

A Two-dimensional Capacitive Human-detection System

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Abstract: A capacitive human-detection system for human-computer interfacing or for protecting critical infrastructures is presented. The detector is composed of several electrodes called transmitters or receiver. The electrode connected to the input side of the interface circuit is called receiver electrode; the electrodes that are connected to an excitation-voltage source are called transmitter electrodes.

The detector principle is based on the measurement of changes of capacitances between electrodes, which are affected by the location of a human-body. For the purpose of rapid evaluation of the features of the system, based on several simplifications and assumptions a draft model has been developed. Three-signal auto-calibration technique is applied to eliminate drift, gain and offset errors of the electronics. Furthermore, overall system calibration is applied to eliminate environmental effects.

Keywords: 2-D Capacitive Human Detection, Capacitive Sensors, human-computer interface

1. INTRODUCTION

In their environment, capacitive detector systems can easily be camouflaged, which could be very suited to protect critical infrastructures e.g. paintings in museums, or to warn people for not entering a dangerous machine area. Another interesting field of applications of for capacitive detector systems is that for human-computer interfacing, where, within a specific area, the presence and movement of a person is detected.

The present work presents a system for detecting both the presence of a person and his direction of movement. This detection system is simple, reliable, and easy to camouflage in a natural environment.

For a first evaluation of the features of this system, a simple model is used that lacks accuracy but is rather suited for a rapid understanding of the system features.

2. OVERVIEW OF THE CAPACITIVE SYSTEM

Capacitive sensor systems utilize capacitance changes to measure a physical quantity for which it is made for. A physical modifier (in our case the person to be detected) will change one or more capacitances in the system in a linear or non-linear way. A well-designed system will be selectively sensitive for the measurand modifier only (the person to be detected). For this reason, most of the capacitive sensors have shielding electrodes. Shielding electrodes insulate the sensing elements from others modifiers, e.g. electromagnetic interference. However, when the size of the electrodes is comparable or

smaller than the electrode distance, the robustness of the system is deteriorated and the analytic representation of the capacitances becomes rather complex.

2.1 Electronic interface

In the detector presented here, several capacitances have to be measured. These measurements are affected by parasitic capacitances in the connecting cables and the capacitance between the shielding electrodes and the sensing electrodes. In order to reduce these parasitic effects, the so-called “two-port technique” has been used [1].

Figure 1 shows a block diagram of the electronic-system setup. The capacitive detector electrodes are connected to a sensor interface [2], which is commercially available under the name Universal Transducer Interface –UTI- [3]. The electrodes connected to the input side of the interface circuit are called receiver electrodes; the electrodes that are connected to an excitation-voltage source are called transmitter electrodes.

The output of the UTI is connected to a PIC16F876 microcontroller that measures the oscillation period with $0.2 \mu\text{s}$ resolution. For five capacitors, the total measurement time is about 100 ms. The electrodes have been connected to line drivers (LT1030CN) in order to achieve ± 15 volts excitation signals. In the applied mode the UTI can measure a maximum capacitance of about 2 pF with a resolution of 14 bits. At the cost of a slightly decreasing resolution [2] the maximum parasitic capacitance to ground is allowed to be about 1 nF.

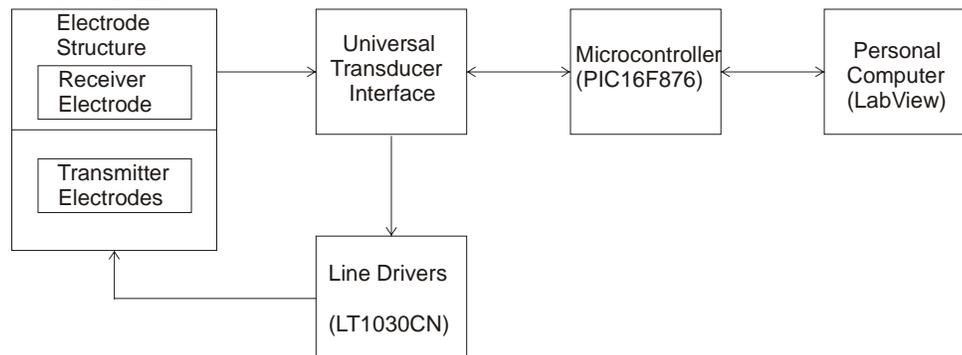


Fig. 1. Block diagram for the human detector.

2.2 Calibration procedure

For systems that cannot be shielded very well from the environment, calibration of the overall system is an important issue. A good calibration procedure can reduce the installation cost and reduce maintenance.

