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Tests Measurement of UHF RFID for Autonomous Vehicle Navigation

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***Abstract*— This article provides a discussion of the testing and measurement of UHF RFID with distance and facing angle parameters on static and moving state conditions. This study is necessary for implementing RFID technology in the development of autonomous vehicle navigation systems. Navigation systems in autonomous vehicles generally never leave the global positioning system (GPS) as a navigation sensor. The use of GPS independently has weaknesses related to the accuracy, so a navigation system using GPS requires correction of the navigation route based on coordinates, this correction can be done by adding another sensor. The integration of GPS and RFID technology has several advantages besides being cost-effective. Studies that have been carried out enable an autonomous vehicle navigation system to be run by combining data between RFID Reader readings in retrieving location data points marked with RFID tags and coordinate vehicle position data on maps by the GPS which generates route and location information passed by vehicles using the GPS/RFID method localization. Tests and measurements are performed by reading on three types of RFID tags with varying distances and angles of view. The results showed that the best reading distance for RFID tags is at a distance of 4 meters with a reading angle of the RFID Reader at 90 degrees on the z-axis and y-axis. While the best RFID tag performance is the tag on the Passive UHF RFID metal, both for testing in static or moving state condition.**

Keywords—navigation; autonomous vehicle; UHF RFID; test measurement, localization

I. Introduction

Autonomous vehicles are vehicles that can be operated safely and effectively without having to be controlled by humans. This vehicle consists of an integration of systems that work together to connect the vehicle through the environment, one of the most important systems is the sensor [1]. This autonomous vehicle consists of two systems, internal vehicle systems and external world sensing. Internal vehicle systems consist may of steering inputs devices, wheel speed sensors, yaw rate sensors, lateral/longitudinal sensors, and transmission outputs [2]. The vehicle navigation system is one of the most important systems in external world sensing. Navigation is needed in order that autonomous vehicles can drive on the track independently by using sensors and specific algorithms.

In several publications relating to the design of autonomous vehicles, the use of several sensors combined to produce navigation data input is an absolute necessity, where data fusion methods often never abandon the use of global positioning systems (GPS). The use of GPS independently has shortcomings related to accuracy, so in the GPS navigation system, vehicle navigation routes based on coordinates need to be corrected. This correction can be implemented by adding a compass module to the navigation system [3], or adding other sensors such as lane marking sensors, IMU/INS and also uses Radio Frequency Identification (RFID) technology [4]–[6] and other sensors.

RFID technology is an automatic identification technology that enables tracking people and objects. the information obtained is the identity and location data, the method used to obtain these two types of data is to localize the RFID tag that is affixed to the device or human object [7]. Besides being lightweight, low power consumption, and practically unlimited identification capacity, RFID tags have their advantages. By marking objects with RFID tags, the environment can be identified in a way that cost-effective and energy-efficient [8] and this technology has proven to be able to overcome problems in terms of cost and good accuracy [9]. An autonomous vehicle navigation system can be implemented by combining RFID reader data readings on RFID tags installed on the roadside and GPS data readings in the form of vehicle position data coordinates. With the navigation algorithm, the data is processed into the route and location information that is passed by the vehicle using GPS-RFID localization methods. [10].

From this explanation, problems arise related to the performance of UHF RFID technology, including which types of RFID tags can be used in the needs of autonomous vehicle navigation and how to install an RFID reader in order to get the most optimal reading area when used as a sensor that is expected to improve GPS accuracy.

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II. RELATED WORK

A. UHF RFID Tests Measurement

Research related to testing measurement of UHF RFID is a very minimal reference, so to plan UHF RFID technology for autonomous vehicle navigation, in-depth research with appropriate test parameters is needed [10].

The selection of passive RFID UHF type is determined because the reading range of UHF RFID technology can reach relatively large distances, depending on the type of RFID reader and RFID tags used in addition to the advantages of the tags used do not require their own power supply. Some distance testing that has been done shows that this passive UHF RFID technology has an effective distance of 6-8 meters [11]–[13], depends on the type of tags used.

RFID testing to obtain tags performance can be carried out by varying in addition to the angle and frequency, also the protocol parameters and the power supplied. [14], including conditioning tags at varying temperatures [12], [15]. In testing with the measurement range of RFID tags at temperatures from 0 to 74 °C, the reading range of tags in an empty space can reach more than 7 meters [12]. Testing the effect of temperature on the UHF reading performance of RFID tags dynamically by changing the reading distance of RFID tags measured at different temperatures shows that the distance of the RFID tag reading decreases with increasing test temperature [15]. The RFID reader read range is quite wide, that is up to 40 ° from the normal reader line and the reader response is still well read at a speed of 60 km/h [16].

