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Improving Children Tracking System with Kalman Filter

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***Abstract*— Children tracking system is a solution for parents to supervise their children remotely. The existing system provides a monitoring function that can report when the child enters and leaves the school bus. However, this system is not equipped with the function to report to the parents when the child leaves the bus at restricted areas, such as the mall. To implement such system a GPS with high accuracy is required. It will be a problem if a shopping mall and a school are neighbors and due to low accuracy the system gives false reports to the parent. Kalman filter can improve the accuracy of a GPS point. This paper presents a research that applies Kalman filter to the described children tracking system. Improvements are proved by comparing a system minus Kalman filter with a system that applies Kalman Filter. The result is Kalman filter improves the accuracy of the system as big as bla percent.**

Index Terms*— Children Tracking, Active RFID Reader, GPS, Kalman Filter, Internet of Things

I. INTRODUCTION

Children tracking will help parents supervise their children remotely, particularly on the way to school. Existing systems can report to the parents when their children enter and leave the school bus [1]. However such system is not equipped with reports that tell when the child leaves the bus at the wrong place, even worse, unsuitable places, such as the mall.

Adding features about when a child leaves at the right spot and when a child leaves at the wrong spot requires the function of a locating device. A GPS can be used.

In some cases a situation can happen where the restricted area are neighbors with the school. For example, a shopping mall is right beside a school. If a GPS with low accuracy in location detection is used wrong reports can occur. A child dropping of a bus in front of school can be detected in the area of the shopping mall, resulting in the system reporting to the parents that their children is at the wrong place at the wrong time. In the other hand, the child is playing at the mall but the parents get no notification of this activity because the system reports that the child is at school. This can be catastrophe.

It is knows that the error rate of GPS devices is as big as 10 to 15 m [2]. This can cause the system to become really faulty an unreliable.

There are many methods to increase sensor and metering devices accuracy, one of them is Kalman filter [3]. Kalman filter has the method to correct the value reading to approach the real value by time. By such method Kalman filter can increase the accuracy of a GPS by 97 percent [4].

The aim of the research presented by this paper is to apply Kalman filter to the children tracking system and test the improvement of the accuracy of the system by comparing the system's accuracy before the Kalman filter is applied with the accuracy of the system after Kalman filter is applied.

Similar to existing systems, this system will also be equipped with GPS as the location pointer, also, an active RFID is used to detect where the child leaves and enters the school bus. This system uses a microcontroller with Wi-Fi module, giving the microcontroller Internet of Things (IoT) functions. This eases communication with the parent's tracking application. The parent's tracking application is also equipped with a data base. This data base stores the location of the school of the child and locations that the child is prohibited to enter. In this research we limit the user to two users.

The methodology of the research is started by studying familiar researches, finding the state of the art of the problem in the area of children tracking. After that, the children tracking system is designed. From the design, hardware and software specifications are defined. Testing scenarios are also created. Before comparing two systems and calculating the improvement of the system accuracy, tests are held to see the performance of the applied Kalman filter. There is also a test to determine the gain of the Kalman filter. Kalman filter gain depends on the bias of the measured value. After Kalman filter is applied, two systems are created. A system without Kalman filter, and a system with Kalman filter. These two systems are measured with several scenarios to determine the accuracy of both systems. Accuracy means that the system reports the actual events.

The systematics of the paper is started with introduction. Introduction provides motivation for this research. The second chapter contains related work to provide insight of the improvement prior to the paper. The third chapter contains two main parts. First is the theoretical and mathematical explanation of the Kalman filter implemented. Second is the design of the system and also the hardware and software specification. In the fourth chapter, results of the research are presented. There are graphics of the performance of the Kalman filter and also a map that exposes the comparison of the system with Kalman filter and without it. The last chapter will provide conclusions of the research and opportunities for future study.

II. RELATED WORKS

A research about clustered children tracking was conducted in 2009 and 2011 [5] [6]. Clustered tracking in this study is obtained by an adhoc network that combines both Wi-Fi and Bluetooth. From the adhoc network the system will deliver reports to parents in the form of groups of children.

In the year 2014 a research was conducted for children tracking with reports for individuals [7]. This study considers cluster tracking is a weakness because of less detailed information. This system also comes with the detection of a child's cry.