Two types of calibration have been implemented. The first one concerns the use of the three-signal auto-calibration technique in the transducer interface, which eliminates additive and multiplicative errors in the electronic circuitry [2]. The second type of calibration is applied to reduce errors caused by, for instance, lack of accuracy of the physical circumstances, and changes in the environmental conditions. Especially in open systems, this last calibration step is important, because such systems are more sensitive

to the electrical and physical environment. Moreover, the capacitance values can change from one installation place to another. At the level of this “physical” calibration the technique is performed in two steps:

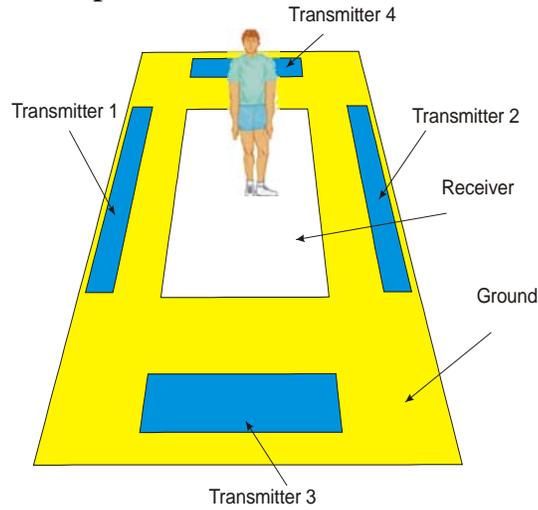


Fig. 2. Overview of the 2-dimensional human detector.

During the first step of this part of the calibration procedure, the maximum and minimum capacitance changes of the measurand capacitance C_m are computed. These values are used to calculate a threshold value for the detection of the presence of a person. At the same time, this procedure allows detection of changes in capacitances by changes in the environmental conditions. During the second step of this part of the calibration procedure, each capacitance is normalized by calculated proportional constants k_i , which eliminates the affects of (physical) offset and scale errors. Finally, the person positions are normalized in the range of ± 1 .

2.3 Unknown parameters and nonidealities of the electrode structure

There are many unknown parameters and non-idealities, which affect the measurement performance. The capacitances to be measured do not only depend on the person’s position. They are also strongly dependant on the person’s size and the person’s shape. In this paper, a person will be considered as being an ideal conductor, with a certain position, size and shape, which modify the capacitances.

The series feet capacitance C_{feet} , that represents the capacitance from the person-feet to the electrode under the shoes is also unknown, because it depends on the area of the feet base, the thickness of the shoes sole and the kind of material of the soles. Fortunately, the capacitance C_{feet} is in the order of 0.01 nF to 0.06 nF, which is much larger than the capacitance that represents the person’s position.

In accurate capacitive sensors guard electrodes are used to eliminate the effect of fringing fields, so that the capacitance of the inner electrodes is insensitive for

movement of parasitic electrodes in the neighboring environment. However, to be effective the guarding electrodes have to be three to four times larger than the electrode distance [4, 5]. In our application, this requirement is very impractical and will not be satisfied. Consequently, in the presented human detectors the effects of fringing fields will be noticeable.

Shielding is applied to reduce the effects of interfering voltage sources. In our applications usually the backside of the receiver electrode is shielded with a slightly larger electrode, which is connected to ground. Therefore, there is a relatively large parasitic capacitance between the receiver electrode and ground. With the applied Universal Transducer Interface for parasitic capacitances less than 1 nF this effect is neglectable.

With respect to contamination and condensation, precautions have to be taken to prevent that conductive paths can be formed between the receiving electrodes and the other ones.

3. MODELLING THE ELECTRODE STRUCTURE

The setup for human detection is a uniplanar 2-dimensional structure (figure 2). The electrode structure consists of four electrodes located at the outer sides and are used as transmitters. The electrode located in the center is used as receiver. A shielding electrode, which is connected to ground, is located at the bottom side of all the previous ones. This system has been designed to detect the presence and movement of a person located at the top of the receiver electrode.

The simplified model of the system is shown figure 3. The capacitances C_{1p} , C_{2p} , C_{3p} , C_{4p} , and C_{5p} represent the parasitic capacitances between the transmitter and receiver electrodes and the grounded shield electrodes. The capacitor C_{feet} represents the capacitance of the person's feet to the receiver electrode; the capacitors C_{air1} , C_{air2} , C_{air3} , and C_{air4} represent the capacitances from the transmitter electrode T_1 , T_2 , T_3 , and T_4 respectively to the receiving electrode. The sensing capacitances C_{x1} , C_{x2} , C_{x3} , and C_{x4} are the capacitances formed from the person to each transmitter electrode. Finally, the capacitance C_x represented the coupling capacitance between the human body and the ground plane under the person detector.

Using the two-port technique [1], the total measurement is performed in four time-multiplexed steps. During the first measurement step, the low-impedance voltage source is connected to transmitter T_1 , while transmitter T_2 , T_3 , T_4 are connected to ground. Furthermore, the low-impedance current meter measures the current I_m , which flows via the capacitor C_{feet} and $C_{air(i)}$ (receiver electrode) to ground. If C_x is ignored during the first approximation, the measurand capacitance is given as

$$C_{m1} = C_{air1} + \frac{C_{x1} * C_{feet}}{C_{x1} + C_{feet}} \approx C_{air1} + C_{x1} \quad (1)$$

During the next measurement steps, the low-impedance voltage source is connected to each transmitter T_i , $i= 2,3,4$ while other transmitters not used for excitation are connected to ground and the low-impedance current meter is still connected to the receiver electrode.

