Final Report: Wireless Sensor Network Application Suite

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Abstract

Non-intrusive occupancy estimation in the home and office environments relies on the performance of the networked sensors that detect human presence. This paper presents an evaluation of a set of Analog to Digital sensors [1] which can readily be used with wireless sensor networks. Further, these sensors were specifically evaluated for occupancy estimation. Finally, the paper presents a distributed algorithm for processing raw sensor data to estimate occupancy.

Keywords: *occupancy estimation, wireless sensor networks application, smart cities*

1 Introduction

Our continued dependence on limited energy resources and an urgent need to combat climate change has spurred an interest in intelligent use of energy. Austerity and clean energy cannot cover for energy deficit caused by the rising urban population.

In a step towards making energy use at homes, offices and buildings intelligent, this paper aims to provide researchers an insight into **occupancy estimation** of rooms. Estimating the number people in a room could indicate the energy requirement of that room, and subsequently of the entire office or building. Gathering reasonably accurate data about occupancy pattern in a building could save energy for a building by controlling lighting and heating/cooling. Information about energy consumption for buildings in a city could help plan and predict energy requirements expected to be fulfilled by the energy grid. A successful deployment of networked sensors could also serve as an emergency response system, a security monitoring system or could even be used to ensure the structural entity of the building.[2]

Coming to the task of estimating occupancy, the primary challenge is that of detecting action of *human entry and exit* to and from a room respectively. Researchers at [3] have proposed the use of a combination ultrasonic sound transceivers, which are placed at the top of the doors of a room to track occupancy. The sensors also provide weak biometric information regarding the height of a person. The Smart Thermostat [4] focussed on saving energy by using occupancy sensors to predict patterns of use, however the primary focus was on detecting occupancy and saving energy, not on estimating the number of people in a room.

In section 2 the experimental setup for evaluation has been discussed. Further in this paper an analysis of eight different sensors which respond to environmental signals has been presented. The following is the list of the sesors that were tested; their detailed analysis follows in Section 3:

- luminosity(light)
- distance
- sound
- motion(temperature difference)
- mechanical vibrations
- touch(capacitive)
- magnetism
- force

Based on the results of evaluation, a selected set of sensors was also evaluated by affixing the sensors at different locations on a door frame. Section 3 also presents the findings on the response of these sensors when a person performs common actions associated with the door. Realizing the collaborative nature of the occupancy estimation problem, a set of sensor combinations for instrumenting a door have been recommended, see section 5.1. Finally, in section 4 a scoring based algorithm for extracting information about motion from raw sensor data has been presented.

2 Experimental setup

All the sensors being evaluated have the same interface (Analog to Digital interface) to Z1 module. This provides us the opportunity to deploy a **single generic application** to evaluate all Phidget ADC sensors available.

2.1 Generic Configuration

The application is generic, and can be configured within a **swift fox program [5]** with the following parameters :

- **Frequency of sampling ADC port** : The ADC driver reads the ADC port at a frequency supplied by the user.
- **Input Channel**: The Z1 module [6] has two variants of ADC ports : *3V and 5V* on *ports 6.7 and 6.0* respectively.
- **Network Enable**: A boolean parameter which decides the medium through which packets would be communicated, i.e. either on the wireless network via the radio or to the computer via the serial port/USB.
- **Destination Node**: Sets the final destination of the node to which the data would be sent.
- **Sample Count**: In order to minimize headers with packets, number of sample counts per packet can be specified at the swift fox program level.

2.1.1 Environment

It is important to note the conditions in which the sensors were evaluated with the generic application, specially because the sensors are reading physical parameters. The initial readings after booting and the variation in reading thereafter is caused by the these parameters. The following list summarizes the testing environment.

- **Location:** Room CS 468, Computer Science Dept., Columbia University, NY.
- **Sources of light and their brightness:** During the day and before sunset, sunlight would eliminate the need for tube-lights,the light coming in the room was ambient. When tube-lights were lit up, their intensity was reasonably bright.
- **Period of the day:** In general readings for the sensors have been taken throughout the day, although most of the readings have been taken late in the night.
- **Environment Noise:** There were multiple sources of noise:
  - *Electronic Noise:* Although it cannot be measured, the presence of running set-top boxes, LED television screens, air conditioning, and computers might contribute to some Electro-Magnetic noise.
  - *Sound Noise:* Sound of trucks, their reverse horns, people making noise, sound from Air conditioner was a common feature during testing.
- **Technical Setup** The tools used for taking readings and evaluation :
  - **Operating System:** Ubuntu 12.04 - upgraded from Ubuntu 11.04.
  - **TinyOS Tools : Printf** This tool listens to the '/dev/ttyUSBx' file to read and interpret data sent over the serial interface with the help of 'printf' function calls in the applications.

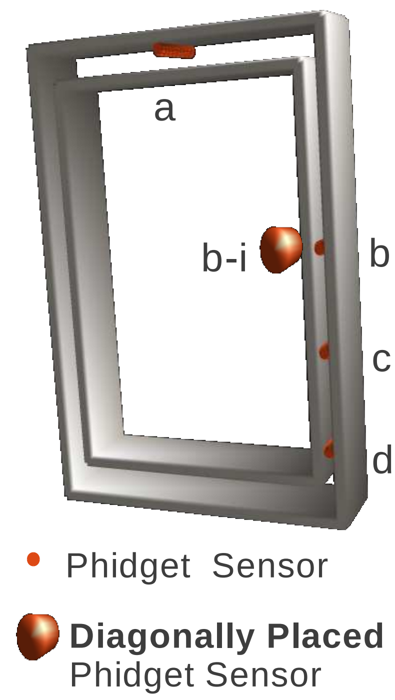

Figure 1: **Position of fixed sensors on the door**

2.2 Testing Application:Implementation

- The application has been designed specifically for the Zolertia Z1 [6] module
- It utilizes Fennec Fox network protocol stack [7], on top of TinyOS [8].
- Given the generic application, the specificity in the application comes from a Swift Fox[5] Program, which configures the generic application with a parameterized interface. This feature makes the deployment of the application very easy.
- Under the hood, the application itself lends support from a ADC driver which is a component implemented in nesC. The role of the driver is to deal with ADC implementation of TI msp430 (Zolertia Z1's microcontroller platform) for TinyOS.
- For the purposes of development a git repository[9] is being used. The application source code and driver source code can be found the repository.