B. RFID Technology for Navigation

Several studies on the use of GPS for vehicle navigation show that GPS receivers installed in vehicles used for positioning are often constrained due to accuracy. To solve this problem, GPS/RFID integration can be considered as a solution [17]–[20], which eventually opened up a lot of studies relating to the use of GPS which aims to improve the accuracy of the GPS position [5].

Research on navigation systems with IMU and RFID technology for people with visual impairments provides an overview of an RFID-based navigation device and inertia that can be used in indoor environments that can help provide guidance for people with visual impairments to reach their destination. This system uses a method of combining several sensors that allows for an accurate pedestrian location [21]. In similar studies, a navigation system for pedestrians with limited vision is possible to be realized by combining GPS and Radio Frequency Identification tags systems [6], [22].

Research on skilled navigation design in Mobile Robot provides a study of cellular robot navigation techniques using RFID readers and a number of standard RFID tags installed in the robot environment to determine its path. By saving moving control commands such as turn right, turn left, acceleration and deceleration etc. The command data is inserted in the tag and the tag is affixed to the predetermined path, the autonomous mobile robot can then read the moving control command from the tag and complete it with the appropriate action [23].

III. DESIGN OF EXPERIMENTATION SYSTEM

The method used in this study is shown in the following flowchart in Fig. 1:

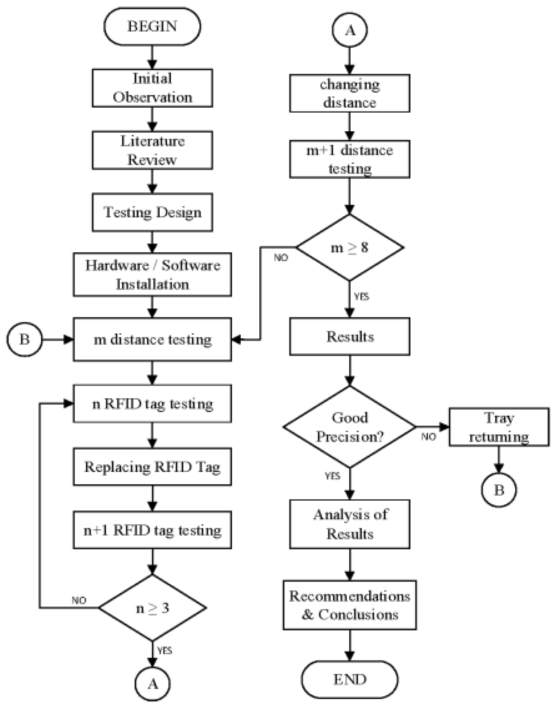

Fig. 1. Procedure of tests and measurement of UHF RFID

A. Initial Observation

Observations were made to obtain initial data testing and measurement. From this stage, an initial hypothesis will be obtained as well as problems related to taking measurement data that has high accuracy and precision. Observations were carried out in the electrical engineering laboratory in the form of testing and measurement of RFID tag readings with test parameters in the form of angles to the RFID reader and reading distance parameters.

From Fig. 2 there are two illustrated images of the installation of RFID reader against RFID tags. The side view picture is when the RFID reader is rotated on the z-axis with the provisions that if rotated clockwise, then the RFID reader will form a positive angle and if rotated counterclockwise then the RFID reader will form a negative angle. In the picture above, the RFID reader is rotated on the y-axis clockwise, then the RFIID Reader will form a positive angle and vice versa, if the RFID reader is rotated counterclockwise it will form a negative angle. This test aims to get the performance of RFID reader reading in detecting RFID tags from several different angles. The reading angle is set to get the RFID reading area [68], and the reading area will later become a reference for RFID reader implementation needs in certain applications.

