A Multi-Channel Data Acquisition System for Capacitive Sensing

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Abstract. Capacitive sensing can be applied to a variety of applications. A multi-channel data acquisition system for capacitive sensing was designed based on an FDC2214 with external L-C resonators. The FDC2214 was used for capacitance-to-digital converting by measuring the ratio of the resonator frequency to a reference frequency. Employing MSP430F5529 as host processor and the two-wire I²C serial bus interface connected with the FDC2214, the system implemented multi-channel data acquisition. As a test system, an 8-channel physical hardware device was provided. Experiments for gesture recognition had been done using the 8-channel capacitive sensing data acquisition system. The good experimental results verified the availability of the designed system.

1. Introduction

The capacitance describes the effects on the electric field due to the space between the two plates and it is determined by the geometry of the conductors, the distance between the electrodes and the dielectric material [1]. Capacitive proximity sensors use oscillating electric fields between an emitter and a ground electrode. The properties of an electric field change if a conductive object is brought into it. The human body, or bio mass in general, falls under this class, thus it is possible to unobtrusively detect a person or body parts of a person that approach such a sensing device [2]. Capacitive sensing is a low-power, low-cost, high-resolution contactless sensing technique that can be applied to a variety of applications [3,4,5]. The main challenge limiting sensitivity in capacitive sensing application is noise susceptibility of the sensors [6].

In this work, a sensing data acquisition system employing Texas Instruments (TI) chip FDC2214 was provided. In order to verify the effectiveness of capacitive sensing, the multi-channel acquisition system for gesture recognition is designed. The system employed a TI MSP430F5529 with two Universal Serial Communication Interfaces (USCIs) as the microprocessor. In I²C mode, a USCI module can provide an interface between MSP430F5529 and FDC2214 connected by the two-wire I²C serial bus, implementing capacitive sensing data acquisition.

2. System Structure

2.1 Capacitance-to-digital converting principle

The FDC2214 is a multi-channel chip for implementing capacitive sensing solution with good noise-resistant, EMI-resistant, high-resolution and high-speed performance. In contrast to traditional
switched-capacitance architectures, the FDC2214 employs an L-C resonator, also known as L-C tank, as a sensor. The narrow-band architecture allows unprecedented EMI immunity and greatly reduced noise floor when compared to other capacitive sensing solutions [7].

Capacitive-to-digital converting diagram of the FDC2214 is shown in figure 1. Each FDC2214 has 4 channels that can be used to capacitive-to-digital convert, namely, each FDC2214 can measure capacitance digital values of 4 sensors. The FDC is composed of front-end resonant circuit drivers, followed by a multiplexer that sequences through the active channels, connecting them to the core that measures and digitizes the sensor frequency ($f_{\text{SENSOR}}$).

![Figure 1. Capacitance-to-digital converting diagram for FDC2214.](image)

Each external L-C resonator is employed as a sensor. The core uses a reference frequency ($f_{\text{REF}}$) to measure the sensor frequency. The $f_{\text{REF}}$ is derived from either an internal oscillator, or an externally supplied clock. The digitized output for each channel is proportional to the ratio of $f_{\text{SENSOR}}/f_{\text{REF}}$. Using this approach, a change in capacitance of the L-C tank can be observed as a shift in the resonant frequency. Using this principle, the FDC2214 is a capacitance-to-digital converter that measures the oscillation frequency of an LC resonator. The device outputs a digital value that is proportional to frequency. This frequency measurement can be converted to an equivalent capacitance value.

2.2 Multi-channel capacitive sensing data acquisition system

Block diagram of the system is shown in figure 2. The system employed MSP430F5529 as the host processor and FDC2214 as capacitance-to-digital converters. A MSP430F5529 has two USCs, USCI-B0 and USCI-B1, which both support I²C mode. The host processor uses I²C interface to configure operating mode of the FDC2214s and receive digital data from the FDC2214s. If necessary, the digital data should be transmitted to the display for observation. A small keyboard can be used for function selection.

![Figure 2. Block diagram of the system.](image)

3. Implementation in Gesture Recognition System

3.1 Gesture recognition task

In order to test capacitive sensing effectiveness, the system was designed to implement two below functions:

1. Hand-gesture game decision by recognizing three gestures as shown in figure 3.
(2) Finger-guessing game decision by recognizing five gestures as shown in figure 4

Figure 3. From left to right: Gesture “stone”, Gesture “scissor”, Gesture “cloth”.

Figure 4. From left to right: Gesture “1”, Gesture “2”, Gesture “3”, Gesture “4”, Gesture “5”.

