Collaborative Location-Based Mobile Game with Error Detection Algorithm

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***Abstract*—In the recent years, there has been an evolution in game input medium. From just using buttons, players can now interact with games through a wider spectrum of inputs which includes touch screen, camera, light sensor, accelerometer, compass and GPS. This is driven by the availability of these modules and sensors within mobile devices that are omnipresent nowadays. As a result, there has been a creative breakthrough on how games are played today where gaming experience can be made more intuitive and immersive. Localization is one of the input medium where the player's physical location is used as part of the gameplay. This paper proposes an original gameplay schema that utilizes indoor mobile Wi-Fi localization technique as game input that does not require additional infrastructure. The game takes advantage of the weakness of Wi-Fi localization where environmental influence is significant and makes it part of the gameplay. A simple error detection algorithm is also introduced to maximize the game playability value by balancing game responsiveness and accuracy level.**

***Index Terms*—Game Technology; Wi-Fi Localization; Location-Based Games; Pervasive Games.**

I. INTRODUCTION

Input for mobile games has seen a drastic evolution from just interacting through buttons towards the application of more advanced input modules which includes the accelerometer, compass and camera. This allows greater flexibility in the design, usage and interaction of mobile games and opens up numerous possibilities for innovation. Games could be played more intuitively and improve overall immersion and satisfaction of players [1]. One of the game input medium that had seen an increase of attention from both game developers and players is player location.

Player location is used within these games either to show the movement of a player based on the real world map or to show relative movement on a created virtual space. This is done through the usage of Global Positioning System (GPS) that utilizes signals from four or more satellites that have a clear line of sight of the player. The need to have an unobstructed line of sight had prevented location-based games to be played indoors especially with the presence of high rise buildings, large malls and intricate subway systems that are an important part of major cities nowadays. Thus, there is a motivation to look for an alternative localization system aside GPS that would enable location-based games to be played indoors.

Elaborate researches have been conducted upon components within the current smartphone technologies for potential systems that could enable indoor localization for navigational purposes. Among the methods that are looked upon are Wi-Fi, RFID, Bluetooth, sonar, visual and multi-modal approach [2]. These methods however produce low accuracy output and as a result made navigation harder and more confusing than without using the navigation system [3]. Accuracy can be improved through installing signal transmitters along the pedestrian pathway every few meters as in [4] but this increases the overall cost of using the system and is seen as not feasible.

There are a number of differences between localization for the purpose of navigation and gaming. Localization for navigation requires the location data to be supplied instantaneously, available in all types of pedestrian environment and the navigation process needs to be very accurate [5]. On the other hand, localization requirement for gaming purposes are more relaxed in nature and relied mostly on the gameplay of the game. Therefore, methods that had been explored for indoor navigation can be investigated and adapted towards location-based games. Wi-Fi localization is chosen for the purpose of this research because it is present on most recent smartphones and considerable amount of research work has been done about it.

Playability is a measure for the quality of a game which envelopes its level of easiness to be played and the amount of time that the game is playable. The focus of the discussion in this paper is to measure how easy it would be to produce the location information and how accurate is the location information. Strategies implemented to overcome the shortcomings of Wi-Fi localization to achieve practical gaming experience are outlined. Lastly, a Proof of Concept mobile application is made to demonstrate the potential of the proposed system. Comparison of accuracy is done between location data obtained with and without using the strategies in order to understand its contribution.

II. RELATED WORK

As the idea of using location as game input is categorized as pervasive gaming, related works on pervasive games will be discussed. Current development on location-based games is investigated and techniques that are used in Wi-Fi localization for navigational purposes are also reviewed in this section.

A. Pervasive Games

Pervasive games are a way of gaming where the game is played in both real and virtual world. Games are played not only limited on the computer screen but also involve real world substances [6]. There are various implementations of pervasive games such as using a board game, real world objects and real world location. Four distinguishing concepts that coexist in most pervasive games are player's mobility, sensing technologies, integration of physical and virtual worlds and social interaction.

