A Capacitive Proximity Sensor in Dual Implementation with Tactile Imaging Capability on a Single Flexible Platform for Robot Assistant Applications

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ABSTRACT

In this paper, we have proposed and demonstrated a dual mode proximity sensor which can detect not only proximity but also touch of an object for robot assistant applications. The sensor operates in two modes: proximity mode and tactile mode. Initially, the sensor operates in proximity mode until it touches an object. When the proximity mode detects the contact of any objects, the sensor will switch its mode into tactile sensing mode for acquiring an image from an object. We have used the same platform that we developed for the tactile sensor which was presented in the last MEMS conference [1]. In the current work, we have assessed if the existing platform is suitable for dual implementation. We have tested various designs and configurations in a simple PCB fixture in order to determine the proper electrode configuration of the proximity sensor. We found that the best detection range has been obtained from the largest electrodes with the smallest gap. This implies that the dual implementation is quite plausible in the original tactile sensor platform which has a 1 *mm* gap between electrodes and 22 *mm* in length. Finally, we have demonstrated that proximity detection up to 10 *cm* is possible in the dual implementation in a flexible platform with adequate electrode configuration and sensing circuitry.

1. INTRODUCTION

The evolution of robot engineering has made a spectacular progress for the past decade, especially in the area of humanoids as we can see in HUBO [2] or ASIMO [3]. Some commercial robots are available such as Roomba, although they are still in a primitive form of assistant robots [4]. Many researches are under their way developing robots which can help human, especially, the handicapped or old people. Those robots often have arm-like manipulators to handle objects. In order for those robots to interact with human being and environment safely, it is imperative to be able to detect not only tactile information but also proximity of objects or obstacles before they are too close. This function will prevent the robots from accidental collision which can bring damage to human or to robots themselves. It is anticipated that a large number of sensors including tactile sensor and proximity sensors will be deployed on robot surface in the near future. However, there are some issues to be addressed for the massive deployment of sensors in the robots such as hardware burdens of signal lines and payload of the manipulator. Therefore, it is desirable to integrate sensors in a unified platform as much as possible. There have been various proximity sensors for robots such as ultrasonic, infrared and capacitive sensors [5-7]. Among them, a capacitive proximity sensor is suitable for integration as it consists of simple electrodes only.

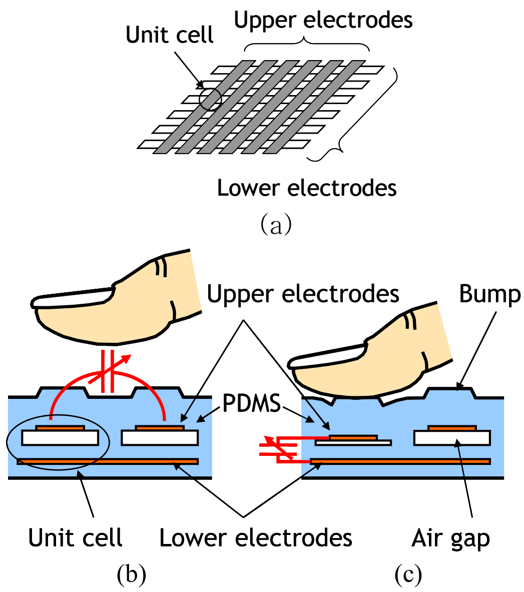


Figure 1: *(a) Conceptual diagram of the proposed dual mode proximity sensor and its operation, (b) proximity mode operation and (c) tactile mode operation.*

In this work, we have implemented a dual mode capacitive sensor working for both proximity and tactile sensing on a flexible PDMS platform for robot assistants. Both sensing functions have been implemented sharing same electrodes on single sensor structure.

