Uppsala University

Embedded Control Systems, Project

Wireless Tracking

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Acronyms

CSI Channel State Information.

IMU Inertial Measurement Unit.

LDCA Location with Dynamic Channel Allocation.

LED Light Emiting Diode.

LLS Linear Least Square.

LoS Line of Sight.

NLoS Non Line of Sight.

NLS Nonlinear Least Suqre.

PDR Pedestrian Dead Reckoning.

RFID Radio Frequency Identification.

RSSI Received Signal Strength Indicator.

ToF Time of Flight.

Glossary

Contiki OS Contiki is an operating system for networked, memory-constrained systems with a focus on low-power wireless Internet of Things devices.

FILA Fine-grained indoor localization. It is the name of the method.

irDA Infrared Data Association, a group of device manufacturers that developed a standard for transmitting data via infrared light waves.

LIFS Device-free localization with fine-grained subcarrier information.

Zee Zero-Effort Crowd sourcing for Indoor Localization.

Abstract

The objectives of this project are to test the feasibility of wireless nodes tracking. As result of that, it is possible to develop systems of object tracking using indoor tracking techniques that do not depend on the line of sight.
As part of our methodology, we started by discussing the current techniques of indoor tracking and compare these techniques. As result of that, We chose two techniques to be investigated, Received Signal Strength Indicator (RSSI) and Inertia Sensors. Some experiments are also conducted to test the feasibility of each technique.
In the end, the proposed solution is a system that consists of an IMU and radio frequency which can collaborate to determine and estimate as the best as they can. They are an inertial sensor, radio frequency (RSSI method), and RFID tag.

Keywords: Indoor tracking, RSSI, IMU.

1 Background

Part assembling is trivial yet important steps in the manufacturing industry. Possibly, the workers miss-assemble the parts during their work. That is because of some factors [13] such as physical conditions and work pressure. Miss-assembling could lead to loss of time and also financial losses, especially if the parts are expensive and can only be assembled once. It can be a big loss for the company if there is a miss-assembling of the parts.

And in order to avoid such case, an aid is needed to help the worker to assemble the components in an accurate and fast way. A reasonable tracking technology can be used to aid the worker and prevent any mistakes.

Visual tracking using image analysis can be proposed but as the items have different shapes so a continuous updates should be implemented, which is not feasible.

2 Introduction

Tracking objects is very important for many applications, including security, comfort and assembly. Because in many cases it is not possible or unwanted to keep visual sight of the object in certain circumstances. The main goal is to be able to track wireless nodes attached to movable objects in a small area of a maximum of 10 square meters. Therefore, the results of this project can be scaled up to bigger areas if necessary.
Many techniques can be proposed to fulfill these requirements including GPS, RSSI [12], [3], [20], [18], Ultra-wideband techniques(UWB) [8], [2], Time of Flight (ToF) [2], low human-effort, device-free localization with fine-grained subcarrier information (LIFS) [16], Inertial measurement unit (IMU), Light Emiting Diode (LED) based localization [11] and hybrid systems [15], [21], [7], [6], [17], [9], each of these techniques has it is own pros and cons and each technique can be used in according to the needs and constraints.

In this report we will briefly discuss the current state of art in indoor tracking, then we will explain an experiment to compare between RSSI and IMU techniques, finally we propose a solution to enhance tracking objects.

3 Related Work

3.1 Received Signal Strength Indication (RSSI)

Some of localization and tracking methods using RSSI are introduced in [12], [3], [20], [1], [16], [18], and [4].
In [12], an interference avoidance RSSI based indoor localization using a single anchor node with sector antennas is discussed, using sector (directional) antennas the known neighbor discovery problem is avoided.

Location with Dynamic Channel Allocation (LDCA) is used to implement interference avoidance. It has 3 phases: initialization phase, dynamic channel allocation phase, and localization phase. Through this technique a mean localization error of 0.4913m and high energy efficiency is obtained.

While in [20], an improved RSS-based lateration methods are proposed; regression-based and correlation-based; The regression-based approach uses linear regression to discover a better fit of signal propagation model between RSS and the distance, while the correlation-based approach utilizes the correlation among RSS in local area to obtain more accurate signal propagation.