Player's mobility is important for pervasive games especially for games that use real world location or objects as part of the gameplay. Availability of wireless communication technology such as 3G, GPRS and GSM permits communication between players as well as game servers while moving around freely. Sensing technologies on the other hand provides the context of what is being communicated [7]. This includes GPS coordinates, camera, microphone, compass, accelerometer and many more components within the smartphone which can supply information of the player to be used as part of gameplay.

In order to integrate the physical and virtual worlds, the use of displays is essential to represent the virtual world. It can be easily represented through the use of smartphone screen however more advanced system could employ the use of the head mounted display or augmented reality glasses [8]. To create a connection between both worlds, real world objects can be recreated within the virtual world or virtual artefacts can be introduced into the player's real world view through augmented reality technique.

Social interaction is considered as one of the core factors of pervasive games as the real world element within the game is naturally shared among people. Example of this is people that lives in the same city will play on the same city map. Interaction between players makes the overall gaming experience richer and provides opportunity to achieve a creative solution together however there will be a need to facilitate proper tools for interaction [9].

In [10], the enjoyment factors of playing pervasive games are studied. Pertaining to game input, two significant points that are discussed consists of control and feedback. To be able to enjoy a pervasive game, the player should feel the sense of control over their actions. This shows the importance to have a reliable game input medium that could reflect the intention of the player. Players must receive appropriate feedback at appropriate times. Therefore, there is a demand for the game input to be supplied in a timely manner and this restricts the amount of allowed computation time.

B. Location-Based Games

Location-based games utilize the player's physical location as an input for the game. It can either be used to track the displacement of the player and move the in-game avatar accordingly or generate a game level based on the player's current location map condition and availability of other players. Currently, most location-based games use the GPS technology as its sensing technology due to its accuracy and ease to use [11]. However, WiFi and Cell-ID solutions are still considered as its complement mainly to overcome GPS signal occlusion problem and battery consumption of the resource hungry GPS receiver.

In order to pick technologies that will be used within location-based games, it is important to utilize technology which is already ubiquitous to maximize the potential user base [12]. Using technology that is not included within the standard current mobile phone will limit the amount of users that are able to play and negatively impact the overall chance of success for the game.

Geo Wars in [13] is a location-based game based on the tower defence gameplay genre. The game uses GPS technology and is played on a map created by extracting terrain information from Google Map while integrating other real-time location-based information such as weather into the game. Player needs to place defensive structures on the map to defend against incoming enemy AI which will utilize the roads available in the map. Due to the large difference of map and terrain available, the game difficulty that a player will face will differ as well. Thus a game difficulty balancing system should be made to ensure the game to have sufficient amount of challenge to retain its players. The design of the game should incorporate excitement of playing the game from different places to offer a dynamic experience. This however creates a need for a mechanism to ensure the game to be playable from all of the places.

Passive RFID technology application of location-based games is explored in PAC-LAN described in [14]. The game is played in a student accommodation park and passive RFID tags are placed around it to sense player location. The player who plays as the PAC-LAN runs around tagging the RFID tags to pick up scores virtually. Four other players play as ghosts and collaboratively try to catch PAC-LAN. They are always alerted on the position of PAC-LAN every time a RFID tag is tagged. The advantage of using passive RFID is it does not need power supply and the tags are not expensive. Yet there would still be a considerable amount of investment to cover the whole map with RFID tags in terms of cost and effort.

Proximity-based games are a gaming concept similar to location-based games. Instead of detecting the exact location coordinate of a person, games are played between random players that are located in close proximity with each other [15]. An example of such system is the StreetPass introduced by Nintendo. Nintendo 3DS owners just need to switch on the StreetPass system and devices that are within range of a proprietary Wi-Fi signal will automatically exchange data. This method however does not support real time play but only provides players with bonus games artefact or suspended transactions.

C. Wi-Fi Localization

Localization can be divided into two parts; distance and direction. Distance is the range between the antennae and the emitter of signal while direction is the angle of emitter with respect to the antennae. To find distance, two basic methods are used. The first one is Received Signal Strength Indication (RSSI) method where Wi-Fi signal strength that dissipates over distance travelled is used as a model to measure distance [16]. This method is easy and less computationally intensive. It is however not very accurate as Wi-Fi signal is susceptible to multipath fading. Secondly, Time of Flight (ToF) method is used to determine distance through measuring time taken for a data package to arrive from the emitter to the antennae by comparing their timestamp [17].