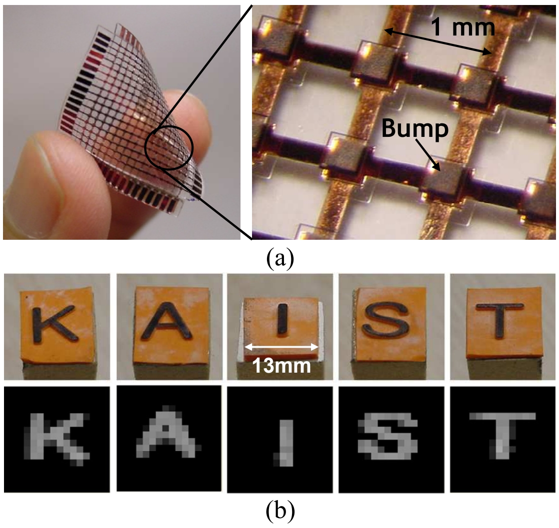


Figure 2: *(a) Photograph of the fabricated dual mode proximity sensor and (b) captured tactile images during tactile mode operation.*

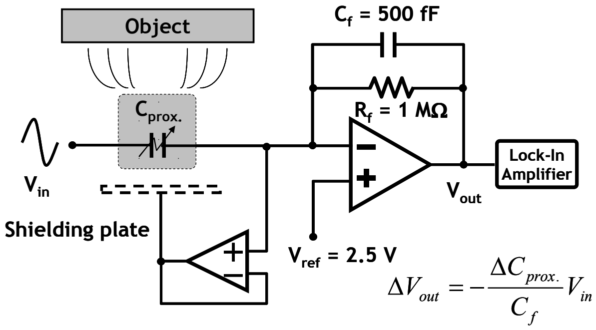


Figure 4: *Schematic diagram of the measurement set up.*

2. SENSOR STRUCTURE

Figure 1 illustrates the conceptual diagram the dual mode proximity sensor and its operation. Basically, the sensor consists of two layers of multiple copper electrodes. The upper and lower electrodes are crossed each other making each cross point a unit cell for tactile sensing. There is an air gap between the two electrodes (upper and lower electrodes) in a unit cell. When an object contacts the bump in a cell, the air gap is squeezed and the capacitance of a unit cell changes as shown in figure 1 (c). The sensor is made from flexible PDMS polymer except electrodes.

In proximity mode, the sensor detects any approaching objects using fringe capacitance change between adjacent upper electrodes. Lower electrodes are not activated for proximity sensor and they are shielded by upper electrodes.

Figure 2 shows the fabricated dual mode proximity/tactile sensor. A few captured images are shown during tactile mode operation [1]. The detailed tactile mode operation was presented at the last year's MEMS conference by our group. Also, the fabrication process can be found in our previous work [1].

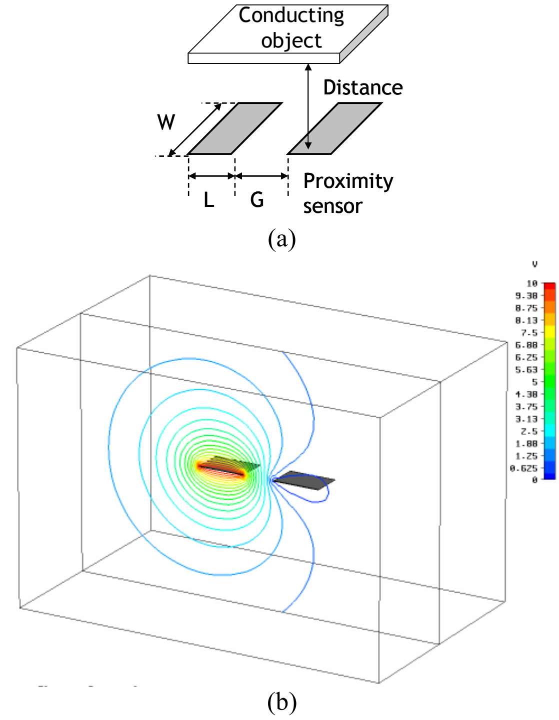


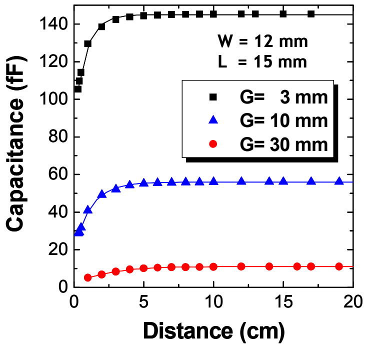
Figure 3: *(a) Schematic diagram of a proximity sensor and (b) its simulation model.*

