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Novel Applications of Force Sensing Resistors in Healthcare Technologies

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***Abstract*— Force Sensing Resistors (FSR) are ultra-thin, low-cost, pressure sensors, which exhibit change in their electrical resistance when force is applied on their surface. The FSR has been used in wide ranging applications in the automotive industry, musical instruments, touch-buttons, portable electronic devices, etc. The FSR is also proving to be promising device for developing applications in healthcare. The present work reviews the reported work on developing novel applications of FSR in non-invasive diagnosis, and monitoring of patients undergoing treatment. The techniques used in biosignal acquisition and its subsequent processing after using FSR, as reported in the literature are briefly reviewed. This is followed by review of the recently reported innovations in diagnostic technology using FSR. The applications of the FSR for diagnosis and monitoring of several major medical disorders are described. The merits and of using FSR are highlighted. The limitations of the technology using FSR are also noted for future advancement. It is observed that application of FSR, despite its present limitations of the technology, opens new opportunities for developing novel applications in bio-medical instrumentation and healthcare.**

Keywords—Force sensing resistor (FSR); Cardiovascular Disease (CVD); Arterial wave pulse ; Sleep apnea ; Foot neuropathy; Scoliosis ; Parkinson's disease ; Carpal tunnel syndrome (CTS);

I. INTRODUCTION (*Heading 1*)

Force sensing resistors (FSRs), are robust polymer thick film devices that exhibit a change in its electrical resistance when a force is applied on to their surface. The FSR is typically made out of a proprietary polymer thick film ink screen, printed on a mylar polyester film. The sensing film of the FSR comprises of both electrically conducting and non-conducting particles suspended in a matrix. The particles are of sub-micrometer sizes, and are formulated to decrease temperature dependence and improve durability. Applying a force to the sensing film of the FSR causes particles to touch the conducting electrodes, in-turn decreasing its resistance. The resistance-force characteristics of a typical FSR is shown in Fig. 1. [Source: FSR 402 Data-Sheet, Interlink Electronics]

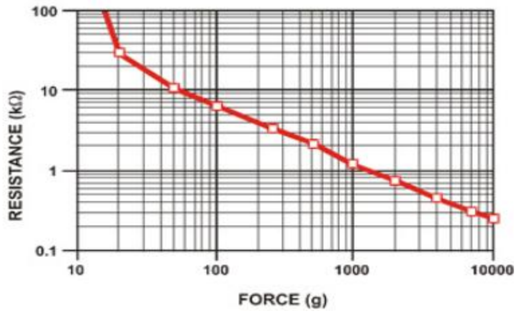

Fig. 1: Variation of resistance (ohm) with force applied on the FSR

When there is no force applied on the FSR, the resistance of the FSR is very high, of the order of hundreds of MΩ, however when force is applied on it, its resistance reduces significantly. Unique properties of the FSR such as requirement of small surface area for activation, low cost, flexibility and high tolerance to temperature, chemicals and moisture make it an ideal sensor material for biomedical applications, wherein force measurement is required.

In this paper, we discuss several major applications of the force sensing resistor in biomedical devices, divided into 5 categories. Owing to its unique properties, the FSR has been used in variety of instruments for diagnosis and monitoring as well as treatment of disorders or diseases observed in humans, such as : (A) Diagnosis of Cardiovascular disease (CVD), (B) Diagnosis of sleep related breathing disorders, Diagnosis of neurodegenerative diseases and carpal tunnel syndrome, (C) Diagnosis of foot neuropathy, measuring forces in assistive devices for scoliosis and bite force measurement, and (D) Application of FSR in surgery for tissue elasticity measurement. The merits and demerits of instruments using the FSR, in comparison to conventional instruments are enumerated. The limitations of FSR which may be taken into account while developing novel applications in future are also identified. Opportunities for developing new application of FSR in healthcare are also highlighted .

II. BIO-SIGNAL ACQUISITION USING THE FSR

In all electronic circuits, only voltage and current signals can be used for performing computations. Thus typically the change in the resistance of the FSR is converted to a voltage signal before the signal processing stage. In most applications, this is performed using the circuit shown in Fig 2.