Direction information is more complex to obtain and most models incorporate the distance calculation technique discussed earlier within the calculation for direction. There are two standard models; multilateration and Angle of Arrival (AoA) method. Multilateration calculates direction through comparing the distance of the emitter from two or more different antennae location [18]. The distance curve from the antennae will coincide at the direction pointing towards the emitter. AoA uses a similar concept to multilateration but the array of antennae is located on a single device which permits hardware calculation and elimination of latency in synchronizing information between antennas which is more efficient [19]. It could utilize ToF method to further increase its effectiveness.

Fingerprinting method uses a database to store distance information of all the emitters in the range from an antenna [20]. The database which holds fingerprint information of all possible locations in the area will indicate the coordinate of the antennae whenever a query with combinations of emitters distance is presented. This strategy produces very accurate result as it considers all of the noise factors within the fingerprints however the initial setup to collect fingerprints to cover the whole area is very labour intensive. It is also very hard to determine the direction when the antenna is not moving as only the coordinate is known. The fingerprint database must be updated if there is any change towards the layout of the area or placements of emitters.

Different mobile device have a different type of Wi-Fi chipset installed. These different chipsets have different signal propagation behaviour thus different constant needs to be used within the distance calculation. Even with the same type of chipset, there is found to be some discrepancies with the propagation behaviour. Still it is better compared with using different types of chipset. It is also important to note that certain types of chipset have signal behaviour that propagates better, relays better RSSI info and introduce minimal interference from its hardware or software operation [21].

III. WI-FI LOCALIZATION TECHNIQUE

This section outlines the Wi-Fi localization technique that is implemented as part of the proposed game input. To ensure that the system could be implemented towards any current smartphone, the RSSI method is used for distance measurement and multilateration method is chosen to compute direction. These methods do not require high computational power, network demand and specialized additional equipment to work.

A. Distance

Wi-Fi signal dissipate over distance and the amount of strength recorded at the receiver is measured to indicate the distance between the receiver and the emitter. In order to calculate the distance, the distance estimation model as proposed by Texas Instruments for their radio model as used in [22] can be observed in Equation (1).

In Equation (1), d is the estimated distance and RSSI is the signal strength in dBm. A is the RSSI value in dBm detected when the receiver is exactly one meter from the emitter and lastly n is the signal propagation constant. This RSSI distance estimation model will be used to obtain all distance value discussed from this point onwards.

$$d = 10^{\frac{A - RSSI}{10 \times n}} \qquad (1)$$

where: d = Estimated distance
A = Signal strength at 1 meter
n = Signal propagation constant

B. Direction

Signal emitted from the transmitter is measured at two separate locations. There are two methods to achieve this. The first one is by using a single antenna time sharing method. This method however requires the emitter to stay in position while the reading is taken from the antenna in both locations which limits the usage of such setup for turn based games. Using a single antenna however can reduce the overall cost where only a single mobile device is needed to locate the emitter.

The second method, multiple antennae enables readings to be taken simultaneously from two locations at the same time. Receivers used in this method need to communicate and synchronize with each other to calculate the direction. The advantage of using this method is calculation can be made in real time and the location of the emitter can be always updated even if it is moving. It also provides the opportunity to make a new reading of the emitter signal in case the initial reading gives erroneous results after calculations. The first method does not provide this prospect as the antenna has already moved from the first location.

After two readings of signal strength are taken at two separate locations, the distance of the emitter from each receiver can be calculated with Equation (1). Their radial distance will coincide at two locations as shown in Figure 1; one indicating the real location of the emitter, and another a mirror image. Relative angle of the emitter from one of the receiver can be obtained from trigonometry calculation shown in Equation (2).