As IoT develops, coordination is further enhanced in subsequent studies. By 2016, the system consequently divides the device into two parts, the bus section and the school section [1]. Communication and coordination between these two parts utilize GSM, meaning a GSM shield is added onto the bus section, and an SMS Gateway is added to the school section. The bus section will report when the students enter and leave the school bus to the school section. Many ways have been used since to improve communication, e.g. using Wi-Fi modules and MQTT brokers [8] [9].

The implementation of active RFID can improve the quality and the way of acquisition of child's bus entering and exiting report. Active RFID is said to be the next generation in people tracking [10]. The Active RFID reader in the bus detects the RFID card, probably in the form of student card, brought by the student when the student gets on and off the bus, without the need to pull out the card and reach the reader. It should be emphasized that the reporting done on this system is sent only when the child drops off the bus at designated points, and when the student drops off at illegal places, no notification is sent at all.

To add various reports to parents on where the children leaves the bus, a GPS needs to be added to the device. In a study of GPS in 2011, tests conducted on several GPS brands show that GPS has an accuracy of 10-15 m. This research uses a method called Wide Area Augmentation System (WAAS) to improve GPS accuracy.

There are various researches in improving accuracy, one field is by employing Kalman filter. Kalman filter is a method to improve measurement accuracy by using series of previous measurements [3]. It is a method reduces noise in a system. This method was published by R. E. Kalman in 1960 and has been used in various systems and research such as Computer Vision, Artificial Intelligence, Economy, and also GPS location detection.

A research that has applied Kalman Filter for GPS is "OTONOM ARAÇLAR İÇİN, GPS VERİSİ ÜZERİNDEN KALMAN FİLTRE İLE KONUM BİLGİSİNİN ÜRETİLMESİ" in 2017 [4]. In this paper, kalman filter improves GPS measurement accuracy by 97%. The study mentions that GPS allocation is used for autonomous vehicles.

III. SYSTEM DESIGN

A. System Engineering Requirements

The system in this research is designed with the following engineering requirements:

- GPS module can get the bus location in real time.
- System can process location data obtained by GPS module with Kalman Filter to improve the accuracy.
- WiFi module can connect to MQTT server and transmit data correctly .
- Active RFID reader can read passive RFID card of students.
- System can provide an updated location to the smartphone app and give notification when the student's board / get off from the bus.

B. System Overview

System will be divided into 2 units, student unit and bus unit. In the student unit, students only need to carry their passive RFID card that is already registered on the system. While on the bus unit, there's an active RFID reader installed at the entrance of the bus with GPS module and WiFi module as data communication.

System will retrieve location data of the bus every 5 seconds by using GPS module. The location obtained by GPS module will be processed using the Kalman Filter method with gain value of 2.5 to improve the accuracy of the location. Then the processed location will be sent to the MQTT server using the WiFi module.

An Active RFID reader automatically scans the student's RFID / tag card with a scan radius of <3 meters. If there is a passive RFID card scanned by the RFID reader, system will check the ID of the card into the system and change the student's status (in/out) assuming that the ID is registered. The student's admission status then will be sent to the MQTT server along with location where they board/get-off on and from the bus. The data in the MQTT server will be used to update location on the parent's smartphone app and give notifications.

This system will also restrict the student's drop-off location. If a student does get-off from the bus in a public place like a mall / recreation place, the system will send a notification of the student's latest location to the parent, so that parents can still monitor their children.

C. Proposed System Design

This system uses GPS module, WiFi module, and active RFID reader where all the modules will be connected to microcontroller Arduino Mega 2560. The microcontroller is loaded with a program to locate, process location, scan tags, and send data to a MQTT server. The program is created on ArduinoIDE which is then uploaded into Arduino Mega 2560 with 9600 baud-rate. Besides that, there's an application for the parents on Android smartphone with functionality to get an updated location of the bus and get notifications if their children leave from the bus on a restricted area (mall/recreation place).