Label	Description
M0	No action
M1	Moving out
M2	Coming in
M3	Walking along the door outside
M4	Waling along the door inside
M5	Standing in the door for 5s, then moving out
M6	Crossing the door very fast
M7	Crossing the door very slowly
M8	Trying to trick the sensor
M9	Walking in and out, back to back

Table 1: **Standard Actions**

2.3 Occupancy Estimation Setup

For evaluating sensors with the door, the sensors were fixed at different locations on the door frame. Fig. 1 shows such positions. [1]

Standardizing Actions There are different actions that are performed by people around a door any room. Occupancy estimation should be able to identify the action of going in the door and coming out of the door from the rest of the actions. In order to record the system's response to various action, all possible actions have been listed in the Table 1.

3 Evaluation of Sensors

Sensors were evaluated in two phases:

- *Application agnostic analysis:* The purpose was to access the merits of each sensors based on claims made by their product specifications.
- *Suitability for Occupancy Estimation:* Select sensors based on the results of the first phase were chosen for occupancy specific evaluation. The sensors were placed on a door frame and were tested for their response to human action. Section 2 describes setup for experiments.

The Table 2 shows a list of sensors that were analyzed along with their product ids and their working principle. The sensors can be categorized into ratiometric1 and non-ratiometric sensors.

Definition. 1. *Ratiometric Sensors: The output of the sensors is proportional to the input voltage. This would mean that the ADC readings would be the same for 3v and 5v input supply.*

All the sensors have a analog output and have been procured from Phidget Inc.

[1]Please refer to section 4 for details on Occupancy Estimation

SNo.	Product-id	Type of Sensor
1	1129_0	Touch
2	1103_0	Infra Red Reflective
3	1104_0	Vibration
4	1111_0	Passive Infra Red Motion
5	1108_0	Magnetic
6	1131	Force
7	1127_0	Precision Light
8	3522_0	Distance measuring

Table 2: **Phidget Sensor Table**

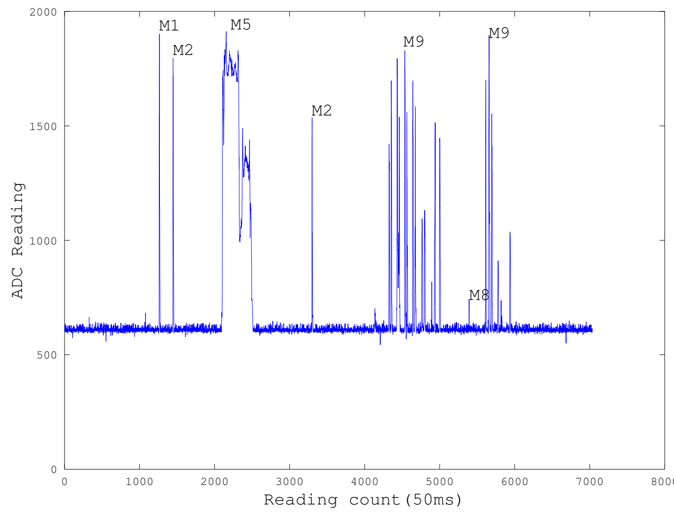

Figure 2: **Sharp Sensor: 3522_0, Position a**

3.1 Sharp Sensor: 3522_0[10]

Sharp sensor, shown on Fig. 4 has a infra-red transceiver on board, it measures the distance from a object in the range of 20 cm to 150 cm. The sensor finds out the distance by triangulation method i.e. it actually measures the angle of reflection, and generates readings corresponding to that angle, thus the reading are inversely proportional to the distance.

Sharp sensor is connected with 3v port of the Z1 mote. When an object is out of its range, the sensor ADC readings are in the range of $900 - 1000$. When placed on the side positions of the door frame (positions b, d), where the sensor receives a reflection from the opposite side of the door, the sensor readings are in the range of $550 - 600$. The sensor readings are the their highest (reaching 2000), when the distance from an object is in the range of 10cm to 20cm. If the object is closer than 10 cm, the sensor readings move to the range of 900 to 1000. The sensor readings stay in the range of 1900 to 2000 when object is between 10 cm to 20 cm. As the width of the instrumented door is about 70cm, when a person walks across without both shoulders crossing the door at the same time, the readings take the range of 1900-2000 (maximum range).

