Embedded sensorboard sensor test

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1 Introduction

The purpose of this document is to summarize our initial impressions and knowledge about the sensors mounted on the *Embedded sensor board* (ESB) sensor module. This document is evolving, i.e., it should grow and change with further and improved experiments.

The ESB was designed by the CST group at Freie Universität (FU) in Berlin, and has its own webpage, `http://www.scatterweb.com`.

A picture of the ESB identifying some of its components is shown in Figure 1. The ESB provides two to main functionalities: *communication* and *sensing*. Communication is performed by three means: radio, (wired) serial, and infrared. The radio communication is handled by a TR-1001 transceiver. The serial interface is shown in the bottom left part of the figure. The associated serial chip is right above it and is capable of transferring data at the maximum rate of 115.2kbit/s. The serial interface can also connect to a mobile phone. We do not have much information about the IR communication. The ESB can also send visual and audial signals (i.e., one-way communication) through its three light emitting diodes (LEDs) and beeper, respectively.

There are five sensors available

Movement A pyro-electric infrared sensor (PIR) that detects changes when a heat emitting source (such as a human being) passes its field of view. The PIR is covered by a so called Fresnel lens.

Light intensity Responds to infrared light in the range from 800nm to 1100nm. The light intensity sensor, just as the PIR sensor, is located under the Fresnel lens.

Temperature Measures temperatures from -55°C to +125°C, with a ±2°C accuracy.

Vibration Monitors vibrations (seismic effects) that the ESB is subjected to.

Microphone Used to detect sound up to 120dB.

The infrastructure was collecting and presenting sensor data was basically the same in all of the following experiments. One or several ESB modules were designated as *sensing*, meaning that they should collect data and continually send data packets of their observations over radio (the sensing ESBs are either stationary or mobile). A unique ESB is called *relaying* and collect all received radio packets and send them (through the serial interface to a computer that process

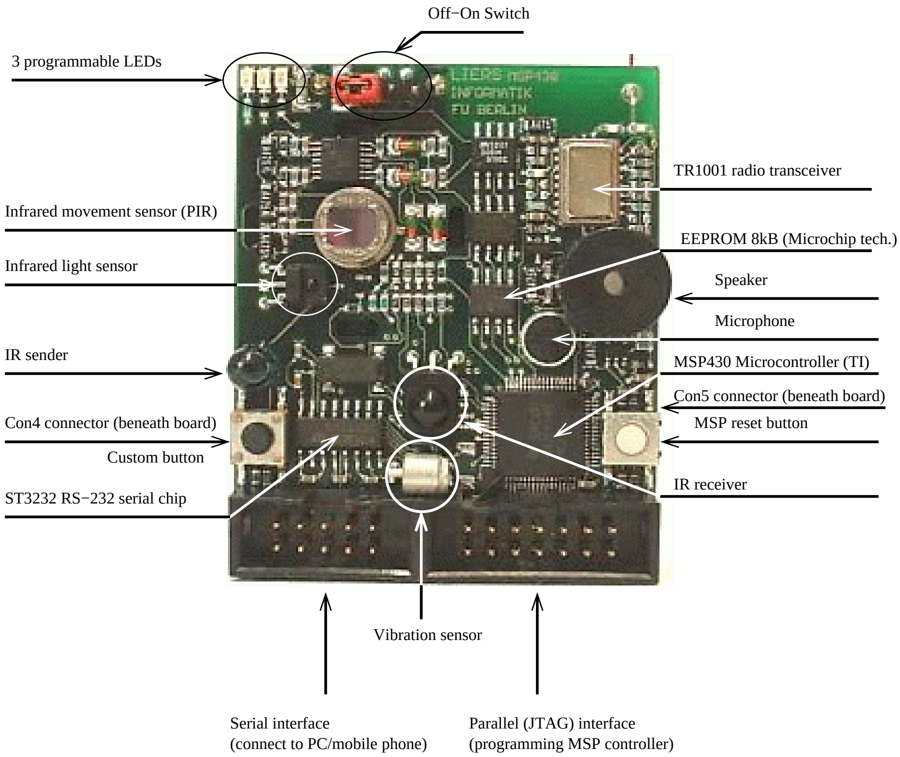


Figure 1: An overview of the ESB sensor module.

the acquired data). The situation is sketched in Figure 2. The sensing modules used the software `Sensortest_ESB` (with the compilation option "sensing") and the relaying module used the same software (but the compilation option "relaying"). The data processing computer uses the `MeasurementCollector` application developed in Java.

