Article

An Antenna Sensor to Identify Finger Postures

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Abstract: An antenna sensor is proposed to execute dual functions of antenna and sensor in the wireless sensor system, in order to reduce data loss and to increase transmission rate by omitting a certain interface. The as-made sensor was test at a center frequency of 46 MHz for measuring human finger postures using principle of dipole antenna. The antenna sensor was attached on a wearable glove. The results showed that the motion sensor can accurately identify finger angles at 0°, 20°, 40°, 60° and 80°.

Keywords: antenna sensor, radio frequency, dipole antenna

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1. Introduction

Wireless sensors are widely adopted in medical, manufacturing, structural monitoring and military applications [1-3]. At present, technological advancements in the field of flexible electronics and wireless communication have promoted a new direction in the healthcare check devices by using non-invasive methods for continuous monitoring of common physiological parameters such as breath detection, blood pressure, body temperature, sports detection and electrical diagram [4-7]. Wearable devices and Internet of Things (IoT) based on these technological advances support in the healthcare model towards personal central management of health, also known as mobile health, that relies a lot on the development of sensors and communications.

As the IoT extends end service to individual person, the application of flexible antennas is fast broadening. The Bluetooth [8], Zig-Bee [9], and wireless local network [10] are popular schemes for current wireless sensor network (WSN). The communications protocols exist in between layers of interface for such WSN to carry the measured data all the way from sensors to microprocessors. Issues such as data loss and constraints in transmission rates are, therefore, inevitably caused by such protocols and analogy-to-digital conversion (ADC) [11]. The inconvenience of data loss and constrained transmission rate can be improved if the number of interfaces could be reduced by using antenna sensors in WSN. The antenna sensor is basically a functional antenna as well as a sensor. With both capabilities of the antenna and the sensor in a monolithic unit, the antenna sensor may work with less interface [12]. To reduce or compensate the influence of variations in geometry on the communication performance of antenna, it is found in related studies that working frequencies will be shifted due to the fluctuated impedance of changing antenna geometry [13-16].

In this study, a low-cost finger motion sensor base on dipole antenna is proposed. Attached on the Proximal Interphalangeal Joint (PIP) of forefinger to detect the angle between the two poles of the dipole antenna. The deformation of the dipole antenna changes the spatial relation between two poles. Such spatial variation induces identifiable magnetic field. The dipole antenna was bent along principal planes YZ, as shown in Figure 1, and reflection coefficient (S_{11}) was measured for comparison purposes.

2. Design of Antenna Sensor for Fingers

2.1. Antenna Sensor Design

The designed antenna sensor was fabricated and test at a radio frequency of 426 MHz for selecting orientation of receiver antenna. A dipole antenna is considered more practical for finger. We can use $L_0 = \lambda/2$, given in [17] to estimate the resonant frequency. L_0 is total length of dipole antenna. The antenna sensor was acted as the wireless finger motion protractor. Being applied to the common size of a human finger, the dipole antenna was fabricated on cellulose filter paper (dielectric constant, $\varepsilon r \sim 4.5$, thickness, h = 0.3 mm and tangent loss, $\delta \sim 0.02$) [18] with a substrate size of 100 mm x 20 mm. In order to achieve miniaturization, the dipole antenna is designed with a geometry of the serpentine structure by cooper strip (h_1 = 0.1 mm, W = 20 mm, L = 7.85 mm, W_1 = 1 mm, L_1 = 46 mm, W_2 = 1 mm, L_2 = 1 mm). The geometrical view of the proposed antenna is shown in Figure 1 and Figure 2.