The median error is improved from 21 feet to 12 feet in WiFi, and from 29 feet to 19 feet in Zigbee for Linear Least Square (LLS), whereas it is improved from 15 feet to 10 feet in WiFi and from 22 feet to 14 feet in Zigbee for Nonlinear Least Suqre (NLS).

Another similar idea is proposed in [16] which is also leverage the Channel State Information (CSI). LIFS is an accurate model-based device-free localization system. It can localize a target accurately without training and without the target carrying a device.

The basic idea: CSI is sensitive to target's location and by modeling the CSI measurements of multiple wireless links as a set of power fading based equation, the target location can be determined. After some experiments, the result is that the LiFS achieves a median accuracy of 0.5 m and 1.1 m in Line of Sight (LoS) and Non Line of Sight (NLoS) respectively.

In [18], RSSI-based localization is easily affected by multi-path phenomenon. So it is analyzed and the effect across physical layer and the account for undesirable RSSI readings being reported. Then FILA is proposed which leverages the CSI to alleviate multi-path effect at the receiver.

Another RSSI-based localization largely used is described in [4] which is the fingerprinting technique. The purpose of the fingerprinting technique is to deal with the interference created by the ambient adversities, for example, refraction.

Those interferences create a heterogeneous received strength rate across the environment in which, in many cases, becomes impossible to determine the distance between base-station and receiver.

To overcome this problem, fingerprinting is used to create a RSSI map in the totality of the monitored area. The disadvantage of this technique is the difficulty to create such map due to its expensiveness.

3.2 Inertial Positioning

Kenneth and Andrew use only IMU sensor for pedestrian tracking in [5]. Because of the drift problem, they proposed a compensation techniques which can compensate the drift by implementing a static-period and dynamic-period compensation methods that allow more accurate position estimation. The result showed that the combination method can track a normal walking condition for 50m with an average error of 1.4% . Furthermore, their system also can track with various paces, gaits, direction, and distance with the error lower than 5%.

In general, Manon et. al. in [10] says that the position estimation using IMU sensor is accurate in a short time duration, but not in a longer time duration. The estimation will have unavoidable drift that is getting worse because of double integration of the acceleration. Ideally, the IMU sensor are typically combined by another sensor to get more accuracy. But there is also mathematical approach to compensate the drift such as in [5].

3.3 Hybrid Technologies

3.3.1 Radio Frequency and Inertial Sensor

Some of localization and tracking methods using both of radio frequency and inertial sensor are introduced in [21], [18], [6], [14], and [9].

In [21] a robust and accurate indoor localization and tracking system using a smart phone built-in inertial measurement unit (IMU) sensors, WiFi received signal strength measurements and opportunistic iBeacon corrections based on particle filter.

The developed system makes substantial progress towards providing accurate, practical and large-scale indoor location based services. While in [7], A comparison between the Viterbi tracking method and the particle filter . Viterbi tracking algorithm showed better performance than the particle filter, especially when Pedestrian Dead Reckoning (PDR) is not properly working. The computation time of each method should also be analyzed along with their memory requirements.

A different idea was implemented in [6] as it uses inertial sensors to track the movement of a person inside buildings. The original system that uses only the data from accelerometers and gyroscopes suffered from accumulation of estimation error. To improve the accuracy of the system infrared beacons were successfully applied. It was shown that infrared beacons can be successfully used to improve the accuracy of the positioning system. The proposed system uses inexpensive IrDA transmitters and receiver to detect the proximity of the user to the base unit what refers to the given location of the user.

Using a Zee was introduced in [14]; a system that makes the calibration zero-effort, by enabling training data to be crowd sourced without any explicit effort on the part of users. Zee utilized the WiFi and inertial sensor in smart phone to determine the location and track the target. The existing WiFi-based localization schemes, both fingerprinting-based and modeling-based, are able to perform accurate localization when trained with data that is crowdsourced automatically using Zee.

In [9], a system relies on very few Bluetooth beacons installed at the area and a magnetic map which has to be measured in advance is introduced. The overall accuracy of the system also depends on the size of the area that is not covered by close beacon signals.

3.3.2 Radio Frequency

In [15] a sensor nodes calculate their positions with GPS and RSSI technology. Meanwhile, a modifying factor in the change of the distances is used to improve the localization accuracy. Using the proposed method, localization accuracy for networks can be improved. The method can be used whether inside or outside the building.

