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TOWARDS SOFT WEARABLE STRAIN SENSORS FOR MUSCLE ACTIVITY MONITORING

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Abstract: The force-generating capacity of skeletal muscleis an importantmetric in the evaluation and diagnosis of musculo skeletal health. Measuring changes in muscle force exertion is essential for tracking the progress of athletes during training, for evaluating patients' recovery after muscle injury, and also for assisting the diagnosis of conditions such as muscular dystrophy, multiple sclerosis, or Parkinson's disease. Traditional hardware for strength evaluation requires technical training for operation, generates discrete time points for muscle assessment, and is implemented in controlled settings. The ability to continuously monitor muscle force without restricting the range of motion or adapting the exercise protocol to suit specific hardware would allow for a richer dataset that can help unlock critical features of muscle health and strength evaluation. In this paper, we employ wearable, ultra-sensitive soft strain sensors for tracking changes in muscle deformation during contractions. We demonstrate the sensors' sensitivity to isometric contractions, as well as the sensors' capacity to track changes in peak torque over the course of an is okinetic fatiguing protocol for the knee extensors. The wearable soft system was able to efficiently estimate peak joint torque reduction caused by muscle fatigue.

Index Terms: Parkinson's Disease, Arduino

1. INTRODUCTION

The force output capacity of skeletal muscle encodes rich information about several aspects of human health. Fluctuations in the force output of skeletal muscle (muscle strength) are indicative of lower-grade injury, for example, exercise-induced muscle damage following intense physical activity [1], [2]. Therefore, the ability to measure the force-generating capacity of muscles over a period of time is useful for individuals seeking to improve their training regimens and reduce the risk of overtraining and injury [3], [4]. Additionally, a decline in the force production capacity of skeletal muscle precedes several medical conditions, such as muscular dystrophy, multiple sclerosis, and Parkinson's disease

[5]. Consequently, the assessment of muscle force generation is also important for clinicians evaluating the overall health or recovery of their patients.

Monitoring muscle force output over a period of time could enable safer and more efficient clinical rehabilitation and athletic training protocols. Longitudinal collection of data at finer time points is less susceptible to within- or across-day fluctuations in force generation. However, long-term evaluation (over the period of hours or days) of muscle force output in real-world contexts is currently challenging, due to a lack of robust techniques capable of taking such measurements outside of the lab or clinical settings [6].

Traditional clinic-based muscle strength assessment methods include manual muscle testing (MMT) and isokinetic dynamometry. MMT is a clinician-administered exam, which scores a patient's muscle strength between zero and five, depending on their ability to both move through a full range of motion and resist applied pressure. The MMT is easily administered with no associated cost, but it is a discrete and subjective measurement subject to high variability [7]. Isokinetic dynamometry is the current gold-standard for evaluating muscle strength. Isokinetic dynamometry measures joint torque during static or constant-velocity movements [8]. Isokinetic dynamometers also measure rotational speed, position, and direction, allowing for precise and controlled measurements of muscle force acting about a joint. However, these machines are cost-prohibitive for most hospitals and clinics. Also, factors such as age, weight, or severity of injury can make evaluation with an isokinetic dynamometer impractical for certain patient populations. Ultimately, both the MMT and isokinetic dynamometry can only be administered in controlled settings and at discrete time points (typically weeks, months, or years) [7]–[10].

Researchers and clinicians have become interested in wearable systems over the last decades because these systems have the potential to continuously monitor muscle activity, in addition to being lightweight, low-profile, and affordable. [11]–[13]. Sensing technologies, such as surface electromyography (sEMG) [14]–[16], mechanomyography (MMG) [17]–[19], and force myography (FMG) [20], [21], have all been proposed as possible solutions to this challenge of ubiquitous monitoring of muscle force, each with varying levels of success.

