MOTION AND TOUCH SENSING RFID TAG FOR ACTIVITY MONITORING

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***Abstract*-** This paper presents a method to improve the accuracy of detecting movement and use of the medical instruments in the trauma bay by integrating the sensing capability into the pre-existing passive RFID tags. Adding the sensing capability to the passive RFID tags will give it the capability to be aware of motion and a user's touch. The semi-passive sensor equipped Gen2 tag is comprised of an ultra-low-power microcontroller, capacitive touch sensor, 3-axis accelerometer and a Gen2 I2C-RFID chip. All the components are being operated at a very strict power constraint that has an expected lifetime of 3 years when equipped with a small 225-mAh coin battery. This sensor enabled RFID tag is used in the trauma bay to track motion and activity by sensing different environmental and physiological data.

INTRODUCTION

Radio-frequency identification (RFID) has proved to be a very good, decisive technique to detect movement of the medical instruments in the trauma bay. It gives a high level of accuracy by sensing the change in RSSI levels received by the RFID receiver. However, there are certain shortcomings linked to this system, which often gives out erroneous signals when it is not in use. This issue can be remedied by introducing more parameters to be analyzed in the existing system. These parameters are recorded by adding sensors to the RFID tag to sense the changes in its surroundings. The physiological study of the project at hand points out that for an object in the trauma bay to be used it needs to be touched and moved. Using this information we have added a capacitive touch sensor and an accelerometer to the passive tag to detect the use of an object with high precision of accuracy. The data collected from the sensors is communicated to the Gen2 RFID chip using the wired I2C protocol using an ultra low power MCU. A 3V coin cell satisfies the power requirement of the added circuitry for the purpose of sensing and updating the memory content of the RFID chip. The power requirements of backscattering the memory content of the RFID chip is taken care by harvesting the energy of RFID query sent out by the RFID reader, just like in the case of a passive RFID tag [**1**].

The tag created is a novel example of touch sensitive low powered Battery-Assisted Passive (BAP) Systems. A Battery-Assisted Passive RFID tag is a type of passive tag that incorporates a crucial active tag feature. While most passive RFID tags use the energy from the RFID reader's signal to power on the tag's chip and backscatter to the reader, BAP tags use an integrated power source (usually a battery) to power on the chip, so all of the captured energy from the reader can be used for backscatter [**2**]. Another similar example of BAP is the wireless identification and sensing platform (WISP) that is a battery-less RFID tag being developed. To the authors' knowledge, the pioneers in conceiving augmented UHF RFID tags were Smith et al. in 2005 with their WISP implementing ID-modulation for sensor data transmission [**3**]. The device relies on an approach exploiting a new-generation RFID chip with dual communication interface: a wired I2C interface managed by a microcontroller and a wireless UHF interface for communication with standard Gen2 readers [**4**]. WISP was considered as a possible solution to our requirements but its size and low distance of operability pose an issue. We propose a simple method of encapsulating the functionalities on the passive sensors being used. As the RFID system at the hospital is already installed and many of their instruments are tagged using the pre-existing passive tags, the proposed solution needs to be backward compatible to be able to work well with the existing system. The sensors and other functionalities are added in a form of encapsulation that gives us the flexibility and scalability to add more sensors and functionalities in the future without affecting the working of the existing tag.

In this research we use capacitive touch in conjunction with an accelerometer to detect if the doctor is interacting with a device. This can be envisioned as a simple example of a person pressing a button on a remote control to indicate that he is using the remote control. We also know that if a doctor uses the equipment in the resuscitation room, the equipment would be displaced from its original position. This displacement of the equipment's position can be detected and its present position can be calculated using an accelerometer. Using these two very reliable techniques to detect utilization of the equipment has the potential to give an accuracy of close to 99%. The research improves the reliability of the system by adding extra parameters to detect motion, taking our findings close to the ground truth.