In Section 2, we discuss some of the properties of the sensors from our experience. In Section 3, we show some empirical results of the ESB sensors when the mounted on a mobile platform. Section 4 shows some results of using multiple stationary sensors.

2 Sensor properties of stationary ESB

The following information is mostly based on sensor tests performed in January 2005 and sensor data sheets. We focused on the sensors that appeared to be the most useful, i.e., the PIR sensor and the microphone. For the following discussion, let us denote the time interval during which measurements are made and accumulated (but not reported) *measurement interval*. At the end of the interval, the sensor counters (mentioned below) are reset to zero.

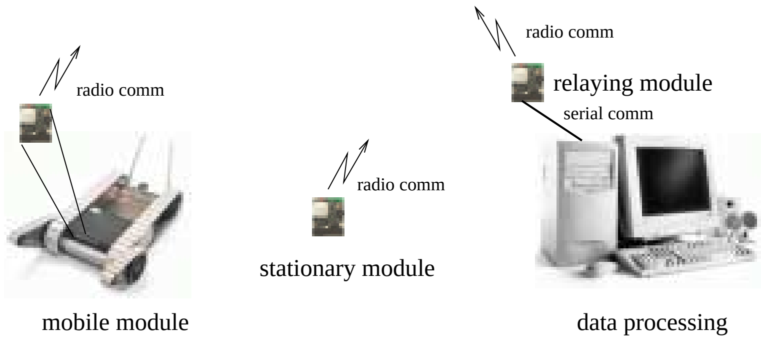


Figure 2: A simplified overview of the experiment infrastructure.

2.1 Movement sensor

The PIR sensor is sensitive to changes in the perceived infrared energy. If a deviation from the average is detected a counter (the `pir_count`) will be increased. If it was not for the Fresnel lens, the PIR sensor would only detect someone (i.e., some infrared emitting source) entering and leaving the room. The Fresnel lens splits the field of view of the sensor so that a target might leave and enter the view while moving around in the same room.

Theoretically, a PIR sensor might fail to detect a target for two reasons (if otherwise working correctly): (i) the target is moving too slow or (ii) too fast. If the target moves very slowly, the sensor will include him in the background, and if it moves very fast there may be too little time for the sensor to incorporate the change in infrared emittance. The range of speeds over which a target can be detected is called the *target velocity range*. An example is shown in Figure 3 (information excerpted from `http://www.fuji-piezo.com`).

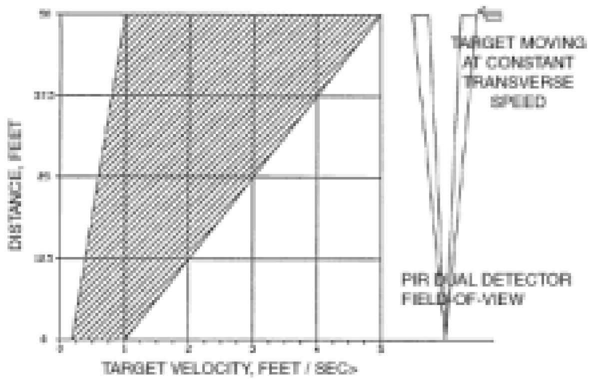


Figure 3: An example of target velocity range for some sensor.

In our experiment, the ESB was placed on chair in Gösta's room directed towards the door (the experiment setup is shown in Figure 4). We did a few experiments, most of them with satisfying results. In the straight forward direction, where the reach of the PIR sensor is the largest, a moving person could easily be detected at a distance of 4 to 5 meters (which agrees with the PIR sensor specification). We did not manage to avoid detection by trying to move very slowly or very fast. However, a consequence of the physical properties described above is that it is difficult to distinguish between a target moving slowly close to the sensor and a target moving fast farther away from the sensor.

2.2 Light intensity sensor

The light intensity is estimated with a high resolution (i.e., possible to detect small changes).

2.3 Temperature sensor

We have nothing in particular to report about the temperature sensor.

2.4 Vibration sensor

Our experiments show that the vibration sensor is not very responsive, e.g., it hardly reacts to footsteps close to the module when placed on the floor. This condition is acknowledged by the manufacturer (FU Berlin), who claim that it is most useful to detect that module is being displaced (which could initiate, e.g., some inter-sensor position calibration depending on application).