3.3.3 RFID and Image

There are also some localization methods which do not use inertial sensor or radio frequency such as in [17]. These methods use RFID and camera to track a mice inside a box. This hybrid-tracking method simultaneously provides X, Y coordinates position, speed and orientation of numerous uniquely identified socially interacting individuals, with a mean spatial precision of ± 0.5 cm and a temporal precision of 30 ms.

3.4 Summary

Most of the position or tracking estimation methods uses either signal strength (RSSI) or inertial measurement unit (IMU) are implemented in the big area such an office room, living room, or shopping mall. The problem of the RSSI-based tracking system is the signal interference and LoS.

The problem of IMU-based tracking system is the drift. In order to get a better position estimation, using a hybrid system should be considered whether using RSSI and IMU, RSSI and image or RSSI and RFID.

The main concept is to mix two methodologies that complements each other for the best possible estimation.

4 Experiment

As result of the previous survey about different indoor localization techniques, it became clear that a hybrid system is necessary to eliminate the errors and time-based drifting. In this case, one technique will be used to verify and correct the position information provided by the other system.

Using a hybrid system that combines RSSI and IMU was proposed as it became clear that, in order to achieve the precision necessary for the proposed application, the IMU is the best solution.

However, this technology suffers from a drawback which is time-based drifting. This means that the data is reliable during the first moments of functioning, after some time, it loses reliability. Therefore, it is proposed to use the RSSI data from wireless nodes triangulation to constantly correct the IMU position, avoiding bigger drifting.

In order to support the feasibility study, some experiments are also conducted. Briefly, there are two experiment categories: IMU sensor and WiFi experiments.

4.1 IMU Sensor

The tools are used to conduct the IMU experiments are: 1) Smart phone; 2) Sensor Fusion Application from Google Play Store; 3) Xsens sensor [19]. There were two types of IMU sensor, in the first experiment, smartphone and Sensor Fusion Apps were used, and in the second experiment the Xsens sensor was used.

During the experiment, the smart phone was moved in some simple directions and the movement was recorded using the Sensor Fusion Application. Using the Sensor Fusion Apps, only accelerometer and orientation data were recorded.

It was decided to run 18 different experiments with the smart phone to determine the precision of different movements. For Xsens sensor only one experiment was conducted. The Xsens sensor was moved 20 cm in x-direction, and the accelerometer and orientation data were recorded.

In the both experiments, Smart phone and Xsens, to estimate the position of the devices, both accelerometer and orientation data were recorded. The position estimation was done using Equation 1.

In order to estimate the position, equation (4) was used along with equation (3). But before using equation (4), the $a^G(t)$ should be determined by using equation (1) and (2). Equation (1) is a MATLAB function to calculate the acceleration in Earth frame.

$$a^G(t) = quadrotate(q^{GS}(t), a^S(t)) \tag{1}$$

$$\tilde{a}^G(t) = a^G(t) - g, \quad g = 9.82ms^{-2} \tag{2}$$

$$V(t) = V(t) + \int (a^G(t)) \tag{3}$$

$$P(t) = P(t) + \int (V(t)) \tag{4}$$

The biggest challenge we faced was the imprecision of the magnetometer sensor in the testing conditions. This kind of sensor is exposed to interferences when used indoors. This makes the result is in unstable orientation which has the inputs offset in one or more axises. In order to overcome this error, a calibration method was implemented.

This algorithm considers unlikely the possibility of a constant acceleration be measured, therefore, any constant value is considered an offset and in those circumstances the actual velocity is set as zero. As result, the algorithm resets the offset every 100 samples.

4.2 IMU Results

The results of both experiments, IMU sensor and radio frequency showed that they are not very reliable. For the Xsens sensor the result was quite precise, from the calculation, the position was estimated that the sensor was moved 17.42 cm. Even though the movement was 20 cm. Table 1 shows the results of the smart phone's IMU sensor experiments.