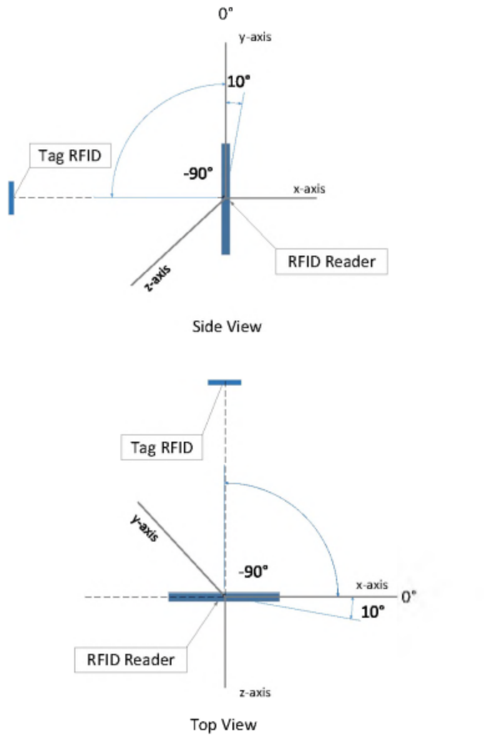

Fig. 2. Perspective of the RFID tag reading angle

B. *Literature Review*

To improve observations, it is necessary to deepen the material obtained from the literature, both sourced from journals, proceedings, or publications related to the research theme. The literature that is widely studied includes, among others, material about the UHF RFID technology testing methods as well as literature on the use of this technology for autonomous vehicle navigation systems. Most of the research studies have been discussed in the related work section.

C. *Testing Design*

The system design stage in the research will be implemented by designing the measurement and testing methods, including preparing all the materials and test equipment as well as the measurement equipment needed.

In this research, the UHF RFID reader used was Electron HW-VX6330K 6 dBi with medium range, 6-8 meters and frequency range: 902-928 MHz [13]. There are three types of UHF RFID tags, including: (1) UHF RFID card PVC material, [24], (2) UHF RFID passive on-metal screw holes & adhesive tags, electron type WZ-G16 UHF [25], and (3) RFID UHF Tag H3 AZ 9662 paper label sticker [26].

D. *Hardware and Software Installation*

Hardware devices installed consists of RFID reader, RFID tag, Laptop, Laser distance measuring, strap for distance and angle markers, tripod stand for RFID reader and RFID tag holder, angle ruler and several other supporting devices. For software tools used are: UHFReader18 Demo software v2.6 for Read / Write UHF RFID, Microsoft Office Application for measurement documentation and measurement data processing. From Fig. 3, the RFID reader is mounted on a tripod with a particular height, and the RFID tag is mounted on a bamboo stick with a height of 50 cm based on the height between the peg on the driving license practice test (SIM) [27] and the minimum height of the highway traffic delineator as well as the height of the traffic cone that is commonly used by PT Jasa Raharja [28], [29]. The RFID tag will be shifted from a distance of 1 m to 8 m assuming the furthest distance from the existing RFID reader datasheet [13].

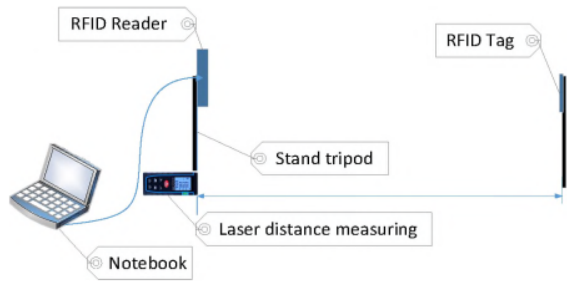

Fig. 3. Test measurement of UHF RFID schematic diagram

E. *System Testing*

There are two methods of RFID testing: static and moving state condition RFID testing. Each of these methods is explained in the test and measurement results. Testing the performance of RFID reader readings on several types of RFID tags is done on campus yard by placing RFID tags at a certain distance from the RFID reader at a certain angle. This measurement test uses a total of 5 RFID tags on each tag type, it's based on the average calculation and standard deviations recommendations in experimental research with small samples using a minimum sample of 5 pieces [30]. The duration of the RFID Reader reading time on tags is 5 seconds with a frequency setting of 928 MHz, transmit power of 30 dBm, and a reading interval setting of 50 ms.

F. *Analysis and Discussion*

This stage will discuss the results of UHF RFID testing and measurement. The test results will be reviewed and analyzed to get the performance of each tag with several test parameters.

G. *Recommendations and Suggestions*

Important results will be summarized in useful recommendations and suggestions for system development.