2.5 Audio sensor

The microphone is one of the ESB's most useful sensors, but it has its limitations. It reports the number of times (denoted `mic_count`) the perceived noise level was outside (above or below) a *custom interval* around a *noise average* during the measurement interval. The noise average could be updated automatically, but by default it is fixed to a specific value, 2040, which appears to be very appropriate for most ESBs. The custom interval is 90 by default.

In our experiment, we placed the ESB on a chair (at about 50 cm height) in the corridor on the fifth floor (Teknikringen 14). The experiment setup is shown in Figure 4. The custom noise interval was 100 and the noise average was the same as the default value. The ESB (and microphone) was facing the staircase (that leads down to the fourth floor). As a first *reference sound* we used the ESB beeper which is easy to reproduce and which appears to keep both a fixed frequency and amplitude. As it turned out the ESB's microphone is not very sensitive to its own beeper, perhaps due to its high frequency. At a short distance (a few decimeters) the ESB does not detect the sound at all. Although this appears to be a poor property it might also mean that the ESB does not detect the sound it generates itself (we have not tested this though).

Low pitch noise, however, is much easier for the microphone to detect. For instance, the sound of doors closing in the other end of the corridor (25 to 30 meters away) was easily detected. Even noise from different floors of the building was at times detected.

We also tested for conversation and footsteps. Conversation was detected at least 10 meters away. Footsteps, however, appeared to be more difficult to detect. Normal footsteps were detected at a distance of about 3 meters (typically

Figure 4: The ESB placed on a chair at about 50 cm height above the floor.

when the heel hit the floor). Sliding the shoes against floor instead of normal walking the person could go unnoticed.

Finally, during our experiments it became clear that it is difficult to distinguish between low pitch remote sounds and close high pitch sounds.

3 Sensor properties of mobile ESB

Initial, simple tests with a mobile ESB indicated that it the PIR sensor might be sensitive to movement, i.e., that it might give false detections while moving. The purpose of the following experiments (performed in February 2005) was to collect sensor data from a ESB when it was mounted on a moving platform (a PackBot in this case).

In this example a sensor module (labeled 2) was mounted on the PackBot to receive data. Another one (labeled 3) was connected to a work station to fulfill two purposes: (i) to receive data from the sensor 2 and (ii) to send the data to the work station for further processing. In this experiment about one packet containing sensor data was received by ESB 2 every second (some packets were lost). The experiment setup is depicted in Figure 5.

In a series of experiments, the PackBot was sent down a corridor (see Figure 6) at constant speed (but different speed for each experiment). The distance traveled for each experiment was about 23 meters.

Figure 7 shows the sensor data from an experiment with the PackBot traveling at the constant speed of 0.2 m/s. There were no targets to detect in the corridor. To be able to show all measurements in the same graph, the values are normalized (i.e., the highest value measured during the trip down the hallway is set to one).

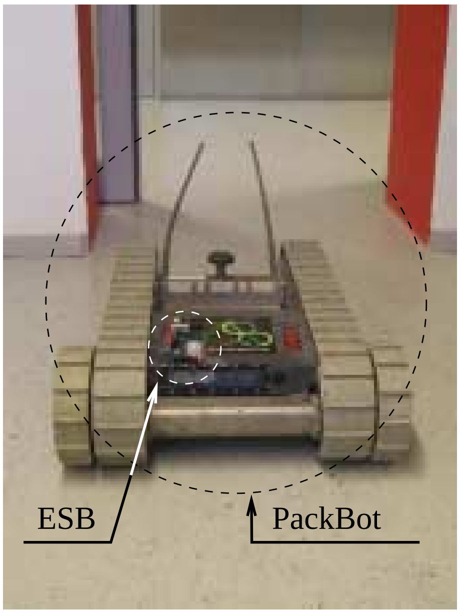


Figure 5: A PackBot with a mounted ESB module.

In the figure, the red graph with circles shows the light intensity measurements. The “hills” of the graph corresponds to the (eight) lamps in the ceiling that the PackBot passes on its way along the corridor. The vibration sensor (cyan squre) and the microphone (blue star) are heavily disturbed by the noise caused by the PackBot itself. Most interesting is the result of PIR sensor (black plus) which is zero during the whole trip. Hence, the PIR sensor was not affected (disturbed) by the travel of the ESB.

In Figure 8, we had the same experiment setup, but the PackBot traveled at speed 0.50 m/s. Here the PIR sensor appears to be affected (just as in the more simple experiment performed in January).

In Figure 9, finally the PackBot travels at 0.20 m/s, but this time a person appears in front of the PackBot (and ESB) at three occasions. This is clearly seen in the graphs.