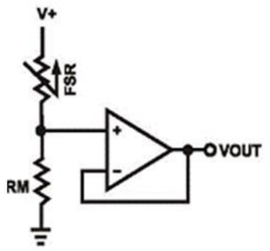

Fig. 2. Signal Conversion Circuit

The above figure shows circuit diagram for achieving conversion of change in resistance to change in voltage. In Fig 2, since the operational amplifier here is connected in an Analog Voltage Buffer Configuration,

$$V_{OUT} = V_+ * R_M / (R_{FSR}+R_M)$$

Thus, as the force on the FSR increases the resistance of the FSR decreases and since V_+ and R_M are kept constant, the output voltage V_{OUT} increases. The variation of V_{OUT} with R_{FSR} is non-linear, and can be approximated as linear variation for values of $R_{FSR} << R_M$. In the circuit in Fig. 2, the Voltage V+ and Resistance R_M are used to adjust the value of the output voltage within a desired range for ease of signal conditioning , hence used to calibrate the output voltage.

If the FSR is used for sensing biosignals which typically present within a frequency band (Typically 0-500 Hz) , then a precision analog-front end is required. This circuit typically consists of a band-pass filter which captures signals within the desired frequency range. Interference from power lines (50 or 60 Hz) is the largest source of extraneous noise in bio-electric signals. Hence, a 50/60 Hz notch filter (such as the twin-T notch filter) is also cascaded at the output of this filter to eliminate this noise [3]. After the analog signal conditioning, the signal should be converted into a digital signal for further processing.

This is done through use of simple Analog to Digital conversion devices (ADCs), with appropriate sampling frequency. This can be achieved through modules such as the NI-My DAQ or NI-ELVIS as in [1][2]. Once these signals are acquired digitally, appropriate digital signal processing and machine learning algorithms can be used to extract the desired information and perform diagnosis.

Simple, user-friendly Graphical User interfaces (GUI) as shown in Fig. 3 can be built which makes interpreting results easier for the user [1] [2].

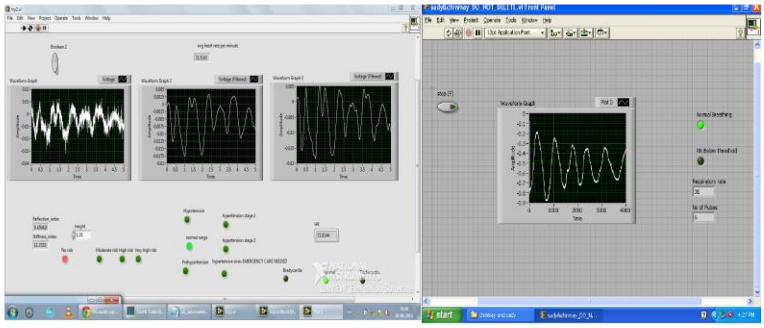

Fig. 3. Simple GUIs built in LabVIEW

III. APPLICATIONS OF THE FORCE SENSING RESISTOR

A. Diagnosis of Cardiovascular Disease (CVD)

Sundar-Venkat [1] have reported that the FSR can be used in non-invasive diagnosis of CVD, and for real-time monitoring of arterial wave-pulse parameters such as heart rate, stiffness index, reflectivity index and pulse wave velocity. In this application, the FSR is strategically placed over the carotid or radial arteries. The variation in volume of blood flowing through arteries, due to systolic and diastolic flow, regularly varies the force exerted on the FSR, which results in generation of proportionate bio-signal. The bio-signal so generated is then acquired and processed to ascertain values of essential biological parameters. The recorded values of these parameters, can be used for the purpose of diagnosis of CVD.

In their work, a circularly shaped force sensing resistor, having diameter of 18.28 mm (FSR 402) was used as shown in Fig 4.

Fig 4. Force Sensor FSR-402 placed over the radial artery

Existing methods of diagnosis of CVD, use either invasive catheterization or mechanical tonometers, which are expensive. Use of the FSR greatly simplifies measurement of the arterial wave pulse and its parameters. Also, the FSR is a low-cost and non-invasive option. The simplicity and cost effectiveness of the FSR based diagnostic method, is particularly suitable for use in medical device in rural-areas. The authors have assessed that the accuracy of the FSR based diagnostic method is very high by comparing their method with the well know technique of Photoplethysmopgraphy. An error of less than 3% was observed by the authors while evaluating the parameters using FSR-based measurement, which is highly accurate.

B. Diagnosis of Sleep Related Breathing Disorders

The work reported Sundar-Das[2] and Abdulkader, et al. [4] have shown that the FSR can also be used for real time monitoring of sleep related breathing disorders, central and obstructive sleep apnea. central sleep apnea (CSA) occurs when the brain fails to send appropriate signals to the breathing muscles to initiate respiration whereas is Obstructive Sleep Apnea (OSA) is caused by presence of certain obstruction in the upper airway. During CSA, Respiratory movements are either absent or attenuated in proportion to the decrease in respiratory drive [5]. Sleep Apnea, is a serious and potentially life-threatening condition and has shown to be associated with increased risk of high blood pressure and diabetes [6], [7]. Sleep Apnea is also a leading cause of SIDS or Sudden Infant Death Syndrome.

