, HL-G108-A-C5 was used for this purpose.

Initially, the foam sheet, alone was used for the experimentation, ie. without the embedded circuit. The experimental setup is shown below.

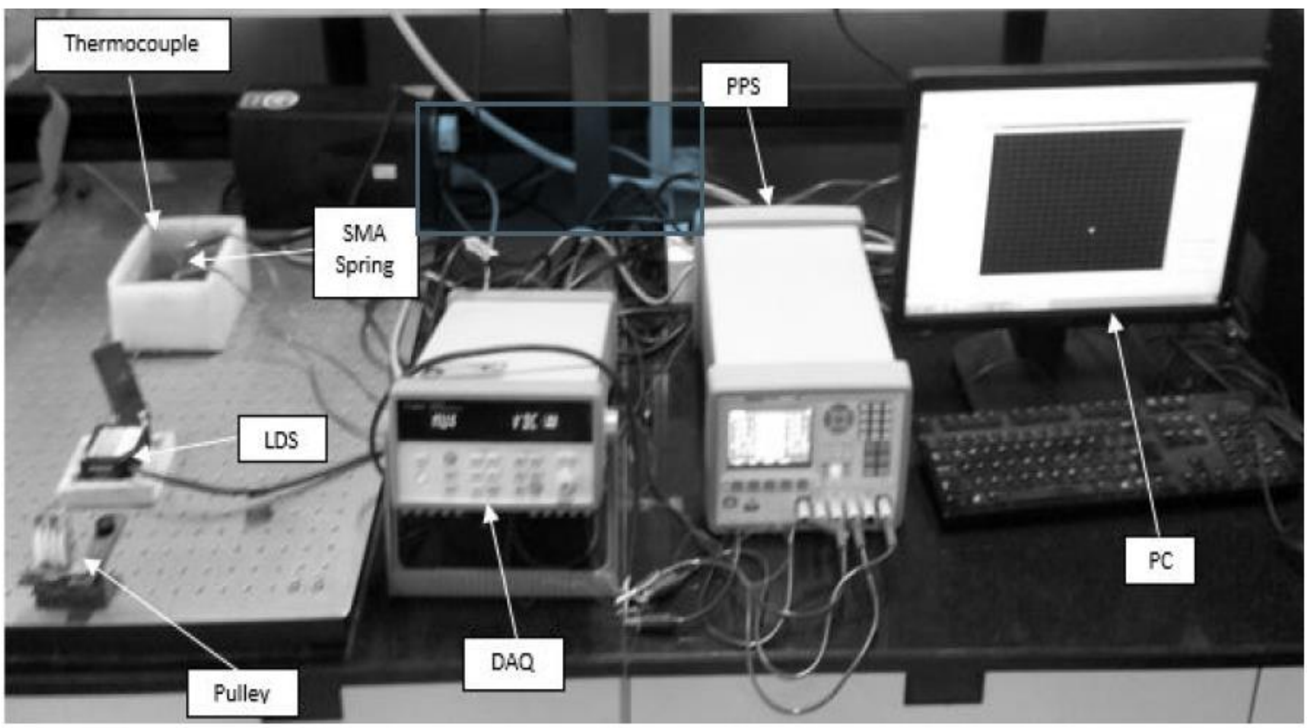


Figure 15. Experimental Setup for measuring displacement of foam sheet using Laser Displacement Sensor

Components:

1) Load: External force was needed to keep the spring extended as the spring was trained to contract upon actuation.

2) **Programmable Power Supply** (PPS): Heating and cooling cycles of the springs required specific voltage signals which were obtained using a PPS.

