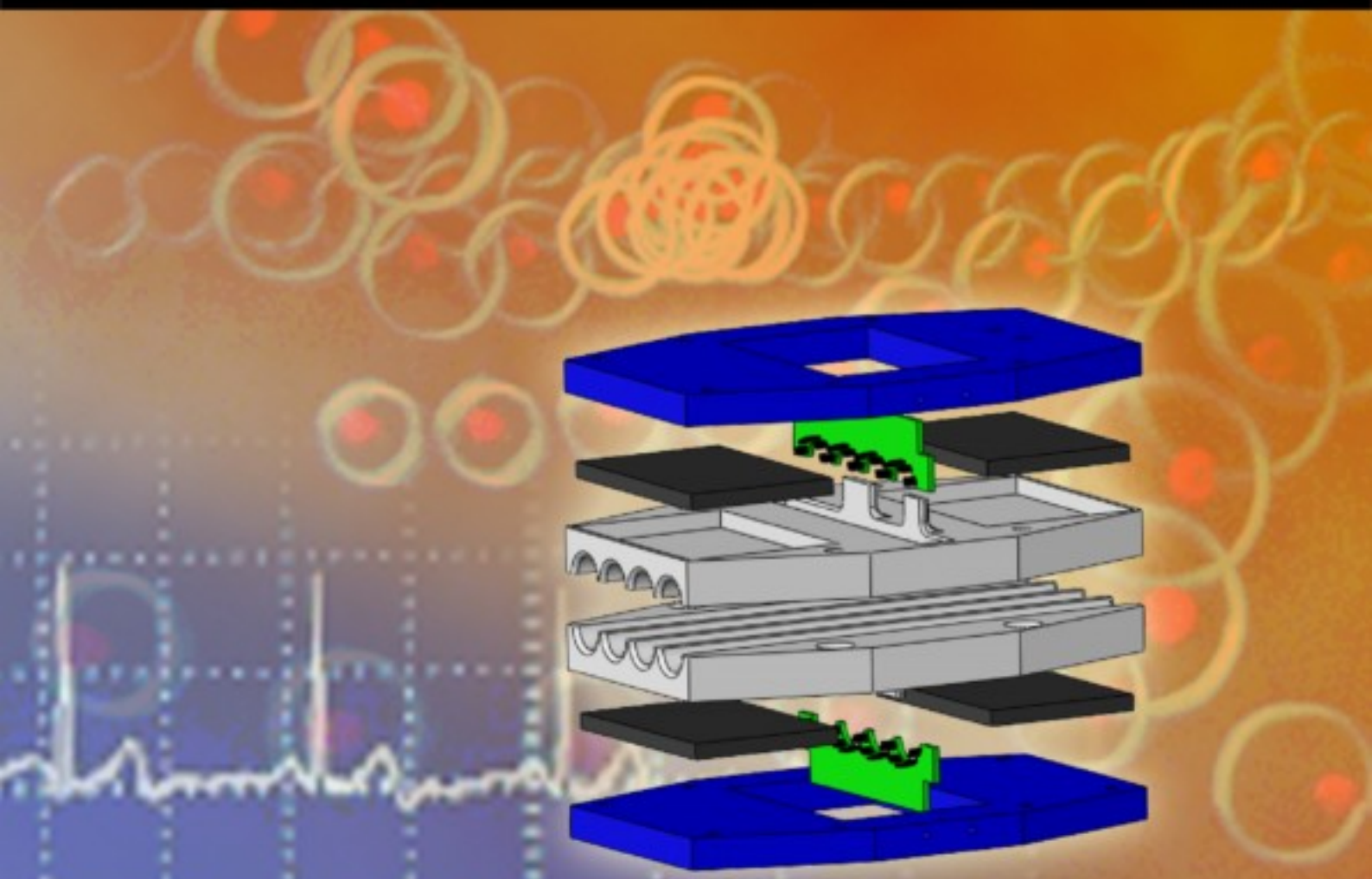


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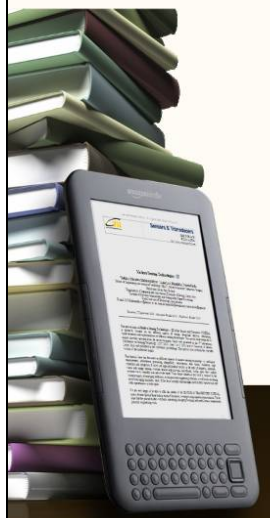
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- Chemoinformatics
- Bioimaging
- Neuroinformatics

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- Biocomputing
- Genetics
- Molecular and Cellular Biology
- Microbiology

**C. Biotechnologies and biomanufacturing**

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- Biodevices
- Biomedical technologies
- Biological technologies
- Biomanufacturing

**Important deadlines:**

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

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**Important deadlines:**

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Notification	February 20, 2011
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- COMAN: Network Control and Management
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- GRIDNS: Grid Networks and Services
- EDNA: Emergency Services and Disaster Recovery of Networks and Applications
- IPv6DFI: Deploying the Future Infrastructure
- IPDy: Internet Packet Dynamics
- GOBS: GRID over Optical Burst Switching Networks



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The Netherlands Antilles



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Registration	November 5, 2010
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- System instrumentation
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- Security and protection systems
- Advanced systems [expert, tutoring, self-adapting, interactive, etc.]
- Application-oriented systems [content, eHealth, radar, financial, vehicular, etc.]
- Safety in industrial systems
- Complex Systems

## Pain Sensing System for Animals

**Ibrahim AL-BAHADLY, Subhas MUKHOPADHYAY and Khalil ALKHUMAISI**

School of Engineering and Advanced Technology  
Massey University, Palmerston North, New Zealand

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**Abstract:** Castration, tail docking and ear tagging are examples of painful process that the lambs in New Zealand undergo in their early life. Massey University is conducting a research to measure the pain sensitivity in animals based upon applying mechanical force. The research will help in better understanding the development of pain sensitivity in the animal, and hence improving the welfare of the lambs and other animals. The traditional measurement system is pneumatic and it has some associated drawbacks such as; inaccuracy in measuring the applied force, inconsistent rate of force application, leaks in the system, and issues of impracticality and safety.

This paper presents a new pain sensing system based on the use of stepping motor for applying force and flexiforce sensor for measuring the applied force. The new sensing system was successfully tested on a frozen lamb leg and then on live sheep. *Copyright © 2010 IFSA.*

**Keywords:** Pain sensing, Flexiforce, Stepping motor.

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### 1. Introduction

There have been strong relationships between animals and human throughout the centuries. As we rely on them in many life aspects such as: sports and recreation, food, companionship, fertilizer, cloths and other products that support and facilitate the living of human in earth. New Zealand economy relies heavily on exporting animal products and live animals. Therefore, a good understanding of animal behaviour and problems that they encounter would guarantee a more efficient production practices [12].

Many problems and difficulties encounter researchers when they study animal behaviour or diseases. One of these problems is to know how much an animal suffer during a certain process such as lameness episode, tail docking, ear tagging or how efficient is the analgesics on the animal.

In UK claw lameness in dairy cows is causing a major welfare problem, where the UK national incidence has announced difficulty in measuring it. Therefore, a study was carried out to develop a better understanding of the claw lameness in heifers. The study was conducted during heifers first parturition to find out the development of claw lameness after the first parturition and to find the relationship between claw pathology, gait score and hyperalgesia, as indicated by nociceptive threshold [8].

The mechanical nociceptive was pressed against the dorsal aspect of the metatarsus until a clear leg lift was detected. By carrying these tests to a number of cows it was possible to obtain information about the nature of the sensitization. However, by applying mechanical nociceptive it is not possible to differentiate between a peripheral sensitization and spinal sensitization, but it confirms that the locomotion changes are likely to be as a result of the animal's hyperalgesic state [8].

Another example where mechanical nociceptive was applied and measured was in domestic cats. The reason behind the experiment of applying pain and measuring it was to gain better understanding of the effect of analgesia in cats, which would lead to a better control of pain in cats. The device used for the experiment was pneumatic having 3 pins within a bracelet on the forearm. The three pins are advanced simultaneously by manual bladder inflation [5].

There are many benefits behind pain measurement; these benefits can be summarized in the following points:

- Finding out at what age the species feels more pain.
- Measuring the pain intensity or level of disability in the measured part of the species.
- Assigning the appropriate treatment according to the pain measurement results. For example, if the species got very intense pain and little disability then analgesic treatment should be given first [15].
- Testing the efficiency of a treatment. This is by looking at what force would the species respond when the medication is taken and checking the effectiveness period of the medication [15].