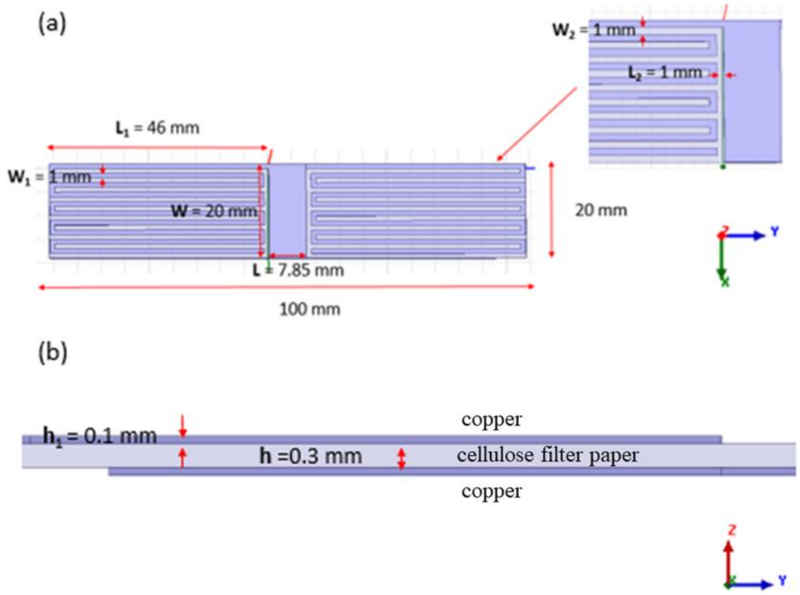


Figure 1. (a)(b) Schematic view of the designed dipole antenna where h_1 = 0.1 mm, W = 20 mm, L = 7.85 mm, W_1 = 1 mm, L_1 = 46 mm, W_2 = 1 mm, L_2 = 1 mm.

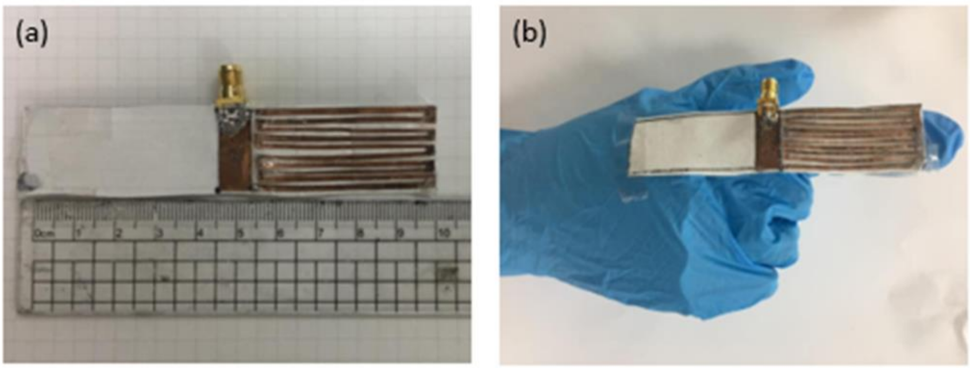


Figure 2. (a) the proposed antenna and (b) the antenna on the hand model.

2.2. Testing of Finger Joints

The finger motions are usually expressed by three joints, the metacarpal (MCP), PIP and distal interphalangeal (DIP) as shown in Figure 3. The PIP and DIP joints each have a single DOF (Degree of Freedom), and the MCP joint is typically modeled as a general joint with two DOFs. The DIP bending is dependent upon PIP bending. The index finger of a hand was chosen for measuring.

The center of the antenna sensor was above the center of the PIP to measure the degree of the bending PIP. However, bending fingers means stretched surface, and the displacement of bending PIP joint was measured as about 3-5 mm. The antenna sensor was fixed on a NBR (Nitrile Butadiene Rubber) glove to match the PIP displacement since the sensor geometry varies with the displacement of the bent PIP joint.