Figure 16. Programmable Power Supply

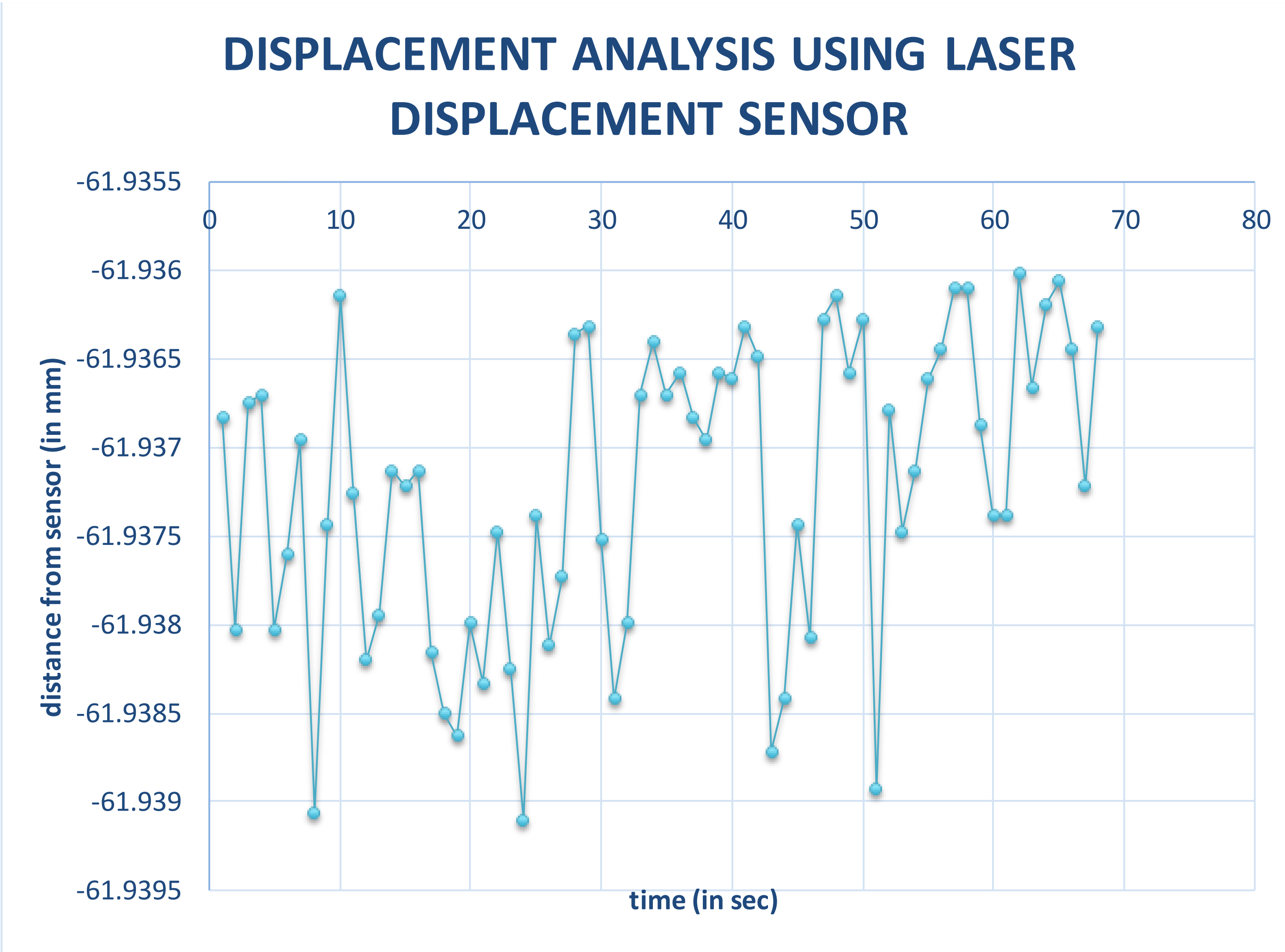
3) **Laser Displacement Sensor** (LDS): As the study involved micro-actuation, LDS was chosen over other displacement measuring devices which gave the resolution of 0.5μm.

Figure 17. Laser Displacement Sensor

4) **Data Acquisition System** (DAQ): Measurements provided by LDS and Thermocouple were recorded using a DAQ and were directly saved into a computer for further study.

3.2 Experimental Procedure

The displacement of a small portion of the foam sheet was measured (which is not visible and is inside the container with the SMA spring connected to it). The values obtained were recorded on the PC using the DAQ. The power was supplied by the PPS. The values obtained were as follows-