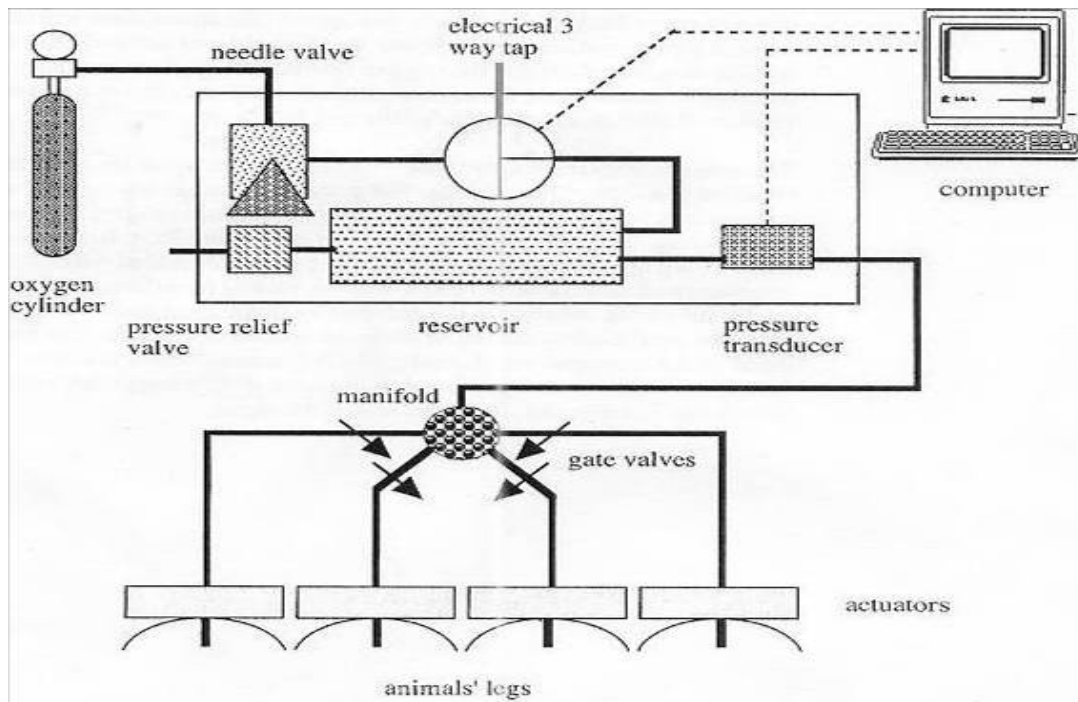
## **2. Traditional System**

At Massey University, research is being conducted based upon applying measurement of mechanical nociceptive thresholds (MNT) in sheep and other large farm animals. Measurement of MNTs involves applying a mechanical stimulus to the animal and measuring the force required to see a behavioural response. The device currently used to apply the mechanical stimulus and measure the pain threshold is shown in Fig. 1.

The device uses pressurized gas to push a blunt-ended pin onto the leg of the subject animal with constantly increasing force. The actuator itself comprises a plastic syringe barrel and modified plunger carrying the pin. As the pressure of the gas in the system increases, it pushes the plunger down the barrel of the syringe, increasing the force with which the pin is pushed onto the animal's leg.

This device is pneumatic and uses compressed oxygen from a size E cylinder to power the equipment. The oxygen passes through a micro-adjustable needle valve, which functions as a variable resistor to control the flow of the oxygen going to the device and to allow changes in the rate of force applied by the pin [10].

After the needle valve, the oxygen passes through a solenoid three way valves. When the power to the solenoid is on the oxygen flows to the reservoir then to the pressure transducer and then to the actuator at the animal end. The transducer is connected by a strain gauge amplifier to computer. When the power to the solenoid is off, the end of the device is open to the atmospheric pressure and the compressed oxygen does not flow to the actuator [10].



**Fig. 1.** Mechanical device for applying and measuring pain in sheep [10].

To reduce the likelihood of tissue damage on the sheep's leg, the MNT device was 'programmed' to limit the maximum force on the pin to 25 N; the force was to be constantly increased to reach this maximum in 1 minute. To achieve this, the regulator was set to limit the gas pressure to that corresponding to 25 N of force on the pin and the needle valve set so that the rate of increase in force was 25 N/min.

The mechanical/pneumatic device currently used to apply the noxious stimulus and measure the force at which the subject responds (pain threshold) has several problems. These problems can be summarized in the following points:

- Friction in the system, particularly between the syringe plunger and barrel, results in inconsistent rate of force application.
- Indirect and inaccurate measurement of the force applied to the animal. As, it is the pressure of the gas at the point of the transducer that is measured, not the actual force applied through the pin to the leg of the animal.
- Leaks in the system. When the regulator is set to limit the gas pressure to 25 N of force on the pin, and the needle valve is set so that the rate of increase is 25 N/min. It is noticed that after 40 seconds of application, the graph shows that the force begins to level off just below 25 N.
- Device is impractical and dangerous to use. This is because of the large size of the components and the unwieldy design. The existing pneumatic MNT device is impractical and can only be used in carefully controlled environments. In addition, because the actuator is not remote, the application of the device is also limited to restrained animals. The use of compressed gas to drive the pin is problematic and potentially dangerous.
- Other problems are slippage of the holder used to attach the actuator to the animal's leg. This means that the pin isn't consistently positioned over the bone of the lower leg, which could have a significant impact on the force required to elicit a withdrawal response. Moreover, frequent damage to connection between the actuator and the rest of the system limits the use of this device.

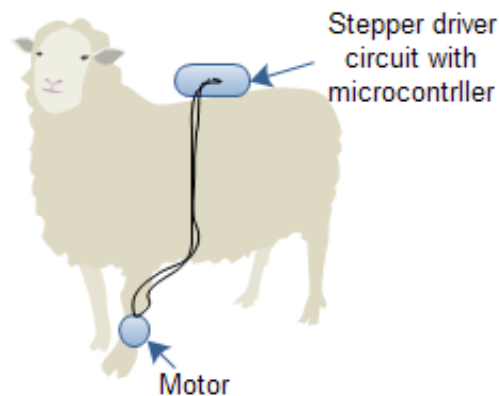
- In addition, a trembler switch used to be used to switch off the device when the animal moved its leg as a result of the pain. However, this switch was abandoned as it could not differentiate between a normal movement and a response to the stimulus.

There were two different approaches taken in account to solve the existing problems:

- 1- Improving the existing pneumatic/mechanical device.
- 2- Replacing the pneumatic device with an electrical one (Motor replaces pressure in pushing the pin on animal).

The decision on what approach should be taken was mainly based upon which approach would best minimize the existing problems.

After searching and analyzing the problems it was found that most of the problems exist in the current device can be minimized. However, the electrical proposed model (motor) would have the advantage of being small, portable and the ability to put everything in small box, which could go to the top of the animal back as shown in Fig. 2.



**Fig. 2.** Proposed model for pain measurement system.

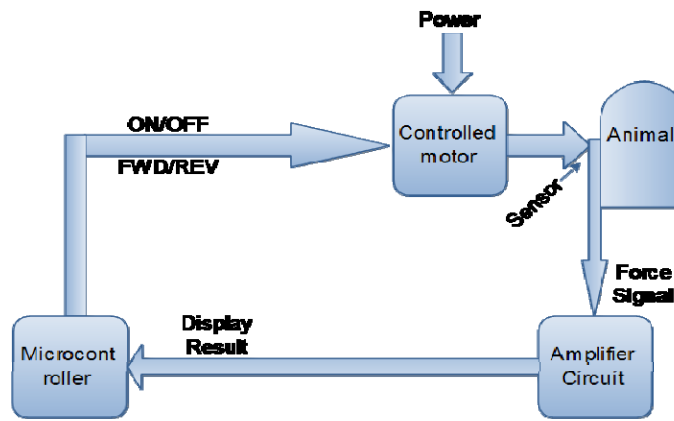
### **3. Proposed System**

The approach taken to solve the existing problems is to replacing the pneumatic device with an electrical one (Motor replaces pressure in pushing the pin on animal). A linear stepper-motor has been chosen in which a pin is fixed in the shaft of the motor.

The movement of the shaft will allow the pin to touch and apply force to the leg muscle of the animal. The motor is fixed on the leg of the animal with the help of flexible holder. Fig. 3 shows a block diagram for the proposed system.

The stepper motor is driven by a standard driver. The drive signal is controlled from the applied force information. A force sensors from Flexiforce [7] has been used to measure the applied force to the animal. The force sensor is mechanically inserted between the motor and the pin which applied force on to the animal.

The force is measured with the help of a embedded microcontroller. The microcontroller has been used with the aim of extending the capability of the system such as remote controlled , fast reversing, quick release of force etc.

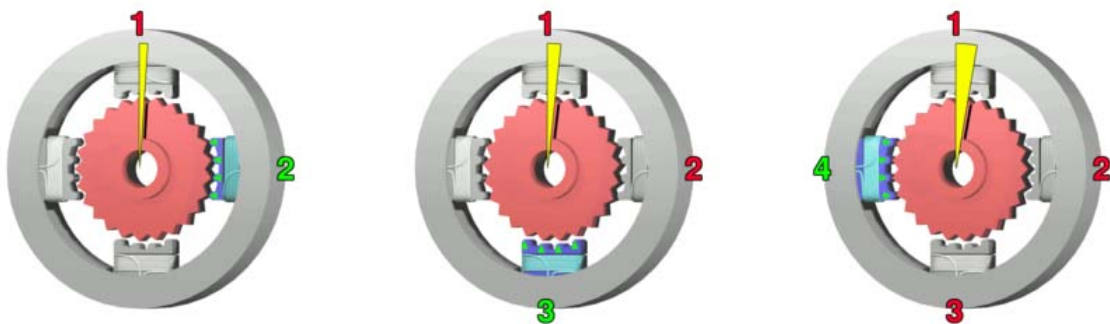


**Fig. 3.** Block diagram of the proposed system.

### 3.1. Stepper Motor

A stepper motor is an electromechanical brushless device that converts electrical pulses into precise movement. The speed and the length of the stepper motor are directly proportional to the applied frequency of the input pulses. This direct relationship between input pulses and the speed and length movement gives the stepper motor the advantage of being controlled precisely without feedback [11].

Stepper motor consists of two main parts: rotor and stator. The rotor part is a magnet rotating shaft, while stator is the electromagnetic part that surrounds the motor. The stepper motor rotating shaft turns or steps when one of the stator electromagnet is powered, which consequently makes the gear's (rotor's) teeth magnetically attracted to the electromagnet's teeth. To make the rotor shaft moves to the next step then the first electromagnet is deactivated and the next electromagnet in stator is powered, which makes rotor teeth align with the next electromagnetic. Stator electromagnets are energized by external circuit; this process is illustrated by Fig. 4 [14].