Table 1: Smartphone IMU sensor Results

Exp. Num.	Action	Position estimation
1	Slow 20cm movement (in X)	271.0 cm
2	Slow 20cm movement (in X)	116.0 cm
3	Slow 20cm movement (in X)	15.2 cm
4	Fast 20cm movement (in X)	29.4 cm
6	Extremely fast 20cm movement (in X)	29.8 cm
7	Slow 60cm movement (in X)	83.9 cm
9	Fast 20cm movement (in X)	40.0 cm
10	Fast 25cm movement (in X)	74.0 cm
11	Fast 20cm movement (in X)	53.8 cm
12	Slow 60cm movement (in X)	122.0 cm
13	Moving up 20 cm (in Z)	20.0 cm
15	Random 60cm movement (in X and Y)	503.0 cm
16	Random 60cm movement (in X and Y)	325.0 cm
17	Moving up 20 cm (in Z)	722.0 cm
18	Move: 20 cm in X, 20 cm in Y, 20 cm in Z	854.0 cm

In the Table 1, the "slow", "fast", and "extremely fast" terms mean that the smartphone was moved by hand at the speed of $\pm 5\ cms^{-1}$, $\pm 13.3\ cms^{-1}$, $\pm 40\ cms^{-1}$ respectively.

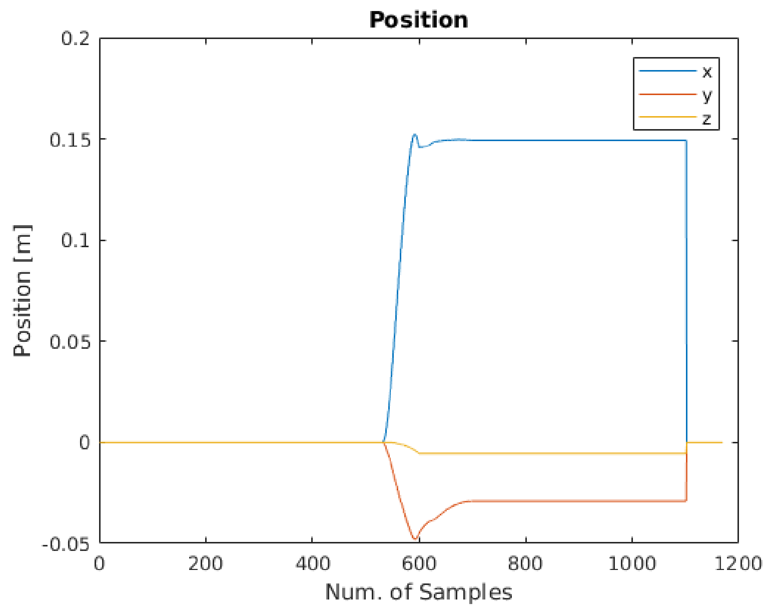

Figure 1: Position of the Smartphone when it was moved 20 cm towards it is x-direction and then the result was transformed to earth frame using (1)

.

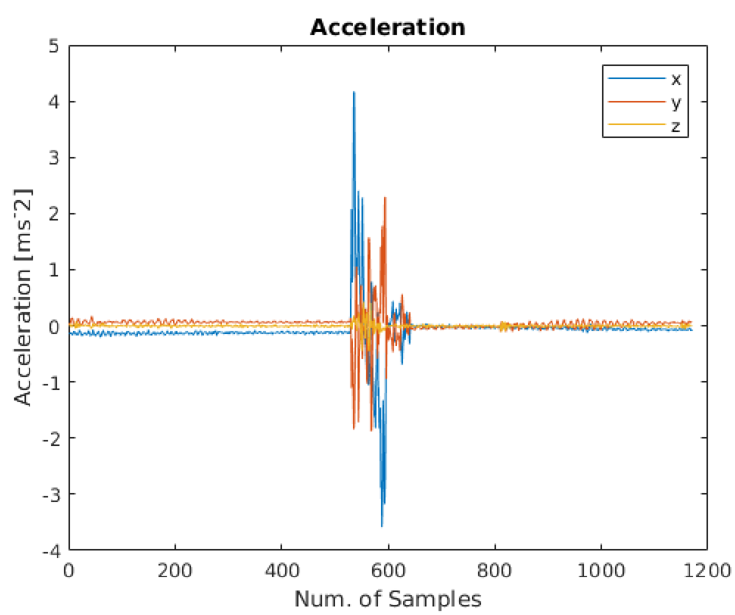

Figure 2: Smartphone acceleration when a force was applied to move it 20 cm towards it is x-direction and then the result was transformed to earth frame using (1)

.

Figure 1 is an example of the results of experiment 3 described in Table 1 which the smart phone is moved 20cm towards it is x-axis. However, the axis of movement is not aligned with the global coordinates, resulting in a component in Y axis. Figure 2 shows the same experiment acceleration data.

