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Real-time Detection Of Seat Occupancy & Hogging

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ABSTRACT

In this paper, we propose a cheap and effective solution to detect if specific seats at a shared public table are occupied – either by humans or by objects (i.e., the seats are being "hogged"). The hogging of seats, in particular, is a big problem for our campus library and required a large amount of manpower to correct (to find and clear hogged seats). We propose using two different cheap sensors, a capacitance sensor and an infrared (IR) sensor, to solve this problem. In the rest of this paper, we show how using these sensors can accurately determine if a seat is occupied by a human or empty. We then show that the capacitance sensor can also accurately distinguish between three different states; 1) seat is empty, 2) seat is occupied by a human, c) seat is empty, but table area at seat is occupied (by a book, laptop, etc. i.e., it is possibly hogged).

Figure 1: Seat hogging in library. Students hog seat by leaving their belongings on the table.

Categories and Subject Descriptors

Topic C.3 [**Special-purpose and Application-Based Systems**]: Real-time and embedded systems

Keywords

capacitive sensing; occupancy detection; hogging detection; electric field sensing; inductive proximity sensing

1. INTRODUCTION

We developed and tested out two sensors, capacitive sensor and IR sensor to detect seat occupancy status in real-time. Our choice of sensors was determined by the 3 design requirements provided to us by our potential users, in this case, our campus library. The 3 requirements were a) the sensors had to be cheap enough to be easily deployable in large numbers, b) the sensors had to be non intrusive and not interfere with regular behavior, and c) the final system still had to be accurate enough to be useful. Hence, after investigating the use of many different sensors (audio, video, accelerometers, etc.), we converged on using the IR and capacitance sensors as they had the best chance of satisfying all 3 requirements.

Capacitive sensing has proven to be robust and reliable measurement technology with low power consumption. In our work, we use capacitive sensor to detect both people occupancy and seat hogging automatically. Prior research have focused on using capacitive sensor to controlling car's airbag system. The closest to our work is to use capacitive sensor to detection occupancy on mini bus [1]. In these previous research, the sensor was installed under chair to detect if someone was sitting on it.

The IR sensors, on other hand, due to their high accuracy and low cost, have found applications in many areas. Our sensor consists of a pair of low cost IR transmitting diode (transmitter) and a photo-diode (receiver), to detect any obstruction in its field. Prior to our research, IR sensors have been used for obstacle detection and color differentiation in the area of robotics [2] and have commercial applications like parking sensors.

Our goals are to solve two real-world problems related to seat availability. The first problem is finding available seats in library or event hall. People have to move around in order to find empty seats, which takes effort and may disturb other people. Using the sensors to detect seat occupancy, we can help in reducing the cost of searching by showing location of empty seats. The second problem is "seat hogging" in library [3]. In our work, seat hogging is when students

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Figure 2: From the top: Copper foil (left), Raspberry Pi with MPR121 chip (middle), IR sensor circuit(right) and the two sensors mounted under the table.

leave their unattended items to block/save seats for later use. Our sensors can provide seats usage statistics, including seat hogging. This helps library's staffs to effectively monitor seat hogging problem remotely.

Unlike previous works, we use the capacitive sensor to detect not only people occupancy, but also seat hogging, with unique detection scheme to distinguish people from other objects in variety of distance. Our work also requires different context, which we discuss more in section 2.1. Overall, both the sensors are installed under table instead of chair. Mounting the sensor under the table gives chair freedom of movement. However, this makes it harder to detect people occupancy due to greater distance between people and the sensors. We tackled the problem by fine-tuning the sensor and using a new people occupancy detection approach based on standard deviation, which we describe in section 3.1. The capacitive sensor achieved high detection accuracy for both people and objects, and IR sensor has best response time.

2. SENSOR DESIGN

2.1 Capacitive Sensor

The most popular form of capacitive sensor used is in phone screens and track-pads that take human finger capacitance as input. In our work, we use proximity capacitive sensor to detect people and objects that is conductive or has dielectric different from that of air.

The device used in our setup is showed in Figure 2. It consists of a Raspberry Pi with capacitive touch sensor controller chip MPR121 from Freescale (www.freescale.com) to control the system and transmit data, and copper foils that act as electrodes for capacitance measurement. The 15-centimeters foil is constructed in round shape to reduce stray capacitance around its edge. Smaller foil has reduced sensitivity, so objects that have low dielectric constant cannot be detected. In contrast, a larger foil has very high sensitivity and it can pick up unwanted signal from nearby sources outside the area of interest.

