Modelling and design of a capacitive touch sensor for urinary tract infection detection at the point-of-care

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***Abstract*— Due to great use of touchscreens in mobile telephones and other electronic devices, there has been great evolution in this technology. Its wide applicability makes the touch sensor technology suitable for detection of specific components in urine, responsible for urinary tract infection (UTI). Integration of a touch sensor in a disposable probe tip to be used in UTI detection represents a powerful tool to develop new point-of-care testing (POCT) devices. The simplified structure of an electrodes array touch screen was simulated using the software COMSOL Multiphysics to prove that capacitive based touch screens can be used for detection of UTI. Besides we assumed presence of *E.coli*, one of the major causes of UTI urine. Results show that global capacitance increases if an *E.coli* sphere is present near the active electrodes, remaining approximately constant when further apart electrodes are excited. The output simulated voltage varies according to the capacitance value, decreasing when the capacitance is increased.**

I. Introduction

Touch screens are electronic displays used to detect and localize a touch event in the display area [1]–[3]. In recent years, touch screens have been widely used in devices as smart phones, car navigation systems and PDAs [1]. The type of technology depends on the method used for sensing touch. Several methods can be used: resistive, infrared, surface acoustic wave (SAW) and capacitive [4], [5]. Capacitive touch sensor technology is very popular due to use in smart phone screens.

There are two types of capacitive sensors used in touch screens, distinguishable by how capacitance is generated: self-capacitance and mutual-capacitance. Self-capacitance method shows similar limitations to the resistive touch sensors, as it measures the signal from an entire row and column and, for that, it can be difficult to detect the exact position of the finger [6]. Mutual-capacitance measures capacitance from intersection of an orthogonal array, allowing accurate detection of touching events, besides multiple touching points at the same time [6].

Point-of-care testing (POCT) allows performance of medical analytical procedures outside the laboratory [7], [8]. A common example of a POCT device is the bedside glucose testing. Won et al. [2] reported a DNA detector using a capacitive touch sensor, without need of sample preparation. Samples were placed in the touch screen and with surface modified electrodes; DNA could be detected at the point of collection.

With this work we show a simplified model of a capacitive touch screen to be used in a disposable probe tip for urinary tract infection (UTI) detection. Diapers can be used as samples of urine, without need to obtain further urine samples. The capacitive touch screen takes advantage of the conductive characteristics of several biomarkers found in urine, and that will induce a capacitance change in the touch sensor. The touch sensor uses the intersection between drive and receive electrodes. If infectious agents are found in urine, they will be bonded to receptors placed in a surface modified structure. This will induce small capacitance variations that can be detected by commercially available controllers.

II. Capacitive Touchscreen Modeling

Monitoring of UTI in hospitals is not always a simple task and analysis of urine can take several hours to be performed. A POCT device, providing in site diagnosis, would be the best tool to reduce time needed for urinalysis. To detect presence of specific bio components causing UTI, a simple touch sensor can be used.

The structure of the touch screen comprises a substrate layer, with a patterned electrode. On top of this, an insulation layer is added and finally another electrode is placed on top of the insulation layer. Considering the top electrode to be the drive electrode, a sequence of pulses excites the electrode and the receive electrode will sense the injected current, forming a mutual capacitance across them (Figure 1(a)) [9]. The mutual capacitance, C_{mutual}, is simply the capacitance in the parallel plate capacitor, given by (1):

$$\mathrm{C_t} = C_{mutual} = \frac{\varepsilon_0 \varepsilon_r A}{d}, \qquad (1)$$

where ε_r and ε_0 are the relative permittivity and the vacuum permittivity, A is the area of the parallel plates and d is the vertical distance measured between plates. From (1) we can assume that in order to increase the value of capacitance, d, which is the thickness of the insulation layer should be as much reduced as possible and the area of the electrodes should be increased.

To identify presence of specific biomolecules causing UTI, specific molecular recognition receptors must be added

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to the top electrode, by surface modification. The receptors will induce more capacitance variation, due to conducting characteristics, adding a capacitance component in parallel to C_{mutual}, $C_{receptors}$, as Figure 1(b) shows. Receptors will steal some of the injected current from the receiver electrode. When the diaper or the urine sample gets in contact with the touch screen, if the target biomolecules are present in urine, they will bond to the molecule receptors, changing again the total capacitance of the touch sensor, as in Figure 1(c). If no target biomolecules are present in urine, capacitance will not change, because there is no bonding of biomolecules to the receptors, remaining the total capacitance as in Figure 1(b).