Fig. 2 shows the response of the sensor when it is placed

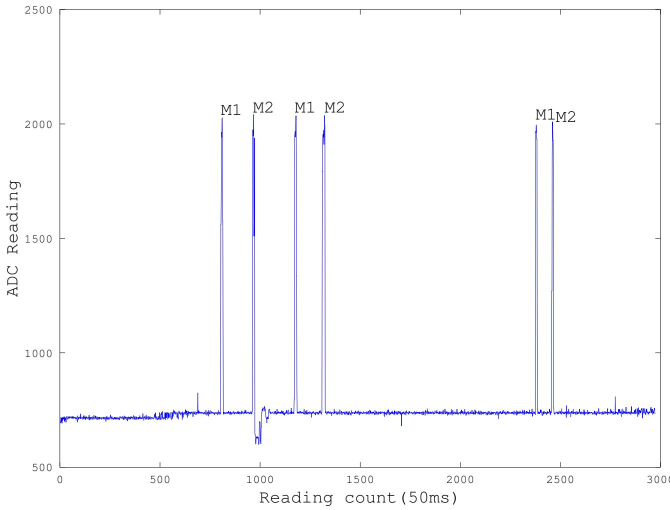

Figure 3: **Sharp Sensor: 3522_0, Position b**

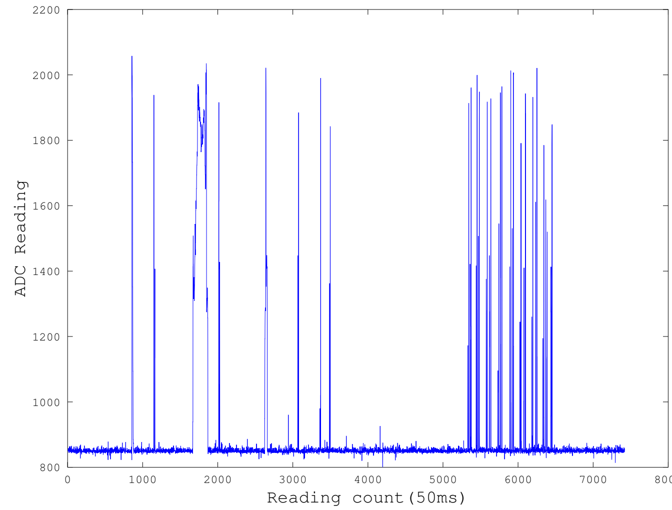

Figure 5: **Sharp Sensor: 3522_0, Position d**

Figure 4: Sharp Sensor 3522

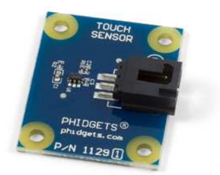

Figure 6: Touch Sensor 3522

at position a (top of the door frame). Notice that for motions M1, M2 the readings are greater than 1500. When a person walks across the door avoiding the center the readings can come down to levels of 750-800 or not change at all, label M8 and some reading labeled as M9 shows this case. Fig. 3 shows sensor's response when placed at position b (waist height on a vertical side of the door). The consistency in the response to motions M1 and M2 is because of crossing the door with both shoulders entering at the same time. Fig. 5 shows the response of the sensor when placed at position d (towards the bottom of the frame), at a position where it can detect individual legs. This gives near consistent pattern of high peak followed by low peak, or a low peak followed by high peak. This pattern represents the different distances of a person's legs from the sharp sensor on the side wall of the door frame, such a pattern could be used to detect if a human is involved in a motion.

Limitations

- **Resilience** The sensor is susceptible to deposition of dust or any other material that would block the IR waves from the receiver.

- **Corner case** A single sharp sensor will only be effective if the width of the door is less than its maximum range. For the sharp sensors (3520-3522) on the door number 468, all of them could be tricked by walking in very close to the opposite side of the sensor.

- **Calibration** The sharp sensor would need calibration once for every door. This is better than light sensor which would need to be calibrated from time to time even for a particular evaluation.

- **Default value** When the sensor faces an object that is either too close ($1cm - 2cm$) or it has no object in the vicinity, it takes to the ADC value of 900-1000. This range also represents a genuine presence of an object. Therefore without a favorable context to these readings they may be ambiguous. Where a favorable context could either be a rising or a falling pattern of ADC readings which indicates a genuine object.

Note: All distances mentioned above are approximate, they have not been measured.

3.2 Touch Sensor: 1129_0[11]

Touch sensor, shown on Fig. 6, detects touch based on principle of capacitance. The specifications[11] claim that the sensor detects touch from glass, paper and plastic. Since it is based on capacitance, it would possibly sense any material that does not have a very low dielectric constant.

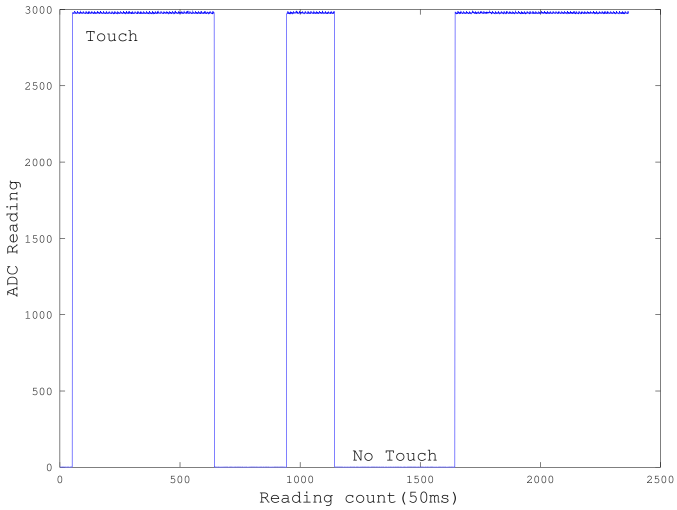

Figure 7: **Touch Sensor: 1129_0**. Touch sensors response to human touch at 5v input supply, response for other materials is similar.

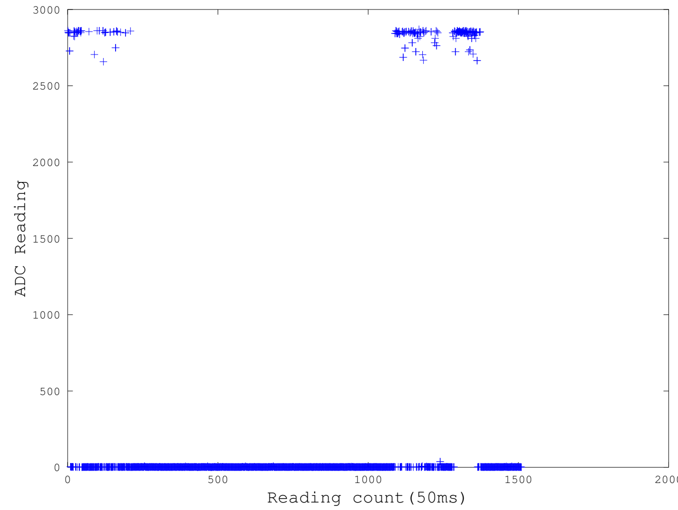

Figure 8: **Response of IR -Reflective sensor to hand**. Hand is kept at a distance of 5 cm from the sensor, for a input supply of 5v

This sensor was tested with human touch, metal and desk surface. The sensor also detects objects that are close enough (1 cm) but do not touch the sensor. The response of the sensor can be seen in Fig. 7, when the sensor is touched the readings are in the range of 2990-2999. When the sensor is suspended the readings drop to the range of 1-2. The sensor is ratiometric and thus has the same response for 3v.

Limitations

- **Sensitive Region:** It is important to note that the entire circuit board of the sensor it sensitive. Therefore it has to be suspended by the wire in order to not detect touch. Alternatively a material with a very low dielectric constant could possibly be used as insulation[2].

- **Limited Range:** Due to the limited range of 1cm - 2 cm the sensor cannot be used for occupancy estimation. Also, it cannot be used to detect whether the door is open/closed, as the detection can be triggered by any material.

3.3 IR(Infra-Red) Reflective Sensor: 1103_0[12]

Infra-Red sensor, shown on Fig. 9 detects the presence of a highly reflective object within range of 10cm. It can detect objects which are less reflective up to a range of $5cm$ [3], as also claimed by the specification [12].