sEMG is considered the gold-standard for wearable sensors measuring muscle activity, given its commercial adoption and wide range of applications. sEMG uses electrodes to measure the bulk electrical potential within muscle fibers, and this signal is indicative of the activation level of muscle [14]. However, as sEMG is primarily a measure of electrical activity within a muscle, its relationship to the mechanical output of muscle remains elusive [15], [22]. Crosstalk from adjacent co-contracting muscles can also contaminate the signal from the muscle of interest, complicating interpretation [16]. MMG, considered the mechanical counterpart to sEMG, measures the lateral oscillations of contracting muscle fibers with microphones or accelerometers, and has steadily gained in popularity over the past years. MMG does not require electrodes for signal transduction and is unaffected by inherent electrical noise, which affects sEMG [19]. The main challenge for MMG is measurement during dynamic contractions, as motion artifacts can severely deteriorate signal quality [17], [18]. Lastly, FMG belongs to a broader category of sensing techniques attempting to measure the force generated by a muscle externally by quantifying how muscle geometry changes. FMG typically uses a band of pressure sensors wrapped around the limb of interest to measure radially-directed pressure as the muscle bulges outwards. However, by radially-constraining all sensors in a band wrapped around the limb of interest, any muscle that bulges under the band will affect the signal of all sensors. The resulting mechanical coupling between the sensors makes interpretation of the FMG output challenging. Sensitivity is another consideration in FMG systems, as most off-the-shelf pressure or force sensors are not able to detect small motions of the underlying muscle, thus FMG bands typically need to be carefully pretensioned to compensate for a lack of sensitivity [20].

Current research on sEMG, MMG, and FMG has focused on gathering more data with additional sensors (e.g. sEMG arrays), combining multiple sensing techniques (e.g. sEMG and MMG), or using algorithmic advances in post-processing methods (e.g. data-driven machine learning models) to compensate for limitations in the respective sensing technologies. Some of these limitations are inherent to the sensing technology, such as crosstalk in sEMG signals, motion artifacts in MMG sensors, or sensor preloading in FMG, and remain a challenge.

Recently, researchers have investigated the relationship between muscle morphological changes and joint torque during contractions [23]–[25]. In these studies, ultrasound is used to quantify the deformation of skeletal muscle (e.g. changes in width and thickness) during isometric contractions. These architectural changes have been shown to correlate with joint torque. Researchers have also demonstrated that during sustained, fatiguing, isometric contractions, the deformation of contracting muscles varies over time, alongside corresponding reductions in measured joint torque [26]. While ultrasound systems are unaffected by crosstalk and motion artifacts, they cannot be easily integrated into wearable hardware and therefore are mainly limited to isometric studies. Being able to measure muscle deformation with a completely wearable and unrestrictive system could provide researchers and clinicians with a new approach of monitoring muscle activity.

In this paper, we propose a method of estimating static and dynamic changes in muscle force using soft strain sensors that can non-invasively measure muscle deformation. The soft strain sensor [27] is low-profile, robust, and hypersensitive to underlying motion, thus being a candidate technology to address the aforementioned challenges. We hypothesize that adhering the soft strain sensors directly to the surface of the skin above a muscle would allow the sensor to capture changes in muscle deformation which would correlate with muscle force. As a proof of concept, we ran an experiment with eight healthy participants to track muscle force during static and dynamic contractions of the quadriceps muscle and compared the results with data collected from a dynamometer as ground truth.

2. LITERATURE REVIEW

Introduction:

The development of soft wearable strain sensors for muscle activity monitoring is an active research area due to their potential applications in health monitoring, rehabilitation, and sports performance. In this literature survey, we will explore the recent advancements in this field and summarize the various soft wearable strain sensor designs, fabrication techniques, and their applications.

Soft Wearable Strain Sensors:

Soft wearable strain sensors are flexible and stretchable sensors that can be easily integrated into clothing or worn directly on the skin. These sensors are designed to detect the mechanical deformation of the underlying tissue, which can be related to muscle activity. Several types of soft wearable strain sensors have been developed, including piezoresistive, capacitive, and optical sensors.

Piezoresistive Sensors:

Piezoresistive sensors are the most commonly used type of soft wearable strain sensor. They are based on the principle that the electrical resistance of a material changes when it is deformed. Several materials, including conductive polymers, carbon nanotubes, and graphene, have been used to fabricate piezoresistive sensors. These sensors have been shown to accurately measure the strain of various tissues, including muscle tissue.

Capacitive Sensors:

Capacitive sensors are another type of soft wearable strain sensor that can be used to measure muscle activity. These sensors consist of two parallel plates separated by a dielectric material. When the tissue is deformed, the distance between the plates changes, leading to a change in capacitance. Several designs of capacitive sensors have been developed, including interdigitated electrode structures and microfluidic capacitive sensors.

Optical Sensors:

Optical sensors are a relatively new type of soft wearable strain sensor. These sensors use optical fibers or thin films to detect changes in the tissue's mechanical properties. They have the advantage of being non-invasive and not requiring direct contact with the tissue. However, they are still in the early stages of development and require further optimization.