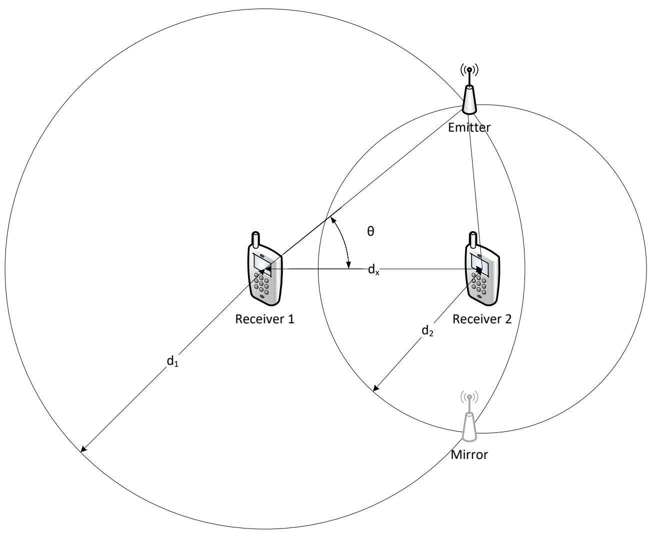

Figure 1: Direction calculation with two receivers

$$\theta = \cos^{-1}\left(\frac{{d_1}^2 + {d_x}^2 - {d_2}^2}{2 \times d_1 \times d_x}\right) \qquad (2)$$

where: θ = Relative angle of emitter
d_1 = Receiver 1 estimated distance
d_2 = Receiver 2 estimated distance
d_x = Distance between receiver 1 and 2

Distance from a third receiver can be used to eliminate the mirror image and select the right direction between the two possible angles available.

IV. METHODOLOGY

Having good accuracy in both distance and direction are major issues of using Wi-Fi technology for game input. The issue with signal multipath fading presents a big challenge to enable practical use of Wi-Fi for localization purposes. A solution framework is presented in this section to solve these issues and it is divided into two main parts; the gameplay and error detection algorithm.

The game and correction algorithm is installed within each player's device. This way there is no need for an external server that will increase the processing time further due to communication time taken and also processing congestion from all of the players at the same time. Furthermore, the processing power needed to run the game and also the correction algorithm is minimal and suitable for mobile devices.

A. Gameplay

In order to decrease the game setup complexity, each player is assigned with a standardised name to be used as their device hotspot name. The game is played in two teams with a minimum of 3 players in each team. Teams are divided automatically within the game through a randomizing process. One player from each team will be the target and the rest will attempt to capture the opposing team's target which identity is only disclosed within their own group members. Each player will carry a mobile device and collaboratively form a triangular formation as shown in Figure 2 to scan for the location of the target that have their mobile Wi-Fi hotspot turned on and labelled with their team's name.

Time taken for calculation increases as more erroneous readings are detected. In order to avoid players to be frustrated due to unresponsiveness of the game, error message is reported on the player device if no accepted result is obtained in the allowed time. This force the players to move physically towards a more favourable position to get a reading without error. Thus the weakness of indoor WiFi localization is utilized as part of the gameplay itself.