In these methods, the FSR 406, a rectangular sensor with 38 mm sensing area is used to sense the bio signal. The in-out motion of the thoracic cavity region causes a variable force to be exerted on the FSR. The placement of the FSR is as shown in Fig 5.

Fig 5. Force Sensor FSR-406 strapped to the thoracic cavity region

These movements are used to generate a breathing motion signal which is used for diagnosis of Sleep Apnea. A similar Bio-signal acquisition procedure was followed, and diagnosis was performed using feature extraction and machine learning algorithms.

The gold standard for assessment and diagnosis of Sleep Apnea is Polysomnography [23]. This method involves a simultaneous recording of EEG, ECG, Chin and leg movement Electromyogram signals and monitoring of blood oxygen levels. This procedure, although provides a detailed analysis of apnea events which can be used for precise treatments, is not only intrusive and very expensive, but diagnosis can only be performed offline, once the signals are recorded overnight

Using the method proposed in [2], the FSR can be used to build a fast and accurate real time sleep apnea diagnosis system. The only disadvantage of using the FSR as a movement sensor here is that it is prone to artifacts such as movement of the test subject. Due to this, a separate step for identification and removal of artifact signals is required in this algorithm .Using the method proposed by Aditya-Chinmay [2], a screening accuracy of up to 95% can be achieved. The system proposed in this work could be used to provide fast real time diagnosis and help reduce infant mortality due to SIDS.

C. Diagnosis of Neurodegenerative Diseases and Capral Tunnel Syndrome

Work performed by Popovic, et al. [8] and Paul, et al.[9] show that the FSR can be used for early detection of motor neuron disorders such as Parkinson's disease and Amyotrophic lateral sclerosis (ALS) Syndrome. Hand tremors associated with such disorders can be measured using FSRs and diagnosis is performed based on extent of observed tremors. An arrangement as shown in Fig. 6 is used.

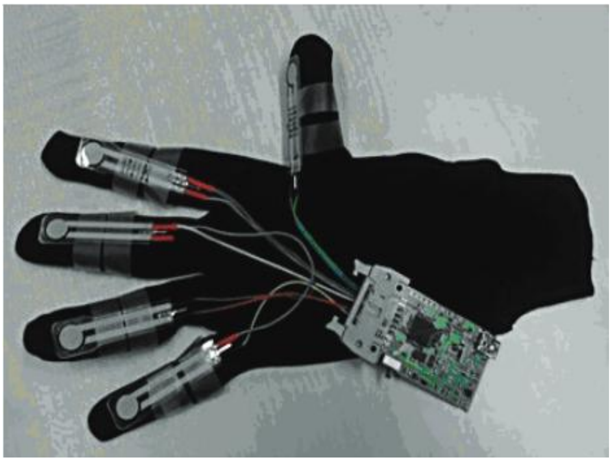

Fig 6. A Sensoried glove used to asses hand tremors

Work proposed by Paul, et al.[9] and similar work by Benoit, et al. [14] use a glove is strapped with FSRs .These signals are fed to a device which wirelessly transmits signals which are used for performing diagnosis. Work in Popovic, et al.[[8] shows that the FSR can be used to estimate gait (limb-movements) and use the same for diagnosis of Parkinson's disease. These signals are later processed to asses and perform diagnosis. Several previous works have shown that pressure exerted by the hand can be quantified easily using FSRs [10].

Using methods similar to those previously discussed, the FSR can also be used to diagnose carpel-tunnel syndrome as presented by Carlos, et al. [11]. In Carpal tunnel syndrome the median nerve is compressed as it travels through the wrist at the carpal tunnel , which causes pain, numbness and tingling, in parts of the hand that receive sensation from the median nerve [12]. Currently, no clear devices exist for diagnosis of the three aforementioned medical disorders. The FSR here thus provides a simple, low-cost solution for building a diagnostic device.

D. Application of FSR in Foot Neuropathy , Scoliosis and Bite Force Measurement

Peripheral neuropathy results in damage to peripheral nerves and often causes weakness, numbness and pain, usually in palms and feet. Foot Neuropathy is a serious medical disorder and can be prevented by the early detection of abnormal pressure patterns under the foot [13]. Work presented by J.Crispino et. al in [13] and Rana N.K.[15] presents a low-cost foot-pressure and movement analysis system, embedded within smart footwear so that subjects can monitor blood flow and foot pressure patterns and detect Foot neuropathy early-on . This device is shown in Fig. 7. The device Trigno 4-Channel Footswitch Sensor by DELSYS also uses an array of force sensing resistors to gather information about foot and heel pressures.