The device is placed under table to detect both people occupancy and seat hogging. Doing this enabled us to use single electrode to detect both objects and people at the seat position. Moreover, we dont mount sensors on chairs because chairs are not restricted in movement, which makes them infeasible to use for seat location mapping. Compared to when the device is installed under chair, the principle drawback being the distance between people and the sensor is much larger and depends more on people's posture. As distance is inversely proportional to capacitance ($C = \frac{\epsilon A}{distance}$), it is harder to detect and distinguish people occupancy from object occupancy. We resolved the problem by fine-tuning the sensor and using *standard deviation* as a feature to distinguish people occupancy. For the object part, our experiments were focused on laptop, book and phone, which are a few commonly placed objects on table by students to hog the seat. Two foils are used in our setup for side-by-side seats.

The capacitive sensor measures changes in voltage, which is inversely proportional to capacitance.

$$V = \frac{Q}{C} = \frac{I \times T}{C} \quad (1)$$

The output result is in form of 10bit ADC (i.e. analog to digital converter) which represents the actual voltage. $ADC\ Counts = \frac{V \times 1024}{Vdd}$ with Vdd is constant supply voltage. Then we can calculate capacitance C knowing charge current I and charge time T

$$C = \frac{Q}{V} = \frac{I \times T}{V} = \frac{I \times T}{ADC\ counts} \times \frac{1}{Vdd \times 1024} \quad (2)$$

Since voltage is inverse proportion to capacitance, lower ADC count means lower voltage, and higher capacitance. We setup charge current I to 50 µA and charge time per half cycle T to 1 µs to charge sensor to near upper count limit, thus maximizing the sensing resolution.

2.2 IR Sensor

The most popular application of IR sensor is obstacle detection and use as proximity sensor. In this research, we use it to detect occupancy.

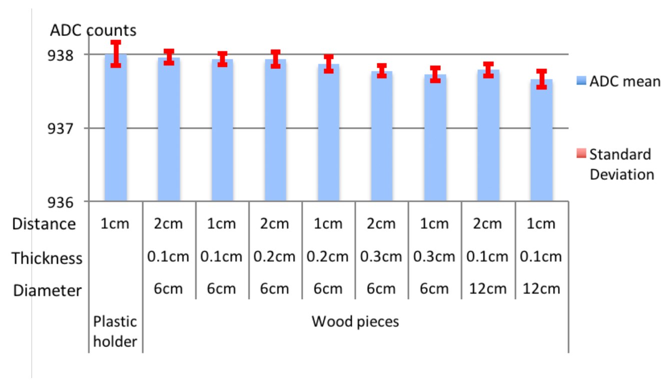
The setup consists of an IR sensor connected to a Raspberry Pi which is used to control the system. The sensor is shown in the Figure 2. The small size of the sensor, of 3cm width and 5cm length, enables it to be mounted without obstructing the occupant and can be easily be concealed. The IR sensor works on a principle similar to a SONAR. The IR transmitting diode transmits infrared radiation. Any object in its filed reflects back the radiation which is detected by the photo-diode. Voltage across the photo-diode is directly proportional to the amount of IR incident on it.

The sensor is interfaced with Raspberry Pi through a MCP3008 ADC IC. This results in output in the form of ADC counts ranging from 0 to 1023, just like capacitive sensor output indicator.

