Comparing Configurations for Car Speed Measurements Using Passive RFID Tags

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Abstract— **The ability to detect instantaneous speed is crucial for several applications. Moving objects such as vehicles and robots need to detect their speeds on a regular basis. Current systems measure speed using radars and speedometers which base the detection of the speed on the Doppler frequency shift phenomenon. Furthermore, Global Positioning Systems (GPS) do not usually work inside closed structures. In this paper, we present a cheap alternative to measure speed using RFID passive tags. The system is based on a RFID reader that reads tags installed within its reading range. The reader can be fixed or moving. Several configurations are tested to determine the best spacing of the tags as well as the possible benefit of using an extra antenna to detect speed. Moreover, calculations will be based on three different selection criteria of the time instances.**

Keywords- RFID, passive tags, localization, diversity readings.

I. INTRODUCTION

RFID, Radio-frequency identification, is an automatic identification system that uses radio waves to transmit the identity of an object or person. The basic components of a RFID system are: RFID tag (transponder), RFID reader (interrogator) and a computer system. There are three types of RFID tags: passive, semi-active, and active tags. Passive tags use energy transmitted by the RFID reader to charge up and respond to it. Semi-active tags have a built-in battery that is activated only when the tag receives a radio signal from the RFID reader. Active tags also have a built-in battery that allows the tag to continuously beam its signal without the need to receive energy from the reader. Passive tags are usually used for short distance applications (within 6 m) while semi-active and active tags are used for longer distance applications (up to 30 m) [1].

RFID-based system has many advantages. The first one is the ability to read tags in bulks rather than on individual basis. This is very important, especially in applications such as asset tracking. The second one is the simplicity and cheapness of the system. Passive tags cost almost 10 cents/ tag, semi-active tags cost almost 5$/tag, and active tags cost almost 50$/tag. This makes the proposed system affordable since only passive tags are used. Another advantage is absence of a power supply for the tags since they receive their energy from the radio signal sent by the reader.

Several experiments have been conducted to determine the validity of using a RFID system to detect speed. Authors of paper [2] reported a successful implementation of a system that used RFID to detect average speed in South Africa in 2004. The system was made up of a PC, a RFID reader, a passive tag and a high-speed server with a database system. The system was used to control traffic and supervise stolen vehicles. The average speed was calculated by placing two antennas 12m apart and using the following formula:

$$v = \frac{d}{(t2 - t1)} \quad (1)$$

where d=12m , t1 is the time detected by antenna 1 and t2 is the time detected by antenna 2. However, this system had several limitations, first of which is the high cost since it relied on multiple antennas. Another limitation is the issue of privacy since vehicles can be indefinitely monitored.

Authors of paper [3] worked on a navigation system that included a RFID reader in addition to a GPS. The concept was to install the tags on the road that stored accurate information about the location. A RFID reader was added to the navigation system to enhance the accuracy of the GPS system. This was done since GPS systems usually diverge by several meters and don't perform well in bad weather or in closed structures such as tunnels.

In paper [4], the authors suggest measuring the speed by determining the distance and angle of two consecutive points with respect to a reference point. As the figure below shows:

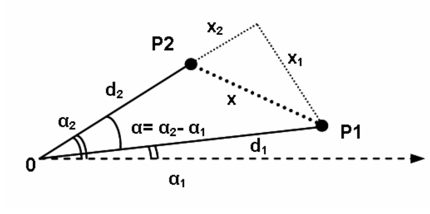

Figure 1: Speed Calculation Algorithm [4]

the speed of the vehicle can be determined using the following equations:

$$x = \sqrt{d_1^2 + d_2^2 - 2.d_1.d_2.\cos\alpha} \quad (2)$$

and

$$v = \frac{x}{\Delta t} = \frac{\sqrt{d_1^2 + d_2^2 - 2.d_1.d_2.\cos\alpha}}{t_2 - t_1} \quad (3)$$

The proposed system had some limitations such as only being able to detect tags within a 60^0 working area. Thus if the vehicle was near the reader, the system will not be able to detect the speed appropriately.

Paper [6] proposes a localization algorithm using RFID tags with the help of a GPRS modem while paper [7] proposes a localization algorithm of vehicles using active RFID tags and existing GPS systems to determine the exact location of the vehicles. An extension to such systems can be implemented to determine the average and instantaneous speeds of vehicles.

Paper [8] discusses a RFID-based system that detects the speed and stopping point of railway trains that travel at high speeds exceeding 500kph. The proposed system uses the UHF band that is not usually associated with such high speed application.