If an array of electrodes is used, several intersection points between top and bottom electrodes are achieved. With this configuration, several different receptors for distinct target biomolecules can be used and, for that, several biomolecules can be detected and eventually quantified, according to the magnitude in capacitance variation. When designing a capacitive touch sensor we should keep in mind that several parameters can change the capacitance induced

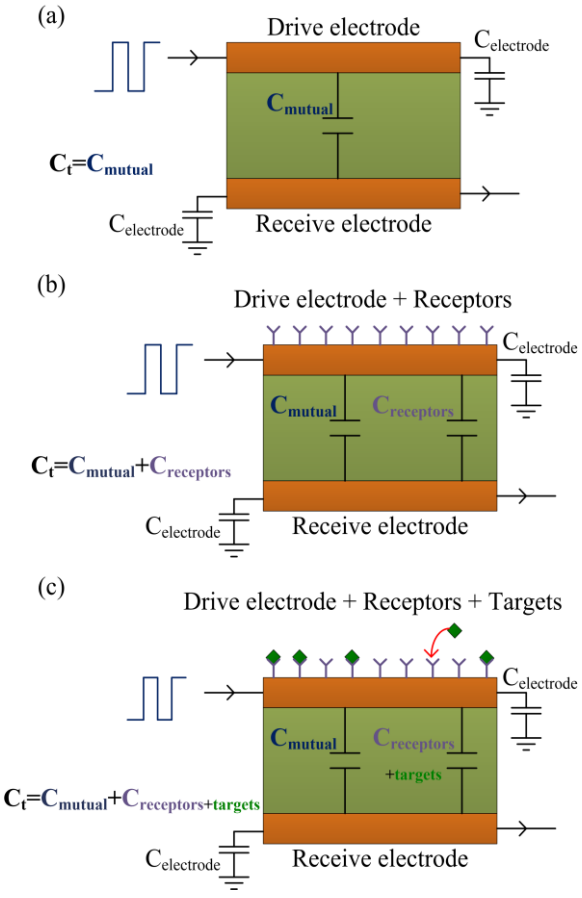

Figure 1. (a) When a pulse wave excites the drive electrode, a mutual capacitance (C_{mutual}) is induced between the top and bottom electrodes, and equals the total capacitance (C_t). (b) The surface of the structure is modified with receptors for molecular recognition, which will induce an alteration in C_t, by addition of the capacitance of the receptors, $C_{receptors}$. (c) When the diaper or the urine sample enters in contact with the touch screen, if the infectious agents are present, they will bond to the receptors, inducing another capacitance variation, $C_{receptors+targets}$. If molecular recognition does not occur, the total capacitance will remain as in (b).

by presence of the biomolecules [9].

The main advantage associated to the use of the touchscreen is the possibility of simultaneous recognition of several different bacteria in urine (if different specific receptors are used in distinct places). When compared to urine sticks that only detect UTI caused by gram-negative bacteria [10], this approach has the advantage of multi-diagnosis in one single tool. The main challenges remains in design a touch area that is able to avoid interferences from other factors that could change the measured capacitance, as presence of dust.

III. Touchscreen Design And Simulation Domain Parameters

The structure of the sensor used in simulations includes a glass substrate and cover, Indium tin oxide (ITO) electrodes in an array disposition and a SU-8 insulation layer between the electrodes, as in Figure 2. The thickness of both the glass substrate and cover is 200µm, the insulation layer thickness is 5µm and the electrodes are 2µm thick. The width of the electrodes is 0.5mm, as well as the gap between electrodes.

The 3D simulations of the capacitive touch screen were performed using the commercial software COMSOL Multiphysics® Ver. 4.3a and the ACDC module. The model was considered to have charge conservation, zero charge and the bottom of the glass substrate was grounded. The electrodes in the x-axis are the receive electrodes and the electrodes in the y-axis are the drive electrodes (Figure 2). As Figure 2 shows, there are two simulated spots, *sp1* and *sp2*, where the *E.coli* structures were placed.

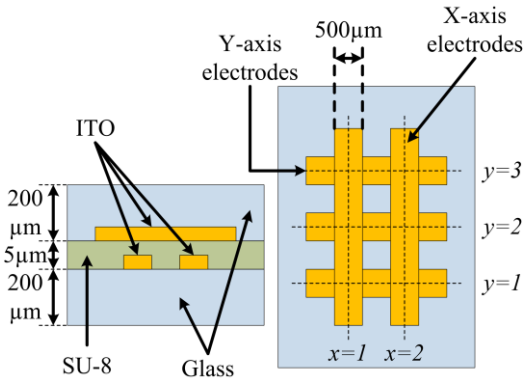

Figure 2. Geometrical structure, dimensions, materials of the simulated capacitive sensor and detection spots one (sp1) and two (sp2).