It appears that the PIR sensor (at some speeds at least) is unaffected by the movement of the ESB. It should be mentioned that more experiments might be necessary as this experiment merely concerns the travel along a straight corridor. More complex motion patterns should be considered.

4 Multiple stationary sensors

A third experiment was performed February 27th 2005. The purpose of the test was to compare measurements made by multiple sensors (more or less) simultaneously. The result of the experiment was expected to give some ideas on how to utilize data from several sensors to, e.g., localize or classify a target.

In the experiment, three sensing ESBs were placed in a corridor. The setup is shown in Figure 10. A fourth ESB (number 1 in the figure) was used for

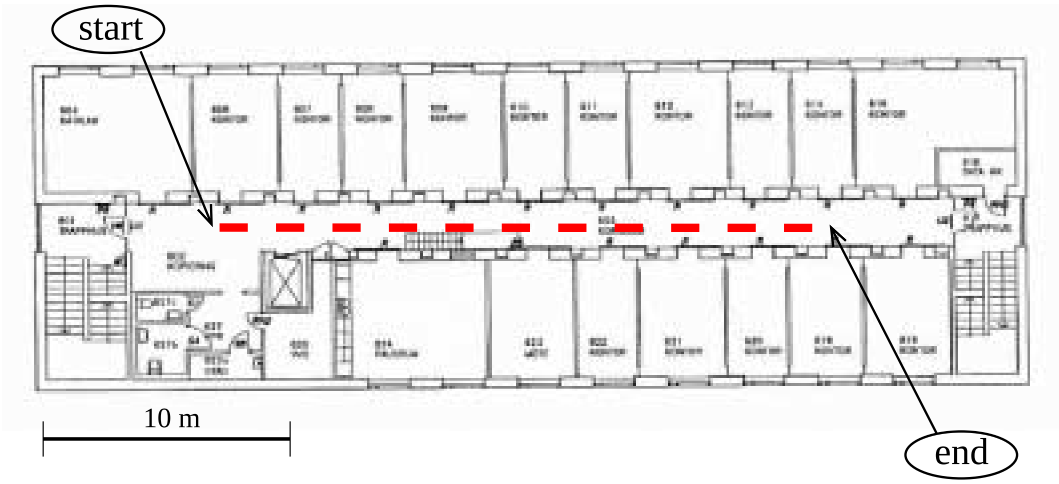


Figure 6: The approximate trip of the packbot.

relaying. A human entered the corridor from the room where ESB number one was located and walked to the door at the end of the corridor, while passing modules 2, 3 and 4 in sequence. The human finally opened the door to the stairway and exited. The passage took about 20 seconds. The readings of the sensors are shown in Figure 4. The high reading of the light intensity for the fourth ESB has to do with that it is exposed to a light source that the other two are not exposed to. The great microphone peak in the end of the time interval corresponds to the closing of the door to the staircase.

An absolute (compared to the relative values in Figure 4) comparison of the microphone and PIR readings are shown in Figure 4.

5 Multiple stationary sensors II

On May 16th some test with multiple sensors were made. Four sensors (those labeled 2, 4, 5 and 6) were used to see how the responded to the same phenomena. The sensors all have a

In the experiment, the four sensor were placed on a table (abt. 50 cm above the floor). There were placed on a line and the purpose was to examine how they (in their initial states) responded to the same type of phenomena (The experiment setup is sketched in Figure 13). The phenomena in this case were handclap sound produced at different distance from the sensors. The maximum distance was about three meters and the minimum about 50 centimeters. The results for the microphone sensors and PIR sensors are shown in Figure 5 (original data saved in file `mic_test_050516_04.m`). As can be seen in the figure the microphone response (in absolute value) is very different from sensor to sensor. The levels of sensitivity might have to be alterned to make all the sensors similar degrees in response (which perhaps is necessary for data fusion).