Section II presents the two configurations tested in this paper. The technical data of the equipment as well as the settings of each configuration are described. Section III discusses the different reading strategies for the two configurations and the speed calculation strategies for each of these reading strategies. Section IV presents and analyzes the results of the measurements obtained. Finally, section V concludes the discussions of the paper and proposes suggestions for future work on this system.

II. System Setup

The experimental data collected was based on two different configurations. The first configuration was used to determine the best spacing distance between the tags while the second configuration is used to determine the possible benefits of employing multiple antennas.

For each configuration, 6 runs were performed at speeds: 20, 30, 40 and 50 km/hr. Desired speeds were reached before the reading range of the antenna and maintained throughout this range to ensure that valid conclusions be deduced. Moreover, given the fact that multiple tags were used with tag spacing of 0.5m between each two tags, it can be viewed as having 6*4=24 runs for 0.5m spacing, 6*3=18 runs for 1m spacing, 6*2=12 runs for 1.5 m spacing, and 6 runs for 2m spacing.

Concerning equipment, the reader used is the Impinj Speedway that operates in the UHF band. For future work, it will definitely be better to use the microwave band as that would provide us with a higher reading rate and directivity. As to the antenna, the laird antenna was used; it has a circular polarity and operates in the wide band range (865-960 MHz). Finally, the tags used work under the EPC Gen 2 standard

A. Configuration 1:

The first configuration consists of placing two or more tags (5 tags) on the road with 0.5m spacing between the tags. The tags are oriented perpendicular to the vehicle's path as previous experiments show that tag orientation has no effect on measurements [5]. This is done for several spacing distances. The RFID reader is installed inside the vehicle and is powered by the vehicle's electrical source. The antenna is installed under the vehicle because if placed inside it, the metallic body of the car inhibits the antenna from receiving the tag reflections.

Such a configuration has many advantages. One advantage is that the distance between the antenna and the tags remains the same at all instances (around 30cm). Moreover, such a setup takes advantage of the field reflections between the road and the vehicle to have more accurate and reliable readings. Furthermore, having multiple tags allows us to calculate the speed of the vehicle using different combinations of tags (tags 1 and 2, tags 1 and 3, tags 2 and 4…) to have more accurate results.

However, this configuration presents several limitations. First, the cost will be relatively high since citizens will have to buy the reader and antenna to be installed on their vehicles. Moreover, the connection between the reader, which is located inside the vehicle, and the antenna, which has to be installed on the bottom of the vehicle, makes the system cumbersome. Thus it is impractical to employ multiple antennas on the vehicle.

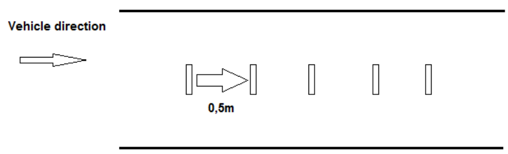

Figure 2: Configuration 1 Settings

B. Configuration 2:

The second configuration consists of placing two tags on the bumpers of the vehicle with 3.72m spacing between them. No tags were placed between these tags because their readings are negatively affected by the presence of metal. Two antennas are installed on the side of the road with 2 m spacing between them at a height parallel's bumper. The distance should not be too small to an extent that makes the use of the 2nd antenna redundant. As a matter of fact, in our experiments, we are not studying antenna quality. Assuming that they are of the same quality, the 2 antennas should give similar results when placed very close to each other.

This distance should not be too large to an extent that the car speed can vary significantly over this range. If this is the case, the readings of the antennas become independent, and thus, they cannot be correlated to each other. They are fed from a regular socket in a booth on the side of the road.

The advantages of such a configuration include a low cost for the citizens since they only need to buy passive tags that are quite cheap. Another advantage is the possibility of measuring the speed using each antenna alone and then combining the results to have a more reliable result.

However, there are several limitations to this configuration. One limitation is that the distance between the antennas and the vehicle is not constant at all times, which might affect the accuracy and reliability of the measurements. Another limitation is the cost of installing the extra antenna. Thus we need to determine the benefit of employing the extra antenna.

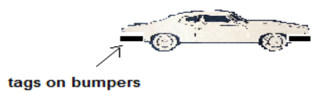

Figure 3: Configuration 2 Settings

III. IMPLEMENTED STRATEGIES

The implemented strategies consist to use several methods for selecting the tag reading time as well as the method of calculation of the corresponding vehicle speed.