IV. EXPERIMENTAL RESULT

A. *RFID Testing on static state*

Static testing method is a testing method by placing RFID reader and RFID tags with no moving condition. On static state condition testing, the RFID reader is rotated both on the z-axis and on y-axis as illustrated in Fig. 2.

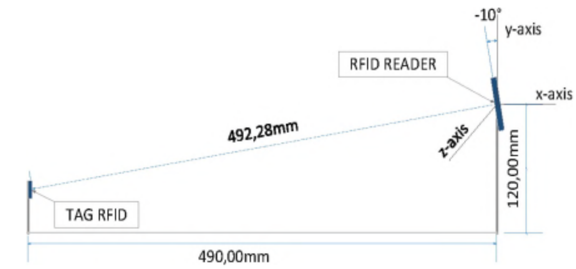

Fig. 4. Illustration of mounting an RFID reader rotating on the z-axis with an angle of -10°

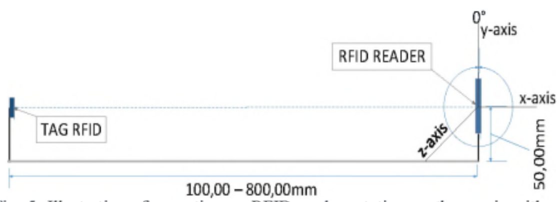

Fig. 5. Illustration of mounting an RFID reader rotating on the z-axis with an angle of 0°

The test has been carried out by placing the RFID reader by rotating on the z-axis forming an angle of -10° (counterclockwise) as illustrated in Fig. 4. The next test is to install an RFID reader with a reading angle of 0° on the z-axis (direction of the RFID reader perpendicular against RFID tags) as illustrated by the angle measurement in Fig. 5.

TABLE 1. RFID TAG READING DATA BY MOUNTING THE RFID READER ROTATES ON THE Z- AXIS WITH AN ANGLE OF -10°

RFID tag types	Distance (meters)							
	1	2	3	4	5	6	7	8
RFID Card (A)	35.5	56.1	19.5	26.9	34.7	28.3	25.8	12.4
RFID Passive Metal Tag (B)	19.6	32.7	17.5	27.9	13.2	3.5	5.4	5.6
Paper Label Sticker Tag (C)	24.6	17.6	28.4	22.9	4.0	0.0	0.0	0.0

The test results as shown in table 1 are the RFID reader readings for all types of RFID tags (each totaling 5 RFID tags). The data is the average reading of each type of RFID tag with three times readings testing at a distance of 1 to 8 meters. This method is also carried out for the following table 2.

TABLE 2. RFID TAG READING DATA BY MOUNTING THE RFID READER ROTATES ON THE Z AXIS WITH AN ANGLE OF 0°

RFID tag types	Distance (meters)							
	1	2	3	4	5	6	7	8
RFID Card (A)	53.1	48.7	52.3	43.3	19.0	8.5	0.6	1.5
RFID Passive Metal Tag (B)	62.9	54.8	27.1	21.9	16.5	13.5	9.2	2.9
Paper Label Sticker Tag (C)	40.8	28.3	19.1	11.6	0.0	0.0	0.0	0.0

From the measurement data as shown in table 2, the type of paper label sticker still has the worst performance and the RFID tag type UHF RFID Passive on-metal Tag has the best and most stable reading, both at the shortest distance and at the farthest distance. It can be concluded that the most suitable RFID tag to be a reference point as identification of localized navigation for autonomous vehicles is the type of UHF RFID Passive on-metal Tag. The best RFID reader for RFID tags is perpendicular or the RFID reader is positioned at an angle of 0° on the z-axis.

The next testing phase is testing and measuring the reading of the RFID tag by the RFID reader with rotation on the y-axis clockwise forming an angle of 0°, 15°, 30°, 45°, 60°, 75° and an angle of 90°. The test has been carried out three times by reading 5 sample tags for all three types of tags as explained in the previous system test. Testing with counter-clockwise rotation on the y-axis forming a negative angle is carried out randomly and the results show similar reading data, so the reading data at this negative angle is assumed to have similarities with the reading data with a positive angle.

The following are surface diagram drawings that present the results of the RFID tag reading test, each RFID card (A), RFID passive metal tag (B), and paper label sticker tag (C) for describing the performance reading of all types of RFID tags.