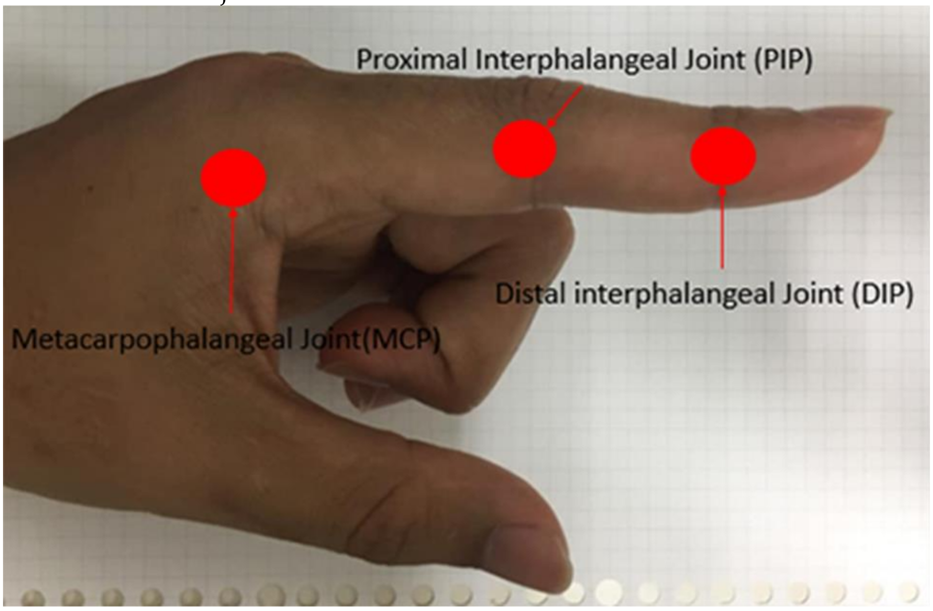


Figure 3. Schematic index finger joints

3. Results and Discussions

The dipole antenna can be regarded as a bending strain sensor. The reflection coefficients (S_{11}) and radiation patterns of the designed antenna sensor with different bending degrees were simulated using HFSS (Ansoft™) and the S_{11}'s were measured using a Network Analyzer (HP ™ 85046A). The shift in resonant frequency by the antenna deformation can be found in both simulated and measured results.

3.1. Setup for Measurement

The feed line and ground plane of the dipole antenna were fabricated on a cellulose filter paper and were soldered with an SMA connector for measurement using a Network Analyzer. The antenna sensor was put on a hand model to test for three bending degrees, 0° (flat), 45° and 90°, as shown in Figure 4.

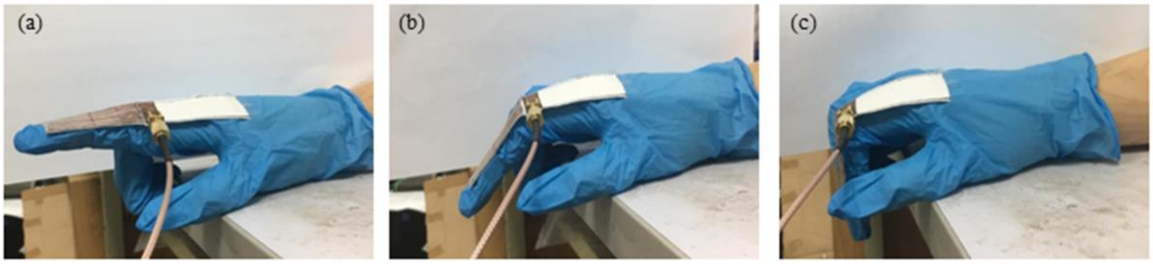


Figure 4. Photographs of the as-made antenna with different bending angle (a) 0° (b) 45° and (c) 90°.

3.1.1. *Measurement and Simulation*

The as-made antenna was bent into three different degrees for measuring the corresponding reflection coefficients, compared with the simulated results, as shown in Figure 5. The tendency of the shift in frequency responses of the dipole antenna are consistent for simulated or measured results and the resonant frequency decreases with the increased bending angle. It is worth noting that simulated and measured results have a certain deviation since the SMA connector and the cable are not included in the simulation. The normalized resonant frequency is defined as f/f_0 and the variation as $(f-f_0)/f_0$, where f is the resonant frequency in bending situation and f_0 is the resonant frequency in flat situation [19]. Figure 6 shows that the normalized resonant frequency would decrease when the bending angle of the antenna increases.

The variations in simulated radiation pattern in YZ-plane when the proposed antenna was bent in three angles, 0°, 45° and 90°, were shown in Figure 7. To receive distinguishable radiation levels, two theta ranges, 60-90° and 240-270°, were selected for the position of the receiver coil. Otherwise, the orientations around 0° and 180° were not suitable for the receiver. Therefore, the receiver coil was placed in the preferable orientation with maximum variation in radiation which assists in effectively sensing bending angles of the finger.