A. Reading Strategy

The reading count of every tag depends on how long the tag remained within the reading range of the utilized antenna. Therefore, it is important to decide on a specific reading time for speed calculation. For this reason, 3 reading strategies are tried out.

i) Method 1: consists of selecting the first reading time for each tag. The expectations from this method are affected by the following. Each tag has only one time stamp, the first reading time. Therefore, there is no variation in the number of time stamps for each tag where one would be read more than another. This should provide a certain level of consistency in the results. A disadvantage may be that a tag can be read much earlier than expected. Its reading time might be too small; hence, it can give erroneous results.

ii) Method 2: uses the average reading time of all the time stamps of the corresponding tag. The significance of this method lies in obtaining meaningful values for tags with large reading counts. Thus it is expected to have desired results when using this strategy.

iii) Method 3: detects the time stamp that has the highest RSSI (Received Signal Strength Indicator). The advantage of this strategy lies in the fact that for the tag to be read at highest power, it is usually located in the proximity of the antenna. However, highest RSSI doesn't always mean the tag is read in a reliable manner, i.e. a tag may be read by chance at high power at a far distance from the antenna. Thus the timestamp will be small, resulting in erroneous results.

The 3 strategies use the following basic formula for speed calculation:

$$v = \frac{(3.6 * d)}{(t_2 - t_1)} \quad (4)$$

where d is the spacing between the tags, t1 and t2 are the reading times of tags 1 and 2 respectively

B. Calculation Algorithms

Several algorithms are proposed for each configuration to calculate the speed of the vehicle. Two algorithms are suggested for configuration 1, and three are suggested for configuration 2.

i) Configuration 1, Algorithm 1: With 5 tags placed on the ground, all possible selections of 2 of the 5 tags are made. The average speed will be calculated for each spacing over each run. This will clearly depict the best spacing for this configuration.

ii) Configuration 1, Algorithm 2: In this algorithm, the average readings for each run are calculated. This makes the algorithm independent from the spacing of the tags as we are taking the average across all spacings within each run. Hence, the better results will correspond to the preferable method for calculations.

iii) Configuration 2, Algorithm 3: This algorithm employs 2 antennas for speed calculations. The readings of the tag on the front bumper will be extracted from each antenna to be used. The distance separating the tag being read corresponds to the 2 m antenna spacing. However, concerning the reading times, the highest RSSI cannot be used since antenna1 might read the tag with the highest RSSI at an earlier or later time from antenna 2. Therefore, to make the 2m distance used in the calculations justifiable, the average reading time of the tag from each antenna will be used.

iv) Configuration 2. Algorithm 4: This algorithm uses the readings of one antenna placed on the road and the 2 tags on the car bumpers.

v) Configuration 2, Algorithm 5: This algorithm performs the calculations on the readings of each antenna using the best calculation method. These results are then averaged in case the readings of one antenna deviated from expected. Even if this was not the case, averaging the results from the 2 antennas may decrease the overall percentage error of the desired speed.

IV. EXPERIMENTAL RESULTS

In the following analysis, the percentage error is calculated as follows:

$$Percentage\ error = \left| \frac{(V_{calc} - V_{theo.}) * 10}{V_{theo}} \right| \quad (5)$$

where $V_{calc.}$ is the calculated speed and $V_{theo.}$ is the theoretical speed.

A. Configuration1,Algorithm 1:

The results obtained can be viewed with the following figures:

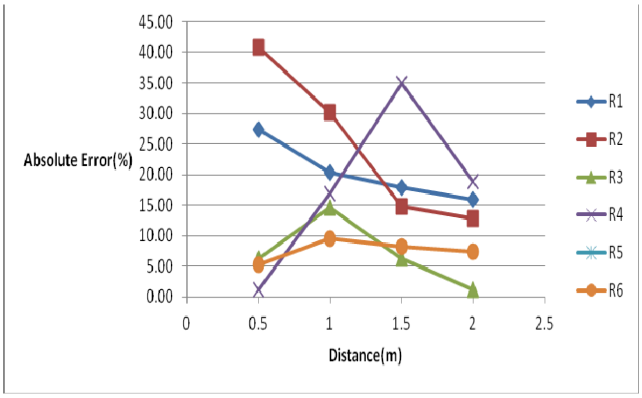

Figure 4: Variation of Absolute Error as a function of distance at 20 km/hr (Method1)

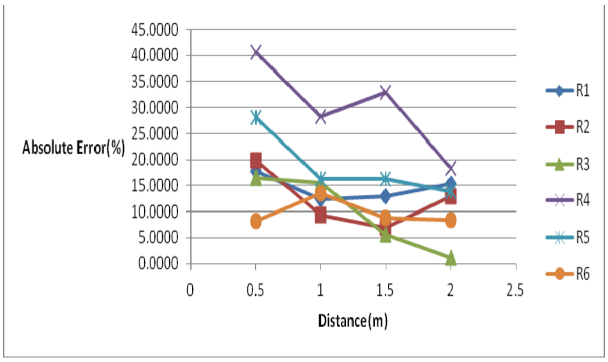

Figure 5: Variation of Absolute Error as a function of distance at 20 km/hr (Method 2)

