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Miniaturized Wireless Wearable Force Measurement System for Sports Science and Beyound

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A wearable sensing module that was extensively miniaturized from the existing one was proposed, designed, fabricated, and verified in this work. The signal response was based on the capacitance change generated by the force acting on a corresponding capacitive pressure sensing element. Wireless communication was achieved through Bluetooth from practical viewpoint, along with the development of a user interface and database. Results indicate that the measurement tolerance was below 1% and the module was reduced by 85% in volume when compared with its previous counterpart.

Keywords: Database, force sensor, system miniaturization, wearable device,

Introduction

In the contemporary era of technological advancements, various types of sensors are being developed for monitoring various physical quantities, contributing to the widespread adoption of the Internet of Things

Among various system integration scenarios, one approach involves the miniaturization or scaling of sensor components compactly. An existing system composed of sensor components and wearable devices showed limited support on functionality and user experience (such as non-ergonomic feeling, bulky volume, heavy weight, and complex wiring) [1].

Our previous work [2] demonstrated that the capacitance measurement had to be done through a commercialized printed circuit board (PCB). When paired with another Bluetooth module, the transmission port was capable of data collection and processing.

Nevertheless, the size of the transmission port that includes the evaluation PCB, Bluetooth module, and battery was showed the aforementioned drawbacks. Consequently, we report an extensively miniaturized module that enhances the feasibility of practical applications by optimizing electronic components and their routings, particularly for wearable and sports science applications.

Design and Realization

To realize force sensing, a control unit was designed (Fig. 1). The signal processor captured the capacitive responses through the sensor in milliseconds, converted them into digital signals, and repassed them to the microprocessor. Subsequently, the microprocessor was able to transmit the digitized signals to the host computer by the Bluetooth low energy technique. After comparing with the database, the corresponding force values were calculated and exhibited to the user, completing the force sensing measurement.

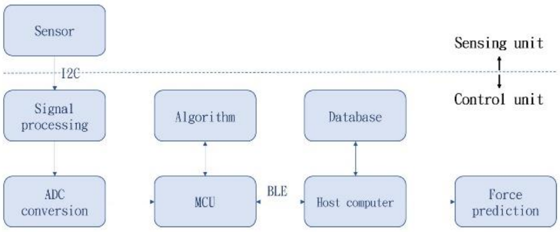

Fig. 1. System integration block diagram of the control and sensing unit

The control unit was integrated on a PCB. To connect the capacitive pressure sensing sensor, an edge connector with gold fingers was utilized, ensuring stable contact between the connector and interface. The overall circuit board size was measured 26.7 mm x 46.5 mm in the xy-plane (Fig. 2). Additionally, a lithium-ion polymer battery of similar same size (capacity of 1500 mAh) was stacked underneath in a watch fashion (Fig. 3(a)). The entire circuit board was further mounted in a 44 mm x 39 mm x 17 mm housing with an overall weight of 48 grams (Fig. 3(b)) and detachable wristband (Fig. 3(c)).

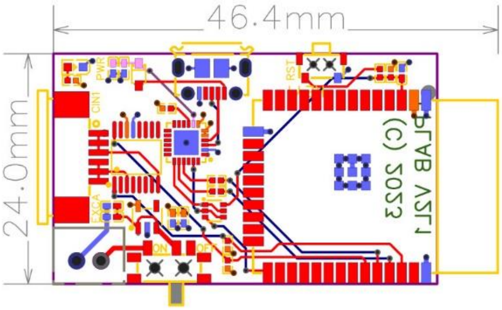

Fig. 2. Capacitance of Ceramic capacitors vs measured capacitance.

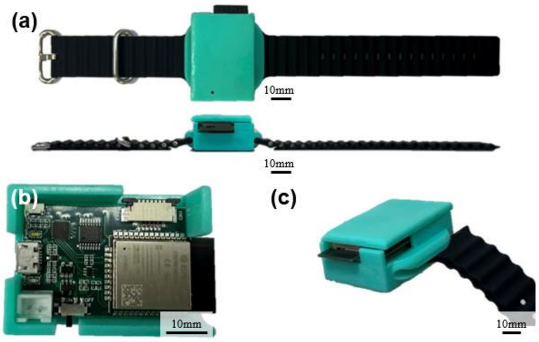

Fig. 3. The proof-of-concept of the (a) transmission port in whole, (b) enlarged housing and circuits, and (c) detachable wristband design. Scales are all 10 mm.

Figure 4 shows the accuracy verification of the proof-of-concept, in which capacitance measurement was conducted through commercialized standard ceramic capacitors (Fig. 4). The module exhibited a response delay of approximately 100 ms, and the measurement error was less than 0.3%.

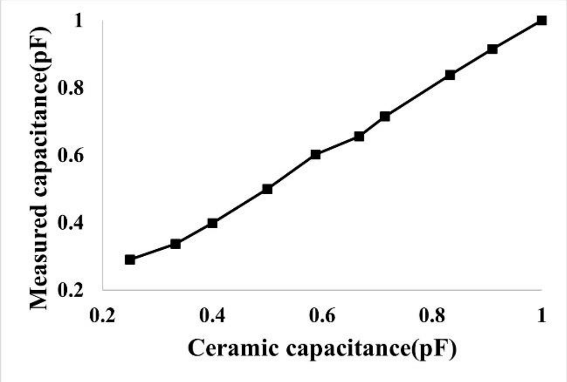

Fig. 4. Verification of capacitive responses between the commercialized capacitor and measured capacitance.

Results

Figure 5 shows the relationship between force and capacitance. The relative capacitance values of the pressure sensing element show a positive correlation, with followed the expectation and complied with the findings in literature [3]. The highest sensitivity occurred in the force range of 0 N to 1 N, which satisfied the required dynamic window of badminton posture monitoring [2]. The linear coefficient of determination reached 0.9975, indicating the accuracy of the existing sensor and the realized miniaturized transmission port.

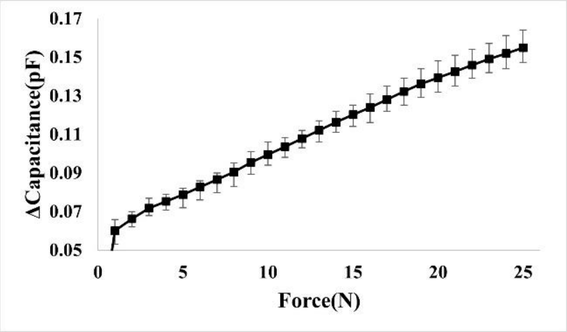

Fig. 5. Capacitance changes in actual application.

Figure 6 shows the results of a blind test of the control unit by installing the sensing unit on the industrial gripper (robot). the detection tolerance between the predicted and the actual force was less than 1%.

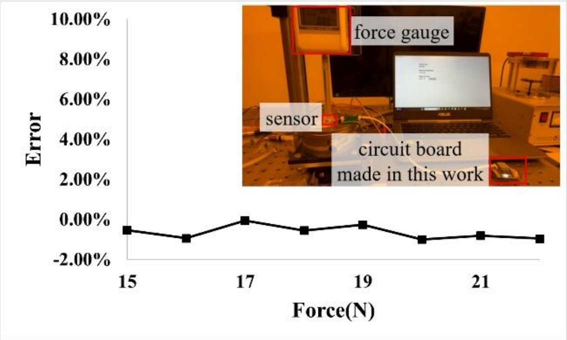

Fig. 6. The blind test results of the force measurement system with existing sensor and the proposed transmission port.

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