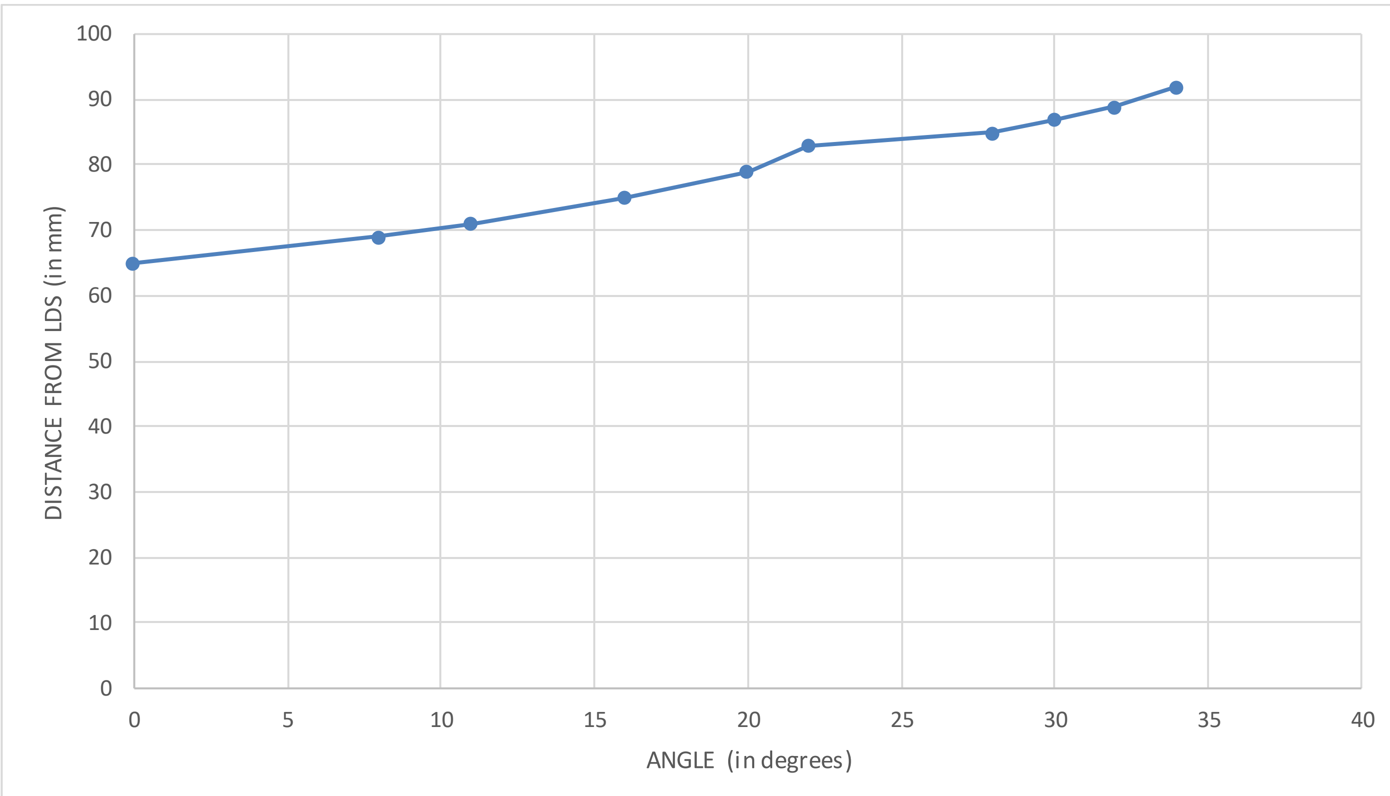


The above graph shows the distance of the foam sheet from the Laser Displacement Sensor relative to time. The fluctuations in the graph show the displacement of the foam sheet from time to time. This gives us the maximum displacement of the spring w.r.t. time.

This shows the extent to which the sheet can bend for the given spring and power input. This amount of displacement by the foam sheet (neck collar) is feasible for the human body and also, not hazardous.

3.3 Experimental Procedure – Flex Sensor

The next step was to calculate the displacement of the foam sheet (neck collar) with the change in the bend angle of the sensor. This, too was done with the help of the Laser Displacement Sensor. A similar experimental setup as above was used to study this scenario too.



The above graph shows the displacement of the foam sheet (neck collar) w.r.t. the change in angle of the Flex Sensor. This exhibits the linear relationship between the displacement of the Foam Sheet and the bend angle of the Flex Sensor.

3.4 Final Product

The final product/prototype is shown below. The components have been marked as shown in the figure.