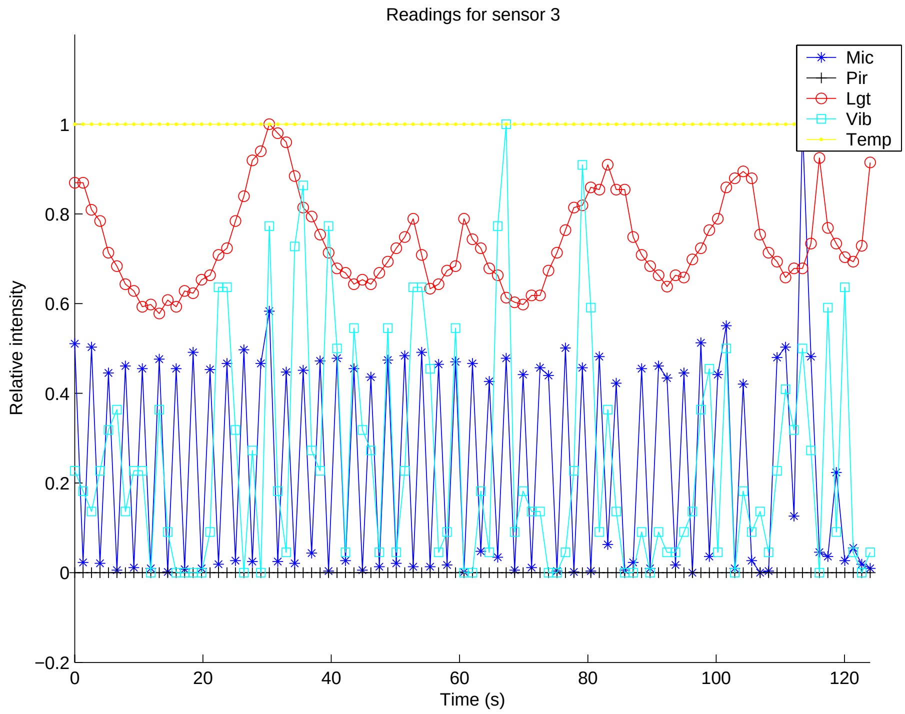


Figure 7: The PackBot traveling at the constant speed of 0.20 m/s.

6 PIR-based classification

Experiments have also been made to see if it is possible to do classification based on PIR measurements. PIR is the sensor that appears to be the most promising for classification. The temperature is not interesting in this case. The light sensor might be interesting as a support sensor (for fusion of data) if the conditions are right. For instance, if the sensor observes a light source (such as a curtainless window, or, even better, a lamp), the presumable occlusion of the lamp might indicate the shape of the object that occluded it, i.e., because it might be impossible for a very low object to occlude the lamp). The microphone may be used to confirm that something is really there. However, the microphone is highly unreliable for this purpose as it can pick up very distant sounds at the same time as it can completely miss some sounds that are close to the sensors.

It turns out that the PIR sensor measurements are distance sensitive. A human walking by the the sensor will result with very different sensor readings depending on his or her distance to the sensor. (Show figures of human walking at distance 1m and 3m)

The sensor measuremnts for another object, in our case a low mobile robot are radically different.

If the sensor has the chance to observe an object over some period of time it might accumulate observations and make a more qualified guess. . . .

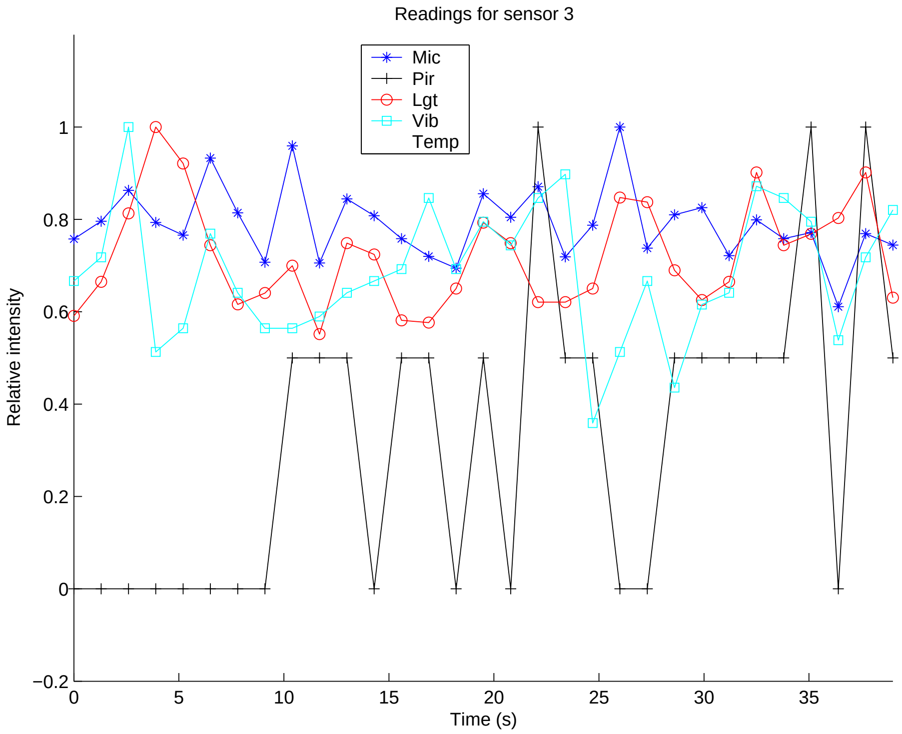


Figure 8: The PackBot traveling at the constant speed of 0.50 m/s.