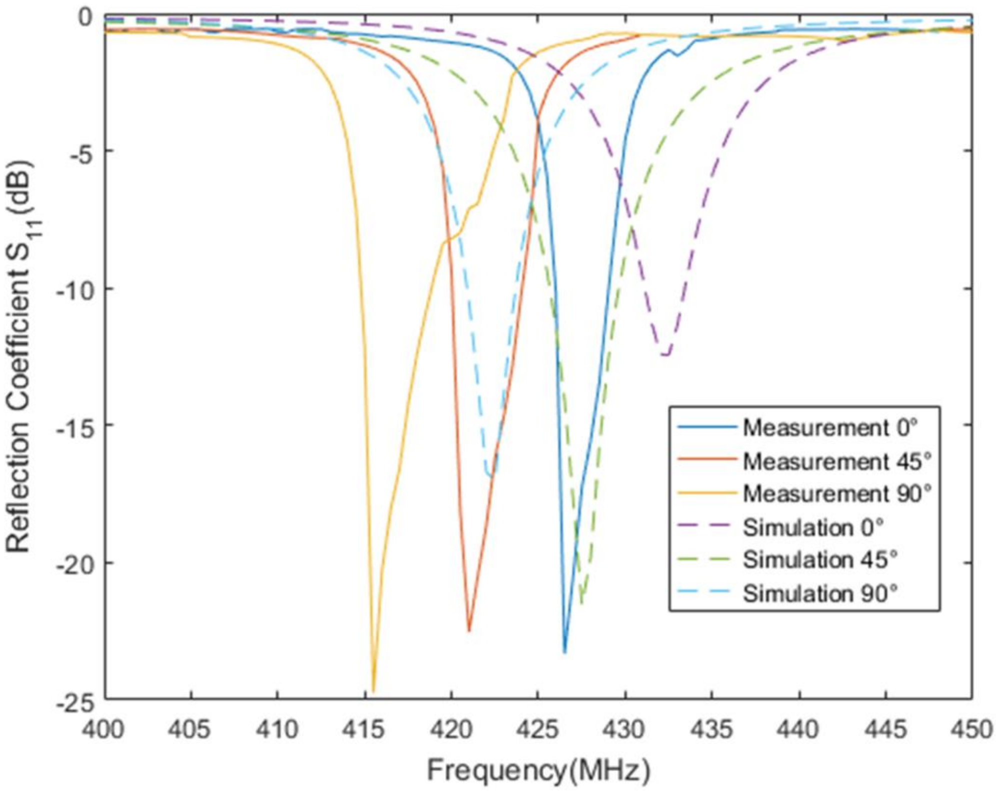
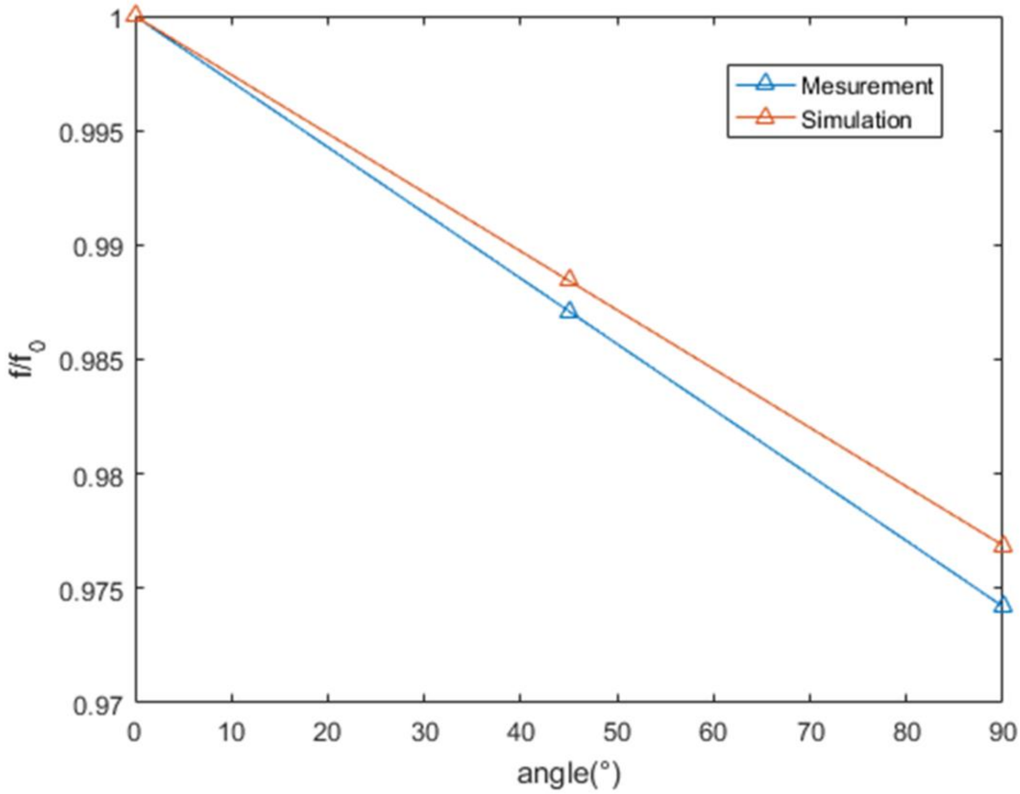
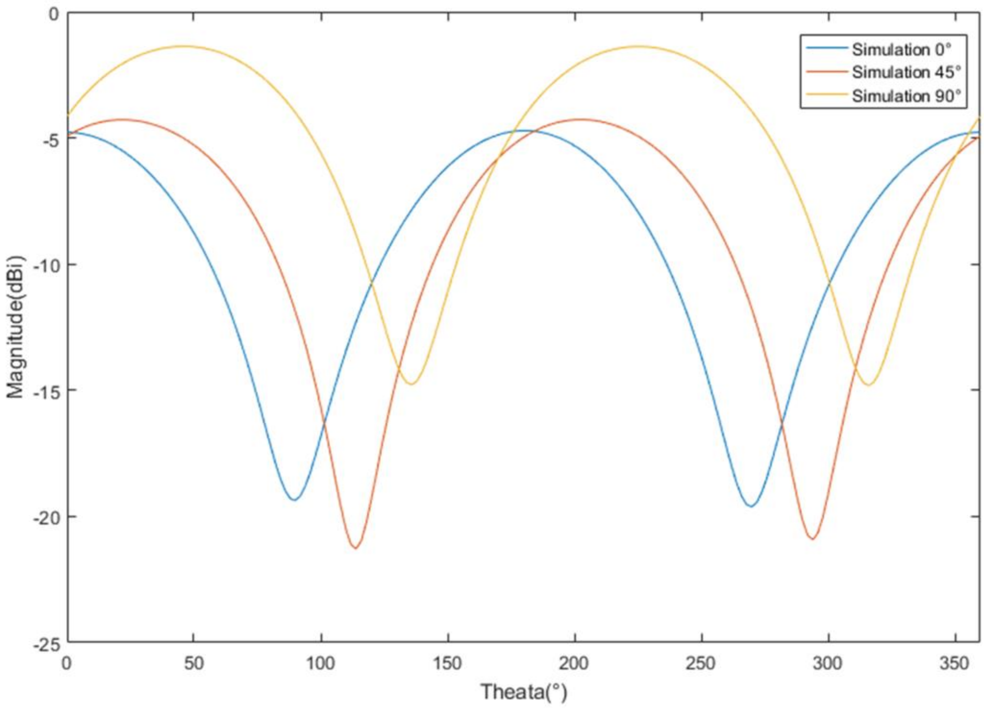