UTI urine has a minimum concentration of 10^5CFU/mL [11], besides *E.coli* bacteria has a relative permittivity of 100 [12] and each bacteria has a maximum volume of 1.1µm^3 [13]. Considering that a volume of 1mL urine is in contact with the disposable probe and that all *E.coli* bacteria present will adhere to the surface of the sensor, a total volume of *E.coli* of $1.1\text{x}10^5$µm^3 will be in contact with the sensor. The structure simulated as *E.coli* is a sphere with variable radius to better understand the sensitivity of the sensor and the minimum possible samples volume needed to achieve a measurable variation. For each mL of urine, a sphere with a

radius of 30µm can represent the *E.coli* bacteria. We simulated three distinct radius spheres: 60µm, 120µm and 240µm, for 2mL, 4mL and 8mL of urine, respectively. For the simulations we did not consider presence of the receptors in the surface of the touch sensor, being the only influence in the sensor given by the *E.coli* structure.

Besides, considering the capacitance variation obtained in the simulations, we used LTspice to achieve the correspondent voltage variation.

IV. Results and Discussion

In this section we present and discuss the results obtained in the simulations, both with COMSOL Multiphysics® and LTspice.

A. Capacitance variation

In the simulations with Comsol Multiphysics, several combinations of active electrodes were used to evaluate the sensor capability to identify the presence and position of the *E.coli*. Besides, variable sizes of the *E.coli* structure were studied to better understand the sensitivity of the sensor. All possible combinations of electrodes and sizes of *E.coli* were tested for the two spots identified in Figure 2. The capacitance variations when the *E.coli* is on spot one and on spot two are presented in Figure 3(a) and Figure 3(b), respectively.

When the global capacitance of the sensor was measured without the *E.coli* structure (Figures 3(a) and 3(b), for the sphere radius equal to zero), the obtained value was always lower than when *E.coli* was present. This situation is justified by the fact that the relative permittivity of the *E.coli* is higher than the relative permittivity of air, causing an increase in the measured global capacitance. Also, an increase in the radius of the *E.coli* sphere will lead to a higher increase in capacitance, because more material with higher relative permittivity is present in the model. In spite of this, the capacitance variation only becomes meaningful when the radius of the sphere is higher than 120µm, which is equivalent of needing at least a volume of 4mL of urine (Figures 3(a) and 3(b)).

We should notice that when the interior drive electrode (*y=2*) is used, the initial capacitance is higher. This is due to better distribution of the electric potential in the sensor. When the edge electrodes are used as driven electrodes, the electric potential is also distributed to an area that is exterior to the sensor, which will cause a lower value for the initial capacitance.

The measured capacitance is also dependent on the relative position of the *E.coli* structure towards the active electrodes. If the electrodes which are being excited are close to the spot where the *E.coli* structure is present, the capacitance variation is higher than when the excited electrodes are further away from the spot where the *E.coli* is attached. When the sphere is on *spot 1* and the *y=3* electrode is used as drive electrode, the capacitance variation is low (Figure 3(a)); similarly, when the sphere is on *spot 2* and the *y=1* electrode is used as drive electrode, capacitance variation is also low (Figure 3(b)). This is a useful tool, because not only we can detect presence of the *E.coli*, but we can also detect where it is positioned. This would be extremely useful if several bio-receptors for different bacteria responsible for UTI could be placed in a surface modified structure. This would allow not only to detect UTI, but also to directly know the cause of infection. In addition, as capacitance variation depends on the size of the sample, a quantification of the number of cells present can also be achieved.

The higher capacitance variation verified is approximately 0.03pF when the 240µm radius *E. coli* structure is on *spot 1*and the *x=2* and *y=2* electrodes are used as a drive and receive electrodes, respectively. When the used drive electrode is further away from the *E.coli*, capacitance variation is never higher than 0.005pF. This means that presence of the bacteria will always affect the total capacitance, however the variation will tend to decrease as the distance from the *E.coli* to the active electrodes is increased.