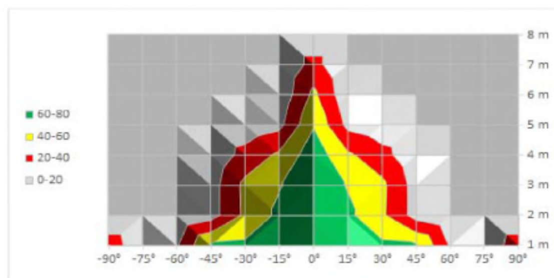

Fig. 6. RFID reader reading area chart with rotation on the y-axis for the type of RFID card tags (A)

Fig. 6 shows that the type of card tag reads sixty to eighty times at a distance of 1-4 meters with an angle of -45° to 45° (green color on the surface graph). This test has a precision level of 98.92%.

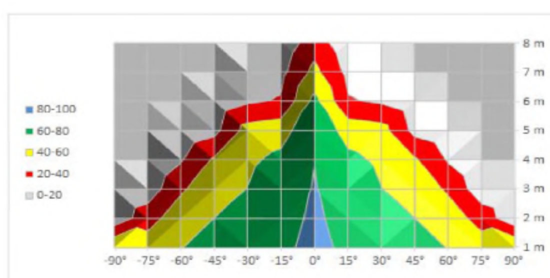

Fig. 7. RFID reader reading area chart with rotation on the y-axis for the type of RFID Passive Metal tags (B)

Fig. 7 illustrates the characteristics of RFID Passive Metal tags that can be read effectively at a distance of 1 to 6 meters with a reading of sixty to eighty times at an angle of -60° to 60°, the best number of readings (eighty to one hundred times reading) is still possible at a distance of 4 meters at an angle of 0°. This type of tag can even be read at a distance of 8 meters even with a relatively lower number of readings. The test measurement has a precision of 98.88%.

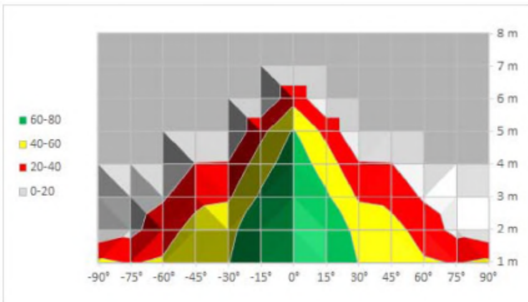

Fig. 8. RFID reader reading area chart with rotation on the y-axis for the type of RFID paper label sticker tags (C)

In Fig. 8, it appears that the type of RFID paper label sticker has the highest number of readings at sixty to eighty times with a distance of 1 to 5 meters at an angle of -30° to 30°. This test has a precision of 98.87%.

B. *RFID Testing on moving state condition*

This testing method is by placing an RFID reader and a moving tag at a predetermined speed. This test purpose to get the performance of RFID tag reading when moving at a certain speed.

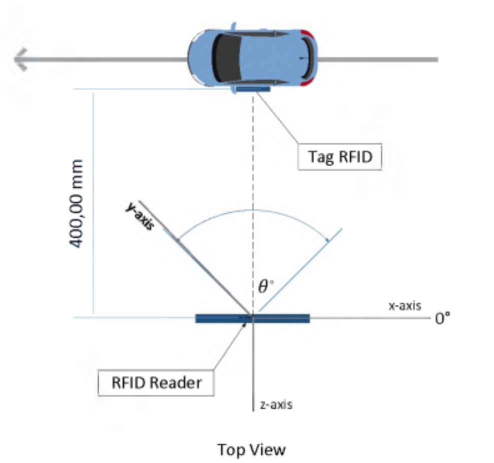

Fig. 9. Illustration for testing of RFID reader on moving state condition RFID tags

The testing stage is carried out by placing the RFID reader at a distance of 4 meters from the vehicle lane and the tag is attached to the vehicle that will advance on the specified lane as illustrated in Fig. 9 (the RFID reader is unmoving and tags are moving at a predetermined speed). Determination of the distance of 4 meters is based on the assumption of the best distance from all readings of tags by RFID reader from the testing of the static condition for all types of tags as shown in Fig.s 6, 7, and 8. In the pictures, green indicates the number of readings between sixty to eighty times of reading in 5 seconds of reading the tags with a reading interval of 5 ms. The worst performance of tag reading is on tag type label A, with the farthest distance is 4 meters.