**Fig. 4.** The rotational process of stepper [13].

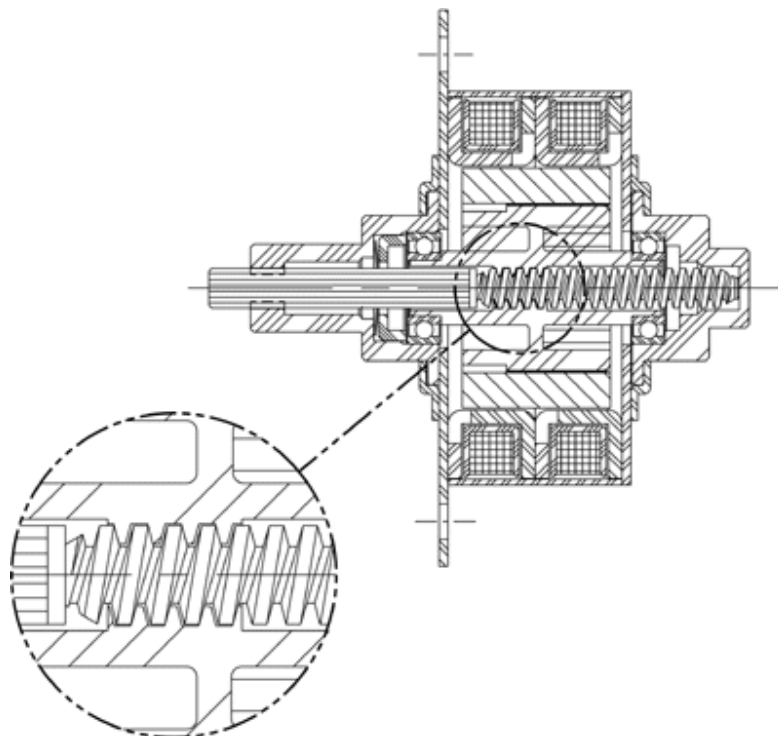
There are two types of stepper motor in terms of winding arrangement: unipolar motor and bipolar motor. The Table 1 summarizes the fundamental differences between the two different motors:

The principle operation of linear stepper motor is very similar to rotary stepper motor. However, in the case of the linear stepper motor the rotary motion is translated into linear movement; this can be done by many ways such as: rack & pinion, belt and pulleys, but the best conversion is the one happening inside or within the motor.

**Table 1.** The differences between unipolar and bipolar stepper motor.

<b>Unipolar stepper motor</b>	<b>Bipolar stepper motor</b>
Two winding per phase, one for each direction	One winding per phase
2 windings mean, no need to change current direction to reverse the motor	Reversing requires switching current in the reverse direction in the winding
Driving circuit can be very simple for each winding	The driving circuit is usually more complicated
less powerful than the Bipolar motor with the same weight	More powerful than the Unipolar motor with the same weight

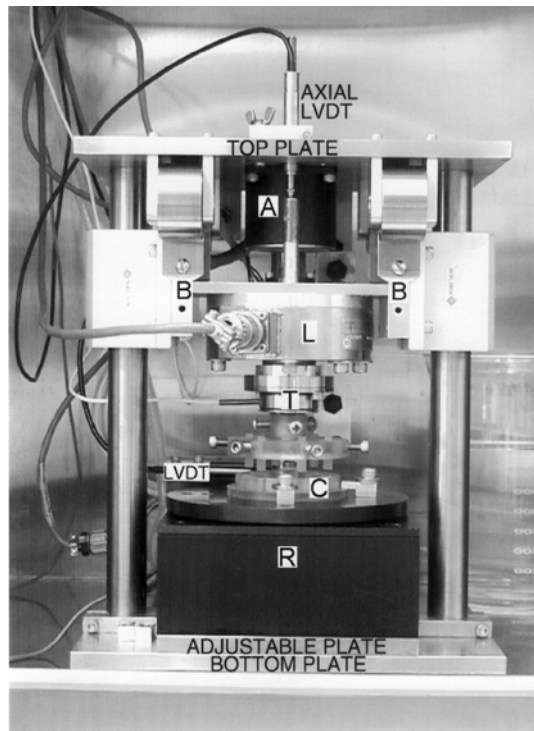
Fig. 5 shows a method of converting rotor motion into linear movement within the motor. This translation process requires thread, nut and lead screw. The rotor is threaded and the shaft is replaced with the lead screw, so that when rotor is in a rotation motion it moves the lead screw in a linear motion, and to reverse the lead screw the rotor change the rotation direction [14].



**Fig. 5.** Translation of rotational motion to linear movement [14].

The distance the lead screw travels is determined by several factors: step angle of the rotary, pitch size of the rotor thread and thread size of the lead screw.

Several studies have showed that applying various loads into cartilage play roles in metabolic regulation; this is because of the ability of the fluid pressure to stimulate cartilage metabolism. Since the role of pressure force without the fluid is unknown a study was carried out to find the relationship between the shear force and compression applied to the cartilage and its improvement and maintenance. To apply the different forces that are required to analyze the problem the device in Fig. 6 was created [9].



**Fig. 6.** Shear/compression apparatus [9].

The device in Fig. 6 has a dimension of 30 cm high x 25 cm x 20 cm, and the main parts it consists of:

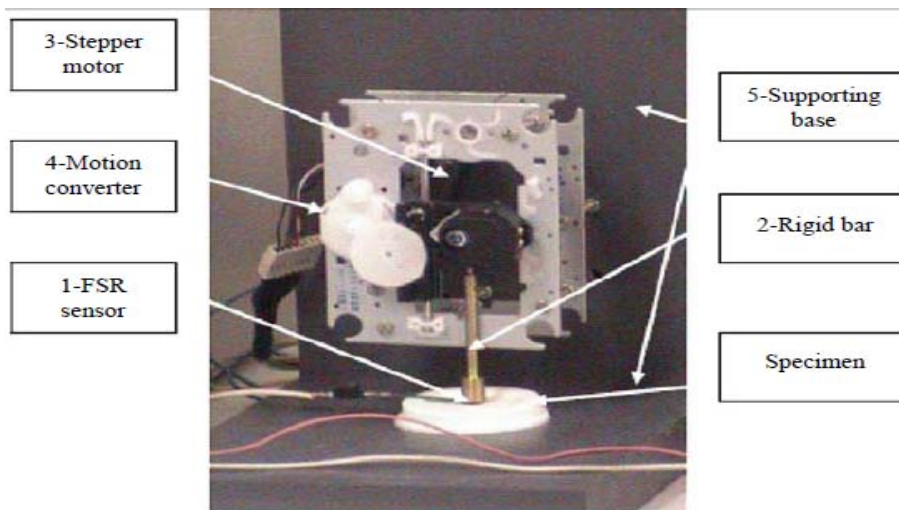
- Top, bottom and adjustable stainless steel plates
- Linear stepper motor, marked as A in Fig. 6
- IM483 stepper driver
- Sample chamber, part C in Fig. 6.
- Rotary position table part R.
- Variable differential transformer(LVDT)

The stepper motor has axial and rotational resolution of 50 nm and 0.0005° relatively. The axial and the linear displacement are measured using Linear Variable Differential Transformer (LVDT). From this example it can be seen that the stepper motor is used for applying compression and shear forces in medical and scientific researchers [9].

Knowing some properties of the animal tissue is of an interest to many researchers especially in the medical field as it carries much useful information such as: age, gender and whether the organ is healthy or not. Some of the important tissue properties are viscosity, passion ratio and the most important one is stiffness since it is directly related to the composition of the tissue [7].

The device in Fig. 7 is created to measure the elasticity of a tissue. There many tools that measure elasticity like: imaging using X Ray, coherent radiation (laser, sonar, and ultra sound), tactile sensing and Atomic force microscopy (AFM), however their high price was against their wide spreading. Tactile testing depends upon imitating the sense f touch, and it is the one performed by the device in Fig. 7 [7].

The main parts that the system consists of are shown in Fig. 7 and they are: FSR sensor, rigid bar, stepper motor, motion converter and supporting base. This device works by applying the force via the stepper motor to the specimen and the FSR sensor attached to the specimen measures the force which is then processed to the PC to be plotted as stress-strain curve [7].



**Fig. 7.** Tactile probe parts with a specimen in its place [7].

## 4. System Design

An important part of the project was the mechanical design of the device. The mechanical design has to be robust in order to eliminate the problems existing with the pneumatic device, and to withstand in the testing environment (like animal kicking it). The mechanical design consists of:

- The linear stepper motor
- Stepper motor driver board
- Motor casing
- Motor casing holder
- Wiring and casing the stepper motor driver board

The traditional sensing system was able to apply a force up to 25N, and it does not go beyond this force as that might cause some tissue damage to the animal. Therefore one important characteristic that has to be taken into account when finding the appropriate motor is the range of force the motor can apply.

The size and the weight of the motor is an important aspect of the design. Since the device is going to be attached to the animal leg with different ranges of age, then the device size and weight have to be reduced as much as possible, to ensure that it can be carried by the sheep.

Another consideration that was taken into account is the requirement of having linear motion. This is because the type of force required to be applied to the animal is compression or pressure, but having cycling motion with compression would change the nature of testing.

There were two options available to obtain linear motion of motors. The first one is to find a rotational motor, and translate the rotational motion into linear motion by building an external motion converter. The advantage of this option is giving more variety of motor to choose from. However, the big disadvantage of it is having a bigger system, which is against the important aspect of the design which is keeping it small.

The second option was looking for a linear actuator. The advantage of this option is minimizing the size and the weight of the device and the internal motion converter is more effective. The only disadvantage of this option is limitations of choice, as there are few types of linear actuators especially in New Zealand stocks.