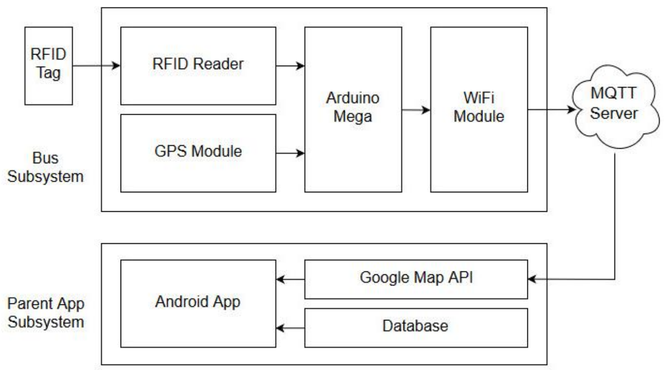

Fig. 1. System Architecture

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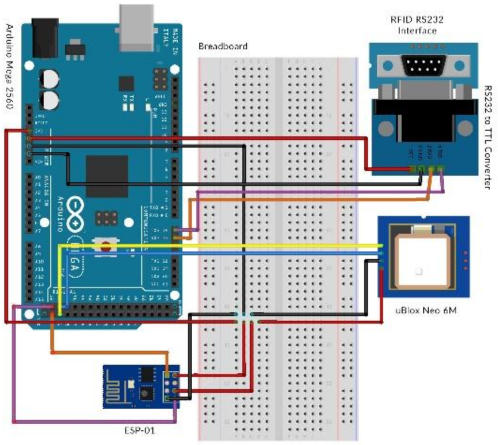


Fig. 2. Wiring diagram of the proposed system.

D. Test Scenarios

- GPS Accuracy Test Scenario

The aim of this test to see the output data that has been filtered by using Kalman Filter. The purpose of Kalman Filter is to improve accuracy by reducing the noise of GPS module when bus is on the move. From this test, the accuracy will be compared between the coordinates of the GPS module with the coordinates of the Kalman Filter in order to see the Kalman Filter method accuracy improvement.

- Location Update & Notification Test Scenario

The aim of this test to see the suitability of the data sent by Arduino to MQTT server. The format of data sent to MQTT server is as in Table I.

Table 1. Data Format Sent to MQTT Server

Latitude	/	Longitude	/	RFID tag ID	Student Status

Description:
- Latitude and longitude sent are coordinates that have been filtered with Kalman Filter. Latitude dan longitude sent is limited to a 7 digit decimal.
- RFID ID is 5 characters length.
- Student status is an integer with value 0 (for student condition when exit the bus) and value 1 (for student condition when enter the bus).

The other aim of this test to see if the parent application can give notification when students enter/exit the bus and also to check the validity of the notification when the student exits from the bus in the restricted area. Table 2 presents the Test Validation Parameters.

Table 2. Notification Test Parameter

No	Bus Location	Student Status	Violation Detected	Validity
1	Restriction Area	Enter	No	Yes
2	Restriction Area	Exit	Yes	Yes
3	Allowed Area	Enter	No	Yes
4	Allowed Area	Exit	No	Yes
5	School	Enter	No	Yes
6	School	Exit	No	Yes

IV. IMPLEMENTATION & TESTING

A. Coordinate Comparison of GPS Module and Kalman Filter

The purpose of this test is to see which outpout is better between the data from GPS module with data with use of Kalman Filter. Fig. 1. Presents a measurement comparison graph of GPS Module and Kalman Filter based on time.

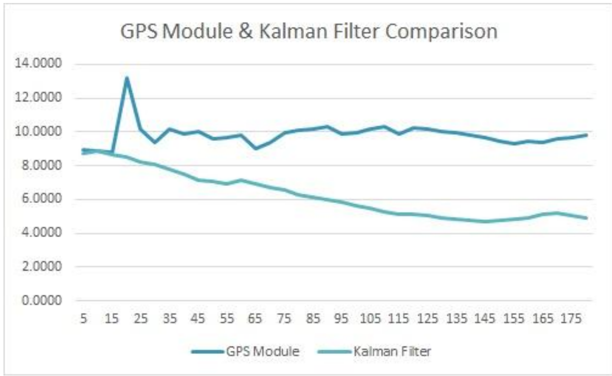
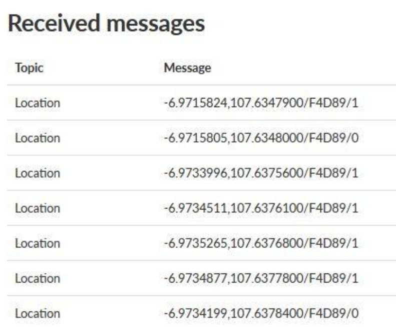


