Wearable Sensors for Unobtrusive Monitoring of Joint Kinematics

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***Abstract*—We introduce a new class of wearable joint sensors that can be unobtrusively embroidered into a garment in order to effectively monitor the joint kinematics of a patient. Contrary to conventional joint monitoring techniques, the wearable sensors show potential for high-accuracy, lightweight, flexible, robust, and low-cost sensing of joint kinematics. Additionally, due to the unobtrusive nature of the technology, the wearable sensors can be worn for longer periods of time than the conventional technology—leading to an increased set of data for medical practitioners to better track the recovery of patients. The wearable sensor is composed of a transmitter (transmitting at the ISM band of 433 MHz) and receiver coil embroidered into either end of a joint sleeve. The variances in the magnetic flux captured at the receiver can be utilized in order to accurately determine the angle of joint flexion.**

***Index Terms*—wearable sensors, medical sensing, and biomedical telemetry**

I. INTRODUCTION

Monitoring elbow joint kinematics after a medical procedure (tennis elbow, broken elbow surgery, etc.) is critical for maximizing/accelerating rehabilitation, and preventing future injuries. The most common technologies used to date for monitoring elbow joint kinematics include 3D/2D motion capturing cameras [1] and goniometers. Unfortunately, these technologies are not portable, implying that they cannot capture elbow kinematics in the individual's daily environment. Wearable joint monitoring sensors have recently been proposed [2], however they raise concerns as to their obtrusiveness and maximum number of flexions they can withstand. Therefore, there is a large discrepancy between the capabilities of current technologies versus the capabilities required in order to efficiently and effectively monitor elbow joint kinematics in real-time and while the patient is performing daily tasks (e.g., exercising, running, or simply walking or sitting). The project seeks to bridge this gap and develop a high-accuracy, lightweight, flexible, robust, and low-cost wearable joint sensor that is unobtrusively embroidered into a shirt (see Fig. 1).

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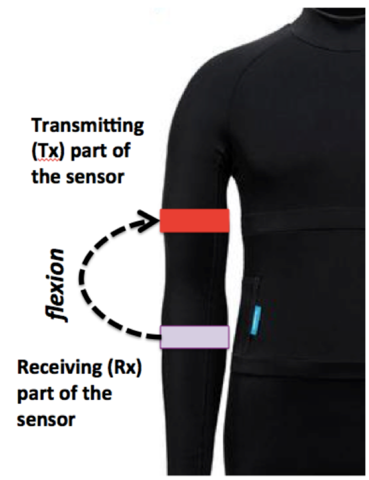

Fig. 1. Proposed concept of placing a RF transmitter and receiver on opposite ends of a wearable joint sleeve.

II. DESIGN

The proposed wearable joint monitoring sensor operates on the principle of magnetic flux, and the system is made up of two coils as shown in Fig. 1. When the receiving and transmitting coils are perfectly parallel (no bending of the joint) and an RF signal is fed through the transmitter, then the magnetic flux captured at the receiver is at a maximum. In contrast, any bending of the joint will reduce the magnetic flux captured at the receiver, reducing the voltage at the receiving coil; this decrease can be experimentally measured in order to determine the joint flexion. The designed wearable joint monitoring sensor can be decomposed into three components in order to better analyze the findings: a sensing interface, a wireless interface, and a power interface.

A. Sensing Interface

The sensing interface consisted of two coils serving as a transmitter and receiver located at either end of the wearable sleeve. A low-power RF signal is fed into the transmitter that generates a magnetic field, and the flux captured at the receiver generates a voltage on the receiver coil. The ISM band of 433 MHz was selected in order to avoid EM interference with other wireless transmissions and to ensure good coupling between the coils as attributed to its inherent long wavelength.

The designed sensing interface was simulated with Finite Element analysis performed in ANSYS HFSS with the transmitter and receiver coil separated by a distance of 5.5 cm. The limb was simulated by a cylinder with electrical properties similar to human muscle tissue. Simulations carried out at the 433 MHz ISM frequency showed accurate detection of joint flexion angles between 0 and 50 degrees. Next, an experimental prototype was devised as shown in Fig. 2. Notably, there is still refinement and work being done on the experimental prototype in order to better match the simulation results.