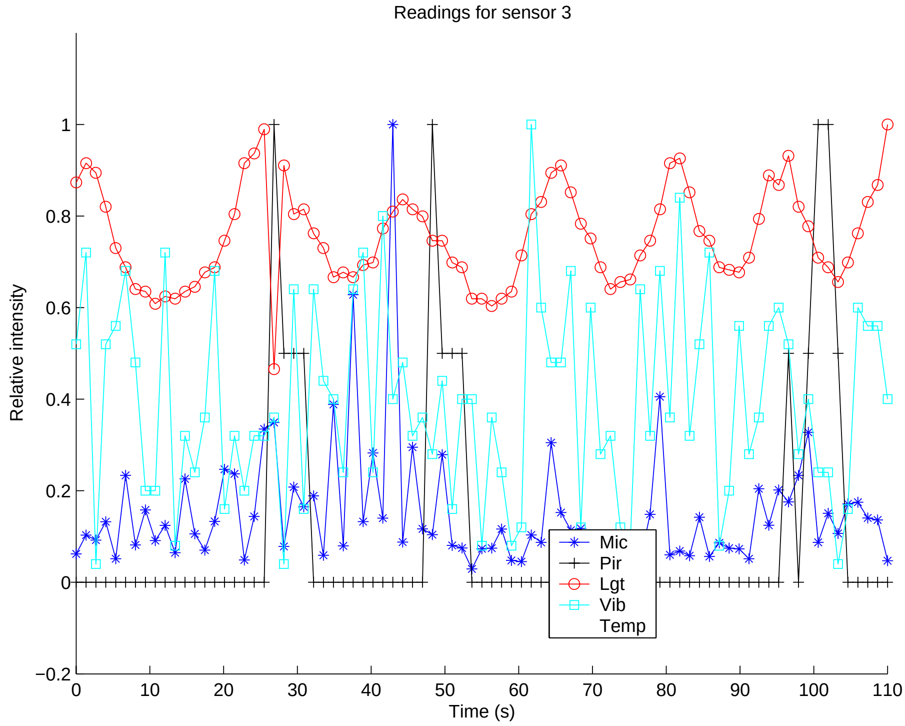
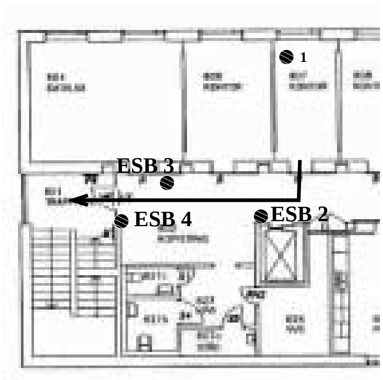


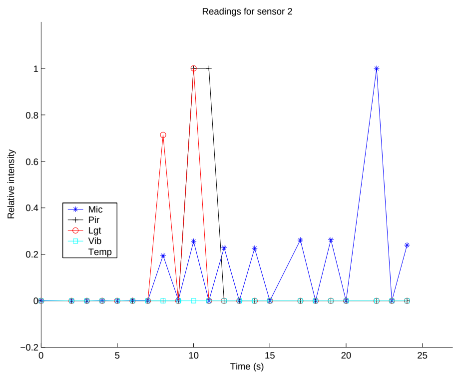
Figure 9: The PackBot traveling at the constant speed of 0.20 m/s.



(a)

(b)

Figure 10: The three sensing ESB modules (number 2 to 4) are marked on the map. A human enters the corridor from an open door and passes the three sensors in order. The human finally opens the door to the stairway and exits the corridor.