Fabrication Techniques:

Several fabrication techniques have been developed to fabricate soft wearable strain sensors, including screen printing, inkjet printing, and 3D printing. Screen printing is the most commonly used technique for fabricating piezoresistive sensors, while inkjet printing is commonly used for capacitive sensors. 3D printing has also been used to fabricate complex sensor structures.

Applications:

Soft wearable strain sensors have several potential applications, including health monitoring, rehabilitation, and sports performance. In health monitoring, these sensors can be used to monitor muscle activity in patients with neuromuscular disorders. In rehabilitation, they can be used to monitor and track the progress of patients recovering from injuries. In sports performance, they can be used to monitor muscle activity during training and optimize athletic performance.

Conclusion:

Soft wearable strain sensors have the potential to revolutionize health monitoring, rehabilitation, and sports performance. Several types of sensors and fabrication techniques have been developed, each with its advantages and disadvantages. Further optimization of these sensors is needed to improve their accuracy and sensitivity.

3. METHODOLOGY

EXISTING SYSTEM:

sEMG is considered the gold-standard for wearable sensorsmeasuring muscle activity, given its commercial adoption andwide range of applications. sEMG uses electrodes to measurethe bulk electrical potential within muscle fibers, and thissignal is indicative of the activation level of muscle.However, as sEMG is primarily a measure of electrical activitywithin a muscle, its relationship to the mechanical output ofmuscle remains elusive. Crosstalk from adjacentco-contracting muscles can also contaminate the signal fromthe muscle of interest, complicating interpretation.

PROPOSED SYSTEM:

We propose a method of estimating static anddynamic changes in muscle force using soft strain sensorsthat can non-invasively measure muscle deformation. The softstrain sensor [27] is low-profile, robust, and hypersensitiveto underlying motion, thus being a candidate technology toaddress the aforementioned challenges. We hypothesize thatadhering the soft strain sensors directly to the surface ofthe skin above a muscle would allow the sensor to capturechanges in muscle deformation which would correlate withmuscle force.

Components Used

- Arduino
- Pressure Sensor
- Flex Sensor
- MEMS Sensor
- LCD
- Alarm
- Bluetooth

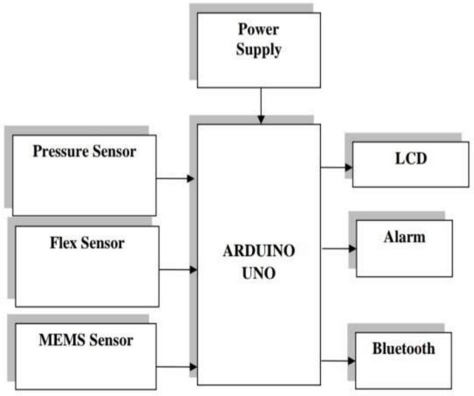


Fig 1 Block diagram For Proposed System

Arduino: The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

LCD: Liquid Crystal Display also called as LCD is very helpful in providing user interface as well as for debugging purpose. The most commonly used Character based LCDs are based on Hitachi's HD44780 controller or other which are compatible with HD44580. The most commonly used LCDs found in the market today are 1 Line, 2 Line or 4 Line LCDs which have only 1 controller and support at most of 80 characters, whereas LCDs supporting more than 80 characters make use of 2 HD44780 controllers.

Pressure Sensor: A pressure sensor is a device which senses pressure and converts it into an analog electric signal whose magnitude depends upon the pressure applied. Since they convert pressure into an electrical signal, they are also termed as pressure transducers.

Flex Sensor: A flex sensor or bend sensor is a sensor that measures the amount of deflection or bending. Usually the sensor is stuck to the surface, and resistance of sensor element is varied by bending the surface. Since the resistance is directly proportional to amount of bend it is used as goniometer, and often called flexible potentiometer.

Relay: A relay is an electromechanical switch, which perform ON and OFF operations without any human interaction. General representation of double contact relay is shown in fig. Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal.

MEMS Sensor: An accelerometer is a micro-electromechanical device that measures acceleration forces. These forces may be static, like the constant force of gravity pulling at our feet, or they could be dynamic - caused by moving or vibrating the accelerometer. There are many types of accelerometers developed and reported in the literature. The vast majority is based on piezoelectric crystals, but they are too big and too clumsy. People tried to develop something smaller, that could increase applicability and started searching in the field of microelectronics. They developed MEMS (micro electromechanical systems) accelerometers.

