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# Intelligent Capacitive Sensor Array for Removement Detection from Various Surfaces of Tagged Equipment in Hospitals

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## Abstract

Knowing the location of special equipment is a big advantage in large hospitals. Active and intelligent removement detection helps to prevents theft and manipulation. Driven by just a coin battery, ultra low power modules extend the battery life to one month and more. An intelligent detection system could adapt on many different surfaces and materials. The main item of the application is an ultra low power Microcontroller from TI, which is driven 99.44% in “sleep mode”. Therefore a high efficient DC/DC converter provides voltage for the controller to work continuously. The sensor itself is build by four single, rectangular shaped capacitive sensor areas. It is possible to differ the change of material in front of its sensitive side and supplying it with only one coin battery one month or longer. With the four sensor elements it is possible to differ between replacement and slip. The component is small and weighs little, so it can be placed directly on skin like a watch or almost invisible on technical equipment. With an additional radio transceiver the replacement of the sensor can be transmitted wirelessly.

## 1 Introduction

The application range for capacitive touch technology grows fast and is more and more popular in any kind of use. Touchsensors enable an attractive and flexible product design. Avoiding mechanical components extends the lifetime and reliability and it is cheap in production. The shape and layout of the sensing component can be designed in a very flexible way.
A reduced bill of materials and a surface without gaps make capacitive touch screens and touch sensors attractive for use in hospitals where surfaces have to be disinfected.
The influence of materials in the near environment to the electrical field of a capacitor, allow using it as a removement detector. It is interacting with different types materials. Manipulation or removement means a change of the material nearby the sensor and an alarm will be triggered. In combination with a wireless transmitter and receiver module a live status of a ward in a hospital could be inspected.
In addition the sensor has to run on minimal current consumption. Therefore the choice of the optimal components and power supply is fundamental.

## 2 Methods

The components that are needed to build a capacitive touch panel are sparse, but have to be chosen wisely. It implies the dimensioning of the capacitor itself, the microcontroller as the key element and the power supply. To keep the current consumption as low as possible, every single component is worth discussing.

### 1.1 Microcontroller

The sleep or so-called Low Power Mode (LPM) is the key feature to safe energy. Some of the microcontrollers have different LPM and it is possible to switch between them during operation. This can save a lot of energy, by “sleeping” over 90 percent per cycle, decreasing the overall current consumption to a minimum (Fig. 1).
Furthermore, devices from Microchip and Texas Instruments provide an extra feature for capacitive measuring in cooperation with low power application. Just the sensor itself has to be connected as an external component. The internal oscillator is set as clock for counting the number of failing and rising edges (caused by charging and discharging the capacitor). Therefore a change in capacitance results as a change in the number of counting. While oscillating, the MCU enters a low power level, which keeps only the used components active. Between the measurements the microcontroller enters a LPM, where only the CPU remains active (deep sleep mode).
In this work the best fitting solution is the MSP430G2423 from Texas Instruments. It provides five low power modes and an internal pin oscillation system, called PinOsc. In this scenario the Microcontroller is suppose to run at Low

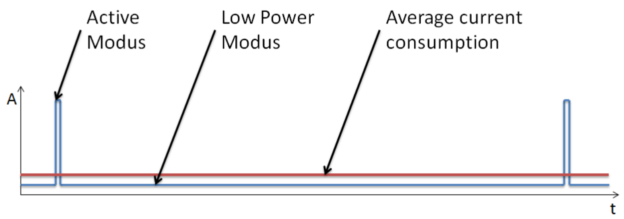


Fig. 1. The overall current consumption can be decreased by using Low Power Modus.

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Power Mode 3 (LPM3, between measurement cycles) with a current consumption of 0.5 µA, during oscillation 56 µA and in active mode 330µA [Inc11].

## 1.2 Power supply

Power supply is a coin battery with a voltage range between 1.2 V and 1.5 V. Powering the microcontroller continuously, requires a supply voltage of at least 1.8 V, up to a maximum of 3.6 V. A step up voltage converter solves this problem, but means unfortunately an additional consumer in the circuit. Choosing the optimal device keeps the overall current consumption low. The MSP430G2xx3 family and the TPS61220, both Texas Instruments, offer good parameters to work together and its also recommended by the manufacturer. Choosing a low input supply voltage enables an efficiency of more than 90% (figure Fig. 4) [Inc09]. The use of this step up converter implicates a variation of its output voltage in a range of about 0.5 V. A constant power supply is essential for capacitive measurements and the used PinOsc System directly depends on the power supply of the microcontroller. There are different ways to stabilize and smooth a voltage. In order to save space and energy, a reference element is not the best choice. An output voltage of 3.4 V in addition with two capacitors with 100 µF and 220 µF at the output of the TPS61220 provides a smoothed voltage with a minimized ripple.