[2]No insulation material has been tested

[3]Phidget Inc. has come up with revised sensor. As per specifications reflective properties of the object no longer matter

Figure 9: Infra-Red Sensor 1103

Fig. 8 shows the behavior of the sensor when a less reflective object such as a hand is kept over it at a distance of about 5 cm. When the sensor does not detect any object, the ADC readings are in the range of 2900-2990, when the sensor detects an object the readings drop to a range of 1-10. As can bee seen from the Fig. 8, the sensor does not detect the hand several times as their are multiple readings with values more that 2900. The occasional non-detection is because of the irregularly curved surface of the hand, which even when moved slightly, can cause loss of detection. The sensor is ratiometric therefore the ADC readings for 3v are similar to that of 5v.

Limitations

- **Missing detection** As has been stated above, the sensor does not always detect an object within range specially if the surface is not very reflective.

- **Limited Range** As with the Touch sensor in section 3.2, due to its limited range the IR-reflective sensor is not suitable for occupancy estimation.

- **Detecting light sources** As per specifications [12], the sensor cannot detect bright light sources such as a light bulb.

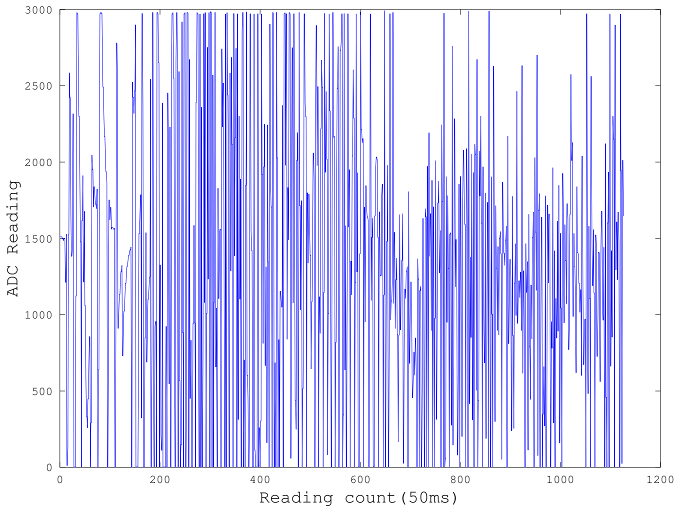

Figure 10: **Vibration Sensor: 1104_0**.Constant tapping with fingers

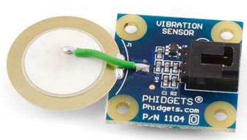

Figure 11: Vibration Sensor 1104

3.4 Vibration Sensor: 1104_0[13]

Vibration Sensor, shown on Fig. 11, is a piezoelectric buffer, which reacts to strain experienced when it is displace from its axis. The axis of the piezoelectric is horizontally along the surface of the circuit board. Its ratiometric 3V readings are the same as its 5v readings.

In the absence of a source of vibration which could be coupled with the piezoelectric disk, the following techniques were used to generate vibrations:

- Tapping the sensor : can be detected, see Fig. 10
- Pushing the sensor disk upwards : can be detected 12
- Detecting vibrations of cell phone: is not convincingly detected

The ADC readings are roughly proportional to the force applied in either direction. If the piezoelectric disk is pushed upwards, the readings increase to to a level of 2900-2990. If the disk is pushed downwards the readings start decreasing and plunge to level of 2-10. After being pushed when the disk is released the disk would start to oscillate, thus the readings also oscillate and finally die out and stabilize with ADC readings at 1380-1593, indicating the no-vibration range for the sensor. The readings are similar for input of 3v.

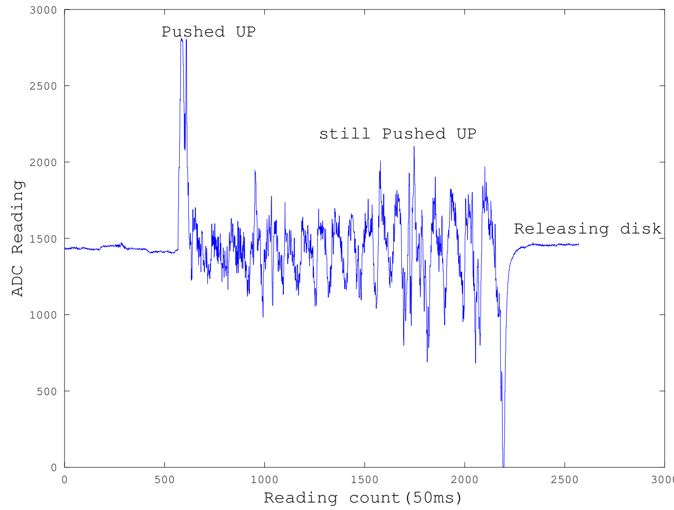

Figure 12: **Vibration Sensor: 1104_0**. Pushing piezoelectric disk upwards. After being pushed up, the readings stabilize and oscillate within 1000-2000. When the disk is released, as a reaction the disk is pushed downwards by the axis, which plunges the readings to 0.

Fig. 10 shows the response to continuous tapping,where the readings fluctuate in the entire range of ADC values. Fig. 12 shows the response to the disk being pushed upwards.

Limitations

- **Experimental limitations** A better performance evaluation of the sensor would need the sensor firmly mounted with screws to a stable surface. The disk needs to be coupled with vibration source (or left suspended in the air), such that surface and the disk vibrate as a single entity. The current setup is inadequate to completely asses the performance of the sensor.
- **Delicate device** As the specifications mention [13], the piezoelectric disk is not intended to be bent. If jerks from vibration bend the axis, it can damage the sensor.
- **Suitability for occupancy** The was pressed to the floor with a hope to detect vibrations from foot steps. The sensor could not detect any vibrations, thus it is not recommended to be used for estimating occupancy.