Taking all these design aspects into consideration, the purchased motor was four phase unipolar linear stepper motor.

The output force of the motor is between 27 and 45 N, has a weight of 90 g, a diameter of 46 mm and a height of 56.4 mm including the shaft. A picture of the stepper motor is shown in Fig. 8.



**Fig. 8.** Linear stepper motor used for the device [4].

#### **4.1. Stepper Motor Driver Boards**

Stepper motor driver board is responsible for controlling the stepper motor (forward, reverse, speed) by providing the appropriate pulses. The driver board has the major role in improving the performance characteristics of the motor.

There was the possibility of building the stepper motor driver circuit in the lab, but to concentrate more in solving the existed problems, instead of spending time on building the driver board, it was decided to buy a ready stepper motor driver. The most important point to take in account when buying the driver board is that it is compatible with stepper motor. The purchased stepper motor is 4 phase unipolar motor drive. The driver board is compatible with the most stepper motors up to 2 A, and it got full step and half step driving mode.

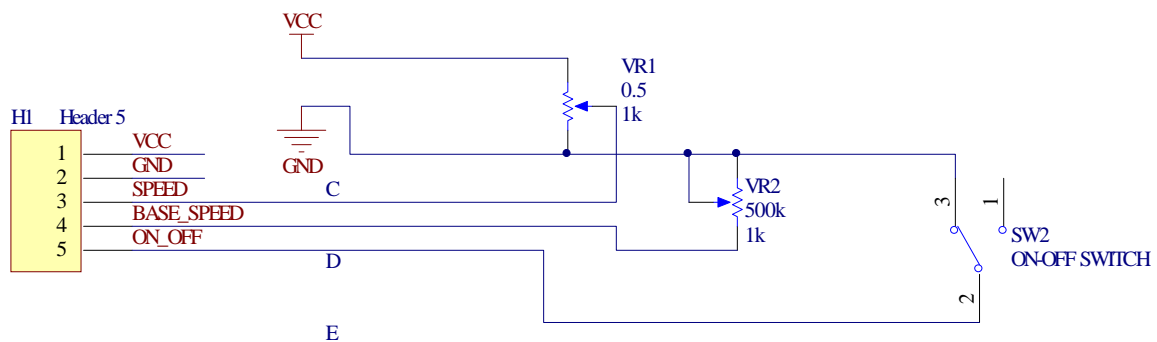
The driving board gives the option of using external clock source or making on board oscillator by assembling the required components into the place. The second option was chosen in this project. Fig. 9 is showing the stepper motor driver board.



**Fig. 9.** The driver board used to run the motor [3].

The only disadvantage of the purchased driver board in this design is that it has a large size relatively. The dimension of the driver board is 168 x 100 x 15 mm. On the other hand the driver board has several advantages such as: being able to run the motor with two different speeds, the first speed is the starting running speed, and the second speed is the running speed. These two different speeds were used in the design to run the motor forward at low speed and fast when the motor is reversing. The other advantage is having a variable resistor to change the speed of the motor; this was important in order to set the required forward and reverse speed.

Part of the oscillator design is building an external board that is responsible for alternating the speed of the motor using VR2 as shown in the schematic in Fig. 10. The circuit also has an ON and OFF power switch. The circuit has two drawbacks: first the ON and OFF switch cuts the power going to the driver board, but it does not cut the power going to the motor, as a result the motor keeps receiving power which leads to motor getting very hot. The second drawback is that the circuit only provides one speed, but it was found later that there is a requirement for two different set of speeds one for the forward direction and one for the motor when it is reversing.



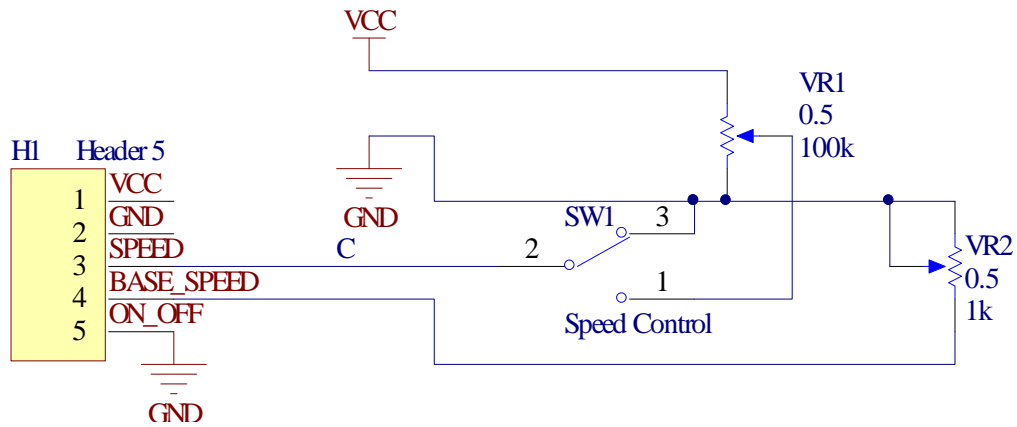
**Fig. 10.** The circuit is part of the oscillator system, this circuit on and off switch but only provide one speed.

In order to solve the two problems a little change was made on the existing circuit, and a new circuit was made shown in Fig. 11. The ON and OFF switch was taken out of the circuit and pin 5 is connected to ground so that it is always ON. Then, an external ON and OFF switch was made to control the power going to both the stepper motor and the driver board. The second problem was solved by connecting a switch between the running speed and the ground, so that two speeds are provided by the stepper motor driver. The slow speed or base speed is ON when pin three (speed) is grounded, and the running speed (fast) is ON when pin three is connected to the speed control potentiometer.

## 4.2. Motor Casing

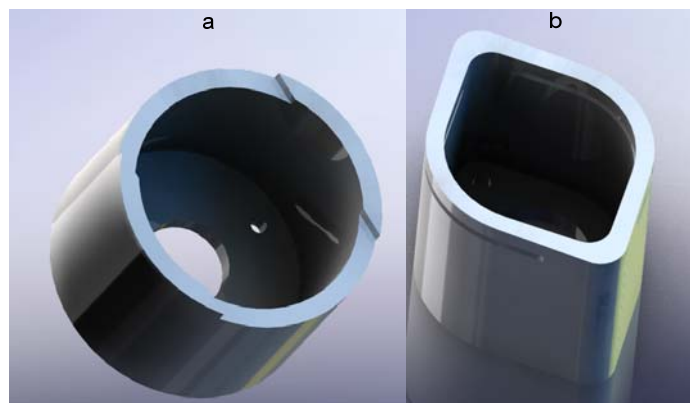
When designing the motor case there many design aspects that have to be taken into account; these aspects can be summarized in the following points:

- 1- Weight and size of the case, so it was very important to find appropriate and light material to build the motor.
- 2- The case must be designed to protect the motor. This is important to protect it against impact resulting from animal kicking and movement.
- 3- The case should be easily attached to the belt which is going to be attached to the sheep leg.



**Fig. 11.** The circuit is part of the oscillator system; this circuit got a switch that is responsible for providing two different speeds.

Trying to take all these points into consideration a motor case was designed as shown in Fig. 12 a. However, after machining it in a CNC machine, it appeared that it could be more improved in terms of size and shape. Therefore a new case design was made which is shown in Fig. 12 b.



**Fig. 12.** The motor case, (a) was designed first, (b) the improved design of the case.

Case two is different in terms of having shape that is very close to the motor so that it fits it tightly, and the second thing is the opening for the belt is through the case, which would prevent the belt slippage, instead of being at the top surface of the case.

### 4.3. Motor Case Holder

The motor case holder seems to be very simple thing, but it plays a big role in reducing experimental errors and making the experiment consistent. One of the problems that faced the pneumatic device is slippage, so in order to solve or reduce the problem effect a good design for the holder is required.

Some of the points that need consideration when designing the holder are: the method required to stick the motor case with holder, and the simplicity of getting the holder around the sheep leg.

Due to the difficulties in finding the appropriate material to make the holder, and the requirement for a tailor to sew the holder together, it was suggested to utilize some of the ready made parts. After search

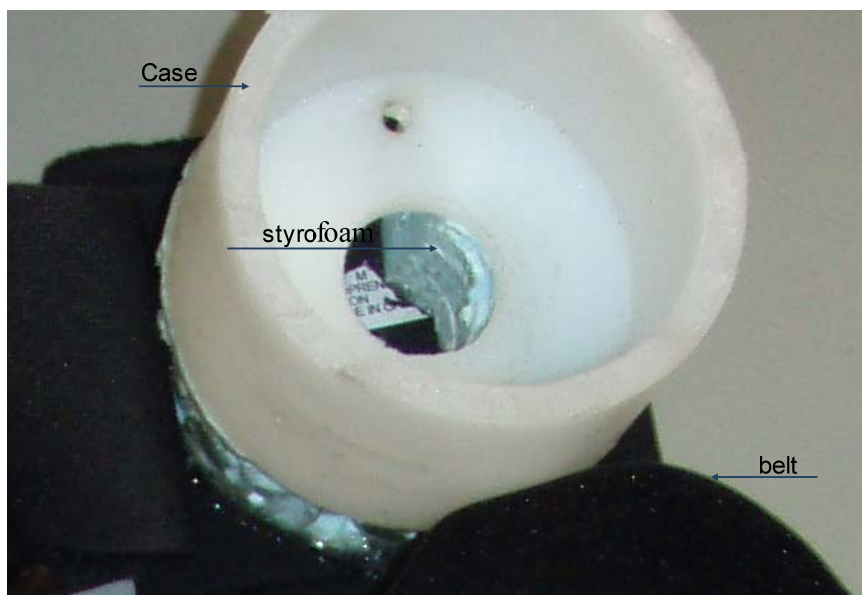
it was found that wrist belt or wrist support best fit the application of case holder. This is because of the material is made of: stretch nylon with neoprene, and because it consists of two parts strip and a band. The strip used to lock the band and they both provide compression which helps in making holder stable on the sheep leg (the two parts of the wrist support are shown in Fig. 13).