4.3 WiFi Experiment

RSSI and package loss rate experiment were conducted to see how reliable the radio frequency signal to estimate the position. During the experiment, two Zolertia Z1 were used as the device along with Contiki OS as the OS of the WiFi node. For the Zolertia Z1 node, one node acted as the base station and the other as the client. The client periodically sends messages to the base station and in the base station RSSI and package loss rate were measured.

The experiments were conducted in two ways. First, both of the nodes were moved 5 cm by 5 cm in certain directions starting from 0 cm until they both were separated by 100 cm. The RSSI and package loss rate data which were printed on the screen were recorded accordingly.

Second, both of the nodes were moved 20 cm by 20 cm in certain direction starting from 0 cm until they were separated by100 cm. But in this case, both nodes were in orthogonal orientation. The intent of this orientations is to align the antennas of the nodes in the most effective way and the least effective in terms of power.

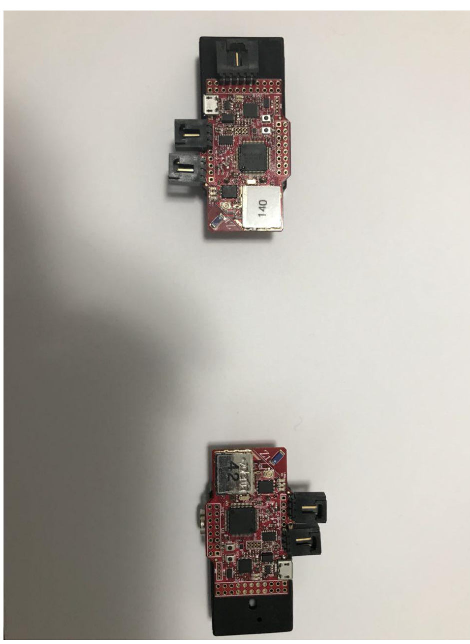

Figure 3: Position of the Zolertia Z1 nodes when did the RSSI experiment in the normal direction

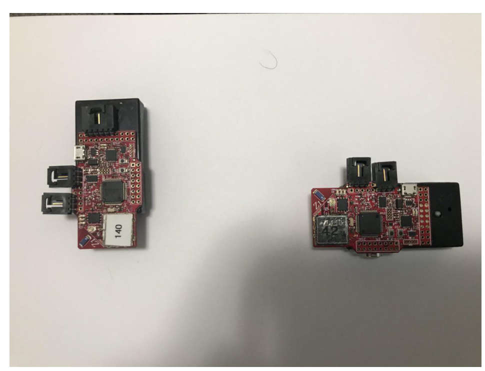

Figure 4: Position of the Zolertia Z1 nodes when did the RSSI experiment in the 90-degrees direction

4.4 WiFi Results

The result of RSSI and package loss rate experiment were also not reliable. Figure 5 show how the power and distance relation. From the figures, it shows that the RSSI is decreasing with increasing the distance between the two nodes.

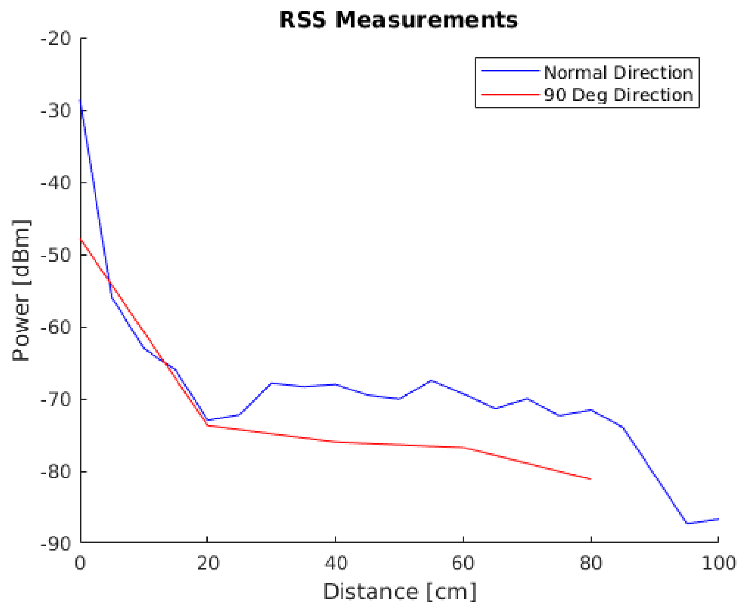

Figure 5: RSSI measurement comparison between the normal and 90 Degree directions

5 Proposed Solution

The proposed solution is a system that consists of an IMU and radio frequency which can collaborate to determine and estimate as best as they can. The collaboration will be like in the following scenario.