INITIAL APPROACH

The initial approach to detect whether the object was being used was based on sensing touch using a capacitive touch sensor controlled using a MCU. The pins of the MCU were connected to four different RF switches that were capable of transforming a perfectly tuned antenna into an out of tune state. Owing to the fact that a RFID chip connected to an out of tune antenna would not be read by the reader, give the RFID tags two distinct state so it can depict a bit 1 in case its antenna is tuned, and a bit 0 if its antenna is out of tune. This technique basically turns on and off the four RFID tags connected to the MCU via the switches, giving 24 different states that can be used to represent 24 bits of information [**5**]. The MCU was capable of sending the recorded data from the capacitive touch sensor to the RFID receiver by altering the state of the four antennas. The image of this model can be seen in Fig. 1 below.

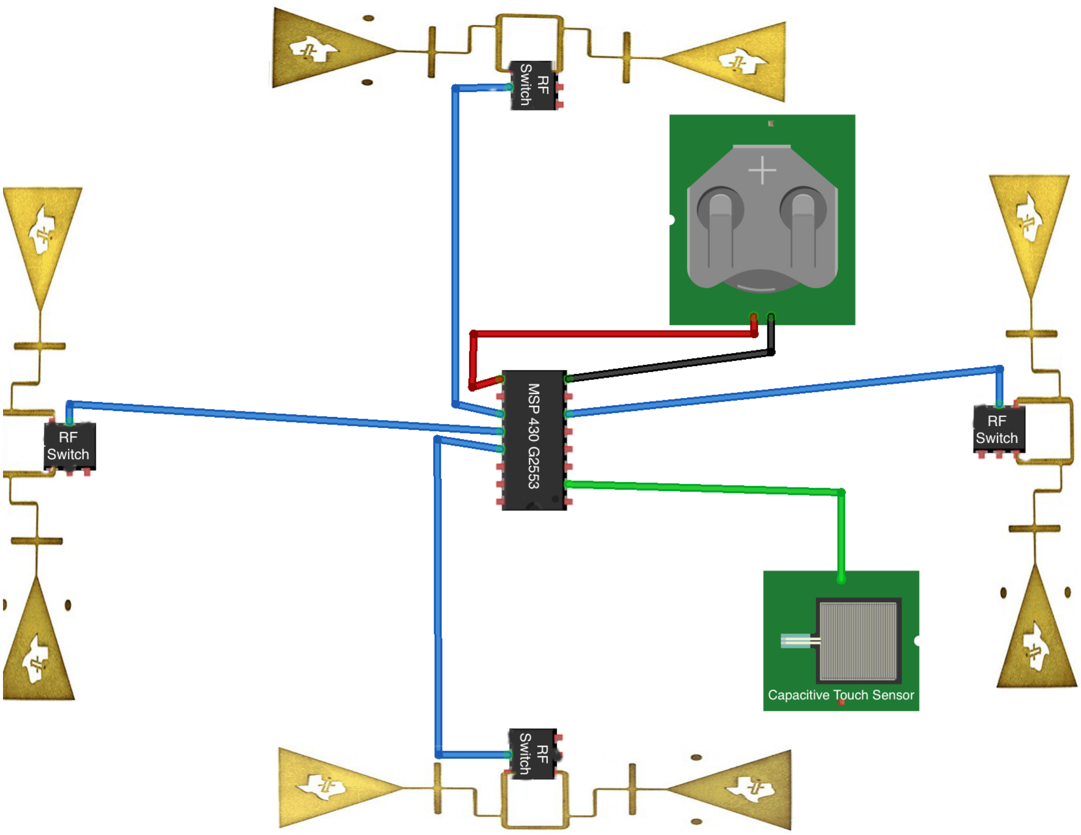

Figure 1. S-Tag type model

This approach was discarded for two main reasons: firstly the size of the combinational tag, which was bigger than the combined size of four RFID tags; and secondly the use of four RFID tags raised erroneous cases and false detection, because even if one of the RFID tags' RSSI signal has an error, it would cause a faulty result. In an attempt to avoid these issues, and for the purpose of tracking the activity in the trauma bay, we devised the new approach of using a BAP that is immune to such problems.