Figure 5. Measured and simulated reflection coefficients of the proposed antenna.



100 **Figure 6.** The measured and simulated normalized resonant frequencies of the antenna sensor.



101 **Figure 7.** Plot of the phi slice of the proposed antenna in rectangular coordinates at different angles in YZ-plane.

102 *3.2. Experiment of Motion Antenna Sensor*

103 The finger bent at angles of 0°, 20°, 40°, 60° and 80° and the responding signals received at the
104 receiver coil were then analyzed. The working frequency was picked at a center frequency of 46

MHz for practical purpose since the radiation pattern of the antenna, from Figure 7, can be applied to select the location of the receiver.

3.2.1. *Experimental Setup*

A loop coil, working at a radio frequency of 44 MHz and with a reflection coefficient of nearly -20 dB, was fabricated as a receiver antenna which had a coil diameter of 60 mm and was made of copper wire with the wire diameter of 1 mm. Three seriesly-connected capacitors were used for harmonic stability and voltage resistivity while matching the antenna impedance [20]. The measurement setup of antenna sensor is shown in Figure 8 and Figure 9. Rohde & Schwarz ™ SNE03 and Keysight ™ Infiniti Vision SSOX2014A Digital Storage Oscilloscope were used to generate sine wave signal, measure and record working frequencies. The signal generator sends component signals to RF and LO ports of the mixer with Analog Devices ™ Low Distortion Mixer AD 831. The mixer then output synthesized signal to the antenna sensor. The receiver coil connects LNA will reveal response from antenna sensor on the oscilloscope. For each angle, the emitting signal was sent to the bent antenna, and the responded signal received at the receiver coil was processed using the fast-Fourier-transform (FFT) algorithm into frequency-domain data to identify finger motion. The receiver coil was placed in the YZ-plane at the area corresponding to theta ranged 60-90°. The distance between the emitting antenna sensor and the receiver coil was fixed to be 0.5 m.