3.5 Motion Sensor : 1111_0 [14]

Motion sensor, shown on Fig. 14, is sensitive to change in temperature (infrared radiation) of the surroundings. It can sense moving object up to a distance of about 5m. The sensor is not sensitive on its side walls, the cylindrical sensor is sensitive only to radiation at the top face, thus it

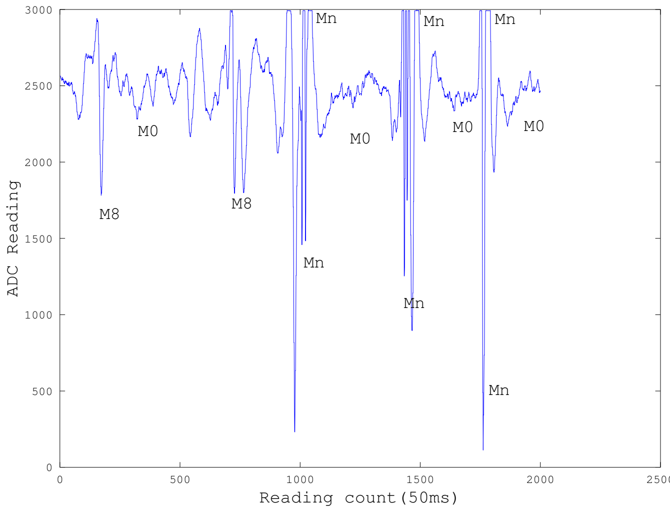

Figure 13: **Motion Sensor: 111_0, Position a**. If the oscillations are of a lower amplitude, it could be noise from stationary object, motion M8 denotes these instances. Motion M0 denotes no motion. Mn where n is in 1,2 denotes moving or moving out.

Figure 14: Motion Sensor 1111

has narrow sensitive region. The sensor in not ratiometric [4], both 3v and 5v have different ranges.

When there is no motion around the sensor, the ADC readings fluctuate in the range of 1248-1796 for 3v and are in the range of 2300-2600 for 5v. When then sensor detects motion the sensor readings fluctuate in the range of 2998-17. The magnitude of oscillation amplitude (range of oscillation) indicates the change in the amount of radiation experienced by the sensor, which can be related to the size, temperature, distance and speed of the moving object. For instance fluctuation caused by a hand at a short distance (1cm-5cm) would be equivalent to the fluctuation cause by a moving human body at a slightly longer distance of 10cm-20 cm. Fig. 13 shows the response of motion sensor when placed on the door frame. Notice the different amplitudes of oscillations for each separate motion. Higher the amplitude of oscillations more is surety of motion.

Limitations

- **Limited Positions** When motion sensor is placed on the sides of the door frame (positions b,d), it detects people moving across the sensor even at a distance of 5m. This can lead to noise and false positives. This can be curtailed by placing the motion sensor on the top of the door frame (position a), such that it only remains sensitive to motion that is relevant to us. Although it still does remain sensitive to motions M3,M4 (moving along the door).
- **Stationary Objects** If a person simply stands in front of the sensor, the sensor oscillates in a range of *'base value-maximum'*, the base value depends on the input voltage and where as maximum is always at 2998.

[4] specifications claim the sensor to be ratiometric

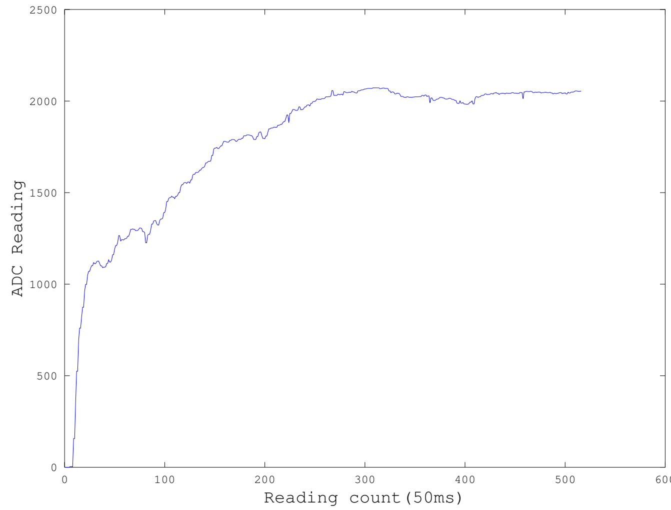

Figure 15: **Thin Force Sensor: 1131, at 5v**. A finger is pressed to the sensor film, such that it covers the entire area of thin film. Force is gradually increased till the readings do not increase any further

Figure 16: This Force Sensor 1131

3.6 Thin Force Sensor: Phidget Sensor 1131[15]

Shown on Fig. 16, the thin force sensor has a thin film which is sensitive to application of force. The Thin Force Sensor can measure force of up to $2kgs$, the output ADC readings increase with the increase in force applied to the sensor. It is claimed to be a ratiometric sensor[5].

[5] Could not be verified

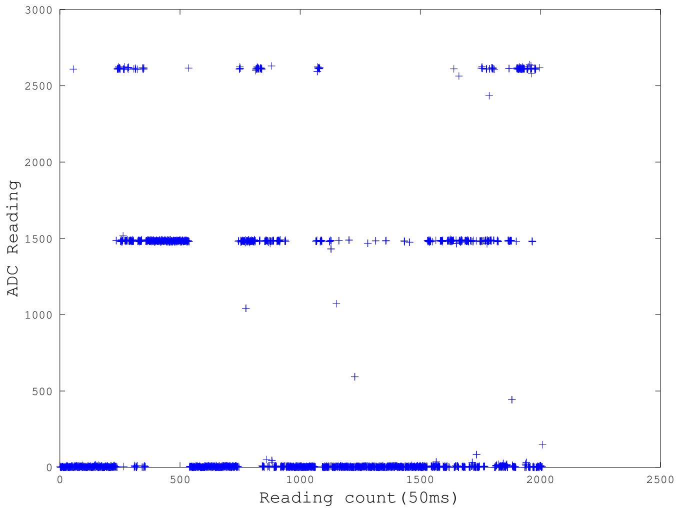

Figure 17: **Magnetic Sensor : 1108_0**. No magnetic field is applied, the sensor does not stabilize on a particular range.

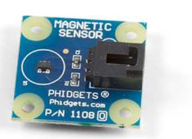

Figure 18: Magnetic Sensor 1108

With no force applied to the sensor the ADC readings are in the range 1-2 at 5v input supply, but are in the range of 0-29 for 3v input supply. The ADC readings increase with increasing force to the maximum value of 2384. Application of same force to lesser area of the sensor will generate lower ADC readings as compared when similar force is applied to the entire sensor. The accuracy of the ADC readings was not measured, the figure 15 shows the application of force on the sensor.

Limitations For occupancy estimation the sensor could have been used to detect force exerted by footsteps on the sensor, which could have been used as secondary input for confirmation sake. However the following reasons make it unsuitable:

- **Small Area:** The thin film sensor area is very small. For detecting feet on person entering the door would need at about 5-10 sensors.

- **Max force of 2 kg:** The sensor could be triggered by a falling object of more than 2 kg, which lead to false positives.