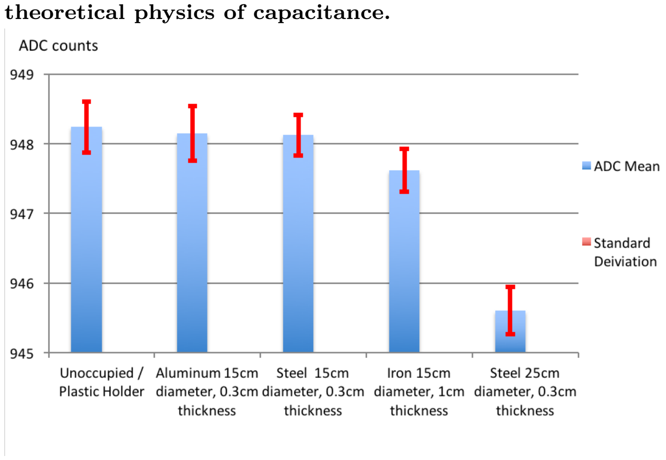
3. OCCUPANCY AND HOGGING DETECTION

3.1 Capacitive Sensor-based Method

Sensor's sensitivity measurement: The sensor can measure small change in capacitance, which is showed in Figure 3a. When we increase object size, or when we reduce its distance from the sensor, the capacitance increases (lower ADC counts). The largest capacitance measured on 12cm diameter piece of wood. When including error, all measured capacitances are still in range of unoccupied state. This means these small wooden objects can't be detected as an occupier. However, we can still detect bigger wooden objects like books. In second state, we measure capacitance of different kind of metals. In theory, most kind of metals has approximately same dielectric constant at same temperature. It holds true when we measure capacitance of Aluminum and Steel, which we show in Figure 3b. In this case, 1cm thickness iron and 25cm diameter steel piece are detected as occupiers, since their capacitances are well above unoccupied state.



(a) Wood capacitance measurement. Blue bars are measured capacitances in form of ADC counts, higher ADC counts mean higher measured voltage and lower capacitance. Holder is made from plastic which is low dialectic constant material to hold the object. Round pieces of wood of different size and thickness are measured in one or two centimeters distance from the sensor. Output capacitance is higher (lower ADC counts) when we increase size of the object, or reduce distance. This output is in alignment with theoretical physics of capacitance.



(b) Metal capacitance measurement. Blue bars are measured capacitances in form of ADC counts. Round pieces of different kind of metals are measured. Capacitance increases (lower ADC counts) as diameter or thickness of measured object increase. Largest capacitance measured with 25cm diameter steel piece.

Figure 3: Sensor's sensitivity measurement on different materials.

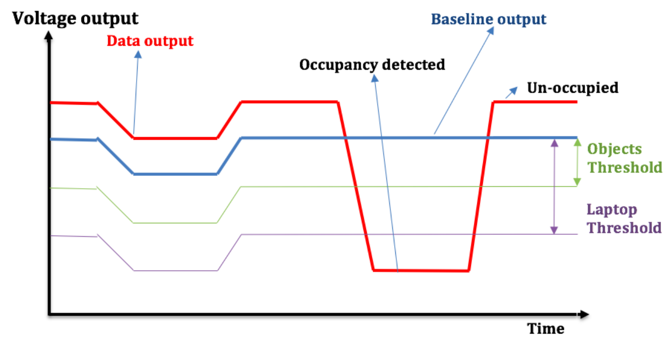


Figure 4: Occupied and Unoccupied seat detection. Red line is output data from the sensor, and blue line is baseline. We then compare deviation of the output data to the baseline value with thresholds for laptop and other objects to detect occupancy states.

We analyzed the capacitance of objects that can be put on table. Detection result is described in Figure 5. As the result suggests, based on signal magnitude, we can easily separate objects that have low dielectric constant like phone and book from laptop. On the other hand, people occupying the seat has capacitance overlapping with both book and laptop capacitance range, depending on their postures. The reason is, compared to the case when sensor is installed on chair, people sit in near proximity to the electrodes rather than sit directly on it. We noticed more variance in their signal for a person occupying the seat as compared to an object, which can be used as feature to differentiate human occupancy from the rest. We use this feature in form of sample-queue standard deviation.

Occupancy detection algorithm: To identify human occupancy and object occupancy, we utilized a two-states approach;

1. First, check deviation value of output signal from baseline to detect if seat is occupied.
2. If it is then check standard deviation to differentiate people from object occupancy.

In the first state, the baseline is calculate using adaptive running average algorithm [4] on output signal. We then check deviation of output data from output baseline to detect occupancy as in Figure 4. Using baseline deviation ensures that capacitive sensor will work in any surrounding environment and can auto calibrate itself.

In the second state, standard deviation is used to separate people occupancy from hogging. It is calculated on a queue of signal samples:

$$Standard\ deviation = sd(Queue)$$

The queue is updated over time by adding new samples and remove old ones. In our experiment, we setup the queue size to 1000 samples. The sample rate is approximated at 48 samples per second, that takes 21 seconds to fill up the queue.