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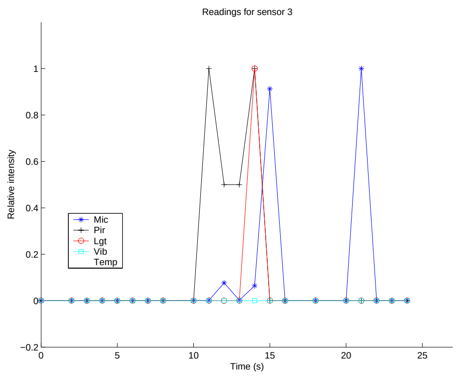

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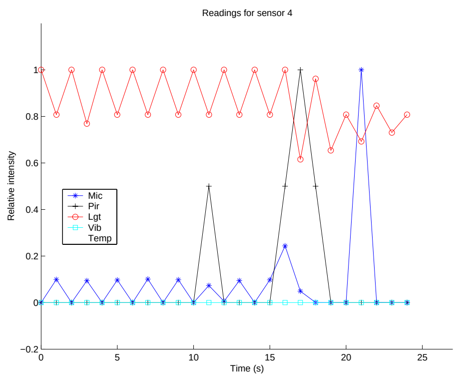
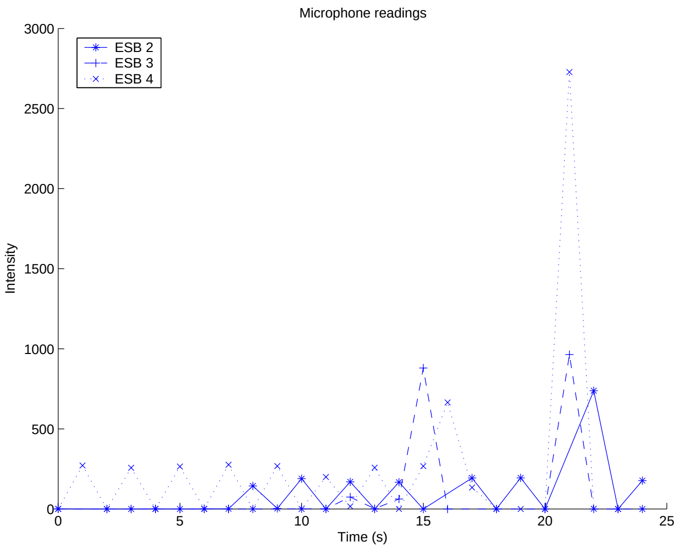


(c)

Figure 11: (a) The sensor readings of sensor 2. (b) The sensor readings of sensor 3. (c) The sensor readings of sensor 4.



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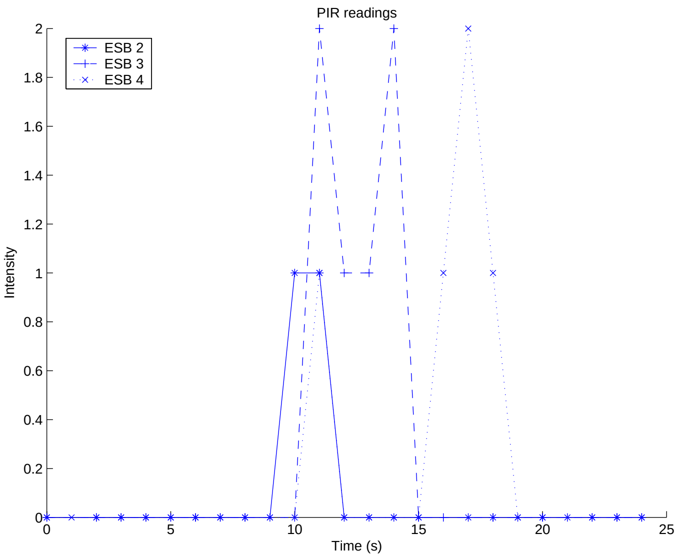


(b)

Figure 12: (a) The absolute microphone readings of the sensors. (b) The absolute movement readings of the sensors.