DESIGN AND IMPLEMENTATION

The scope of this project revolves around a microprocessor known as the MSP430 G2335. This MCU will be used primarily to modify the behavior of RFID tags as a proximity device or a touch sensor attached to medical equipment. This unit will be used because of its power efficiency and ability to compute at high speeds. The MCU has ultra low power sleep modes that are used extensively. It is capable of I2C communication with a slave that can then read or write information. The name I2C comes from Inter IC or IIC, meaning Inter-Integrated Circuit. I2C is a bus to allow communication between components of a circuit board. The I2C can also be used to connect multiple devices together, hence giving flexibility to an assortment of applications. The master-slave relationship using I2C is created in order to change memory in our research. The slave end of our system is the I2C enabled Gen2 RFID chip "S13SS4011_4021" by NXP. This chip has a non-volatile memory that is accessible either through I2C connection by the MCU or via EPC gen 2 standard by the RFID receiver. Every time the MCU's decision about whether the object is in use or not changes, it writes these changes of state to the RFID chips non-volatile memory through the I2C connection. The data stored is passed on to the base station that is connected to RFID receiver each time the RFID receiver makes a query.

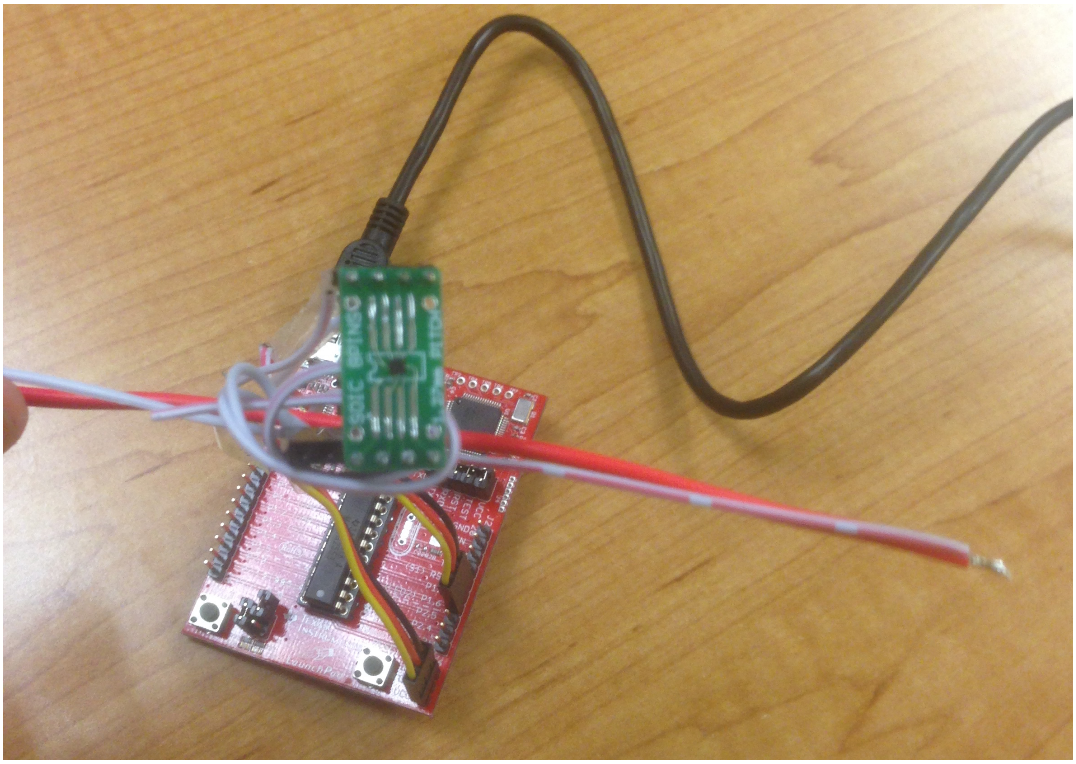

Figure 2. Prototype of motion and touch sensing RFID Tag

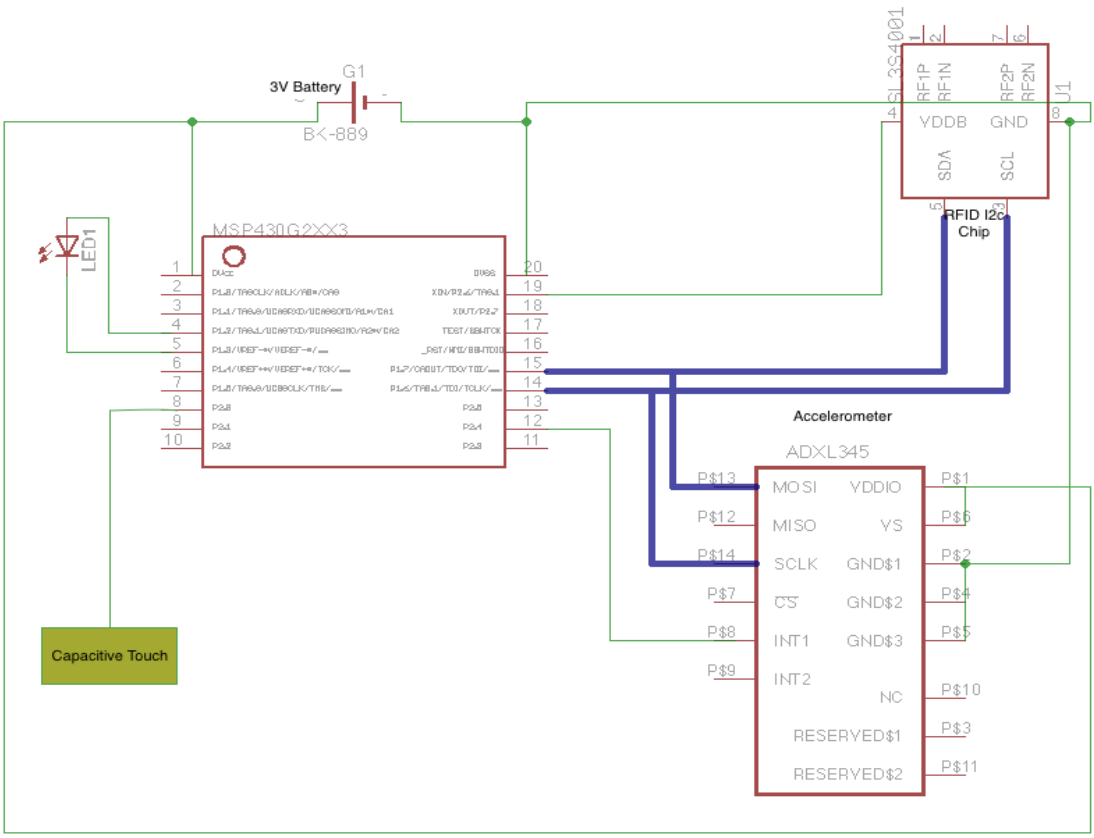

Figure 3. Schematic Diagram

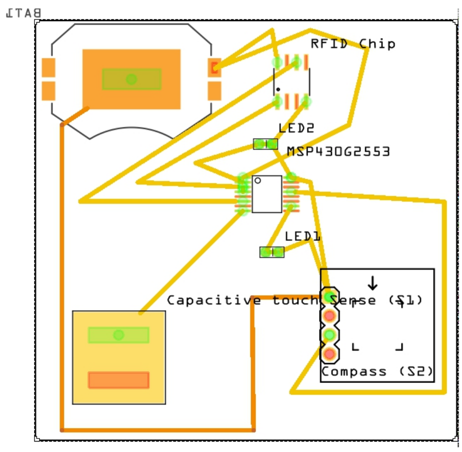

Figure 4. PCB Design

The proposed design for the sensor equipped RFID tag uses a standard UHF RFID tag composed of a dipole antenna and a Gen2 I2C enabled chip that makes up the radio front end. The memory of the RFID chip can be accessed by both wired I2C interface and the Gen2 wireless interface. As a result of this, conventional RFID wireless readers can directly access the sensor data transferred over the wired interface by means of an MCU [**6**].