We experienced small delay for detection of seat hogging after people leaving, depending on size of the queue. In our experiment, it takes at most 21 seconds, which is the needed time for all people occupancy signals which have high variance to be removed before deviation of the queue reduces to that of object hogging range. On the other hand, people

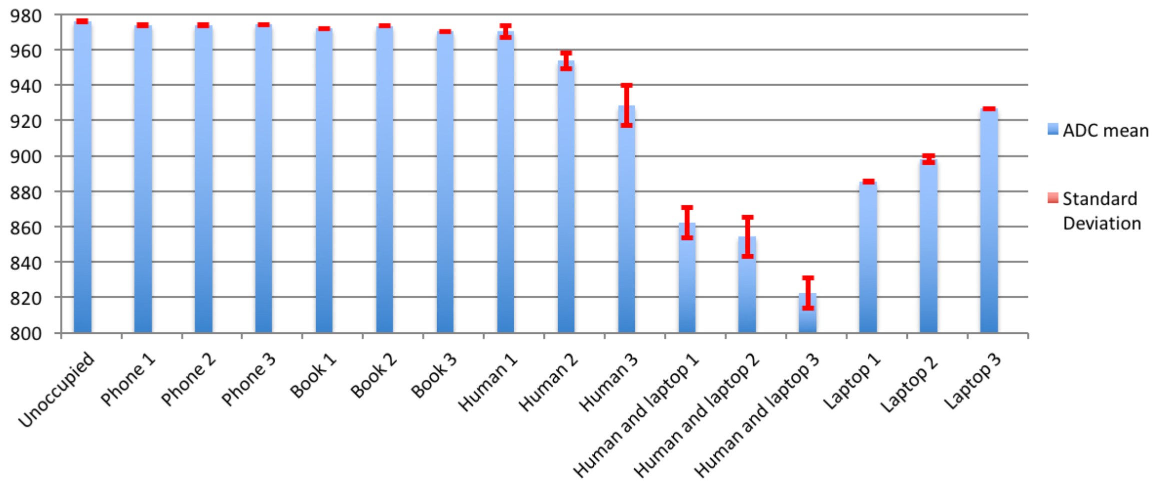


Figure 5: Measured capacitance. Blue bars are ADC counts (voltage) and red bars are standard deviations. Higher ADC counts mean lower capacitance and vice versa. Laptops produce more capacitance than book and phones. People capacitance can reach both book and laptop range, while having higher standard deviation.

occupied and unoccupied state can be detected instantly due to the sudden increase in standard deviation.

3.2 IR Sensor-based Method

Initial analysis of the data indicated that the sensor is susceptible to changes in lighting conditions, this gives rise to noisy data. A low pass filter is implemented which limits drastic changes in the sensor output in comparison to prior data. Figure 6 shows the comparison of filtered and unfiltered output from the sensor. The filtered value is calculated using the following equations:

$$\alpha = \frac{dt}{rc + dt}, \; dt \text{ and } rc \text{ are smoothing parameters} \quad (3)$$

$$Output_t = \alpha \times O_{t-1} + (1 - \alpha) \times Input_t \quad (4)$$

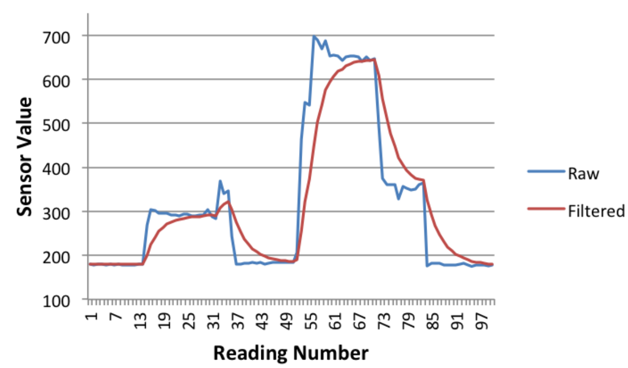
The detection algorithm uses base line deviation approach