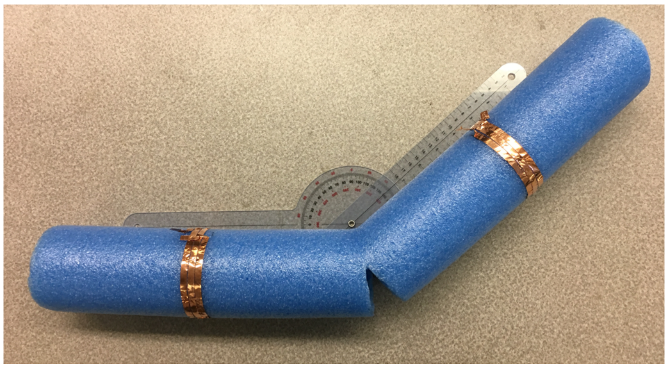

Fig. 2. Experimental setup placing the transmitting and receiving coils at either end of a pool noodle (simulating the flexible joint).

B. Wireless Interface

The BITalino [3] sensor platform was used in order to enable wireless connectivity with the wearable joint monitoring sensor. The platform included a portable, light-weight Bluetooth interface that was used to wirelessly transmit the voltage readings captured at the receiver coil to a laptop or smartphone. Further integration is still being conducted to fully incorporate the BITalino Bluetooth IC into the experimental setup of the sensing interface.

C. Power Interface

A critical design requirement of the wearable joint monitoring sensor was flexibility and unobtrusive integration to a fabric sleeve. Conventional batteries are composed of bulky, rigid components; therefore, electrochemical fabrics were designed in order to serve as the power supply of the wearable sensor [4]. The designed electrochemical fabrics consisted of solid silver and zinc metals deposited onto a flexible, adhered onto the fabric with a polyvinylidene fluoride (PVDF) binding solution. Once the electrochemical fabric was placed in a conducting fluid (sweat, saline solution, etc.), the free ions in the conducting fluid induced a charge across the metal deposits on the fabric. Furthermore, conducting E-threads were used to wire several metal deposits together: providing scalable voltage from a flexible power supply that could be used to power the wearable joint monitoring sensor. Currently, research is still being conducted to fully integrate the designed electrochemical fabric batteries with the wearable sensor.

III. Conclusion

A wearable joint monitoring sensor was successfully simulated using Finite Element analysis techniques. There is continued work being done in order to further refine an experimental prototype of the wearable sensor. Specifically, research is being done to develop accurate and efficient post-processing models in order to increase the precision of the detected flexion angles. Additionally, the need for a flexible, unobtrusive power supply led to the invention of a fully flexible electrochemical fabric. The electrochemical fabrics are capable of producing scalable DC power, enough to unobtrusively power the wearable sensor. Overall, the research has pioneered an effort into creating unobtrusive wearable sensors for medical sensing applications.

Impact of the MTT-S Pre-Graduate Award:

It has been an honor to be a recipient of this prestigious research award offered through the IEEE MTT-S community. The award has solidified a sense of accomplishment and achievement in my undergraduate research career, and, overall, the recognition has been a driving force in my continuing research. Additionally, attending IMS 2017 in Honolulu was truly a once-in-a-lifetime opportunity. I got the opportunity to collaborate and interact with all the leading researchers in the field of microwave electronics—not only listening to their talks, but also having discussions about my research with them. As my future career plan, I intend to pursue a PhD in the field of electrical engineering.

IV. References

[1] D. Gonzalez-Ortega et al., “A Kinetic-based system for cognitive rehabilitation exercises monitoring,” Comp Meth Program Biomed, 113(2): 620-631, 2015.

[2] B. Bonroy et al., “Ambulatory monitoring of physical activity based on knee flexion/extension measured by inductive sensor technology,” Hindawi ISRN Biomed Eng., 2013.

[3] https://www.bitalino.com/en/

[4] R. Vilkhu, C. O’Connor, W. Thio, P. Das Ghatak, A. Co, A. Kiourti, “Scalable Power Generation for Wearable Electronics Using Fabric Electrochemistry,” 2018 USNC-URSI National Radio Science Meeting, Boulder CO, Jan. 4 – Jan. 7, 2018.