Fig. 1. Kalman Filter Usage Chart

Fig. 1 shows how the accuracy between Kalman filter and GPS Module compare. From the test that lasted for 180 seconds, the data obtained by the GPS Module for 25 seconds is still fluctuating where the graph is climbing far from 9 meters up to 13 meters. But after the 25th second went through the value tends to be stable in the range of 9-10 meters. On the other hand the graph generated by Kalman filters tends to drop to stable in the range of 4.5 - 5 meters at 115 to 180 seconds. This indicates that the accuracy possessed by Kalman filters is better that after 90 seconds Kalman filters succeeded in providing 48.9551% accuracy improvement.

B. Location Update & Notification Test

The aim of this test to see if the location in the parent application has been updated correctly and also gives notification on the condition when students enter/exit to and from the bus. Fig. 2. Shows the results of location updates in the app based on data sent to the MQTT server:


Received messages

Topic	Message
Location	-6.9715824,107.6347900/F4D89/1
Location	-6.9715805,107.6348000/F4D89/0
Location	-6.9733996,107.6375600/F4D89/1
Location	-6.9734511,107.6376100/F4D89/1
Location	-6.9735265,107.6376800/F4D89/1
Location	-6.9734877,107.6377800/F4D89/1
Location	-6.9734199,107.6378400/F4D89/0

Fig. 2. Data Sent by Sytem to MQTT Server

Also in this test, if the students exit from the bus in certain areas that are restricted such as: a mall or a recreation place, the system will give notifications to the parent's application. Fig. 3 shows one of the test area.

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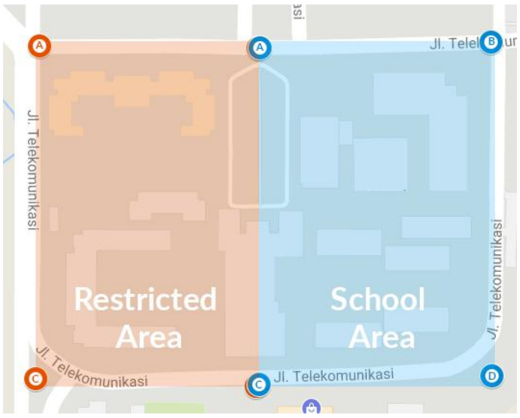

Fig. 3. Notification Test Area

In Fig 3, the red coloured area is the restricted area. If students get off from the bus here, the system will give the notification *"Student gets off at restricted area"*. The blue coloured area is the school area. If students get off from the bus here, the system will give the notification *"Student arrive at school"*.

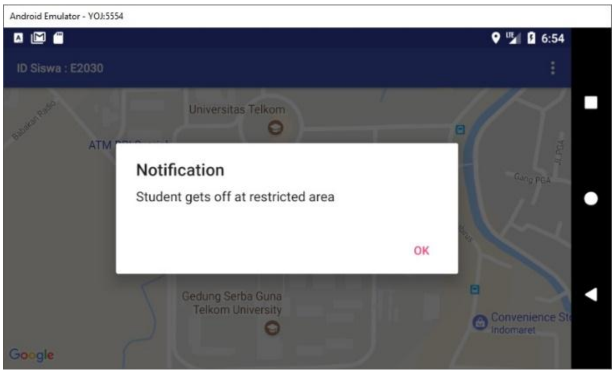

Fig. 4. Notification in Restriction Area

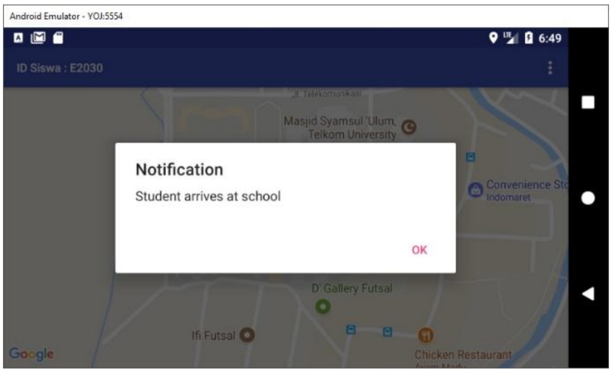

Fig. 5. Notification in School Area

To limit specific area, it needs 4 angle coordinates that are marked with labels A, B, C, D. Table 1 shows coordinates that are the test area from Fig.3.