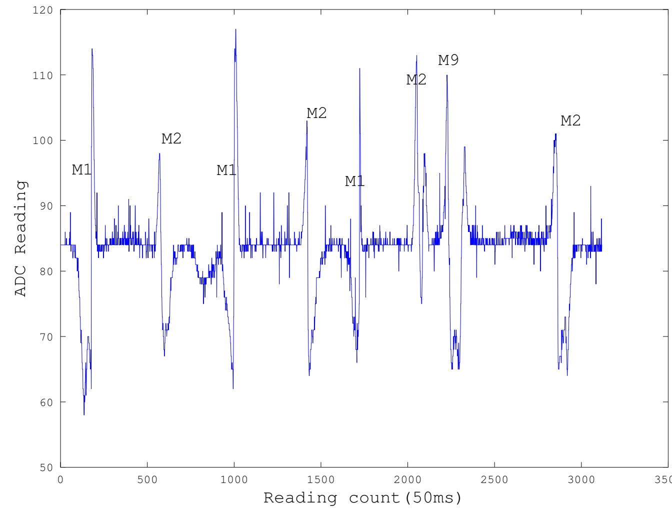

Figure 19: **Light Sensor:1127, input 3v at position b-i (b + facing diagonally**. When M1(person walks out) light is blocked first, then it reflects from the back of the person and falls on the sensor. The opposite sequence takes place with motion M2 (walking in the room).

Figure 20: Light Sensor 1127

3.7 Magnetic Sensor : 1108_0[16]

Magnetic sensor, shown on Fig. 18, senses the magnetic field and represents it in terms of voltage level. It is a hall effect sensor. As per specifications the sensor has a measurement error of 0.5%. The sensor was not found to be consistent with its readings when tested with Neodymium magnets[6].

The magnetic sensor readings did not settle down to a range of values even when there was no magnetic field applied to the sensor. The readings change arbitrarily even when touched with fingers or when the connecting wires were twisted. Fig. 17 shows a plot where no magnetic field was applied to the sensor, notice that the readings do not stabilize on a particular range.

3.8 Precision Light Sensor : 1127_0[17]

Precision light sensor, shown on Fig. 20, measures the luminosity or the intensity of light falling on the light sensor. Light sensor revision 1127_0 can measure human perceptible light in the range of 1 lux to 600 lux when connected

[6]There could be manufacturing fault with the sensor

with an input voltage of 3.3v. With 5v input supply the sensor can measure light up to 1000 lux. Indoor Light Sensor: 1142_0 has been replaced by Phidget Inc. The new version claims better precision and consistency of readings between different two different units of the sensor. For the experimental setup explained in section 2 both the versions were found to be equivalent in terms of behavior. The sensor is not ratiometric.

As per specifications, the ADC readings of light sensor might vary from unit to unit, and thus each light sensor would **have to be calibrated**. Therefore the response of sensors as seen in Fig. 19 might vary in terms of the ADC readings, though the behavior patterns of the sensor would be the same.

When the lights in the room are switched on, for input voltage 5v, the ADC range is about 990-1045. With lights switched off, the sensor readings falls, but detects the faint light coming from the windows. The sensor reaches its maximum value(2982) when light from a camera flash light is shown on the sensor.

Importance for Occupancy Estimation When the sensor is used with the door for occupancy estimation, a unique pattern can be observed for the ADC readings, which can under certain conditions differentiate between a person walking in, and a person walking out. This can be seen in the Fig. 19 where individual motions can be identified. This is more prominent in cases where the light sensor has a bias towards the one of the light sources: lights inside the room, lights in the hall. This can be either due to a diagonally positioned light source or due to one of the light sources being more effective than the other.

Limitations

- **Calibration** As ambient light in rooms changes with time, the light sensor would need to automatically re-calibrate ambient light, in order to sense motion properly.

- **Movement Direction** The different pattern for ADC readings is not fixed for motion M1 or M2, with light conditions changing, the pattern may reverse or may not be observed at all. Section 5.1 offers solutions to this problem.

- **Extreme Light Conditions** The sensors will not be useful for occupancy estimation in either absolute dark or with extreme bright light (with multiple light sources). In either case the sensor will not be able to detect a change.

4 Occupancy Estimation

As has been mentioned in section 1, this paper attempts to find a solution to the problem of occupancy estimation by instrumenting the door with Analog *Phidget* sensors and tracking the direction of human motion. The significance of occupancy estimation was discussed briefly in section 1. This section describes the progress made towards designing and implementing the algorithm for occupancy estimation. The design assumes the same setup discussed in section 2.

4.1 Objectives for Occupancy Estimation

The primary objective of estimating number of people in a room with the help of data obtained from Phidget Analog sensors connected to Zolertia Z1 [6]. The sensors will help keep track of people entering and leaving the room. Other important objectives are as follows:

- **Minimal Communication:** In order to avoid network latency issues and achieve lower usage of power, the wireless motes should send minimal data.

- **Easy Relocation:**[7] The algorithm should not be restricted to a particular installation setup. Deployment at a new location should need change in the algorithm.

- **Maintenance Friendly:** The same program should be used for all Phidget ADC sensors. All sensor specific changes should be possible from the Swift Fox [5] configuration file. This will also make the deployment easier.

4.2 Algorithm for Motion Detection

Assuming it takes 100 ms to cross a door, each mote connected to the sensor has to sample the sensor at least at 50 ms, in order to not miss a person crossing the door. Considering occupancy estimation for home or office, the sensor in most cases will not be sensing motion. Therefore, raw data from the sensor is first processed by the node and a decision about motion is made by the local node. The FSA for detecting motion is shown in Fig. 21. As can be seen from the Fig. 21, the mote changes state from being NORMAL(no motion) to MOVEMENT(motion) based on the value of a score. The following section explains how scoring works.