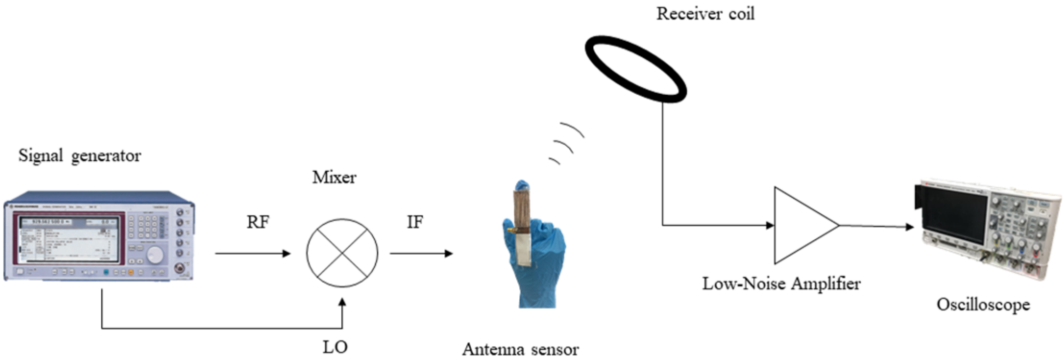


Figure 8. The measurement setup of the antenna sensor.

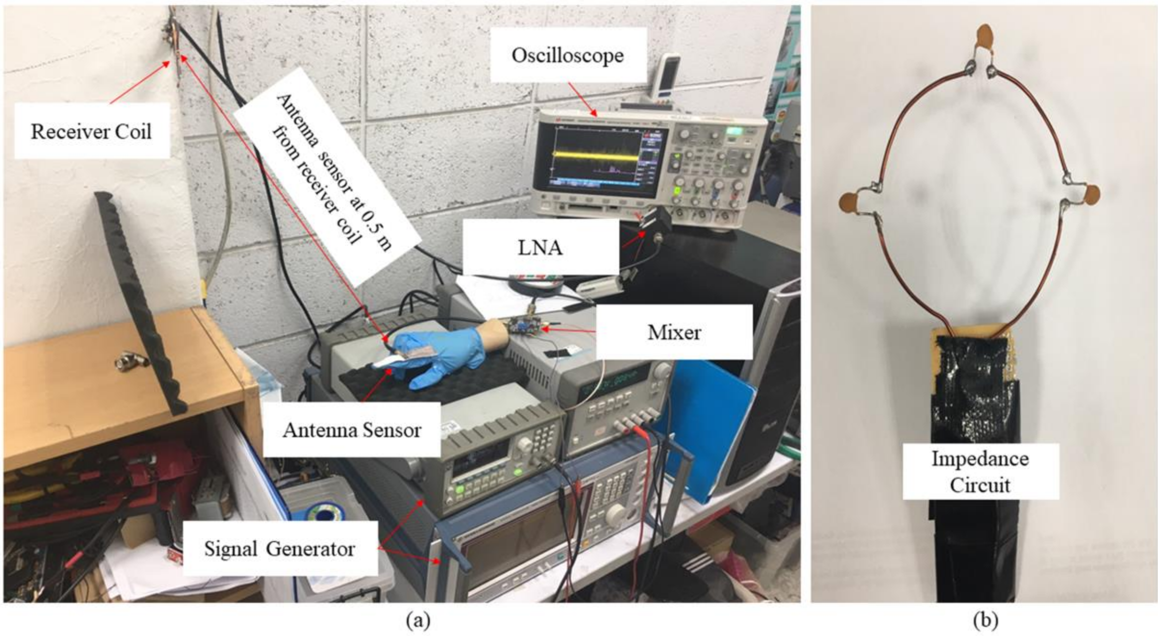


Figure 9. Experimental setup for sensing finger bending angles by antenna sensor. (a) Experimental setup (b) Receiver coil.