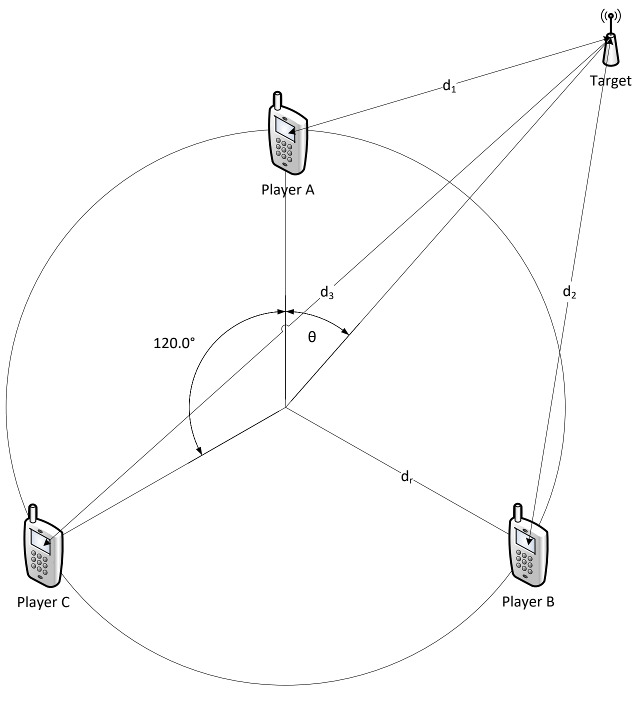

Figure 2: Scanning for the opposing team's target

On the event that they had detected the identity of the opposing team's target, they need to unanimously register the target's name on the game interface while having the target within their interconnected area to score points. Minus point is given if the team captured the wrong target. These game situations are shown in Figure 3. Game continues until either team has scored an agreed number of points and become the winning team. The same setup can be implemented with more than two teams to increase level of excitement.

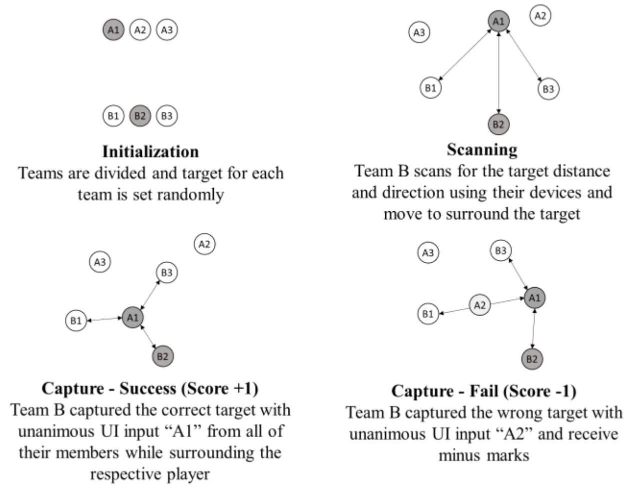

Figure 3: Scenarios during the game

Having an unobstructed line of sight between the target and other players is important for experiment result verification purposes however the game could be played with barricades in the field. Game is best played in a large space and out of bounds line may be constructed to enforce players to stay away from walls or other obstructions that can increase multipath fading issues.

B. Error Detection Algorithm

Due to signal multipath fading issue, it is presumed that the RSSI value obtained will produce erroneous distance value. If it is not corrected, this will then be used to calculate and produce erroneous direction data as well. Thus it is important to have a system that is able to self-check the value scanned and enforce recalculating process if error is detected.

Figure 4 shows the error detection process flowchart that is designed to improve overall accuracy of scanning the opponent team's target. There are three phase of error detection that occurs. The first phase filters the RSSI outlier values that lies beyond the standard deviation from the numerous RSSI values read. Having 3 players as signal receivers in formation shown in Figure 2 gives the opportunity to compare the distance from the centre of the circle to the target that is calculated from each player independently. High discrepancy may invoke recalculation to occur. Direction is checked in the final phase where calculation is done from the combination of distance from Player A and B, Player B and C and Player A and C. Results are crosschecked and recalculation process is done if they differ beyond the allowed acceptance level.

The number of initial RSSI value reading taken and acceptance level for both the distance and direction value can be increased to obtain a more accurate result. Doing this however increases the amount of time taken to produce a result and being too demanding can cause no results to be produced and render the game unplayable. It is important to provide timely result to the players to ensure continuous gaming experience.