Bluetooth: Bluetooth is a wireless technology standard for exchanging data over short distances (using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz) from fixed and mobile devices and building personal area networks (PANs). In 1994 a group of engineers at Ericsson, a Swedish company, invented a wireless communication technology, later called Bluetooth. In 1998, the original group of Promoter companies—Ericsson, Intel, Nokia, Toshiba and IBM—came together to form the Bluetooth Special Interest Group (SIG).

Buzzer: A buzzer or beeper is a signaling device, usually electronic, typically used in automobiles, house hold appliances such as a microwave oven, or game shows. It most commonly consists of a number of switches or sensors connected to a control unit that determines if and which button was pushed or a preset time has lapsed, and usually illuminates a light on the appropriate button or control panel, and sounds a warning in the form of a continuous or intermittent buzzing or beeping sound. Initially this device was based on an electromechanical system which was identical to an electric bell without the metal gong (which makes the ringing noise). Often these units were anchored to a wall or ceiling and used the ceiling or wall as a sounding board.

4. IMPLEMENTATION

The item for the proposed system is executed utilizing the Arduino IDE.

Integrated Development Environment (IDE) for Arduino: A substance chief for composing code, a message region, a message terminal, a toolbar with buttons for normal undertakings, and a progression of menus are totally expected for the Arduino IDE. It talks with the Arduino equipment and sends dares to it.

File

New creates a new supervisor instance with all of the essential features of the drawing present.

allows you to browse the envelopes and papers on your PC to create a sketch record.

At the point when you open Later, a rundown of the latest drawings that might be gotten to is shown.

Within the envelope structure of Sketchbook, the corresponding representation is displayed in a different proofreading case whenever any name is mentioned.

Models All models provided by the Arduino Programming (IDE) or library are displayed when this menu option is selected. The models are arranged in a tree, making it simple to search by library or subject.

closes the Arduino Programming instance clicked.

Save The current name is used to save the artwork. A name will be proposed for the record in a "Save as..." exchange on the off chance that it has not as of now been named.

You can save the current drawing under a different name by selecting "Save as..."

It shows the printing-explicit Page Setting window.

In accordance with the Page Arrangement limits, Print sends the ongoing drawing to the printer.

By clicking Inclinations, you can change many IDE settings, like the language of the IDE interface.

All IDE windows are closed by Stop. The next time you start the IDE, the open drawings that were open when Stopped was selected will be restored immediately.

Edit

- Record at least one stage of modification as a fix or retry; You can use retry again when you come back.
- Cut The chose text is replicated to the clipboard and eliminated from the editor.
- After reproducing the text from the proofreader, duplicate copies the selected text and copies it to the clipboard.
- Copy the code for your sketch to the clipboard in a format that is suitable for presenting on the discussion with punctuation shading. Duplicate for Collection
- Duplicate as HTML recovers the code from your sketch and copies it to the clipboard as HTML, ready for use on websites.
- Glue the contents of the clipboard into the supervisor by copying them there from the clipboard.
- The entire selection made by the manager is included in Select All.
- Remark/Uncomment Inserts the /remark tag at the beginning of each line or removes it altogether.
- Indent adds or subtracts a space at the beginning of each selected line, moving the text one space to the side or removing a space.
- When you click "Find," the "Find and Supplement" window opens. Here, you can use a few models to figure out the text you need to look for in the ongoing plan.
- Depending on where the cursor is, Find Next will highlight the following event, if any, of the string that was entered in the Find window as the pursuit object.
- Based on where the cursor is, Find Earlier highlights the preceding event of the string in the Track down window.

Sketch

Verify or arrange your drawing after checking for errors while it was being made. In the control center section, it will show the factors and the amount of memory used by your code.

Transfer stacks the parallel record onto the designated board via the predefined Port after aggregation.

Using a software engineer to transfer This will replace the board's bootloader; Go to Devices > Consume Bootloader to reactivate the option to transfer to the USB sequential port. Nevertheless, it enables you to make use of the entire Blaze RAM for your artwork. Keep in mind that following this advice will not result in the wires lighting up, assuming it isn't too much work. Navigate to Apparatuses > Consume Bootloader to accomplish this.

Send Out Completed Double produces a.hex file that can be filed or sent to the board using a variety of tools.

In the ongoing representation organizer, open the Presentation the Sketch Envelope order.