Microcontroller	
Type	TI MSP430G2553
Non-Volatile memory (KB)	16
SRAM (kB)	0.5
Minimum operation (VCC)	1.8
Active power (µA/MHz)	330
Standby power (LPM3-µA)	0.7
Wakeup time (microseconds)	1.5

RFID Controller	
Protocol	EPCglobal Class-1 Generation-2
Operating frequencies	860MHz-960MHz
Chip	SL3S4011_4021
Modulation	Backscatter
Storage (bits)	3328(user memory)
R/W sensitivity S_{chip}	-23dBm
Active Current (µA)	10(read)/40(write)

On-board sensors	
3-axis accelerometer	ADXL362 13-bit/axis digital output (I2C) 3.0 µA supply current
Capacitive touch resistor	

Interfaces	
Expansions	Spy-Bi-Wire, I^2C, SPI, 12 10-bit ADC channels, 47 GPIO
Bus	I^2C

Figure 5. Specs of the BAP Tag

A 3-V/225-mAh CR2032 button-cell lithium battery powers the RFID tag. The core of the system is an ultra-low-power 16-bit MSP430G2553 MCU that can run up to 16 MHz and consumes approximately 330µA/MHz. The supply current reduces to 0.7µA/MHz in sleep mode and 1.5 microsecond wakeup time. The MCU provides 16kB of flash memory, 0.5kB of SRAM.

The MCU is programmed with an energy-efficient firmware running at 1 MHz and implementing I2C read/write and capacitive touch sensing that is mentioned in the power management section below. The readings from an ADXL362 accelerometer are taken via the I2C interface. The ADXL362 is an ultra-low power (3µA current consumption) 3-axis accelerometer with 13-bit resolution measurements for each axis up to +_8g. The sensor readings are wrapped in a 64-bit data chunk-10-bit temperature, 13-bit acceleration for each of the three axes, and 15-bit read counter-which is written (via the I2C bus) into the password protected user memory of the RFID Gen2 chip.

The RFID controller is a SL3S4011_4021 chip which is an UHF RFID Gen2 IC with an I2C interface. As an I2C, SL3S4011_4021 operates as a standard EEPROM whose contents can also be accessed wirelessly via the Gen2 protocol.

POWER MANAGEMENT ALGORITHM

The low power consumption requirements of the RFID tag can be accomplished by ensuring that MCU consumes as little power as possible. This can be achieved by reducing the duty cycle of the MCU by oscillating it between its active and sleep states. By ensuring that the MCU remains in the sleep mode for most of the time when it is not being used, it is possible to operate the RFID tag at very low power consumption. During the period when the MCU is in its sleep mode, the total current consumption of all the circuits is within a few micro-amps.