4.2.1 Scoring Algorithm

None of the sensors discussed guarantee complete accuracy in detecting motion. Read limitations of each sensor from section 3. In order for a mote to make a decision about the state of motion, it needs to follow a pattern like humans do when looking at a plot of sensor readings. For instance, see figure 19, a person can visually identify M1 and M2 motions as patterns of *decreasing, increasing* and *increasing, decreasing* values respectively. The following

[7] Not considered in the current design

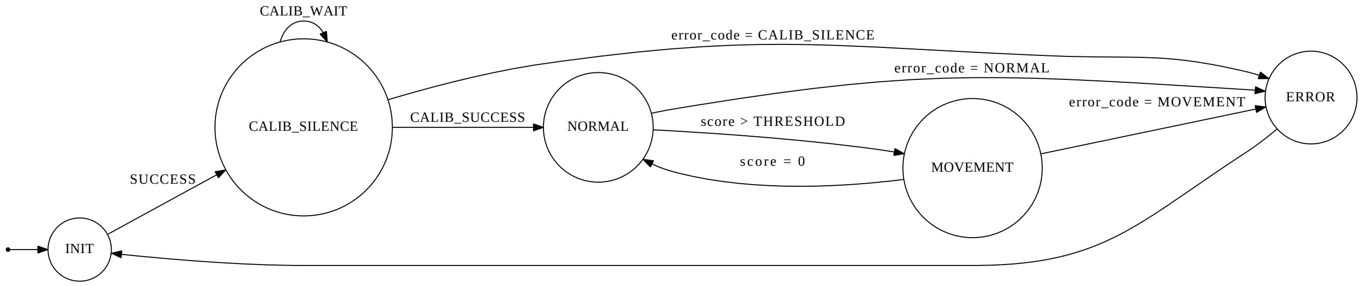

Figure 21: **Generic Algorithm for detecting motion**. Algorithm will determine the internal state of a mote. Each mote will send the its new state to the central mote for analysis of direction.

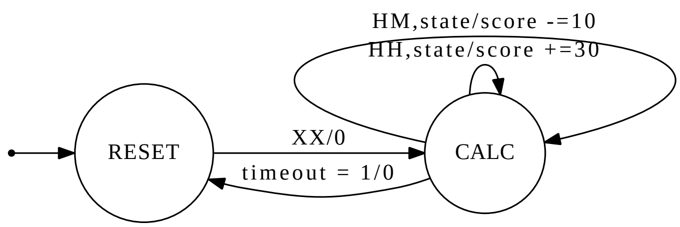

Figure 22: **FSA for Scoring Algorithm**. Raw data from sensor is slotted into a category. Each type of sensor has a specific implementation for scoring. Slotted category and the current state of the mote decide the change to the score.

list explains the flow of operations for the scoring algorithm:

- **Slotting Data:** Since behavior of sensors are associated with ranges of ADC values. Raw data values are put into behavior ranges or slots, thus converting raw data to have logical form, where data input now is in the form of slot, which has a particular meaning for the sensor. Table 3 shows the slots for the Motion sensor.

- **Calculating change in score:** Based on the information available: data slot, previous slot and expected behavior of the particular type of sensor with these slots, this stage comes with the value to either increment or decrement the score.

The scoring algorithm implements the pattern for mote, which increments or decrements the score taking into account the following:

- **Type of Sensor**

- **Input Voltage:** Non ratiometric sensors have different ranges for 3v and 5v input supply.

- **Current Slot:** Range in which the current data point is slotted.

Range	Interpretation for Scoring
> 2800	Object present for sure
$2800 - 2000$	Object present/Noise
$2000 - 1500$	Noise/Normal
$1500 - 1000$	Noise/Normal
$1000 - 500$	Movement for sure

Table 3: **Interpretation of Slots for Motion Sensor[14]**. After considering other inputs for scoring, the interpretation would translate to a change in the score.

- **Current State:** Depending on the current state, the magnitude of change to the score may vary, e.g. if a mote is in NORMAL state, if the current raw data suggests motion, the score would be incremented significantly, else if it is in the MOVEMENT state, the score would remain unchanged.

Slotting Raw Data For the current implementation raw data is slotted into ranges based on information of calibration and the ranges identified in section 3. Table 3 shows the interpretation of slots for Motion Sensor. For sensors that do not need calibration (Motion sensor), the range table would remain the same, it will have to be update for light sensors (periodically), sharp sensors (from location to location).

4.2.2 FSA for Motion Detection

The following provides an explanation of the FSA in the Fig. 21:

- **INIT:** The state does the initialization, and also acts as a reset state.

- **CALIB_SILENCE:** Based on the type of sensor, calibration is initiated, once the calibration finds a base value for a sensor, the sensor is ready to detect motion.

- **NORMAL:** The mote does not detect motion in area covered by the sensor.

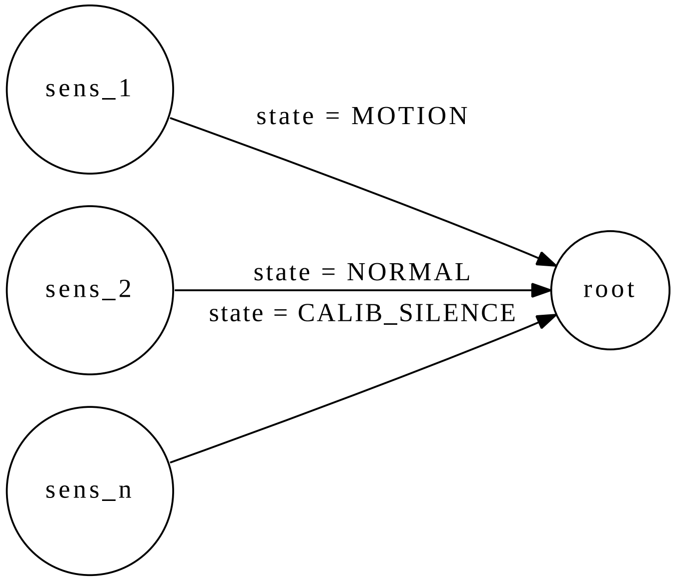

Figure 23: **Proposed System Architecture**. Motes with sensor only send information about the current state

- **MOVEMENT:** The mote can confirm motion in the area covered by the sensor.
- **ERROR:** The mote visits this state if anything unplanned happens[8]. It is sent to the INIT state to reinitialize.

4.3 Proposed System Architecture

The architecture envisioned from the point of the application is a two level tree with central mote at the top and the motes with the sensors on the second level. See Fig. 23, motes at the lower level would be connected to the analog sensors. These sensors will be instrumented on the door. In order to make an informed decision at the root node, the 2-level motes will send the following information:

- **Current State**
- **Previous State:** Information is only sent on change of state.a
- **Direction:** If the sensor can decipher a direction of motion[9].
- **Type of Sensor:** Motion, Light, Sharp or any other sensor.
- **Position of Sensor:** The standardized position of the sensor. See Fig. 1 for an illustration of positions.
- **Data:** N-number of raw data points.