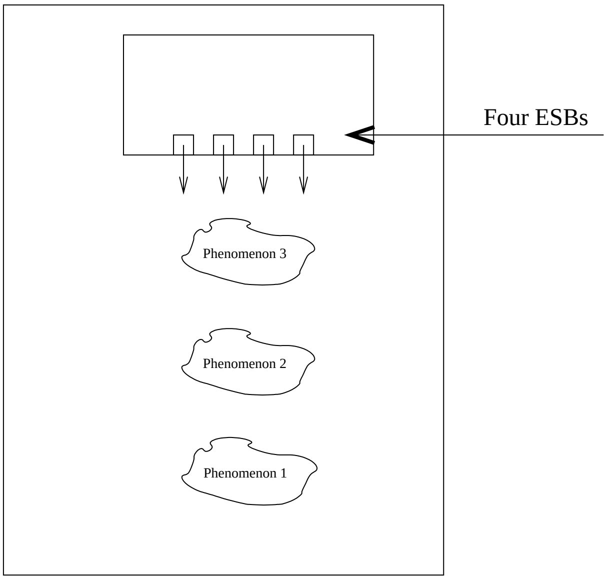
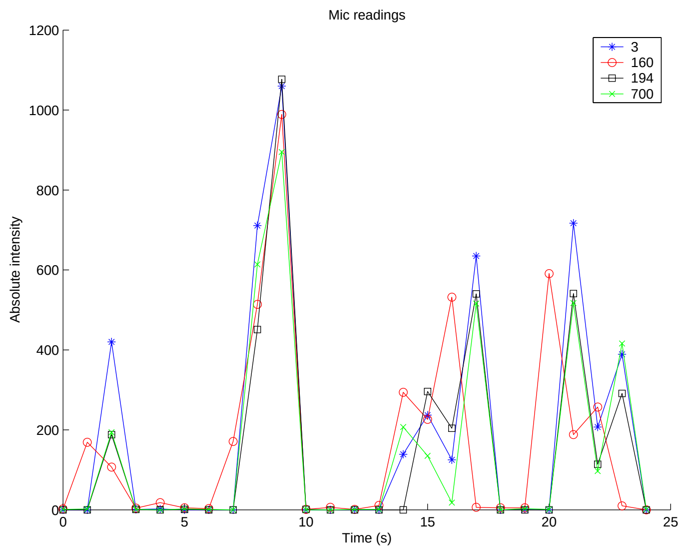


Figure 13: A sketch of the experiment setup.



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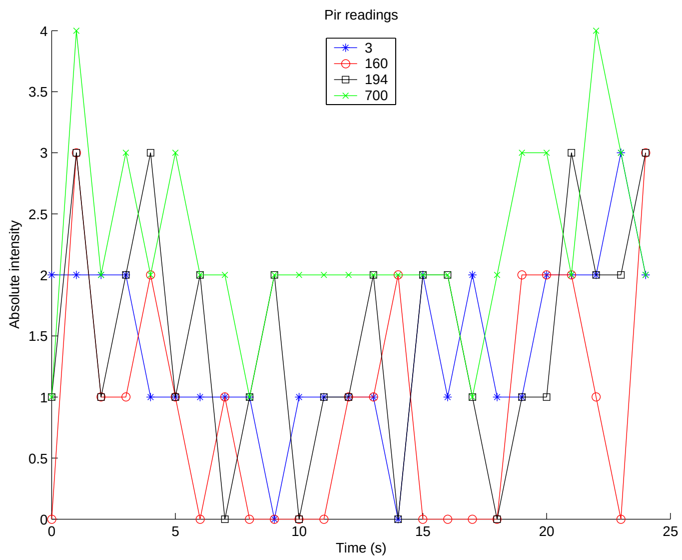

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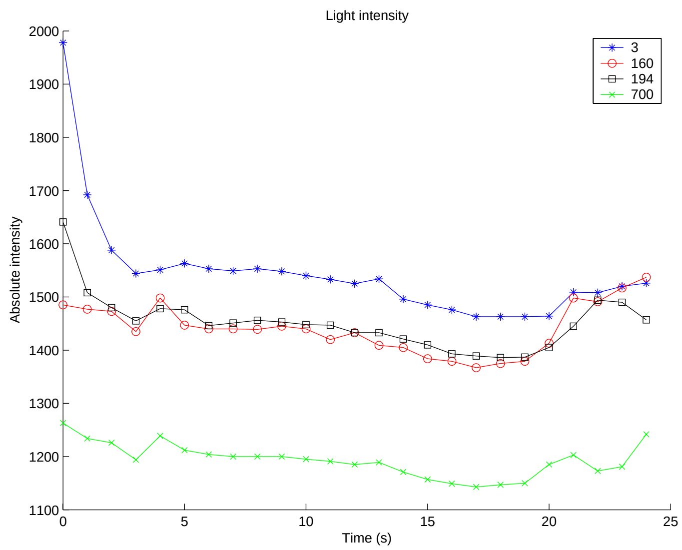

(c)

Figure 14: (a) The microphone response of the four aligned ESBs. (b) The PIR response of the four aligned ESBs. (c) The ligth intensity sensor response of the ESBs.