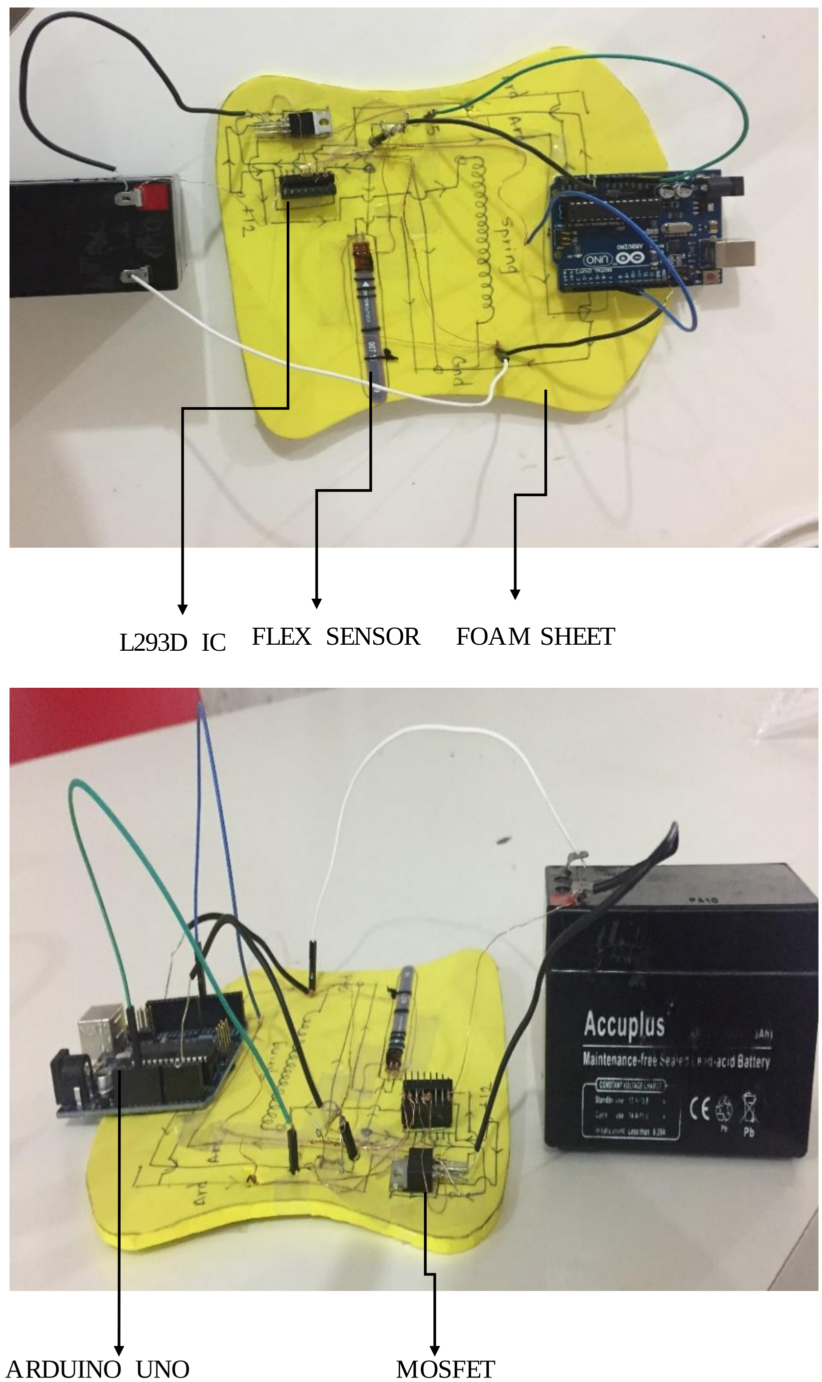


Figure 18. Final Prototype – Smart Neck Collar Belt

Chapter 4. CONCLUSIONS

The Smart Cervical Collar Belt mainly serves the purpose of Ergonomics. To provide comfort to the wearer is the main motive of the product. Major problems being faced by patients are mainly those of discomfort and development of soreness in the muscles, callous in the occipital area, weakness in the clavicle and shoulders, crease in the trapezius etc. They also face other problems like immobility of the neck and surrounding areas, manual tightening and loosening of the neck collar belt. This product mainly serves to check these problems and provide for a lighter, cheaper and more durable alternative. The freedom from manually adjusting the belt is another major advantage of the belt in the given structure.

The **Process** and **Product** have been filed for patent and it is under review. If brought out in the public domain, this invention has the power to usher a revolution in the biomedical industry.

The belt described earlier is very compact, still its compactness can be increased by using a Lilypad Arduino instead of a conventional one. The belt, however is much lighter than what is available in the market today.

As far as the cost is concerned, it is still cheaper than the already available options in the market. The only major cost includes the SMA Spring.

All in all, this product has the potential to break the conventional methods of curing/healing the victims of various cervical injuries or problems.

REFERENCES

[1] INSOLE AND FOOT ORTHOTICS MADE OF SHAPE MEMORY MATERIAL (SMM) THREE-DIMENSIONAL SPACER FABRICS

Matthew Fonte, Matthew Palmer [Appl. No.: 13/936,866; Filed: Jul. 8, 2013]

[2] DYNAMIC POROUS COATING FOR ORTHOPEDIC IMPLANT

Matthew Palmer, Matthew Fonte [App1.No.: 13/843,656; Filed: Mar. 15, 2013]

[3] JOINT BRACES AND TRACTION DEVICES INCORPORATING SUPERELASTIC SUPPORTS

Russell A. Houser, James G. Whayne [Appl. No.: 09/965,542; Filed: Sep. 27, 2001]

[4] http://www.aspenmp.com/products/upper-spine/aspen-collar

[5] https://www.ossur.com/injury-solutions/products/spine/hospital-and-rehabilitation-collars/miami-j