[8]It has been merely used as a debugging construct. As of now it as a dummy implementation

[9]Only light sensor[17] can decipher direction of motion under certain conditions, see section 3.

The above mention list serves as the network packet format for the 2-level motes.

4.4 Suitable Sensors

Based on the sensor evaluations in section 3, the following sensors are suitable for Occupancy Estimation:

- **Sharp Sensor : 3522** [**10**]
- **Light Sensor : 1127_0, 1142_0** [**17**]
- **Motion Sensor: 1111_0** [**14**]

4.5 Implementation Status

As of writing this document, the implementation for this algorithm in nesC is incomplete.

5 Suggestions and Feedback

This section offers a few suggestions which could help future researchers interested in continuing the research.

5.1 Sensor Combinations

Individual sensors are not fool proof as each of them has certain weaknesses. A combination of sensors is expected to give better results. Section 4.4 lists the sensors suitable for occupancy estimation. The following list has two suggested combinations of sensors with their positions(indicated in braces) on the door frame :

- 2 Sharp sensors (d, b) , 2 light sensors (b-i, b-j)[10], 1 motion sensor(a)
- 4 Sharp sensors (d, b, b-i, b-j), 1 motion sensor(a)

To summarize:

- Sharp Sensor (d) can confirm **human** movement.
- Light/Sharp Sensors (b-i, b-j) can detect direction of motion.
- Motion Sensor (a) confirms actual motion.

5.2 Open Test Bed Framework

Open Test Bed Framework [18] can be used program a group of motes connected to routers (via-usb cable) at the same time. The binary file to be programmed is uploaded to the server which in turns sends it to each router (via a wireless ad-hoc network). Serial channel output from the mote can be collected at the server via the wifi-routers. The process of installing OTF was carried out as an exercise to test OTF larger deployments in future.

[10]Refer to figure 1 for location of positions. b-j points diagonally outside towards the hall.

Experience & Feedback (OTF)

- Installing for the first time may take time.
- Installation tutorial is useful and easy to understand.
- The web interface to the OTF server could used as the interface to install the entire framework.
- **Streaming Output:** Streaming output of log data rather than transferring an entire file could reduce log latency and could open possibilities of using tools for analyzing data at the user end.
- **Two-way serial communication:** The web interface could communicate with the sensors at runtime by enabling two way serial communication between router and the mote.

5.3 Overall Feedback

Logging data for occupancy estimation could be made more efficient if there could be 2 persons working. One could perform the motions and the other could log and analyze data. This could save time and improve the quality of data being logged. It would be nice to decide to have limiting scope and long term vision for the project.

6 Conclusion

Out of the all the sensors analyzed, Sharp sensor, Light Sensor and Motion Sensor were found suitable to use for occupancy estimation. Touch sensor, thin force sensor and infra red reflective sensors operated as per their expected behavior[11]. Magnetic sensor did not exhibit consistent behavior, neither did the specifications match with its behavior. Algorithm for detecting movement and estimating occupancy was designed. Future work would involve completing the implementation of the algorithm and testing the system for estimating occupancy.

[11] Claims of accuracy could not be tested

References

[1] P. Inc., "Phidget inc." www.phidgets.com/, 2012, [Online; accessed 18-Oct-2012].

[2] J. Stankovic, I. Lee, A. Mok, and R. Rajkumar, "Opportunities and obligations for physical computing systems," *Computer*, vol. 38, no. 11, pp. 23–31, November 2005.

[3] T. Hnat, E. Griffiths, R. Dawson, and K. Whitehouse, "Doorjamb: Unobtrusive room-level tracking of people in homes using doorway sensors," in *The 10th ACM Conference on Embedded Networked Sensing Systems*, ser. SenSys'12, 2012.

[4] J. Lu, T. Sookoor, V. Srinivasan, G. Gao, B. Holben, J. Stankovic, E. Field, and K. Whitehouse, "The smart thermostat: using occupancy sensors to save energy in homes," in *Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems*, ser. SenSys '10. New York, NY, USA: ACM, 2010, pp. 211–224. [Online]. Available: http://doi.acm.org/10.1145/1869983.1870005

[5] Marcin, "Swift fox," http://smartcity.cs.columbia.edu/swiftfox/swiftfox_about.php, 2012, [Online; accessed 23-Oct-2012].

[6] Zolertia, "Z1 platform," http://www.zolertia.com/ti, 2012, [Online; accessed 23-Oct-2012].

[7] Marcin Szczodrak, "Fennec fox network stack," http://smartcity.cs.columbia.edu/fennecfox/fennecfox_about.php, 2012, [Online; accessed 23-Oct-2012].

[8] Tiny OS Community, "Tiny os," http://www.zolertia.com/ti, 2012, [Online; accessed 23-Oct-2012].

[9] M. Dhananjay Palshikar, "Application suite for wireless sensor networks: git repository," git@git.sld.cs.columbia.edu:wsn_apps.git, 2012, [Online; accessed 23-Oct-2012].

[10] P. Inc., "3522_0 - thin force sensor," www.phidgets.com/products.php?product_id=3522_0, 2012, [Online; accessed 19-Oct-2012].

[11] ——, "1129_0 - touch sensor," www.phidgets.com/products.php?product_id=1129_0, 2012, [Online; accessed 18-Oct-2012].

[12] ——, "1129_0 - ir reflective sensor," www.phidgets.com/products.php?product_id=1103_0, 2012, [Online; accessed 18-Oct-2012].

[13] ——, "1104_0 - vibration sensor," www.phidgets.com/products.php?product_id=1104_0, 2012, [Online; accessed 18-Oct-2012].

[14] ——, "1111_0 - motion sensor," www.phidgets.com/products.php?product_id=1111_0, 2012, [Online; accessed 18-Oct-2012].

[15] ——, "1131_0 - thin force sensor," www.phidgets.com/products.php?product_id=1131_0, 2012, [Online; accessed 19-Oct-2012].

[16] ——, "1108_0 - magnetic sensor," www.phidgets.com/products.php?product_id=1108_0, 2012, [Online; accessed 18-Oct-2012].

[17] ——, "1127_0 - precision light sensor," www.phidgets.com/products.php?product_id=1127_0, 2012, [Online; accessed 18-Oct-2012].

[18] M. Szczodrak, Y. Yang, D. Cavalcanti, and L. Carloni, “An open framework to deploy heterogeneous wireless testbeds for cyber-physical systems(submitted),” *ICCPS 2013*, 2012.