Add a library to your drawing by using the #include instruction at the beginning of your code. For more details, see the libraries listed below. From this menu item, you can also import new libraries from.zip files and launch the Library Director.

A new document is added to the drawing using Embed Document... it will be duplicated from its current location). As is customary for assets like documentation, the record is saved in the sketch's data subfolder. The sketch programming excludes the objects in the information envelope because they have not been gathered.

Tools

Your code is precisely arranged by Auto Arrangement by indenting it so that the declarations contained within the wavy supports are also indented and the opening and closing wavy supports line up.

The current drawing is saved as a.zip file using Document Sketch. The chronicle and the artwork are kept in the same envelope.

Reload the page and resolve the encoding issue. The proofreader's single map encoding and the roast guides of other functioning frameworks are unaffected by this.

Screen for Successive beginnings the information exchange with any connected board on the at present chosen Port and opens the comparing screen window. On the off chance that the board upholds it, this for the most part resets it. Perform a reset to prevent the sequential port from opening.

Board Select your preferred board. The various sheets are depicted in the following image.

All of your PC's real and simulated sequential devices are stored in this menu. You should feel immediately energized as soon as you enter the high level gadgets menu.

Software developer: Programming a board or chip without using the USB-sequential connection that is already installed is done with a hardware developer. In any case, if you want to modify a brand-new microcontroller, you will require this.

Consume Bootloader You can embed a bootloader into the microcontroller of an Arduino board by utilizing the options in this menu. This is useful if you buy a different ATmega microcontroller, which sometimes doesn't have a bootloader, but it doesn't affect how the Arduino board works on its own. Make sure that the appropriate board has been selected from the Sheets selection before eating the bootloader on the goal board. The necessary wiring was also installed as a result of this direction.

5. RESULTS AND DISCUSSION

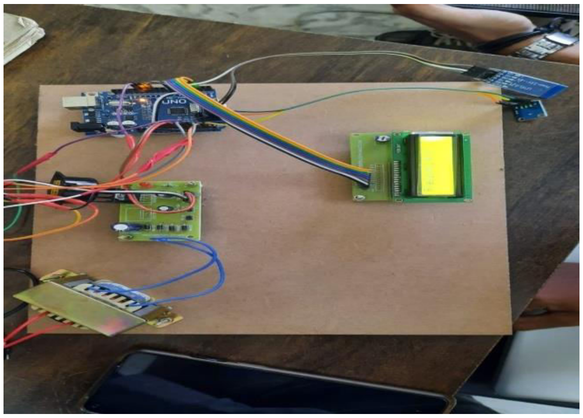
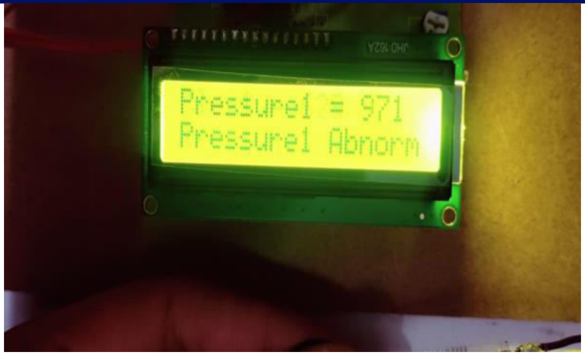
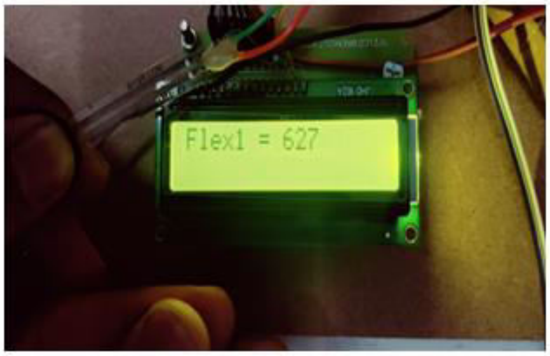


Fig 2 Output Screen



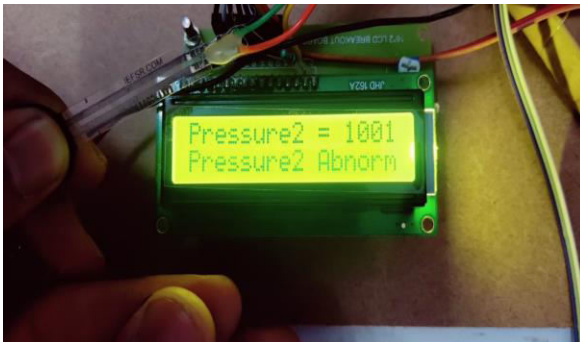
```
Pressure1 = 971
Pressure1 Abnorm
```