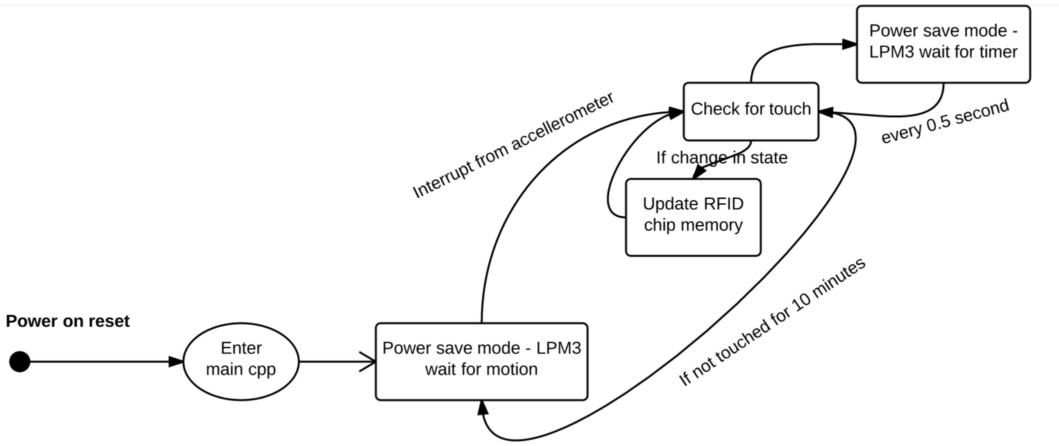

Figure 6. Power Management State Diagram

The state diagram of the power management algorithm is shown in Fig. 6. The external interrupt, timer, and software are responsible for triggering state transition. When the Tag is turned on, the MCU goes into a sleep mode (LMP3) as quickly as possible to avoid wasting any power. Once the MCU is in LMP3 mode an interrupt is triggered by the accelerometer when the object is in motion. This interrupt wakes up the MCU and the state machine transitions to touch detection stage. Next, the MCU is sent into a sleep mode (LMP3) once it has checked for touch. The MCU stays in the sleep mode for half of a second and is interrupted by the timer to transit the state machine back to active state to perform the touch sensing. The power efficiency of the tag is increased by updating the EEPROM of the RFID chip only when the previous reading of the touch sensor differs from the present reading; this means that the EEPROM write, which consumes most of the power, only takes place in the event of an update in the response of the touch sensor. The software is then responsible for detecting the instance when the object is not being used and has not been used for a considerable amount of time. If such a situation arises, the MCU considers the usage event to have ended and goes back to sleep mode from where it can be brought back to active state if the object is moved.

OPERATIONS

The objective of detecting the utilization of the medical instrument is realized by incorporating a touch sensor and an accelerometer to the passive tag. The flow chart depicted in the Fig. 7, gives a brief graphical description of the operations of the tag. Such a tag is a semi-passive tag and falls under the category of class 3 gen2 RFID tags also known as BAP, as explained above [**7**]. The two sensors used have been used very efficiently in a power constraint environment. Each of the two sensors has been allotted their specific job in the algorithm in a way that they complement each other to obtain maximum accuracy in detecting movement of the medical instrument. The accelerometer is a 3-axis accelerometer that is capable of accurate detection of motion in the object it is attached to. This accelerometer has a feature of causing an interrupt when it is moved, which makes it our first choice to be deployed as the sensor to wake up the MCU in the event of motion. From experience it is known that the first stage of using an object at the trauma bay is picking up the object, which causes the accelerometer to wakeup the MCU due to motion. We cannot rely on only the data gathered from the accelerometer, because in some instruments the doctor might hold them stationary while using them, this issue is addressed by the capacitive touch sensor which would be the final decision maker in deciding whether the object is being used or not. Once the accelerometer establishes that the object has been put into motion, the capacitive touch sensor checks for touch twice per second. The process of capacitive touch sensing is repeated until no touch has been detected for a predetermined amount of time sufficient to recognize a false detection by the accelerometer, or as an end of the process (case in which the event being recorded has been ended). The use of two sensors helps in reducing the event of false detection in motion, as the finding of one sensor crosschecks with the findings of the second sensor.