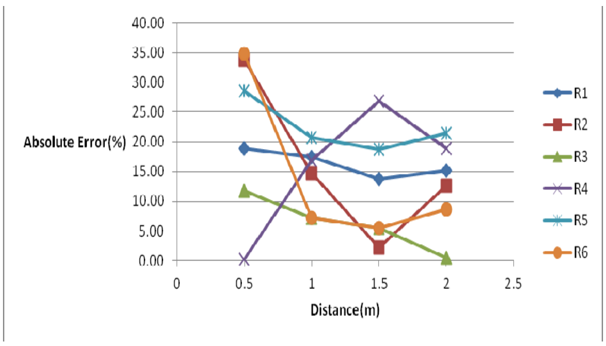

Figure 6: Variation of Absolute Error as a function of distance at 20 km/hr (Method 3)

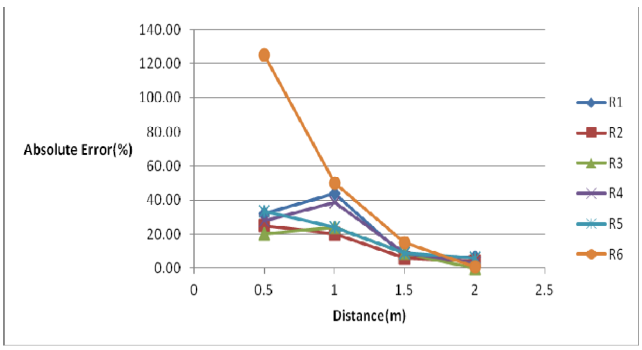

Figure 7: Variation of Absolute Error as a function of distance at 50 km/hr (Method 1)

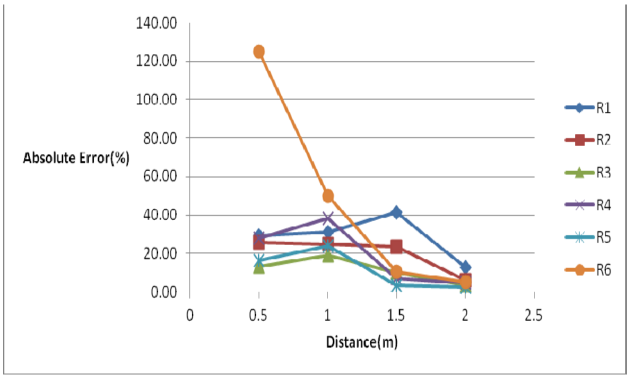

Figure 8: Variation of Absolute Error as a function of distance at 50 km/hr (Method 2)

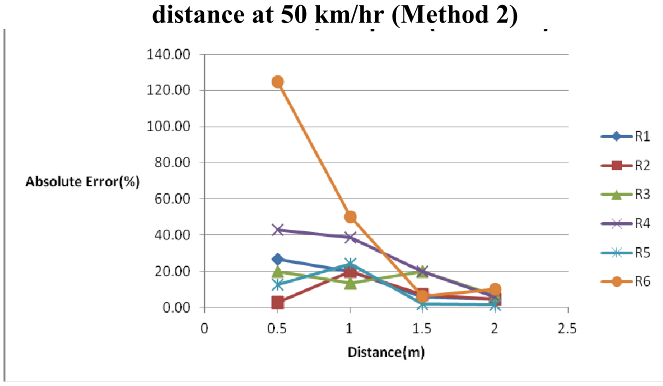

Figure 9: Variation of Absolute Error as a function of distance at 50 km/hr (Method 3)

The average absolute errors for all methods at each speed are shown below:

Distance / Method	Method 1	Method 2	Method 3
0.5	18.140	21.761	21.338
1	17.793	15.842	14.011
1.5	16.438	13.915	12.047
2	11.595	11.705	12.852

Table 1: Average Absolute Error for different spacings at 20 km/hr

Distance / Method	Method 1	Method 2	Method 3
0.5	21.031	18.682	20.790
1	14.678	11.177	12.284
1.5	12.099	9.826	11.809
2	7.273	8.097	8.730