3. EXPERIMENTS

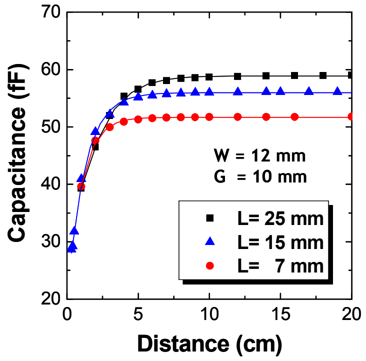
We have many choices of electrode configurations for our dual mode proximity sensor because there are total 16 upper electrodes as shown in Figure 2. Therefore, before we test our dual mode proximity sensor, we have conducted some prior experiments using PCBs in order to validate the choice of proper electrode configuration.

Figure 3 (a) shows the structure of a simple mock-up PCB proximity sensor. There are two planar electrodes on the same plane and the fringe capacitance between these two electrodes changes as an object approaches. Because human body can be regarded as a conducting object, we have only evaluated the conducting objects in our proximity measurements. In the electrode configuration, there are two design parameters: gap (G) between the two electrodes and electrode length (L), assuming that we can fix the electrode width (W). In order to determine the adequate electrode configuration, we tested many of PCB based proximity sensors of various gaps and lengths. In all cases, the electrode width was fixed at 12 mm. The gap was split into 3, 10, and 30 mm, respectively, for the fixed length of 15 mm. The length was split into 7, 15, and 25 mm, respectively, for the fixed gap of 10 mm. The qualitative behavior of these proximity sensors was simulated using CST EM STUDIO™ for initial estimation. Figure 3 (b) shows the simulation model using EM STUDIO.

Figure 4 illustrates the schematic diagram of the measurement setup. Simple charge amplifier circuit has been used with a digital lock-in amplifier for low-noise

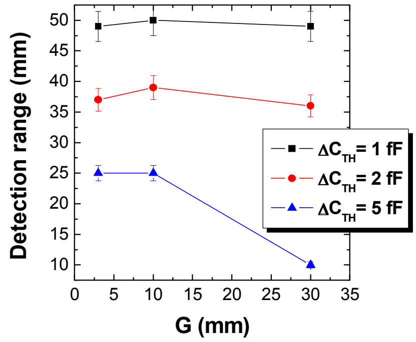


(a)

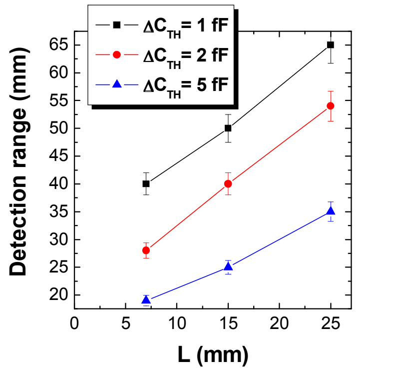


(b)

Figure 5: *Measurement results of PCB proximity sensors as a function of (a) gap between electrodes and (b) length of electrodes.*



(a)



(b)

Figure 6: *Measured detection range of PCB proximity sensors as a function of (a) gap between electrodes and (b) electrode length for various threshold capacitance change (ΔC_{TH}).*

measurement with a 250 kHz sinusoidal wave signal. In order to block any parasitic electric fields from the backside, a shielding plate with a buffer was placed 10 mm below the sensing electrodes as can be seen in Fig. 4. A thick conducting metal plate was used as an approaching object.

4. RESULTS AND DISCUSSION

Figure 5 displays the measurement results of the PCB proximity sensors with various gap sizes (G) and electrode lengths (L). The results show the same behavior with simulation results using EM STUDIO. The fringe capacitance decreases as metal plate approaches since the plate deviates more electric field as it approaches. As shown in Fig. 5, the smaller the gap is the faster the capacitance drops rapidly at a close distance. However, at a far distance (when the distance is comparable to the gap size) all three sensors show almost similar capacitance change. Electrode length (L) only affects the absolute value of initial capacitance.