Algorithm 1: IR sensor occupancy detection algorithm

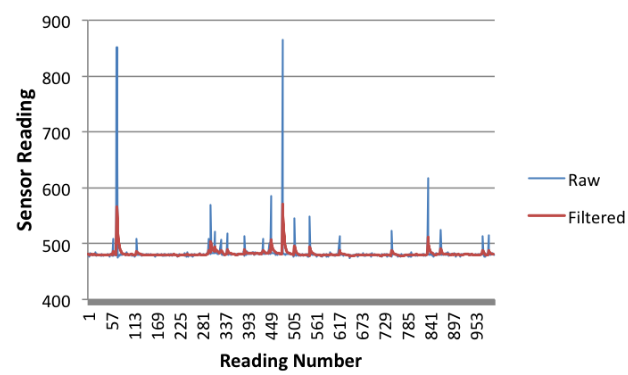
Input: baseline,threshold,$state_{t-1}$,value
Output: $state_t$

1. Calculate $value_{filtered}$ from $value$
2. **if** $baseline + threshold >= value_{filtered}$ and $state_{t-1} = unoccupied$ **then**
   $state_t = occupied$
3. **if** $baseline + threshold < value_{filtered}$ and $state_{t-1} = occupied$ **then**
   $state_t = unoccupied$

just like one we used for capacitive sensor. The base line is calculated by averaging a sample of 1000 readings. The base line is periodically recalculated to ensure the sensor adapts to the changing light conditions throughout the day. Algorithm 1 describes the detection phases.



(a) Filtered data changes slowly unlike raw data.



(b) Filtered data has less spikes which leads to a more stable baseline calculation.

Figure 6: Comparison between raw sensor data and filtered data.

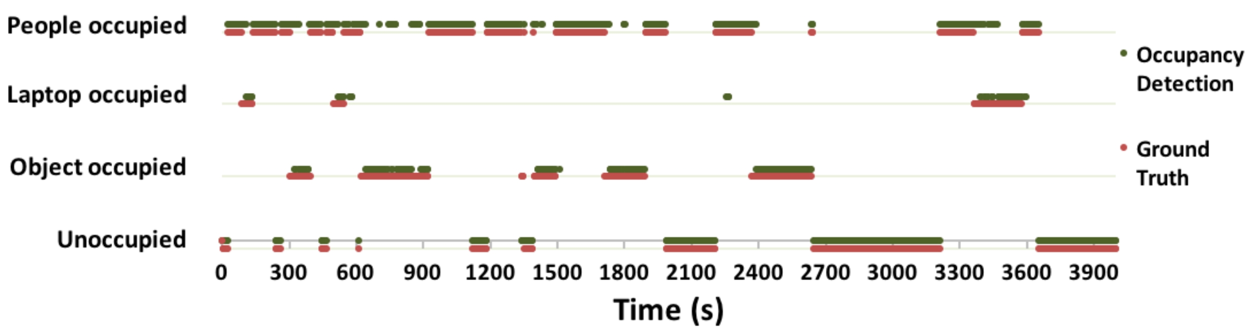


Figure 7: Capacitive sensor occupancy detection experiment. There are four possible states of occupancy that can be detected, including *People occupied*, *Laptop occupied*, *Object occupied* and *Unoccupied*. The green lines are detected states of capacitive sensor, and orange lines are ground truths. If the green and orange lines are exactly the same, our system is working perfectly. When the green line is longer than the orange, our system is making a mistake. For example, at t=300, there is an object on the table but our system only detects it 21 seconds later. At t=3300, a user vacates the seat but leave their laptop behind. Our system also takes 21 seconds to change from "People Occupied" to "Laptop Occupied", this is an expected delay due to the nature of our algorithm. We have some false alarms for people occupancy after that. However, overall, our system is still very accurate as shown in Table 1.

Table 1: Detection performance of capacitive sensor

States	Precision	Recall
Unoccupied	100 %	100 %
Object Occupied	97 %	100 %
Laptop Occupied	66 %	97 %
People Occupied	97 %	95 %

Table 2: Occupancy states confusion matrix

States	Unoccupied	Object	Laptop	People
Unoccupied	629	0	0	0
Object	0	360	0	0
Laptop	0	0	247	66
People	0	11	129	2546

4. EXPERIMENT

The experiment consists of recording occupancy states of the seats. People were asked to bring their book, laptop or phone with them. We do not control sitting time and posture of participants in order to better mimic real-life scenario. The occupancy states are detected by sensors, and ground truths are collected manually. The detection results of one of the capacitive sensors are presented in Figure 7.