**Fig. 13.** Motor case holder.

After finding the appropriate holder for the case motor, the next step was finding a suitable and efficient way to combine the holder with the stepper motor case. One thing to take in account when thinking of combining the motor case and the holder is that the pushing pin which is attached to the stepper motor shaft has to be at zero point or just little of the sheep skin.

Since the motor shaft is about 21.5 mm long and the pin is a round 5 mm long then a piece of material of 26.5 mm long is required between the motor case and the holder. Since it is important to keep the weight of the device light a styrofoam material was used. This material was glued with both the motor case and the belt as shown in Fig. 14.

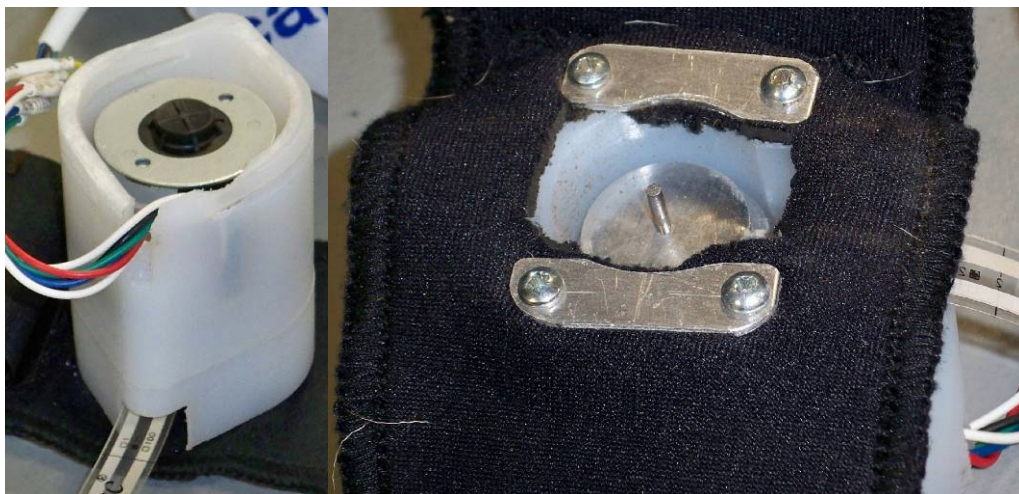


**Fig. 14.** First design of the motor case and the holder.

After testing the design it was found that gluing the parts together is not good option as it is not durable. There were many points suggested and implemented to improve the design:

- 1- Change the motor case design which was mentioned in part 2.3 of the report
- 2- To decrease the size of the system shown in Fig. 15 a big part of the motor shaft was cut and only 5 mm of it remains to allow the attachments of the pin to it.
- 3- Changing the styrofoam with plastic part.
- 4- Instead of gluing parts together, screwing them together makes it more durable and flexible, especially if there is any requirement of taking any piece of the system out.

Furthermore, trying to reduce the weight of the system especially the motor case, some extra milling and drilling was done on the case in order to allow for weight reduction. In the motor case there was also a small slot for the motor wire. This slot is important for wires' protection as leaving the wires at the edge of the case could result in wires getting damage especially that sheep usually try to kick the device against the cage. Fig. 15 shows the design of the new case and the way the case is connected to the belt.



**Fig. 15.** The improved motor case, and the way of attaching the motor case with the case holder.

Compact design of a system and ease of use are both very important and fundamental requirement for a device. To enhance the protection of the system and to make it ready to be used in the field, the stepper motor driver board was cased and included some appropriate interface for the user to deal with.

Most of the wiring between the driver board connection and the user interface (switches & motor connection) was done using Vero board. The user interface included two switches: the first one is single pole, double switch which is responsible for switching the device ON and OFF, and the second switch is double pole double throw and is responsible for changing the direction and speed of the motor together, so that when the motor is switched to the forward direction it goes slowly at the rate of 10 mm / 60 s, and when it is reversed the speed changes to the rate of 100 mm/4s.

To connect the motor with its driver board a 9 pin serial port was used. The last port in the driver board interface is the dc power connection. The power to the motor can be supplied by either using two 9 V batteries in series or any other form of dc power supply that can provide a minimum of 12 V and 0.4 A. Fig. 16 shows the driver board case and the available interface.



**Fig. 16.** Driver board case.

## **5. Force Measurement**

Force measurement is the most important aspect of the system, since the purpose of the device is measuring the force at which the animal exhibits behavioural response. The first method purposed for measuring force was the distance or time of stepper motor movement versus force.

One of the advantages of using stepper motor is the ability of identifying its distance travel without a feed back loop. This is because the speed of travel of the stepper motor is directly proportional to the frequency supplied by the driver board. Since this is the case then it is quite easy to identify the travel distance at any time.

The idea of measuring force depending upon the time travel of the stepper motor requires calibration to see the relationship between time and force appearing in the scale. However, this method is found to be unpractical for measuring the force applied to the sheep for two reasons.

The first reason is that the relationship between distance traveled and force depends upon the pushed body. Say for example that there is two parts one made of cotton and the second one is made out of wood. When it comes to pushing the cotton the motor might travel the maximum distance, which does not mean that the motor has pushed with maximum force. On the other hand, when it comes to pushing the wood part that might require the maximum force of the motor but the distance travel of the motor does not exceed few millimeters.

An experiment was carried out to illustrate the relationship between distance and force for three different materials: Styrofoam, wood, and harsh washing sponge. The experiment was done using milling machine that has digital display of the z axis movement (drill) and scale. A picture of the experiment setup and the result are shown in Fig. 17 and 18 respectively.

Calibrating the stepper motor travel distance versus force on a lamb leg will reflect the true relation between distance travel and force to some extent especially if there consistency in placing the stepper motor at the same location on lamb leg every time.

The second reason for not being able to use distance for force measurement is the difficulties to find a method to calibrate the distance traveled by the motor versus a force when it is attached to the lamb leg.

Being unable to use distance to measure force required a search for an alternative method. After searching it was found that the best method that can be taken to measure the force applied to the animal is using a force sensor, and the proposed sensor for this application was flexiforce sensor.

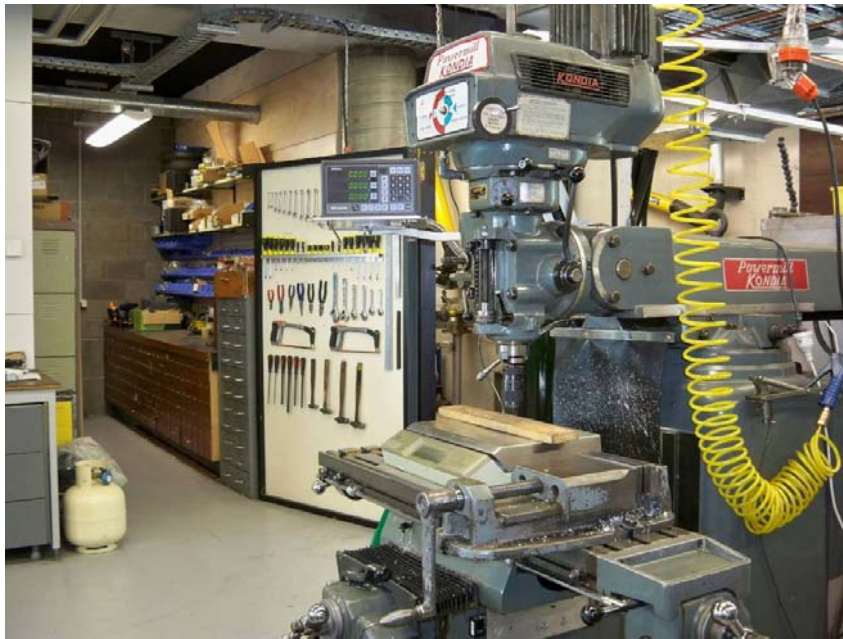


Fig. 17. Setup done to find the relationship between distance and force for three different materials.

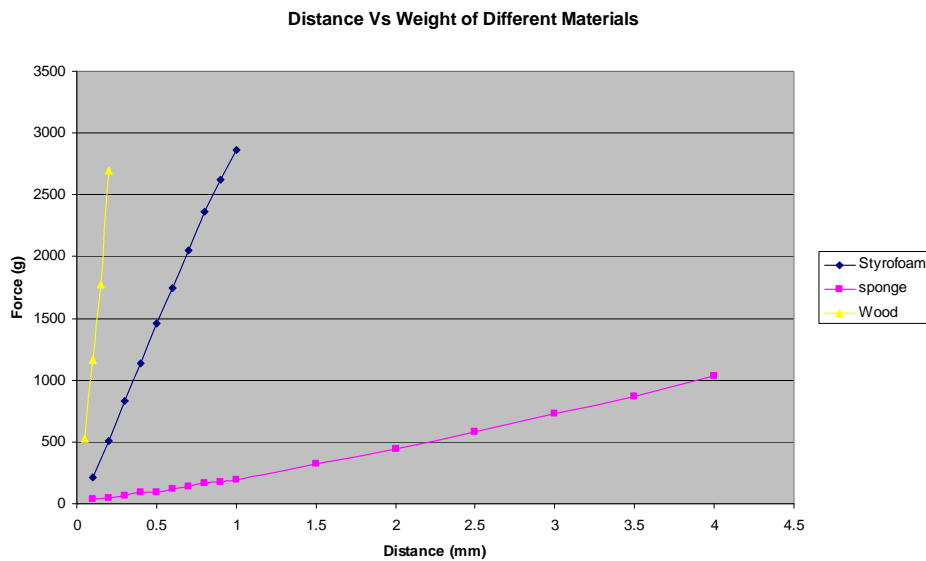


Fig. 18. Distance versus weight of different materials.