The final position X-Y is obtained by using ratiometric measurement as

$$\hat{x} \approx \frac{C_{air1} + C_{x1} - (C_{air2} + C_{x2})}{C_{air1} + C_{x1} + (C_{air2} + C_{x2})} \quad (2)$$

$$\hat{y} \approx \frac{C_{air3} + C_{x3} - (C_{air4} + C_{x4})}{C_{air3} + C_{x3} + (C_{air4} + C_{x4})} \quad (3)$$

Later on, an overall calibration procedure is performed to eliminate the environment effects produced by surrounding elements, which result in offset and scale changes.

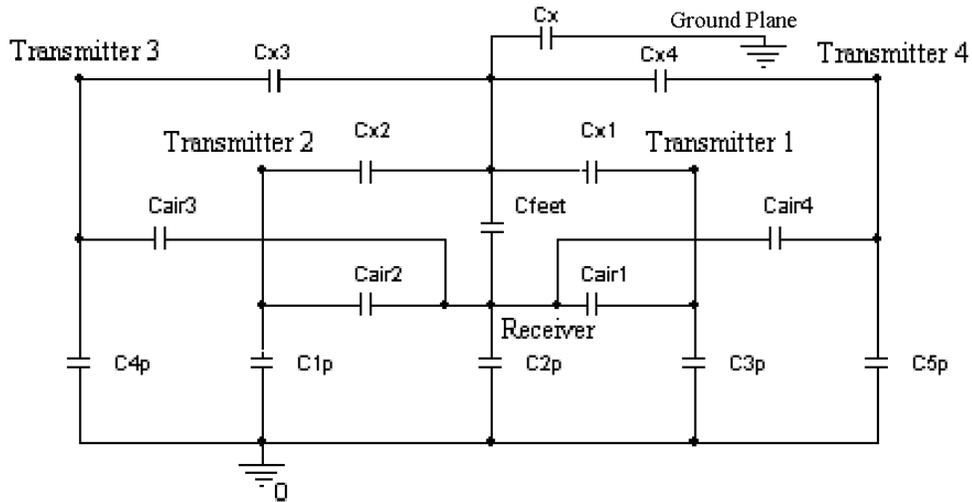


Fig. 3. Simplified electrical model of the capacitances for the 2-D human detector.

4. EXPERIMENTAL RESULTS

The transmitter electrodes have been implemented with a rectangular size of 30 cm x 200 cm. The receiver measures 200 cm x 200 cm. The position error for X-Y position is shown in figure 4. At the center of the detector the errors achieve its minimum values. However, large errors around 30% can be found at each corner. The main errors can be justified by the stronger interaction between the person to the ground plane at each corner represented in the model (figure 3) as C_x together the non-linear relation of the person position with the C_{xi} and $C_{air(i)}$ capacitances.

The errors in the final X-Y position have been estimated as: Firstly, a person has been located at 16 different positions $((x_i, y_i); i=1..16)$ on the receiver electrode.

Secondly, the estimated positions $(\hat{x}_i, \hat{y}_i); i=1..16$ have been computed using equation 2 and 3. Third, the (\hat{x}_i, \hat{y}_i) positions have been corrected for offset and scale drift due to environment effects. Finally, an interpolation of the absolute error computed as $error = \sqrt{(x - \hat{x})^2 + (y - \hat{y})^2}$ has been plotted in figure 4.

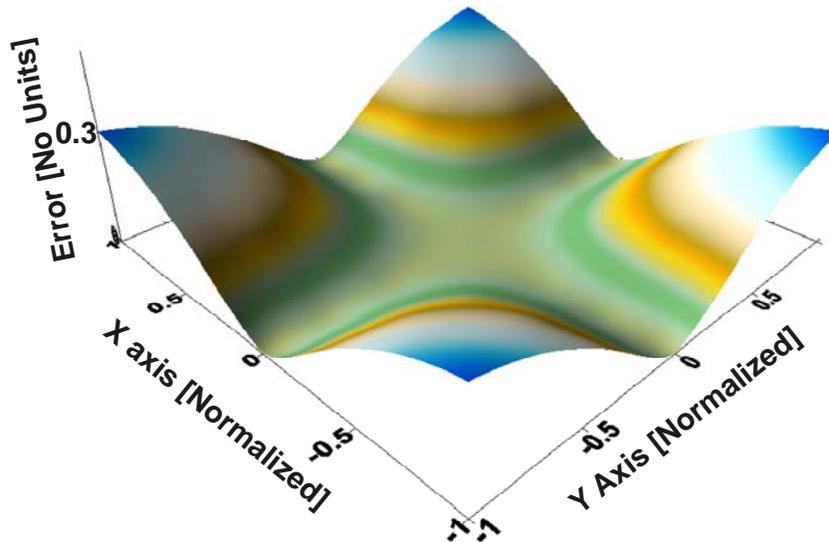


Figure 4. Error for X-Y position estimation.

5. CONCLUSIONS

A 2-D human detector for protecting critical infrastructures or for human-computer interfaces has been presented. The detector can provide information within a specific area about the presence and movement of a person.

The position estimation has been computed from a draft model, which lack of accuracy but still provides useful information for the design of the system. The system is suited to detect person movement over a distance of 2 m by 2 m.

6. REFERENCES

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