This moving state condition testing uses 5 tags for the three types of RFID tags used. Each of these tags is tested attaching tags to vehicles that go with speeds of between 10 km/h to 60 km/h on the trajectory

The following tables present the results of RFID testing in moving state condition:

TABLE 3. TESTING OF TYPE OF RFID CARD TAGS (A) IN MOVING CONDITION

No.	Label	Vehicle Speed (km/hour)					
		10	**20**	**30**	**40**	**50**	**60**
1	A1	30	12	8	5	4	3
2	A2	32	14	12	8	8	2
3	A3	19	9	10	7	4	4
4	A4	28	13	8	8	5	1
5	A5	17	13	8	8	5	1
Average		25,2	25.2	12.2	9.2	7.2	5.2
D (Average Deviation)		5,76	5.76	1.36	1.44	0.96	1.12
Precision (%)		94,24	94.24	98.64	98.56	99.04	98.88

Table 3 shows that the reading of the card type tags still reads well at speeds of 60 km/h, even though the number of readers is relatively small. This test has an average precision of 98.05%.

TABLE 4. TESTING OF RFID PASSIVE METAL TAGS (B) ON MOVING STATE

No.	Label	Vehicle Speed (km/hour)					
		10	**20**	**30**	**40**	**50**	**60**
1	B1	28	13	12	6	6	3
2	B2	23	14	6	4	3	3
3	B3	26	15	9	6	5	4
4	B4	25	15	10	9	5	3
5	B5	28	14	8	8	3	3
Average		26	26	14.2	9	6.6	4.4
D (Average Deviation)		1,6	1.6	0.64	1.6	1.52	1.12
Precision (%)		98,4	98.4	99.36	98.4	98.48	98.88

Table 4 shows the reading of RFID Passive Metal Tag type tags still reads well at speeds of 60 km/h, the number of readers is better than card type tags. This test has an average precision level of 98.86%

TABLE 5. TESTING OF PAPER LABEL STICKER TAGS (C) ON MOVING STATE

No.	Label	Vehicle Speed (km/hour)					
		10	20	30	40	50	60
1	C1	26	11	5	2	0	0
2	C2	21	19	7	2	0	0
3	C3	20	12	7	4	0	0
4	C4	18	11	7	3	0	0
5	C5	25	18	8	6	0	0
Average		22	14,2	6,8	3,4	0	0
D (Average Deviation)		2,8	3,44	0,72	1,28	0	0
Precision (%)		97,2	96,56	99,28	98,72	100	100

Table 5 shows that the reading of the Paper Label Sticker Tag type is not read at the speed of 50 km/h. This test has an average precision level of 98.62%.

From the three card types testing can be made a comparison table of the average reading of the tags as presented in table 6.

TABLE 6. AVERAGE TAG READING ON TESTING ON MOVING STATE

Label	Vehicle Speed (km/hour)					
	10	20	30	40	50	60
RFID Card tags (A)	25.2	12.2	9.2	7.2	5.2	2.2
RFID Passive Metal Tags (B)	26.0	14.2	9.0	6.6	4.4	3.2
Paper Label Sticker Tags (C)	22.0	14.2	6.8	3.4	0.0	0.0

Table 6 shows that the type of tag with the best reading is the type of metal tag (B) which is still able to read with a moving speed of 60 km/h and worst the type of sticker tag label that is already unable to read at a speed of 50 km/h.

Assuming the accuracy of the reading of RFID tags is 100% when RFID reader can read the tags, the accuracy of reading tags on the moving condition is 100% for the tags types of card tags and metal tags, and 66.67% for type of label sticker tags. From this static and moving state RFID testing, RFID passive metal tag type RFID tags have the best performance. Reading at a distance of 4 meters, this tag type has an effective reading angle of -45° to 45°. In other words, the metal tag reading area at a distance of 4 meters is an angle of 90°.

V. CONCLUSION

Referring to the test measurement results, it can be concluded that the best position of the RFID reader is facing toward the RFID tag with an angle of 0° on the z-axis and y-axis. The RFID tag that has the best accuracy is the type of UHF RFID passive on-metal tag, both for testing in a static state or moving state conditions and at a read-range distance of 4 meters as the best reading distance, it has a reading angle of 90°.

Validation of the reading results of the three types of RFID tags on the test measurement of the static state is shown with an average precision level of 98.89% and 98.52 on the test of moving state condition. The representation of measurement test data produced very well is indicated by the standard deviation of each test measurement of each RFID tag is very small compared to the average value obtained.

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