### 5.1. Flexiforce Sensor

Flexiforce sensor is very thin, resistive sensor that can measure the force between two surfaces. Flexiforce sensor works as a resistor in a circuit when the sensor is unloaded then the sensor resistivity is very high, and by loading the sensor its resistance decreases resulting in more voltage coming out. Flexiforce sensor has circular active sensing area of 0.375 centimeter diameter [2] (Flexiforce sensor is pictured in Fig. 19).



**Fig. 19.** Flexiforce sensor.

Flexiforce sensor is used in many application including: medical equipment manufacturing, high temperature application, Automotive manufacturers and recreational and entertainment industry. One example of using flexiforce sensor in medical equipment is the use of sensor in CPR training [1].

In first aid Cardiopulmonary resuscitation (CPR) is one of the most important part that can save the life of the casualty. To help in improving the first aid course and to check whether the trainees are applying the force in the right place, a flexiforce sensor was integrated into the manikins. The flexiforce sensor helped the trainer and trainees by pinpointing the position of hand compression in the manikins.

Flexiforce sensor was chosen to be used for this project due to its operation characteristics such as linearity (the relationship between the applied load and the sensor output being linear), repeatability (the sensor response is the same when applying the same load) and its small and thin structure, which makes it easily integrated in many applications and one of them is this project.

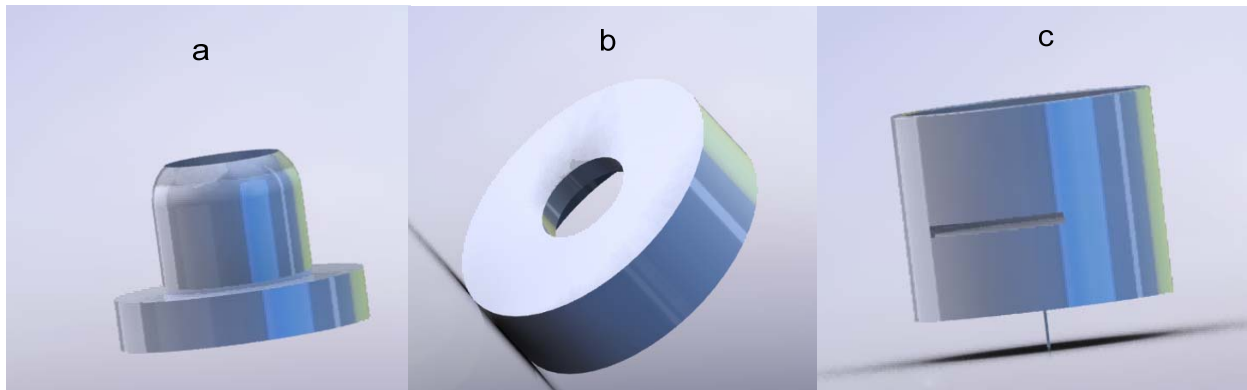
However, one of the disadvantages of the flexiforce sensor is being very sensitive in terms of the force location applied on the active sensing area. For example if a force was applied by a pin to the center of the active sensing area and the same pin used to apply the same force but in the different location on the active sensing area then the output reading would be different. To eliminate the effects of this problem it has to be ensured that the force applied on the active sensing area is always applied in the same location.

To integrate the flexiforce sensor into the mechanical design and make it measure the force applied to the sheep a good design and considerations were requires like: the size and weight of the design, being easily attached to the motor shaft and making sure that the force is always applied to the same point on the active sensing area.

## **5.2. Attaching Flexiforce Sensor With The Motor Shaft**

Before designing the electronic circuit for the sensor and testing its response, it is very important to check first whether the flexiforce sensor can be integrated practically with the mechanical design of the device.

At first it seemed very difficult to insert the flexiforce sensor into the design; especially the device is going to be mounted into a moveable or non static part which is the lamb leg. However, after searching it was found to use and implement the following design. The design consists of three main parts which are shown in Fig. 20.



**Fig. 20.** Mechanical design for flexiforce sensor.

- 1- Part (a) is the one that is going to be connected to the motor shaft, and its bottom circular disc has a dimension similar to the active sensing area of the flexiforce sensor. This part pushes against the flexiforce sensor active area during the movement of the stepper motor against the lamb leg. The part when connected with the motor shaft and part (b) and (c) is very close to the surface of part (c) where the sensor is located so that when the connection between the lamb leg and the pin is achieved it only takes few seconds for the part to push the sensor.
- 2- Part (b) is the part that encloses every thing together. It got an upper hole to allow for the motor shaft to connect with part (b).
- 3- Part (c) consists of the pin that is used to apply force to the lamb leg the pin has a diameter of 1.25 mm. The pin is screwed to the main part, and the main reason behind screwing not welding it is the simplicity of changing it if there is a need for that or bringing the pin forward or sending it backward. Part (c) also consists of a thin slot to allow the entrance of the flexiforce circuit. This slot is made exactly at the top surface of the part, so that it is more stable and ready for the force coming from part (a). The area of the part has been made carefully to exactly fit the square area of the sensor. This is important for ensuring that the sensor is static and does not move.

### **5.3. Designing the Circuit for Flexiforce Sensor**

After successfully designing the parts required for integrating flexiforce sensor with the rest of the mechanical design, the next step was designing an amplifier circuit for the sensor.

The amplifier circuit is important in the design to amplify the signal coming out of the flexiforce sensor and is also used to convey the amplified signals to the microcontroller. Before making printed circuit board (PCB) of the amplifier circuit, it is first built in bread board and tested for linearity and repeatability.

The first circuit used for amplifying the signal produced by flexiforce sensor is shown in Fig. 21. The flexiforce sensor in this circuit is driven by -5 V DC excitation voltage. An inverter operational amplifier is used in this circuit to produce analogue output based upon the change in resistance of the sensor and the fixed  $R_f$  (reference resistance) [1, 2].

After the circuit was built in bread board, it was tested to check its linearity and repeatability. The test was done by applying a force from 0-8 kg, the output voltage was read from the oscilloscope. The experiment was repeated three times and the average was plotted. The tools used for sensor calibration and the output graph are shown in Fig. 22 and 23 respectively.

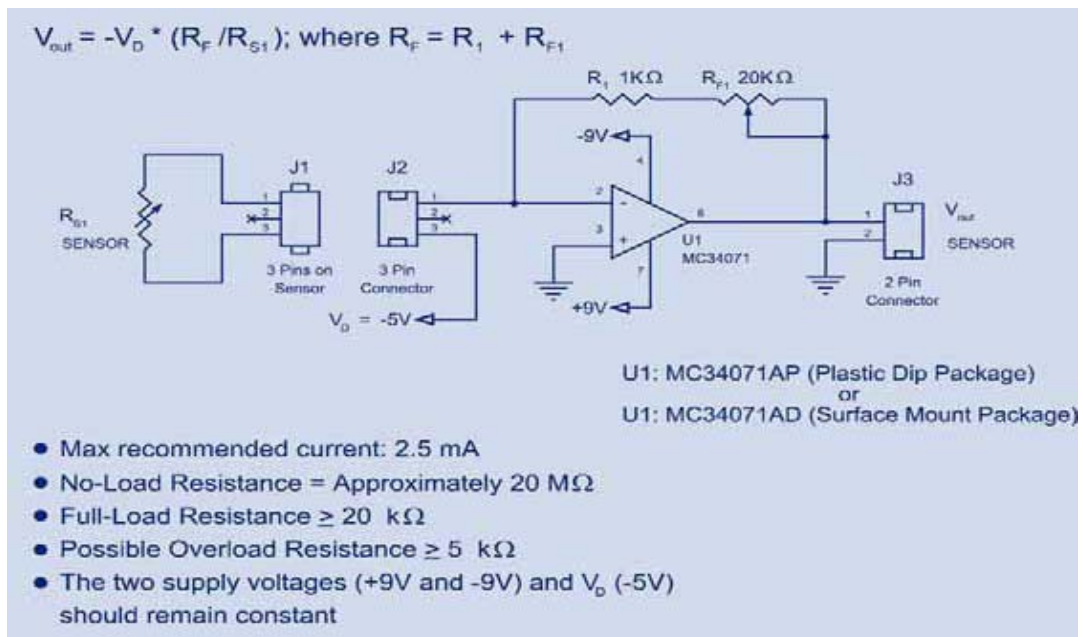


Fig. 21. First proposed amplifier circuit for the sensor.