## 1.3 Sensor panel and Layout

A Sensor layout for the manipulation detector could be really simple by considering some geometric parameters. The main part of the energy is provided between the poles of the capacitor, where the field lines are perpendicularly to the plates. The gap between the plates has to be large enough to obtain field lines. With this flat geometry of the capacitor the streamlines of the field are spread out of the plane (Fig. 2). A bigger pad means a higher capacitance and a higher stability against noise. A smaller pad is better for faster measurements.
Furthermore the device was improved to reduce failures and differ manipulation from dislocation caused by motion. Therefore more than just one sensor plate is required. Our system contains four single, rectangular shaped plates, surrounded by ground area. Each of them is 5.37 mm x 10 mm big, with a gap of about 1.1mm. There will be no alarm if one of the sensor areas has no contact to the surface. A real manipulation takes place, when the sensor probably is replaced at once or more than one sensor area looses contact to the surface.
The number of electrical components is reduced: the DC/DC converter plus the recommended and needed passive parts, the additional capacitors for voltage stabilization, the programmer interface, the microcontroller, the power supply (battery) and the four sensors itself. The microcontroller should be placed near the sensor plates, to keep the distance as short as possible (noise reduction). Two double layer PCBs are used to save space and keep the device small. One is for the sensor and one for the electrical components.

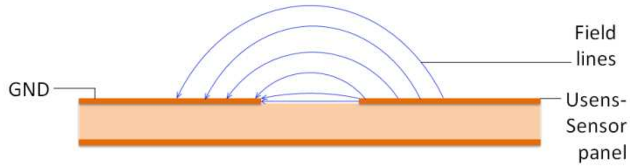


Fig. 2. Streamlines of the field between the sensor voltage (Usens) and Ground (GND) showing the straight lines and the stray filed of the surrounding electrical field (blue).

## 1.4 Measurement and Software

The PinOsc Module is a cohesive system that gives out either logically one or zero, whereby logically one means the supply voltage. This is a so-called relaxation oscillator. The limits are set by the internal Schmitttrigger element depending on the supply voltage of the microcontroller. The sensing capacitors are charged or discharged to an upper or lower level. When the voltage at the pin is at the lower limit ($v_{it-}$) the value of the Schmitttrigger turns 0 and the system begins recharging the sensor again. Up to the higher level ($v_{it+}$) the internal system receive value 1 and start discharging. The value of charge and discharge ranges between the limits $v_{it+}$ and $v_{it-}$ for 0.5ms measuring period. This time is called gate time and is set by the Watchdogtimer (WDT) individually in software. During the gate time, the number of charge and discharge periods is counted. A change of counts is the result of a change of the sensor capacitance and the dielectrically value in the environment.
The software is divided in three main parts; starting with the measurement at the sensing section with the basic differs of data, followed by the process of measurement and at last analyzing the data. The decisive element for measuring capacity is the number of counts within the gate time. If the dielectric permittivity is changing, the counts do it in the same way.
The first measurement, the initialisation, creates a calibration data set for following measurements (basic capacitance). Every sensor is measured and evaluated by its own. The captured value represents the capacitance and with fixed geometric parameters it represents the electrical permittivity. After setting up the WDT to 0.5 ms the oscillation starts. During measurements the microcontroller is put to LPM0, where the CPU and MCLK are disabled and the controller is supposed to run at 55 µA (at 2.2 V). After the gate time is over, the WDT creates an interrupt. The started interrupt service routine (ISR) captures the value of Timer_A and wakes up the system from LPM to active mode. The counts for the sensor are saved for further processing and the measurement starts for the second plate and so on. The value of counts is saved in global variables and can be used on any time.
However, detecting a manipulation requires a reference measurement to find out if the number of counts is changing. Reference or basic capacitance is the average value of

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16 measurements. The value of counts is detected and compared to the base capacitance for every sensor plate. If the sensor value is not within the tolerance, a variable is incrementing. Is the value of this variable after measuring the four sensors higher than 2, the alarm is set (output Pin 1.1 to high). This means that the capacitance changed more than allowed in the predefined limit at more than two plates. It is to assume that this indicates a manipulation.
Otherwise, if the counts are within the tolerances, the controller is set to LPM3 for a certain period of time, where CPU, MCLK, SMCLK and DCO dc generator are disabled (just ACLK remains active). After this sleeping period, the next measurements starting again. After 30 measurement cycles the system calibrates again and creates new reference values. This sanction reduces failures and improves our system to avoid false alarms. Reasons are several, such as the change of temperature or humidity, drifts of the base capacitance caused by aging. If the position of the sensor must be changed, it is able to adapt to new surfaces without manual initialisation or reset.