In the beginning, the IMU sensor will be used because of the IMU reliability is the best to estimate the position during short distance and short amount of time. After some time, i.e 2 minutes, the drift of IMU sensor will be very big which can affect the accuracy of the position estimation. To counter the condition, radio frequency will be utilized.

Despite the accuracy is less then the IMU sensor, radio frequency will not affected by the time-drift as IMU sensor faced. In this case, triangulation method will be used to estimate position.

In the end, when the assembly part were assembled and returned to the desk, the RFID will take part to correct the position. Some pairs of RFID tag were attached to the parts in the very beginning before the assembling was conducted. The following list shows the equipments which are needed for the proposed solution.

Proposed solution equipments:

- High precision IMU sensor
- Wireless nodes
- RFID tags (both in the assembling desk and the assembly parts)

6 Discussion

6.1 IMU Sensor

Regarding the smart phone experiment result, there are only two experiments which had good accuracy. They are experiment number 3 and 13, where experiment number 3 is depicted in Figure 1 and 2. In experiment number 3, the smart phone was moved 20cm only in X direction. However the estimation is 4.8 cm far from the actual position, the estimation is much better than another ones.

The best result of smart phone experiment is experiment number 13, where the smart phone was lifted 20cm. The estimation is very accurate with zero percent error. It looks like calibration of the drift is enhanced by the gravity.

The Xsens result is also very good. When the sensor was moved 20cm only in the x-direction, the end position was estimated as 17.42 cm. That is because of the sensor capability is better than the smart phone sensor. The Xsens sensor is usually used for human motion tracking such as in a Computer Graphic Interface, thus the accuracy is very dependable.

6.2 RSSI

Most of the RSSI position estimation implementation are implemented in a big area such as an office floor or a shopping mall. None of the previous studies like in in [12], [3], [20], [1], [16], and [18] are implemented in a small area i.e 1 m^2.

Based on the experiment, using RSSI to estimate a position in a small area such as 1m x 1m is not feasible. That is because the interference is much bigger than doing a position estimation in a bigger area such as an office or a living room.

7 Conclusion

Summing up our work, it can be concluded that the position and tracking estimation using only radio frequency (RSSI based) in 1 m^2 area is not possible due to interference and other aspects. In the other hand, only using IMU sensor will give more reliable estimation but only for a short period of time.

Our proposed solution seems to be reliable to estimate the position of the device because it leverage three components and methods usability. They are RSSI-based, IMU sensor-based, and RFID tag in each device and table to correct the misplaced position estimation.

8 Problems and Recommendation

The utilized programming languages are MATLAB and C. MATLAB was used for calculating the position estimation during the IMU experiment. On the other experiment, the RSSI, C language was used under the Contiki OS for Zolertia Z1.

The biggest challenge during the project was eliminating the drift of the accelerometer sensor in smart phone in order to have a good experiment. But because of the drift was very bad, the calibrating method in MATLAB program could not take out all the drift.

On the other hand, the Zolertia Z1 seemed not suitable for doing an RSSI experiment. The signal strength is not strong enough to be able to do a good RSSI experiment. Even in a small distance, the signal between two of them was very weak. In this case, another wireless node with stronger signal is recommended. For the programming aspect, C and Contiki OS is also recommended because there are some code examples which can be developed accordingly.

9 Group Collaboration

During the project development, the work was evenly divided between the members. It was possible for all to contribute in different areas in order to reach a satisfactory result. The first part, the background research was evenly divided, so each one could bring different approaches for the project as described in the first part of this report. Since Bassem Hassam, for professional reasons, was not able to be present in most of the meeting, he was responsible for a bigger part of the background research. In the other hand, Pedro Freire and Rahmanu Hermawan were responsible for the physical experimentation and the data gathering. The results were discussed between all the members. Finally, the report was mainly developed by Bassem and Rahmanu, so it could be completed and revised by Pedro.

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