3.2.2. *Analysis of the Antenna Sensor*

The sine waves at 46 MHz and 2 MHz were adopted and input to the mixer which then output the compositional signal. There are two major peaks at 44 and 48 MHz, two secondary peaks at 40 and 52 MHz, and a minor peak at 2 MHz in the frequency-domain of the output signal from the mixer. The emitted electromagnetic waves from the antenna sensor were collected at the receiver coil and then transmitted to the oscilloscope for subsequent FFT transformation. As the receiver coil possesses good filtering performance, the peak at 2 MHz is depressed and there are eight obvious peaks at 40 MHz, 42 MHz, 44 MHz, 46 MHz, 48 MHz, 50 MHz, 52 MHz and 54 MHz in the frequency domain, as shown in Figure 10. The antenna sensor was bent at angels of 0°, 20°, 40°, 60° and 80°. The first eight higher peaks were acquired for establishing the characteristic matrix of the antenna sensor [20], as shown in Figure 11. Five test angles (0°, 20°, 40°, 60°, 80°) were set on the antenna sensor and the identified results are shown in Figure 12. The angle at the calculated minimum distance is identified as the bent angle of the antenna sensor. It is found that this method can be used to precisely identify the bent angle of the finger posture.

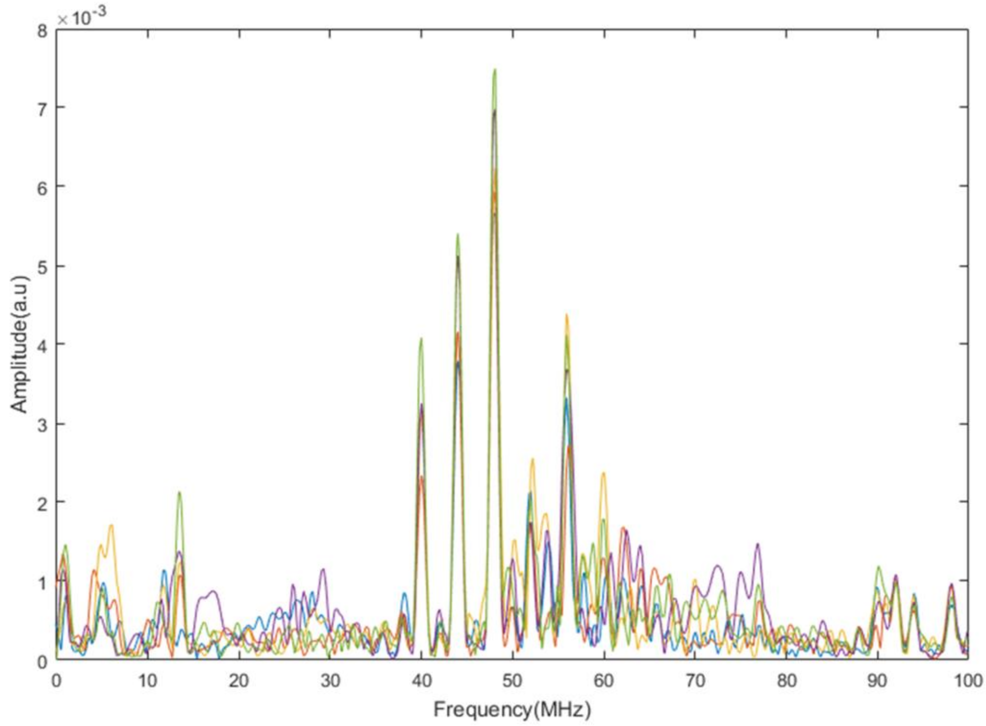


Figure 10. Strong peaks of received signal at seven characteristic frequencies when the sensor is bent at angles of 0°, 20°, 40°, 60°, and 80°.