Fig 7. Trigno, 4 Channel Footswitch Sensor by DELSYS

The FSR has also proven to be useful in treatment of Scoliosis. Scoliosis is a medical condition in which a person's spinal has a three-dimensional deviation. This results in pain and discomfort . Authors Thongudomporn et al. [16], have designed a corset to suit the needs of subjects with Scoliosis . The FSR is used to identify the pressure that different points on the subject's back exert over the corset. The arrangement used in the work is shown in Fig 8.

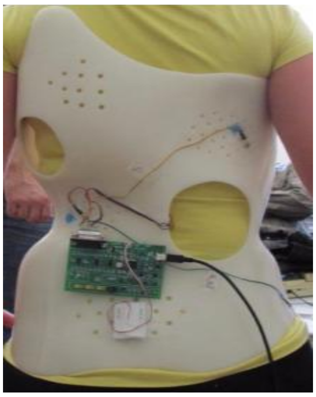

Fig 8. Corset with embedded FSRs for estimating Scoliosis

The FSR has also found applications in measuring Bite-force of the teeth. The parameter Maximum Bite Force (MBF) has been used in measuring strength of human posterior teeth. Work proposed in Thongudomporn et. al [17], Bárbara et. al [19] aims to measure the same using the FSR. The subject is required to place the sensor-jacket in mouth. When the subject bites the sensor-jacket, the force applied on the FSR is measured and digitally recorded using the system proposed in the work [19]. The authors have pointed out that material properties of FSR such as its flexibility, thinness, light-weight, robustness, resistant to temperature, chemicals and moisture, make the FSR a better suited material for this application. However, an inherent problem with using the FSR in this application is that it is prone to hysteresis and provides non-linear relationships between force applied and measured voltage. In successive measurements, the FSR was found to provide 93% reliable results in the later test[18]. An error of up to maximum 8% was found while performing measurements using the FSR. Despite few de-merits, the FSR is a well suited sensor for this application.

E. Applications in Surgery and Tissue Elasticity measurement

The FSR is also a very useful tool in surgery [20] as it provides vital force feedback. This force feedback would help surgeons decide the right amount of force to be placed during Minimal Invasive Surgeries (MIS). Work in [21] employs a custom designed FSR at the grasper tip to quantify the grasper tip force in the study. The study was performed to compare the force exerted by the FSR during finger-grasping and palm-grasping. These studies help surgeons in further understanding and performing Laparoscopic MIS Surgeries. Methods of measuring tissue elasticity using a Force Sensing Resistor have also been proposed in [22]. A novel device termed Elastisorb, is presented by Hamid et. al [22] and it's design, fabrication and use are presented. This device can be used to measure the modulus of elasticity of biological tissues. The combination of an FSR, microcontroller and stepper motor used in Elastirob, provides the ability to apply varying strain on testing specimens. The proposed system could be miniaturized to be used in MIS in the future.

IV. CONCLUSION

A survey of the role of Force Sensing Resistor in Medical Diagnostic, Monitoring and Therapeutic devices is performed. A summary of the observations is presented in Table 1.

Table 1: Merits and de-merits of Force Sensitive Resistors (FSR), in different healthcare applications.

SNo.	Application of FSR	Method	Merits of FSR	Demerits of FSR
1	Diagnosis of CVD	[1]	Low cost	Decreased accuracy
2	Diagnosis of OSA/ CSA	[2][4]	Low Cost, High accuracy, Flexible	Prone to movement artifacts
3	Early detection of Neurodegenerative disease and Carpel Tunnel Syndrome	[8] [9][14]	Low weight, Small area	None
4	Foot neuropathy and Scoliosis	[13][15][16]	Flexible	None
5	Estimating Maximum Bite Force	[17][18][19]	Small area, Resistant to chemicals, temperature and moisture	Hysteresis and Non-linearity
6	MIS surgery	[20][21]	Small area, high sensitivity	None
7	Measurement of Tissue elasticity	[22]	Small area, low cost, flexibility	None

It is argued that FSR based systems have great potential to emerge as option for developing modern diagnostic systems, for use by patients as well as medical practitioners. The robust yet flexible nature of the FSR makes it suitable for several medical applications. The use of FSR however leads to compromise in accuracy as it is prone to hysteresis and non-linearity. However, many merits such as requirement of ultra-thin, low weight and less area, high tolerance to chemicals, moisture and temperature, in such applications, makes the FSR a highly suitable for component for building portable medical devices. The devices using FSR will be particularly appropriate for its use among rural population, and have tremendous potential for cost-effective solutions in healthcare.

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