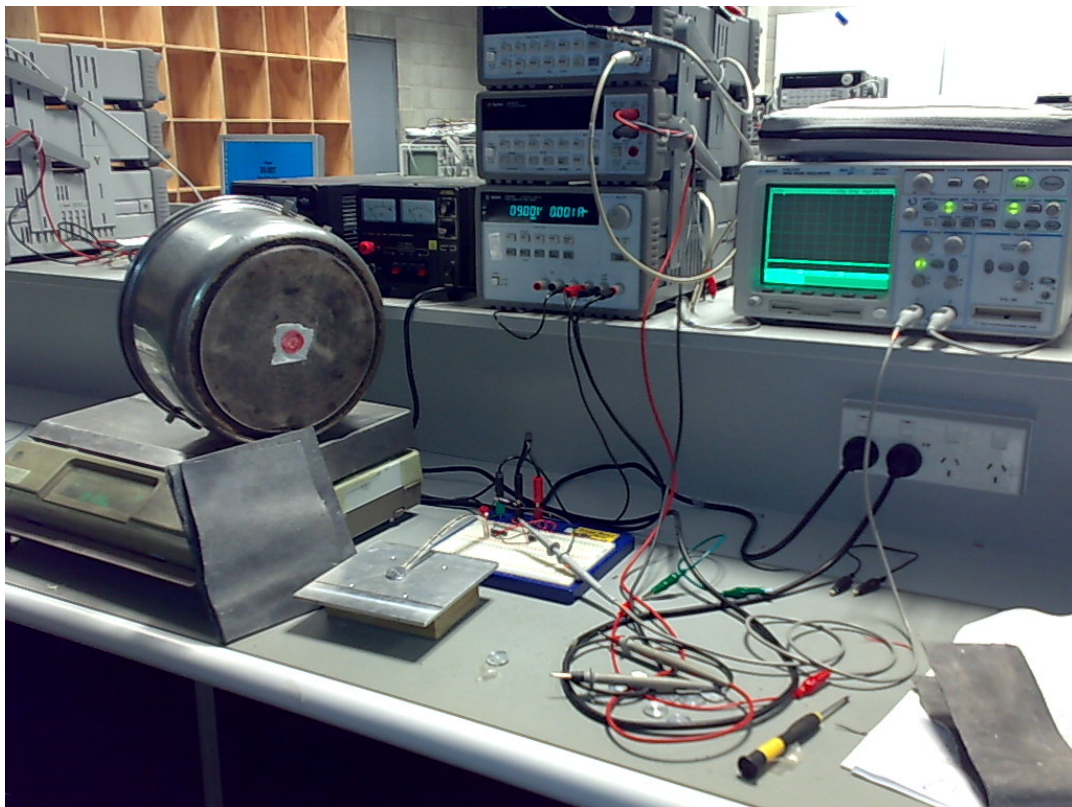


Fig. 22. Tools used for sensor calibration.

To make sure that the load is distributed evenly on the active sensing area two discs were used. These two discs are well polished, one of the discs is placed under the active sensing area and the second is placed at the top of the sensing active area. Moreover, to ensure that the load is always placed in the same way (little different in weight position would change the reading) a red mark has the same diameter as the disc was made in the bottom of the pot.

Force Vs Vout(FlexiForce Sensor)

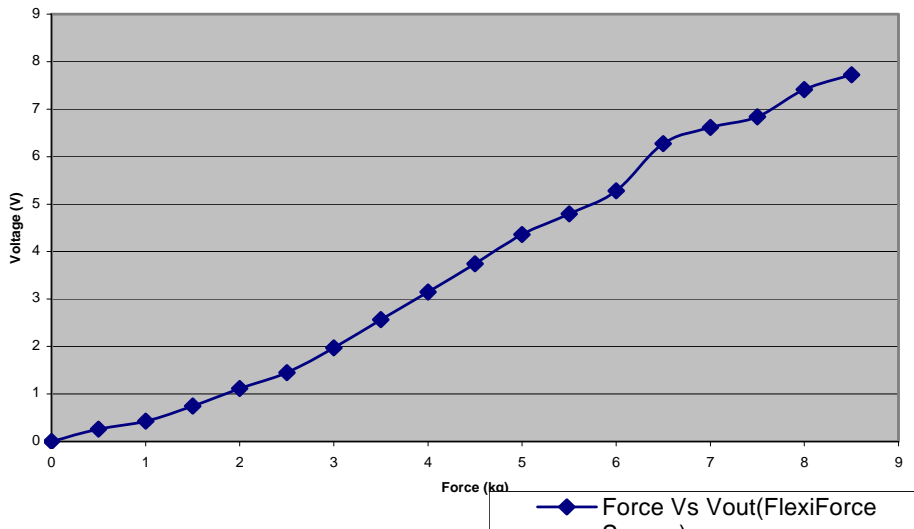


Fig. 23. Result of sensor calibration ( $V_{out}$  vs. Force).

After the circuit has proven to give a linear relationship between applied force and voltage output, a schematic circuit was made to be printed in a circuit board. The hardest part of making the circuit was producing negative 5 and negative 9 volt. However, this problem was solved by using the 555 timer and set of diodes as shown in Fig. 24.

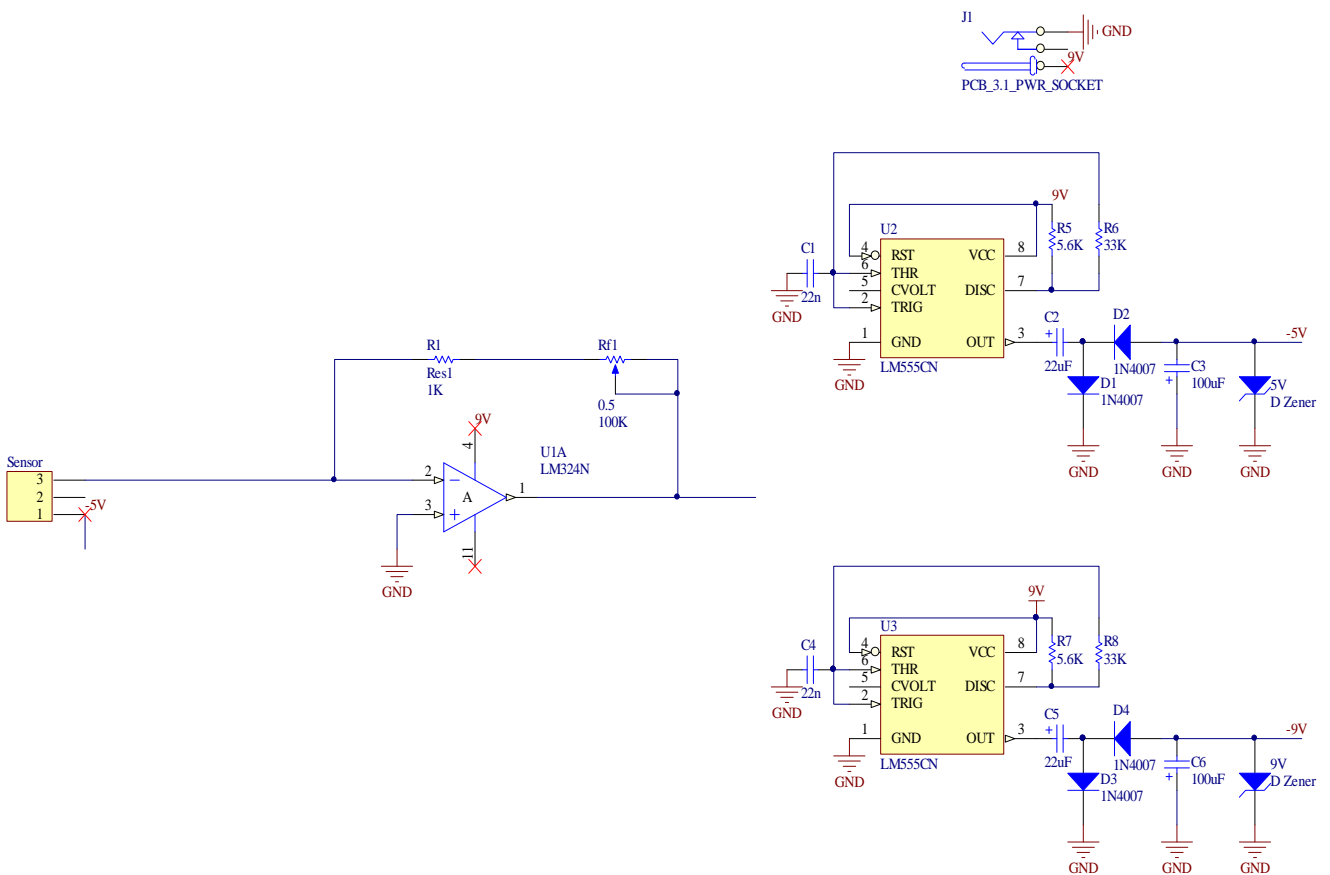
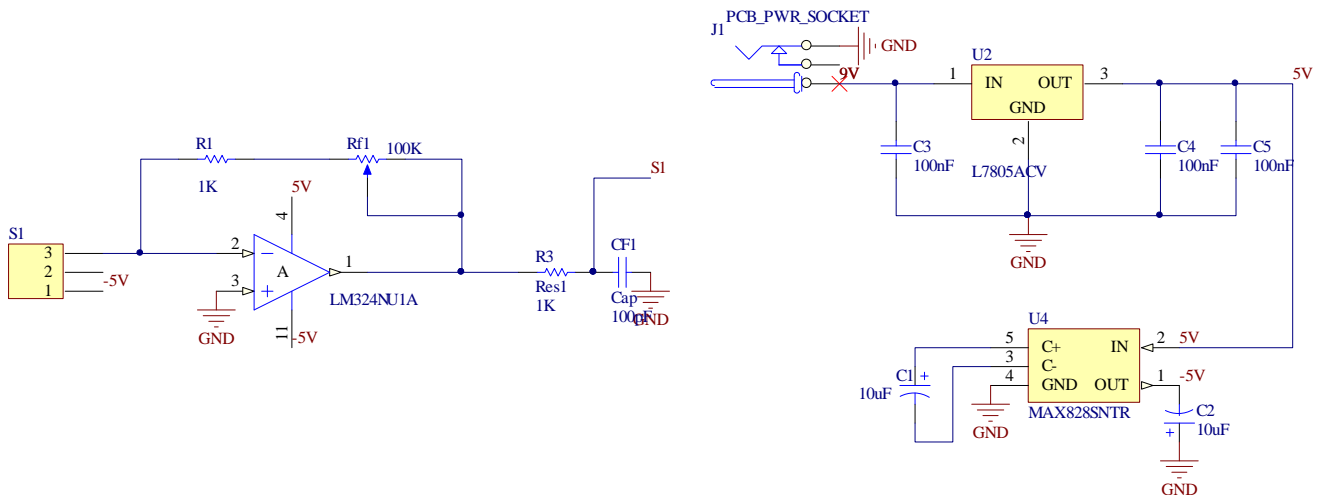


Fig. 24. Circuit design for the sensor amplifier.