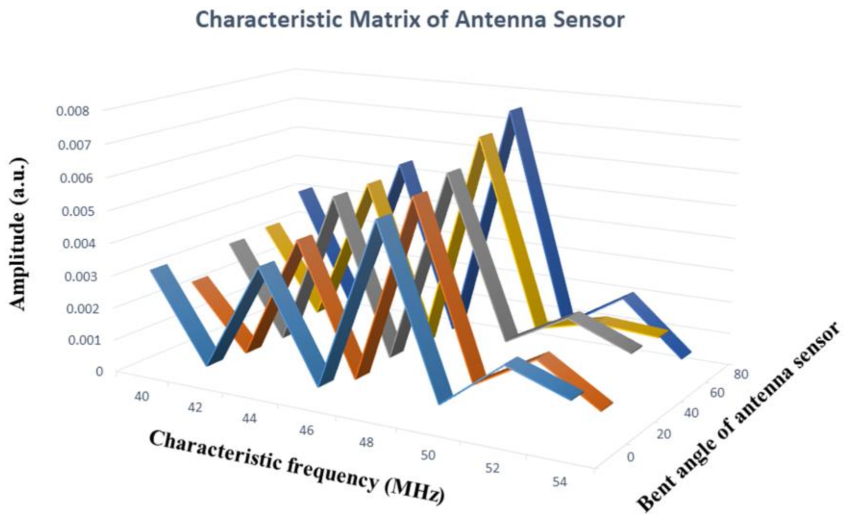


Figure 11. The characteristic matrix of the antenna sensor.

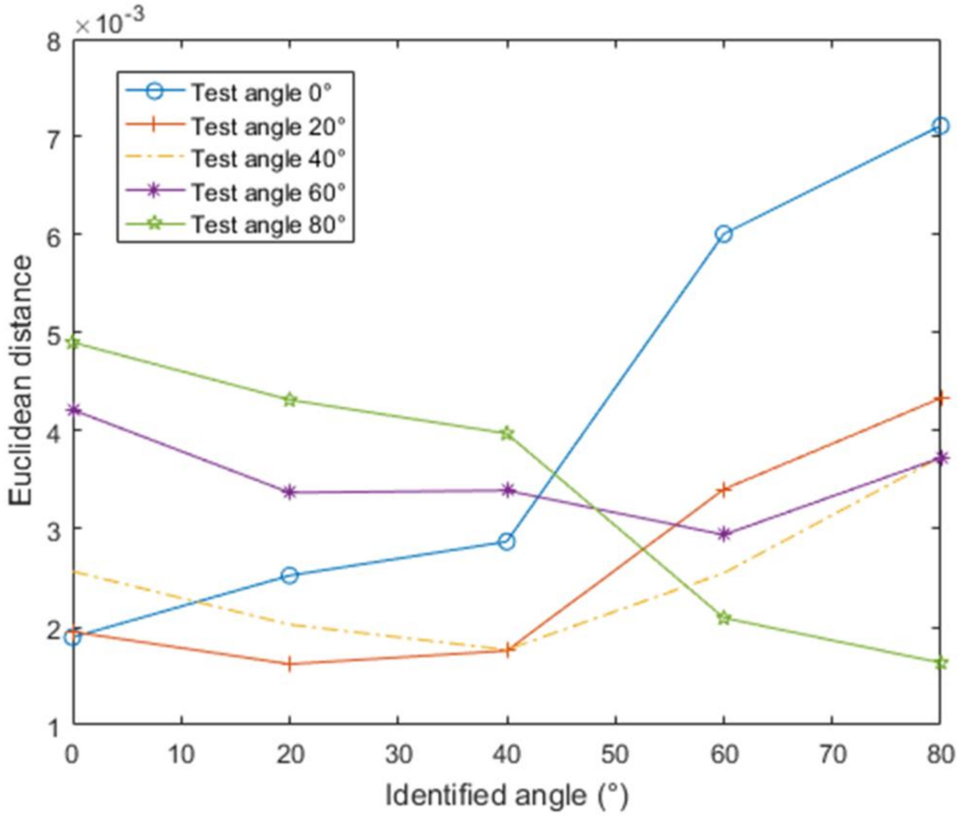


Figure 12. The calculated distances of the test angles. The angle at the minimum distance is identified as the bent angle of the antenna sensor.

4. Conclusions

In this paper, a finger motion sensor based on a dipole antenna with high mechanical flexibility and low cost was demonstrated. The antennas were used in this study to construct the antenna sensor which functions like a protractor. Moreover, this dipole antenna sensor is further attached to human hand model for simulating the actual wearable devices, and the test results show that the finger bending angles at 0°, 20°, 40°, 60° and 80° are identified. The antenna sensor technology could be applied in entertainment, human machine interfacing, virtual reality, robotics and health care.

Author Contributions: "conceptualization, Su; methodology, Su; software, Wu; validation, Su and Wu; formal analysis, Su; investigation, Su; resources, Su; data curation, Su; writing—original draft preparation, Su and Wu; writing—review and editing, Su; visualization, Wu; supervision, Su; project administration, Su; funding acquisition, Su", please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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