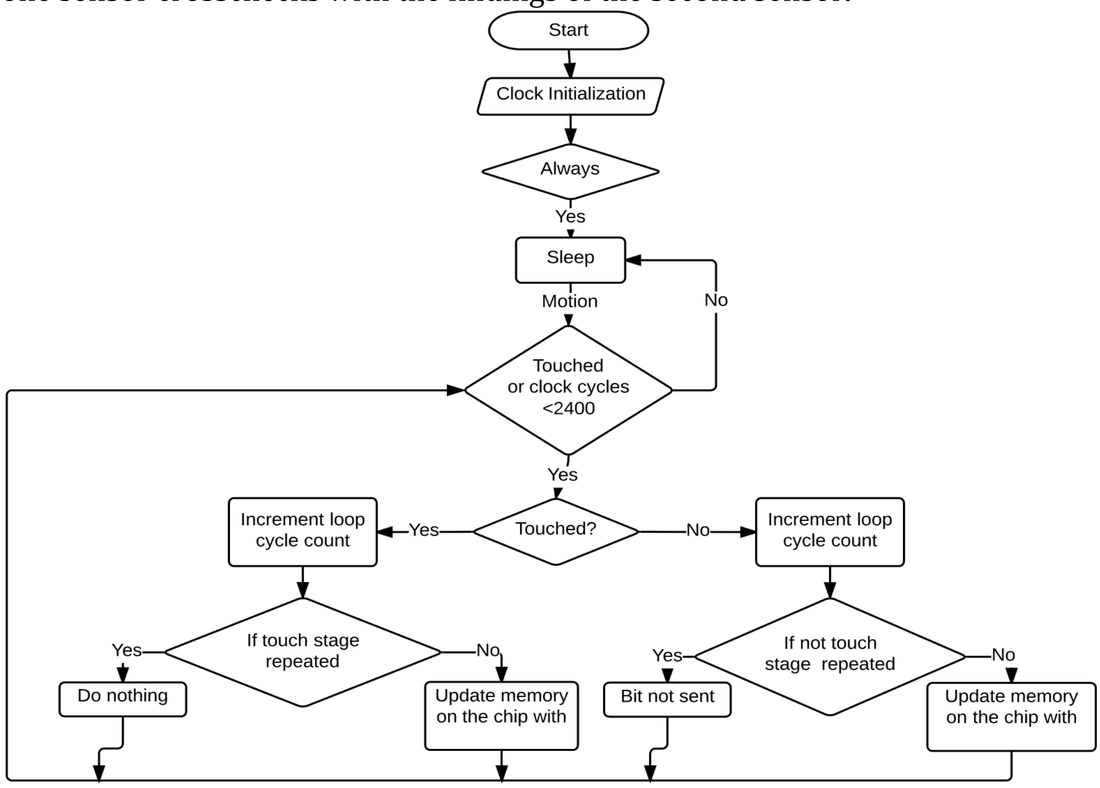

Figure 7. Flow Chart

The ultimate goal of the research is to find out if an object in the trauma bay is being used at that particular time. The present model that is based on observing the change in RSSI value to detect movement of the object can only report that the object is being moved. An object being in motion does not essentially mean that the object is being used. This can be illustrated by a simple example in which a nurse picks up a thermometer and is moving towards the patient and then waiting for the patient to be positioned before using the thermometer on the patient. Using the existing model of determining the instance of an object's usage based on motion will produce an outcome and show that the thermometer was in use from the time the nurse picked it up, irrespective of the fact that it was actually being used or not. By positioning a capacitive touch sensor in particular places where touch would be established only when the thermometer is being used, our system would detect the exact point at which the thermometer is actually being used. Though our algorithm would show the actual use of the object, it would also be programmable to report the movement of the object along with reporting the point at which the object would be actually in use. This scenario gets more complicated in the case of a stethoscope, which is mainly in motion as doctors have the stethoscopes on them at all times. Due to the constant motion the RSSI fails to detect the use of the stethoscope. In contrast, our model would be able to detect and report when the stethoscope is being used by utilizing the touch sensor which would only report a detection if it is in use by considering the point of touching the patients body as the in use state of the stethoscope. The accelerometer is only used to wake up the MCU and its sensed data is not reported to the RFID reader.

Once the decision of whether the object is being used or not has been made by the MCU, the next step is to report this decision to the RFID reader. Writing the appropriate data into the non-volatile memory of the RFID chip using the I2C communication does the work of making the data ready to be reported to the base station. Using the technique of backscatter, the information is communicated to the base station when the query is generated from the RFID receiver [**8**].

TOUCH SENSOR

Capacitive touch sensing is a technology based on capacitive coupling that takes human body's capacitance as an input. This input is fed to the controller to make the tag aware and responsive to its surroundings. Presence of human touch can be determined by observing the charging and discharging times. The discharge time of the circuit is dependent only on the resistance and the capacitance of the circuit. When a human body comes within close proximity of the circuit, the capacitance of the body is added to the capacitance of the circuit causing a change in the discharge time. The Equation for discharge time (τ) can be seen below.

$$\tau = RC = 1/2\pi f_c$$

$$f_c = 1/2\pi RC$$

R = resistance of the circuit
C = Capacitance of the circuit
τ = Discharge time
f_c= Cutoff frequency

MSP430 microcontroller offers a number of peripherals that can be used to perform a capacitance measurement very efficiently. The MSP430 has a special functionality of PinOsc that enables low cost capacitive touch sensing without the need for external components. [**9**] [**10**].