3.2 Capacitive sensors design

The FDC2214 supports two sensor configurations, the single-ended configuration and the differential configuration. Both configurations use an LC tank to set the frequency of oscillation. In the single-ended configuration, a conductive plate is connected INxA. The single-ended configuration allows higher sensing range than the differential configuration for a given total sensor plate area.

In the system, the single-ended configuration was adopted, as shown in figure 5. Together with a hand, the sensor plate forms a capacitor. When the hand gesture changes, the capacitance measurements should be variable for a given distance between the hand and the sensor plate. According the natural shape of the palm, 8 feature points are selected, which respectively corresponding to the 8 sensor plates, as shown in figure 6. The numbers “1”, “2”… “8” indicate positions of the 8 capacitor plates corresponding to the palm feature points. The 8 capacitor plates are fixed on the bottom panel and covered with an acrylic board. The hand with a gesture should be put on the acrylic board waiting for recognition test. “0” indicates the centre of the palm when having a test.

3.3 Hardware circuit design

Figure 7. Simplified schematic. The I^2C slave address for U1 is 0x2B and for U2 is 0x2A.
The I2C interface is used to support device configuration and to transmit the digitized measurement values to a host processor. The FDC2214 uses an extended start sequence with I2C for register access. This sequence follows the standard I2C 7-bit slave address followed by an 8-bit pointer register byte to set the register address. When the ADDR pin is set low, the FDC I2C slave address is 0x2A; when the ADDR pin is set high, the FDC I2C address is 0x2B. USCI-B0 module of MSP430F5529 is connected respectively with two FDC2214s by the two signal wires, SCL and SDA. The schematic is shown in figure 7. The physical prototype is shown in figure 8, in which the black cross indicates the centre position of a test palm.

3.4 Algorithm and Experimental results

The Nearest-Neighbor Rule \cite{8} was used for gesture recognition. Let \( D^n = \{x_1, \ldots, x_n\} \) denote a set of \( n \) labelled prototypes, and \( x' \in D^n \) be the prototype nearest to a test point \( x \). Then the nearest-neighbor rule for classifying \( x \) is to assign it the label associated with \( x' \). Because 8 sensors were used for data acquisition in the experimentation, the prototypes were denoted as 8 dimensional vectors representing 8 feature values of a gesture. It was required here that everyone would have gestured with his right hand. Taking the hand-gesture game of the system function as an example, the experimentation is described as follows.

1) Gesture recognition for the specified persons.

Training stage. Given three specified persons, the prototypes of different gestures for each person were collected in an order, labelled respectively and stored. Ten times data acquisition for each gesture of each person had been done. Thus 10 prototypes for each gesture of everyone was labelled and stored into the memory.

Testing stage. One test must be done with a randomly selected person from the three. For each gesture of the three, 100 tests were performed in the testing stage.

2) Gesture recognition for arbitrary other persons.

For one arbitrary other person, 3 prototypes of each gesture were acquired, labelled and stored into the memory. Then 10 tests were performed for each gesture of the arbitrary other one. In all 10 arbitrary other persons took part in the tests.

For finger-guessing game function of the system, the tests had similarly been done. All the experimental results are shown in table 1.

| Gestures | Stone | scissor | Cloth | 1   | 2   | 3   | 4   | 5   |
|----------|-------|---------|-------|-----|-----|-----|-----|-----|
| Test number | 100   | 100     | 100   | 100 | 100 | 100 | 100 | 100 |
| Rate-S    | 99    | 100     | 100   | 99  | 96  | 98  | 98  | 99  |
| Rate-A    | 100   | 99      | 100   | 95  | 96  | 98  | 100 |     |
| Overall rate | 99.5 | 99      | 100   | 99.5| 95.5| 97  | 98  | 99.5|

4. Conclusion and discussion

A multi-channel data acquisition design for capacitive sensing was proposed based on FDC2214 capacitance-to-digital converter. The multi-channel converted data were transmitted to host processor through the 2-wire I2C bus interface. A practical application system with 8 capacitive sensors was provided using for gesture recognition. The 8 capacitance-to-digital converted data were used as feature values composing 8-dimensional vectors of the gestures. The Nearest-Neighbor Rule was used for classifying gestures. The experimental results showed that the physical test system had good performance.

An interesting avenue of research to explore in the future work is to increase the number of channels and capacitive sensors in the practical application system, which will increase the feature.
number and improves system accuracy. On the other hand, improved classification techniques can be attempted to better the system performance too.

Acknowledgments
The work was supported by Applied Basic Research Program of Hebei Province, China (No. 16960314D), National Natural Science Foundation of China (Grant No.61473167, No. 61801165), Natural Science Foundation of Hebei Province, China (No.F2017207006, No. F2018207038), Research and Practice Project of Higher Education Teaching Reform in Hebei Province, China (No. 2017GJG091).

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