Fig 3 Output Screen



```
Flex1 = 627
```

Fig 4 Output Screen



```
Pressure2 = 1001
Pressure2 Abnorm
```

Fig 5 Output Screen

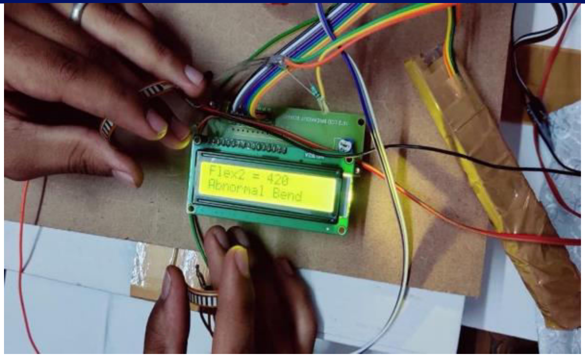


Fig 6 Output Screen

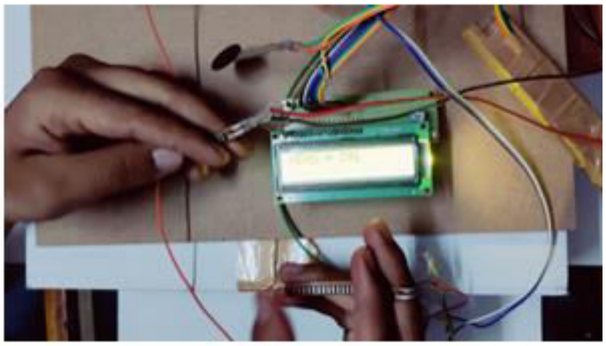
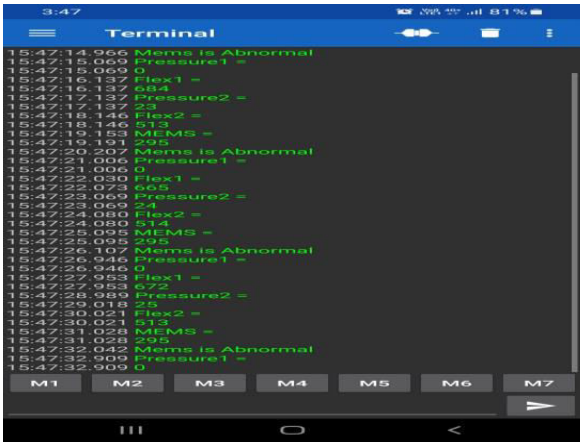


Fig 7 Output Screen



```
15:47:14.966 Mems is Abnormal
15:47:15.069 Pressure1 =
15:47:15.069 0
15:47:16.137 Flex1 =
15:47:16.137 684
15:47:17.137 Pressure2 =
15:47:17.137 23
15:47:18.146 Flex2 =
15:47:18.146 513
15:47:19.153 MEMS =
15:47:19.191 295
15:47:20.207 Mems is Abnormal
15:47:21.006 Pressure1 =
15:47:21.006 0
15:47:22.030 Flex1 =
15:47:22.073 665
15:47:23.069 Pressure2 =
15:47:23.069 24
15:47:24.080 Flex2 =
15:47:24.080 514
15:47:25.095 MEMS =
15:47:25.095 295
15:47:26.107 Mems is Abnormal
15:47:26.946 Pressure1 =
15:47:26.946 0
15:47:27.953 Flex1 =
15:47:27.953 672
15:47:28.989 Pressure2 =
15:47:29.018 25
15:47:30.021 Flex2 =
15:47:30.021 513
15:47:31.028 MEMS =
15:47:31.028 295
15:47:32.042 Mems is Abnormal
15:47:32.909 Pressure1 =
15:47:32.909 0
```

Fig 8 Output Screen

6. CONCLUSION

In this paper, we presented a method capable of trackingchanges in muscle force output with soft strain sensors bynon-invasively measuring muscle deformation. This work aimsat advancing sensing capabilities for evaluation of muscleforce output towards real-world applications. The ability tomonitor muscle force output can offer immense benefits toclinicians or researchers who are looking to track how patientsrespond to treatment and rehabilitation, or athletes who wishto track and improve their performance during exercise.

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