Capacitive touch was chosen for its ability to detect the presence of human presence even at a small distance. This ability of the capacitive touch sensors makes them desirable because doctors wear plastic cloves at all times in the trauma bay, preventing any direct touch between the sensor and the doctor's skin. This ability also doubles the functionality of the capacitive touch sensor as a proximity sensor. The capability of the touch sensor to double as a proximity sensor would be useful in forming position/localization prediction models mentioned under the future work section.

CONCLUSION

A complete passive UHF RFID system for capacitive sensor applications is presented. The design, prototype and the future work of the sensor equipped Gen2 UHF RFID tag are detailed. The tag is equipped with two types of sensors: a touch sensor to detect if the object is touched, and an accelerometer to detect the movement in the tag. A 3V coin cell runs the MCU and sensors, while the RF backscattering is powered by harvesting power from the RFID's receiver. The accuracy of the touch sensor is very high and when it is used in conjunction with the accelerometer, it yields a high level of accuracy. The development of such a tag was possible because of the availability of I2C connection to access and alter the memory of the Gen2 RFID chip.

The tag has been developed using low cost off the shelf components organized and programmed to work at low power consumption. We aim to attach these newly developed tags to the equipment at the hospital to collect the data and provide accurate detection of when the medical equipment is being used. An extensive performance analysis of the proposed design is yet to be done under real world environment conditions. This research is capable of providing solutions to many possible issues that would be addressed in the future.

FUTURE WORK

Incorporating the sensor with the passive RFID tags opens a vast range of options that can be worked on by exploiting the flexibility of the tag developed. The extra influx of parameters introduced by collecting the sensor data can be used in various ways to enhance the study performed at the hospital's trauma bay.
Some of the possibilities for future work are listed below:

1. When the RFID receiver generates a query, all the RFID tags that are in the vicinity of the receiver's antenna send their ID by the process of backscattering. All the backscattered RFID signals undergo interference amongst each other and populate the spectrum with unwanted radio

signals. The backscattered signals from the RFID tags that are attached to equipment not in use results in a waste of energy that might interfere with the backscattered signals from the tags that are attached to the equipment being used. These unwanted signals increase the overall noise energy in the room and also affect the rate at which the RFID receiver antennas detect the backscattered signal.
The issue of unwanted backscattered signals can be addressed by sending a backscattered signal only when the object in use doesn't send a backscattered signal. This can be achieved by using a GaAs RF switch to make the RFID's antenna out of tune when the object is not being used [**11**].

2. In situations where the sensors attached to the RFID tags provide various healthcare services by transmitting environmental and physiological data, any leakage of raw data can cause a privacy violation of both the system and the patient. To prevent such a misfortune from happening, we can use a mutual authentication protocol developed by us [**12**], for RFID systems by implementing the lightweight SIMON's cryptographic algorithm.

3. The benefit of adding the functionality in the form of encapsulating it on top of the preexisting system gives us the freedom to develop a RFID tag that is capable of sensing the vitals from the patient's body and collecting them over the RFID system. This can be realized by adding a specific sensor for each tag that is attached to the equipment directly used on the patient. For example, we can have a temperature sensor on the laryngoscope that goes in the exact position of a thermometer and collects the data of the patient's temperature. Such sensors can collect a vast range of vitals from the patient to study. We have proposed a number of such sensors that can be used on some of the equipment to collect useful data. Some of the proposed sensors and their corresponding equipment are given in the table, Fig. 8.

Figure 8. Sensors Proposed

AMBU BAG		LARYNGOSCOPE	STETHOSCOPE
FLEX SENSOR	AIRFLOW SENSOR	TEMPERATURE SENSOR	HEARTBEAT SENSOR
-Number of Pumps -Amount of air input	-Flow of air -Checks if no flow of air	Checks the Temperature of the Patient. (Under the tongue)	-Rhythm of the beat -Interval of beat -Count of beat

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