# 3 Results

The capacitive key system works continuously on very different surfaces and prevent manipulation. The amount of counts depends on the shape and size of the plates, the supply voltage of the microcontroller and the electrical permittivity.
The dielectric permittivity of biological tissue, e.g. skin, is significant higher than other materials, which means a longer charge and discharge time. With this knowledge it is possible to differ between organic and inorganic material. Materials under 1200 counts can be interpreted as tissue (skin) or other organic material and above as inorganic (metal, etc.). Lower has a tolerance threshold up to 200 counts, everything above has 20 counts as threshold. Measurement results of inorganic material are more stable and have a smaller variation.
This investigated system concept aspires to be Ultra Low Power. With the help of an additional shunt-resistor, the current consumption could be determined. As shunt resistor a low value and precision resistor with 0.068 Ω was used, to avert measurement errors.

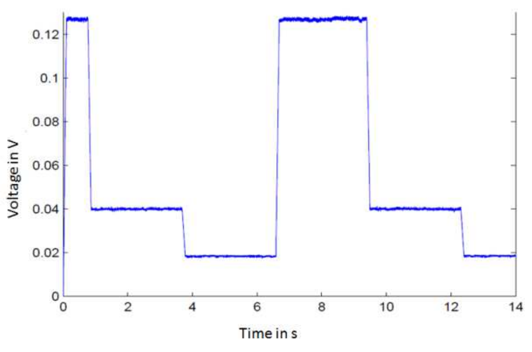


Fig. 3. Three modes of the program: highest is active Mode, middle is Low Power Mode 0 and lowest is Low Power Mode 3 (each mode last three seconds). It is filtered with a moving average filter.

The overall consumption is an amount of all consuming component. In comparison with datasheets and calculation, the maximum consumption of the system is about 1.5 mA (measured value 0.102 mV), and the minimum 0.01 mA (measured value 0.68 µV). This is a wide range and therefore a low side differential amplifier (with a gain of 1000) is used to measure the shunt voltage. The measured signal was noisy and it has to be filtered. Separating the different LPM without the sleeping period gives a good approximation about the value (Fig. 3) and the timing.
The microcontroller firmware has to be modified to detect the processing time in each module. Table 1 presents the duration time of every part of the program.

**Table 1.** Timing during measurement cycle

| Status | time in ms |
|---|---|
| Measuring 4 sensors | 2.4 |
| Processing | 0.4 |
| Low Power Mode 3 | 726 |
| Measuring cycle | 728.8 |
| Cycle (reference – reference) | 21843 |

To measure without the shunt resistor, the power consumption was measured separately for the different modes (Table 2). The used multimeter is high precision compared to the technique with shunt resistor and amplifier, but slower. With this method it is not possible to detect small changes or peaks.

**Table 2.** Current consumption for each single mode

| Status | current consumption in mA |
|---|---|
| Active Mode | 1.8 |
| Low power Mode 0 | 0.5 |
| Low Power Mode 3 | 0.2 |

# 4 Conclusion

The higher supply voltage causes a higher current consumption of the microcontroller. Reducing it would improve the needed power.
The system has an average supply current of 0.2025 mA. It is just a little bit more then the consumption in LPM3 in which the controller is running 99.62 % of the time (table 2). Nonetheless the current consumption is higher than expected. Reason for it is the efficiency behaviour of the TPS61220. The efficiency of the switching converter becomes lower with a decreasing load. Result of the LPM of the microcontroller is higher current consumption of the TPS61220. In 99.62 % the load is at a lowest level (LPM3). The efficiency decreases, which means a higher current consumption. A battery with an energy of 125 mAh could supply this system for minimum 25 days.
Anyhow, the system is able to detect various surfaces, and adapt to them. The difference between skin and inorganic

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material works well and the whole system runs continuously with this low power management concept.
The high measurement error to determine the small current of the device, the noise and the nonlinearity of the amplifier makes this current measurement unconfident.

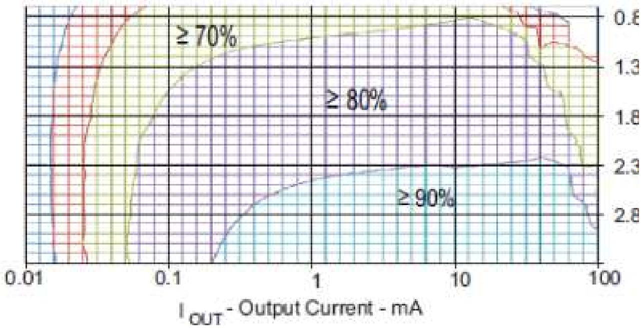


Fig. 4. Efficiency of the TPS61220. [Inc09]

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