Table 2: Average Absolute Error for different spacings at 30 km/hr

Distance / Method	Method 1	Method 2	Method 3
0.5	16.697	18.500	10.009
1	14.233	10.663	9.333
1.5	8.495	7.679	7.778
2	8.292	7.744	6.832

Table 3: Average Absolute Error for different spacings at 40 km/hr

Distance Method	Method 1	Method 2	Method 3
0.5	43.901	39.619	38.265
1	33.468	31.268	27.642
1.5	9.174	15.972	10.119
2	3.405	5.6945	5.477

Table 4: Average Absolute Error for different spacings at 50 km/hr

The errors in the previous tables are calculated after averaging the speeds obtained for each spacing in every run. The tables show that the smallest percentage error occurs at spacing of 2 m at all speeds. However, no pattern appears, thus no preference exists for the choice of reading algorithm.

B. *Configuration 1, Algorithm 2:*

The results of this algorithm are shown in the following table:

Speed Method	Method 1	Method 2	Method 3
20	12.338	11.563	10.947
30	10.317	7.973	7.833
40	9.787	8.009	6.506
50	50.371	55.418	18.134

Table 5: Average Absolute Error for different speeds (Algorithm 2)

It is highly noticeable that the percentage error is at its lowest using method 3. Not only does it give the lowest errors at each speed, but it also generates low percentage errors in general; thus, it is a good and reliable method. This result is logical and can be explained by 2 factors: the proximity of the antenna to the tag allows it to read the tag with high power, and averaging the speed calculation of all combinations will definitely give us better results.

C. *Configuration 2, Algorithm 3:*

The results of this configuration are shown below:

Speed	Average Percentage Error
20	9.897
30	23.001
40	14.404
50	26.869

Table 6: Average Absolute Error for different speeds (Algorithm 3)

This table shows that this algorithm is unreliable since all the percentage errors are significant. Furthermore, there is no consistency as the speed increases. This may be explained by the fact that the antenna is in free space and has a wide reading range. Therefore, the timestamps of each antenna for the tag are overlapping. Hence the average reading time for the 2 antennas are close, resulting in unsatisfactory results.

D. *Configuration 2, Algorithm 4:*

The results for this algorithm are as follows:

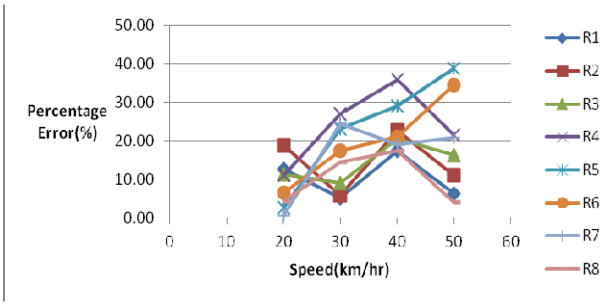

Figure 10: Variation of Absolute Error as a function of speed

To visualize the results, the average error of the 8 runs for each speed is tabulated below:

Speed	Method 1	Method 2	Method 3
20	8.395	16.703	10.756
30	15.772	18.364	10.008
40	22.840	25.713	16.841
50	19.127	25.347	11.385

Table 7: Average Absolute Error for different speeds (Algorithm 4)

It can be concluded from the table that Method 3 (Highest RSSI) gives the smallest percentage error.

E. *Configuration 2, Algorithm 5:*

The results are shown below:

Speed	Average Percentage Error
20	9.984
30	3.095
40	19.578
50	10.688

Table 8: Average Absolute Error for different speeds (Algorithm 5)

We notice a slight improvement as compared to the previous algorithm in which only 1 antenna was used to detect the speed.

V. CONCLUSION

It is important to be able to determine the instantaneous speed of moving objects for many applications, including car speed limitations. Therefore, we have attempted in this paper to come up with a reliable system of relatively cheap cost as compared to the conventional radar systems. For this purpose, 2 configurations have been proposed. The first configuration consists of an antenna fixed on the lower body of the car and 5 tags on the ground. The 1^{st} algorithm conveyed the lowest percentage error at a spacing of 2m, irrespective of the reading strategy used. The 2^{nd} algorithm showed that the best reading strategy is the highest RSSI. As to the 3rd algorithm of configuration 2, unreliable results were obtained. The 4th algorithm has proven that method 3 of the highest RSSI gives the smallest percentage error, and averaging these methods using the 5th algorithm improved the former result. It can be observed that the highest RSSI strategy gives satisfactory results in general.

For future work, it is highly recommended that we operate in the microwave band as it gives a higher data rate. Moreover, semi-active tags will enhance the performance of our system since they can be read at a further distance while maintaining an acceptable cost range.

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