Because the output voltage of the measurement system (Fig. 4) is directly proportional to the fringe capacitance change due to proximity of an object, the detection range of a proximity sensor can be defined as a distance between a proximity sensor and an object which corresponds to the threshold capacitance change (ΔC_{TH}) determined by the measurement system. As ΔC_{TH} of the measurement system becomes smaller, the detection range should be larger. The detection range of the PCB proximity sensor with respect to ΔC_{TH} can be plotted as Figure 6. If ΔC_{TH} is small enough, the detection range should be large and will not be a function of a gap between the electrodes [5]. However, if ΔC_{TH} is large, the detection range should be small and smaller gap sensors show relatively larger detection range. On the other hand, the detection range increases as electrode length increases as shown in Figure 6 (b). Therefore, a smaller gap sensor with large (or long) electrodes is desirable for larger detection range. This means that larger initial fringe capacitance is desirable for sensitive proximity sensing because ΔC_{TH} is generally limited by system noise.

Our actual proximity sensor has the total 16 upper electrodes and 16 lower electrodes in a mesh form as shown in Fig. 2 (a). We have used the upper 16 electrodes for proximity sensing. We tested three different electrode configurations which have the smallest gap and the largest electrode size as shown in Fig. 7. Figure 8 shows their measured responses. Type b configuration has the largest detection range with a moderate initial capacitance of 9 pF. Detection range could be obtained up to 10 cm with type b

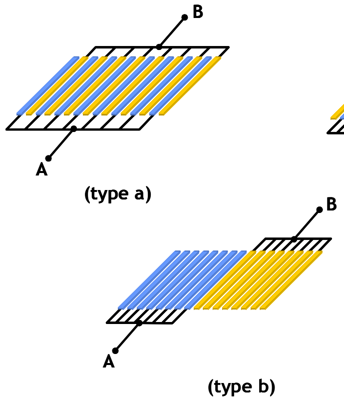


Figure 7: Three types of electrode configurations of the fabricated dual mode proximity sensor for proximity sensing.

configuration when ΔC_{TH} is 1fF. The lower electrodes should be floated during measurement because they consume most of the electric field unless they are floated. Since initial capacitance is quite large compared to the ΔC_{TH}, a smart circuit technique should be used to compensate any large offset in the initial capacitance for reliable detection.

5. CONCLUSIONS

In this paper, we successfully demonstrated a dual mode operation of a capacitive proximity sensor implemented with tactile sensing capability. In order to decide a proper electrode configuration for the proximity sensing, we have tested the response of sensors for various electrode gaps and lengths. We have confirmed that smaller gap with large electrode can give a maximum detection range at a given resolution of measurement system. We have demonstrated that up to 10 cm detection range can be obtained using the proposed proximity sensor.

Because our dual mode sensor can provide two vital sensing functions in single platform and reduce hardware burden and cumbersome signal lines, it can be an attractive choice for robot assistant applications in the future.

6. ACKOWLEDGEMENT

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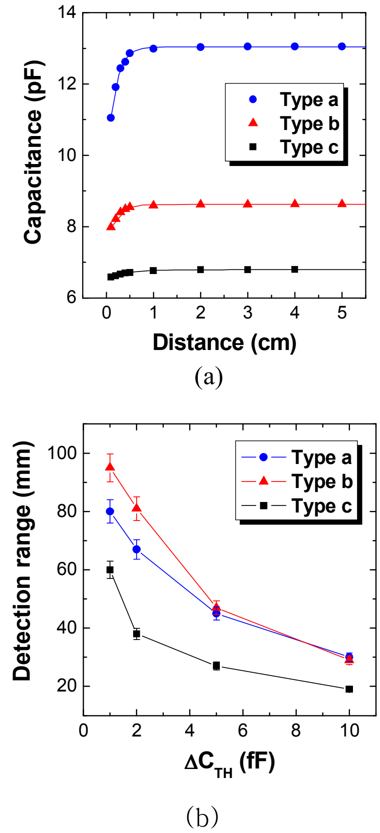

Figure 8: (a) Measured capacitance and (b) detection range of the fabricated proximity sensor as a function of threshold capacitance change (ΔC_{TH}) with respect to three different types of configurations.