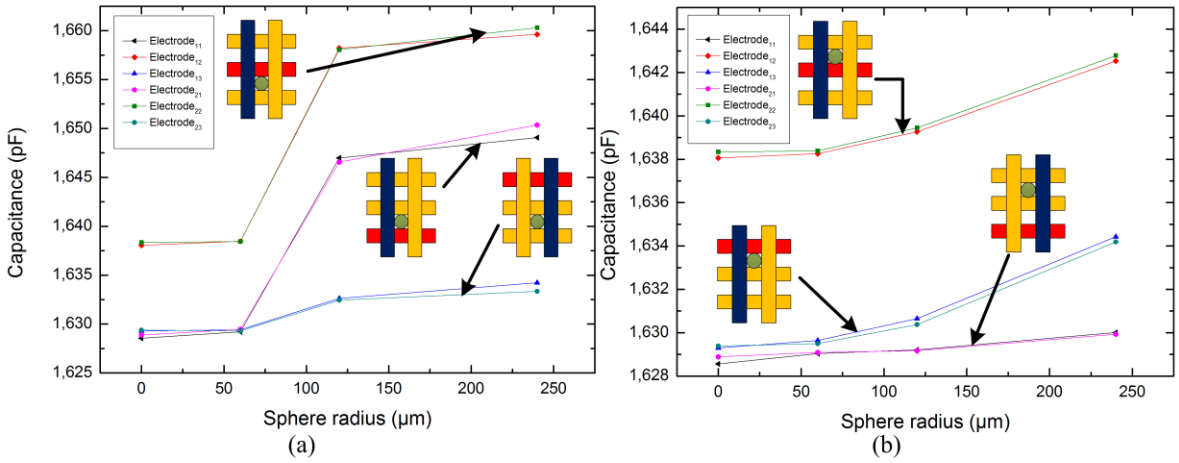

Figure 3. Capacitance variation obtained in simulations when the Electrodes$_{xy}$ are active; the red and blue electrodes in the insets represent the active transmiter and receiver electrodes, respectively. (a) Capacitance variation when the *E.coli* structure is on the *spot 1*, for distinct radius of the structure. (b) Capacitance variation when the *E.coli* structure is on the *spot 2*, for distinct radius of the structure.

B. *Voltage variation*

As previously referred, the higher achieved capacitance variation is 0.03pF when the 240µm radius *E. coli* structure is on *spot 1*and the *x=2* and *y=2* electrodes are used as a drive and receive electrodes, respectively. Considering this variation, we simulated a resistor-capacitor (RC) circuit using LTspice, to understand if the capacitance variation can correctly be detected as a voltage output. For the RC circuit, the value of the resistor was 1MΩ and the pulse wave was 2Vpp and 10µs period. The output voltages achieved for the initial capacitance and the capacitance when the *E.coli* is present, are shown in Figure 4, in the red and blue lines, respectively.

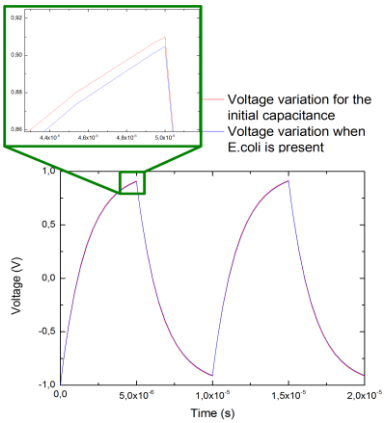

Figure 4. Output voltage variation associated to capacitance variation when the *E.coli* structure with 240µm radius is on *spot 1*1and the *x=2* and *y=2* electrodes are used as a drive and receive electrodes, respectively.

The output voltage when *E.coli* is present is approximately 10mV lower than the initial output voltage. This voltage variation is detectable by common commercial microcontrollers. For the minimum capacitance variation (0.00104pF when the *E.coli* is on *spot 2* and *y=1* and *x=2* electrodes are used as drive and receive electrodes, respectively), the voltage output difference between the initial and final voltage values is 0,1mV. In spite of still being an acceptable value for most microcontrollers, with simple logic functions and programming, we can easily discard these small capacitance variations.

The upper cited situation should be taken in consideration because *E.coli* is present in urine of all human beings, with or without UTI. For this, the system needs to be able to recognize specific levels of bacteria in urine and discard the low levels, so that a correct diagnosis can be achieved.

V. Conclusions and Future Work

With this work we show the design and simulation of a capacitance touch screen based sensor, capable of detecting presence of abnormal *E.coli* concentrations in urine. In this study we show that there is the need to have a minimum concentration of *E.coli* and urine volume so the sensor can detect UTI urine. For a correct diagnosis, some small signal variations should be discarded. Besides detecting UTI caused by *E.coli*, if more spots are added to the sensor, other sources of UTI can be detected.

In the future we intend to build a prototype, based on the operational principle introduced in this work, as in Figure 5, consisting of a probe for automatic detection of UTI, with a disposable tip.

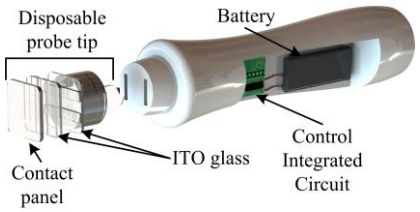

Figure 5. Structure of the prototype of the probe with a disposable tip to be used as POCT device for UTI urine detection.

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