After printing the circuit and testing it there were several problems found to be in this circuit which are:

- 1- the 555 timer produces a lot of noise;
- 2- there are many components used in this circuit which could be eliminated.

For these reasons it was suggested to change the circuit into a simpler one especially if an alternative circuit can be made without -9 V and 9 V. A new circuit was made showing in Fig. 25. The new circuit is also driven by -5 V DC excitation and an inverter operational amplifier is used to produce analogue output based upon the change in sensor resistance and fixed reference voltage.



**Fig. 25.** Schematic of the second amplifier circuit used for the sensor.

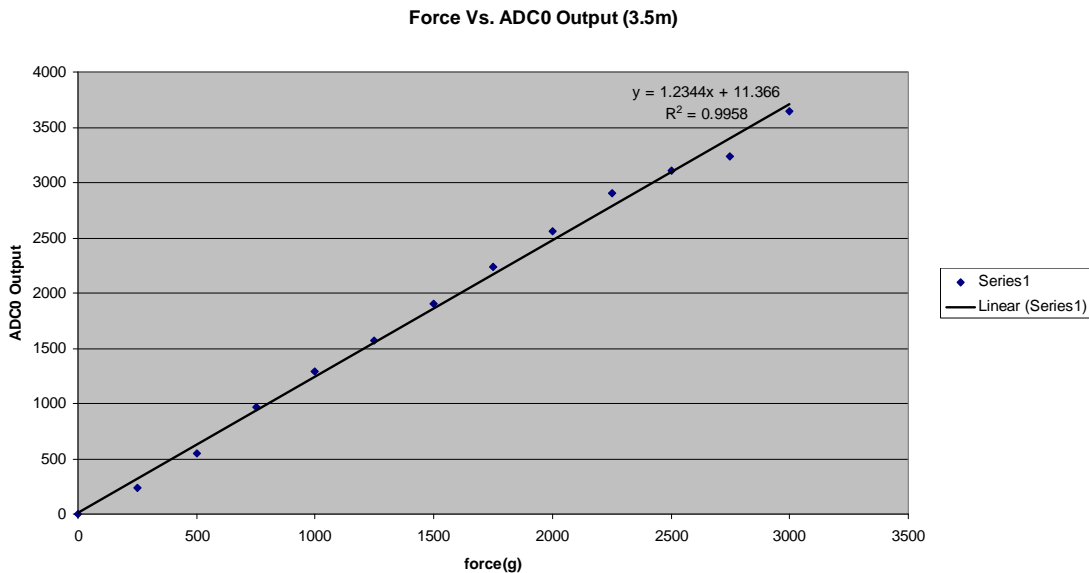
In this circuit the 555 timer and set of diodes used to produce -5 V were replaced by single inverter (max 828), and the 5 V is obtained by using 5 V regulator. In the circuit the sensitivity of the sensor can be controlled by either the reference resistor or/and the drive voltage. The sensitivity of the sensor increases by increasing the reference resistance and/or drive voltage, and it decreases its active force range.

#### 5.4. Sensor Calibration

In the calibration stage it was tried to simulate the real situation, in terms of motor is pushing or applying the force to the sensor. This is just to make sure that the calibration is accurate enough and it is close to the real situation.

Equipments used for calibration are: drill, scale, and the device. The stepper motor was hold on the scale using the drill, and it was important to make sure that before starting the calibration the reading of the sensor is zero which means that the motor is still not pushing the sensor.

After finishing the setups for calibration, the motor is run from 0 kg – 3 kg and stopped in every 250 g interval to take the reading of the microcontroller. This process is repeated three times and then the average reading is plotted against the force. The calibration output graph is shown in Fig. 26.



**Fig. 26.** Calibration result, ADC0 output vs. force.

The calibration was done twice one with 1 meter long wire between the sensor and the amplifier circuit. After that it was required to extend the wire to 3.5 meter which means a little increase in resistance and as consequent a slight change in reading. Therefore another calibration for the sensor was done.

From the output graph it was clear that the sensor is very linear. After the calibration the slope equation was written into the microcontroller program to transfer the ADC0 outputs appearing in the microcontroller LCD screen to force in Newton units.

## 6. Testing

Once it has been proven that the system is ready mechanically and electronically, the next stage was testing the device.

### 6.1. Testing on Frozen Lamb

The device was firstly tested on a frozen lamb leg as shown in Fig. 27.

The main reason behind this testing was to see the performance of the device and to check if there are any drawbacks in the system that can be fixed before implementing it on life sheep.

After testing it was found that there are some problems which need consideration which are:

1. It took the pin around 45 seconds until it comes in contact with the leg
2. The reverse speed of the motor was still slow and needs to be fixed before trying it in life sheep; this is to minimize the pain experienced by the sheep.
3. There was some worry if the connection between the sensor and its amplifier circuit would hold when using it with a life sheep.

The first problem was solved by advancing the pin responsible of applying force. The second problem was solved by changing the circuit in the driving board, and using one switch to control both the speed and direction was achieved.



**Fig. 27.** Testing the system on a frozen lamb leg.

## **6.2. Testing on Life Sheep**

After fixing the problems found when testing the device on the frozen lamb leg, the next step was testing it on life sheep as shown in Fig. 28.



**Fig. 28.** Testing the system on life sheep.

There were three sheep available for testing, but only two of them were used due to the long time the testing took. The test started by placing the motor on the sheep leg, and it was left on the leg for 5 minutes or more before running the motor so that the sheep get used to it. After that the device is

turned ON and the force and time took the sheep to respond to pain were recorded. Three tests were done on each sheep. Table 2 shows the result of the 6 testes done on the two sheep.

Table 2 shows that there are some consistency in terms of time and force reading especially in the second and third run on each trail. The first run of the first trial was very up normal as the motor ran for 30 seconds and the force reading in microcontroller was still zero. There was no clear explanation for this phenomenon, but it might be a loss connection.

**Table 2.** Result of force measurement obtained by trying the system on sheep.

Sheep	Time (s)	Force (N)	Observation
1	30	0	clear
1	30	9	"
1 (first reaction)	34	10	"
1 (2nd reaction)	39	19	"
2	22.5	9	"
2	24	5	"
2	27	5	"

After testing the device on life sheep the following points were observed:

- 1- The device performed very well mechanically as there was no problem of wires coming out and the motor was placed on the sheep successfully and it was accepted by the sheep.
- 2- Force measurement was acceptable, especially the second and third run of each trial as there was clear repeatability.

## 7. Conclusion

The new pain sensitivity measurement system consists of six main parts which are: stepper motor, stepper motor driver board, motor case, motor case holder, force measurement system and microcontroller.

Testing the device on frozen lamb leg and on life sheep it was found that the device performed very well mechanically, as there was no wiring coming out, the lamb accepted the system to be placed on its leg and the lambs did not show any weird movement as a result of the motor sound when the motor was first turned on.

The force measurement part of the system was first calibrated in the lab and the relationship between force and the microcontroller ADC output was obtained. The ADC output was then changed to Newton. When the force measurement system was tested on two life sheep it was found that the system worked as expected.

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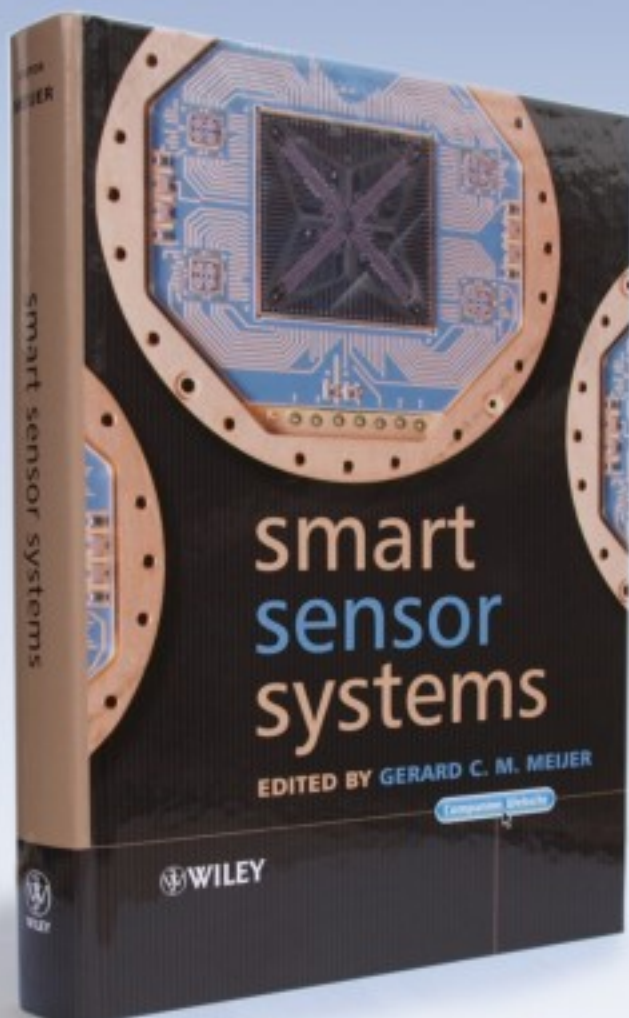
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