Table 2. Test Area Coordinates

Point	Restricted Area		School Area	
	Latitude	Longitude	Latitude	Longitude
A	-6.97523	107.62906	-6.97523	107.63032
B	-6.97523	107.63025	-6.97523	107.63157
C	-6.97714	107.62904	-6.97714	107.63033
D	-6.97714	107.63026	-6.97714	107.63159

Table 2 presents the result of predetermined features testing explained in section 3.D with GPS module coordinates.

Table 2. Notification Test with GPS Module Coordinates

No	Bus Location	Student Status	Violation Detected	Notification Validity
1	Restriction Area	Enter	No	Yes
2	Restriction Area	Enter	No	Yes
3	Restriction Area	Enter	Yes	No
4	Restriction Area	Exit	No	No
5	Restriction Area	Exit	No	No
6	Restriction Area	Exit	Yes	Yes
7	School Area	Enter	No	Yes
8	School Area	Enter	No	Yes
9	School Area	Enter	No	Yes
10	School Area	Exit	No	Yes
11	School Area	Exit	No	Yes
12	School Area	Exit	Yes	No
13	Allowed Area	Enter	No	Yes
14	Allowed Area	Enter	No	Yes
15	Allowed Area	Enter	No	Yes
16	Allowed Area	Exit	No	Yes
17	Allowed Area	Exit	No	No
18	Allowed Area	Exit	No	Yes

Based on the test result in Table 2, the system can give notification correctly according to student location when they're board / get-off from the bus. But from 18 test in 3 area, there're 5 times error when system give notification to application, so percentage of successful function with GPS module coordinate is 72,2%.

Table 3 presents the result of predetermined features testing explained in section 3.D with Kalman Filter coordinates.

Table 3. Notification Test with Kalman Filter Coordinates

No	Bus Location	Student Status	Violation Detected	Notification Validity
1	Restriction Area	Enter	No	Yes
2	Restriction Area	Enter	No	Yes
3	Restriction Area	Enter	No	Yes
4	Restriction Area	Exit	Yes	Yes
5	Restriction Area	Exit	Yes	Yes
6	Restriction Area	Exit	Yes	Yes
7	School Area	Enter	No	Yes
8	School Area	Enter	No	Yes
9	School Area	Enter	No	Yes
10	School Area	Exit	No	Yes
11	School Area	Exit	No	Yes
12	School Area	Exit	No	Yes
13	Allowed Area	Enter	No	Yes
14	Allowed Area	Enter	No	Yes
15	Allowed Area	Enter	No	Yes
16	Allowed Area	Exit	No	Yes
17	Allowed Area	Exit	No	Yes
18	Allowed Area	Exit	No	Yes

Based on the test result in Table 3, the system can give notification correctly according to student location when they're board / get-off from the bus when . The system also give a precise notification if the student get-off from the bus in restricted area or in school area. Based on the test, percentage of successful function is 100%. This prove that logic of the system can work well and accurately in accordance with expectations of the system.

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V. CONCLUSION

A Children Tracking System has been successfully implemented. This system is divided into two main subsystems, the bus and the parent app subsystem. The system employs Arduino Mega for the microcontroller system, Active RFID Reader for on-bus child tracking, Wi-Fi module for communication, MQTT system and an MQTT server for IoT middleware functionality, GPS for children entering/exiting location, Android and an Android App for parents tracking, and a mobile data base to save restricted and school areas.

The Kalman filter applied in this system proves to provide two main enhancements. First, it improves the GPS accuracy by 48.9551%. The average accuracy of the GPS is 9-10 meters. After Kalman filter implementation, the location accuracy develops into 4.5–5 meters. Second, The Kalman filter enables the system to have an additional functionality, i.e. to give notifications if the child leaves the bus in a restricted area. Such functionality requires high location accuracy. With GPS modules coordinates, validity of the system is 72.2 % and with Kalman filter, the validity of the system is 100 %.

For further work a high scale deployment can be accomplished. By executing such proposition, two or more improvements can be achieved, for example, user feedback for further refinement, also, scalability issues can promote appended research.

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