The detection performance of the capacitive sensor is presented in Table 1. For Unoccupied state, we got 100% precision and recall, which means the device can reliably detect if seat is occupied or not. Object and people hogging are also detected accurately. The reason for low detection performance of laptop hogging is because of table's vibration when there were people sitting around. This vibration slightly raises the standard deviation to the range of people occupancy. Because of that, the system incorrectly marked laptop occupancy as people occupancy, which are showed in Table 2 Confusion matrix. Possible solution for this case is increasing detection threshold for laptop to keep standard deviation in laptop's range. The vibration does not have much effect on objects that have small capacitance. To increase detection performance in overall, we can increase the queue size of signal samples so that standard deviation is calculated more reliably. This helps the device distinguish between occupancy states more accurately at expense of response time.

The experiment to test IR sensor was setup in the lab's meeting room for a duration of 2 days. The sensor was mounted under the table facing down (towards the floor). The IR sensor is used to only detect people occupancy and it does not detect hogging. Ground truth data was collected by taking pictures from a web-cam at a fixed interval of 3 seconds. The data collected by the sensor was then manually verified with the ground truth to compute the accuracy of the sensor. The IR sensor identified people occupancy states with an accuracy of 80%. The 20% wrongly classified states are due to the variable lighting conditions and occupants being seated but not in the field of the sensor. Although IR sensor has a lower detection accuracy than capacitive sensor, but the speed of classification is faster. The accuracy of the IR sensor can be improved by the following:
1. Increasing the field of the sensor by constructing an array of sensors
2. Using standard deviation approach for detection algorithm as used for capacitive sensor

5. RELATED WORK

The capacitive sensor senses the capacitance between an electrode and its surrounding [4]. Previous works on seat occupancy focus on controlling airbag system [5][6]. It has also been used to effectively detect present of people and high conductive objects that are put on a chair [7], when the electrode is under chair foam. We have developed a capacitive sensor that works like the one in [1] in a different context with new approach of using *standard deviation* as a unique feature to detect people occupancy state. The IR sensors have been found in many applications as mentioned above, in the context of occupancy detection passive infrared sensors (PIR) [8] have been used extensively. That is due to their ability to detect minute motions. Unlike PIR, IR proximity sensors have not been used in the context of occupancy detection before this study. Other solution is using camera with computer vision to detect and track people. This technique faces difficulty to discover people sitting still. Thermal camera which is used in [9] for occupancy analysis in sport arenas provides better performance and keeps people identity private. However, it needs manual boundary selection and configuration for different camera viewing angles and distances, also the precision is not high.

6. DISCUSSION AND FUTURE WORK

The IR sensor despite being able to detect occupancy states faster, needs improvement in classification. IR sensor can be used along with the capacitance sensor to detect objects that are placed on chairs rather than table. Detection of hogging state using capacitance sensor still has slight delay. We can argue that in practical deployment, seat hogging detection does not need fast response, so this delay will not affect performance of the device. Some device's parameter can be changed to better suit deployment scheme. These parameters are coded in a way for easy editing. For example, changing queue size and laptop occupancy threshold or IR detection threshold to achieve higher accuracy while increase respond time. Both capacitive sensor and IR sensor classification can improved by implementing SVM classifier. This would require setting up a rigorous experiment for collecting learning set data. Further more, data collected by IR and capacitive sensor can be combined using decision tree, all these propositions are future works for our experiment. Our system still relies on power source to function, this puts battery free RFID sensor tag in an interesting proposition, which we want to experiment in our future work.

7. CONCLUSION

In this work, we have presented two kind of sensors for seat occupancy detection. From in depth analysis and experiment, we show our capacitive sensor which can clearly distinguish people occupancy from hogging, with detection accuracy for unoccupied and occupied state of 100%, and promising capability of IR sensor. These simple and low cost sensors have reached our initial goal to build devices that are easy to deploy and have good accuracy for practical use in library. These sensors can be adapted for other static (tables are fixed) public places beside library with minimal effort. We can also use capacitance sensor in scenarios that need people proximity detection capability, which usually require at least two kind of sensors (proximity sensor and motion detection sensor).

8. ACKNOWLEDGMENTS

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