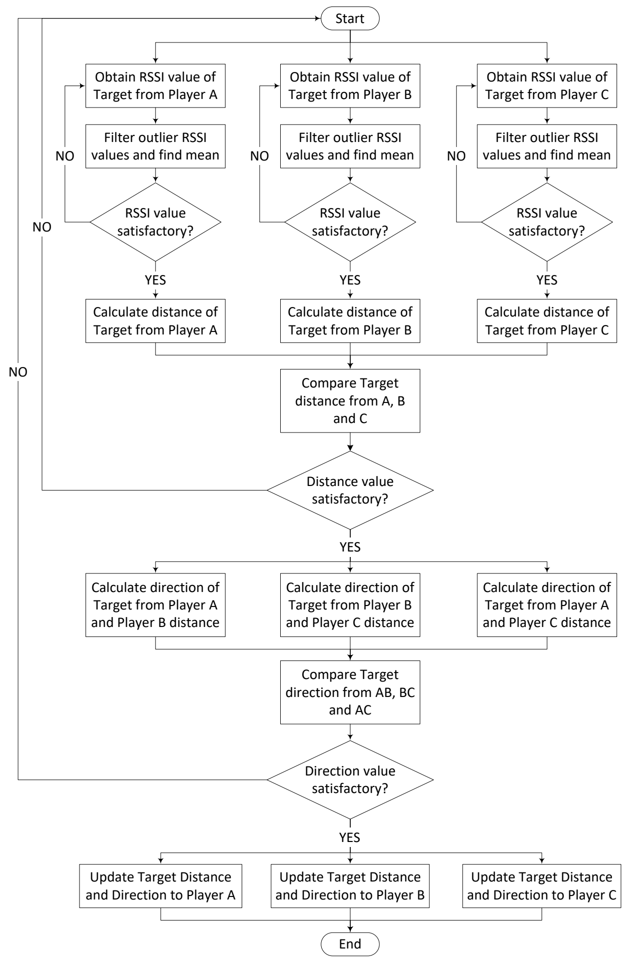

Figure 4: Error detection process flowchart

V. Results and Discussion

A proof-of-concept android application is designed to conduct experiments and test the proposed solution explained in the previous section. The application is then installed on three Motorola Moto G mobile phones that act as the players that need to collaboratively detect the target signal location. Another Motorola Moto G unit is used as the target where its Wi-Fi hotspot is turned on with its SSID assigned as “Target”. Using the same mobile device across the emitters and receivers ensures minimal variance of signal propagation behaviour. Furthermore, the same constant values can be used within the distance calculation in Equation (1) for all of the devices. Three experiments are conducted specifically to test the accuracy of estimated distance, influence of distance between receivers towards accuracy and error injection experiment. Finally, a game simulation is conducted to test the overall accuracy of the system. All experiments are conducted inside a multipurpose hall in University Malaysia Sarawak.

A. Estimated Distance

This simple experiment purpose is to compare the estimated distance calculated by one of the player receiver with actual distance. Target device is being held at one place by one person while another person carries the player receiver moving in a straight line away from the target. Reading is taken at every 1 meter step from 0 meter to 35 meters. Figure 5 shows the result of the experiment.

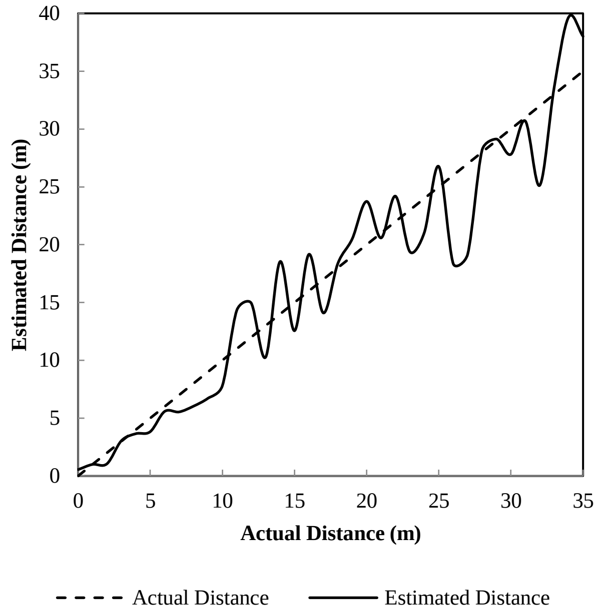

Figure 5: Estimated and actual distance

Overall estimated distances indicate that inaccuracy existed through all readings. This inaccuracy is more prominent for actual distance more than 25 meters. The average inaccuracy value for actual distance from 0 to 25 meters is 1.92 meters. Thus the self-corrective system should be able to handle errors around 2 meters. It is also noted that the maximum effective range between the target and players should be not more than 25 meters.

B. Distance Between Players

Distance between player receivers influence towards accuracy is investigated in this experiment. The experiment is implemented with and without the error detection system to observe its effectiveness in varying player distances. Three player receivers are placed in formation apart from each other. The distance between these receivers are increased with a 1 meter step from 1 to 7 meters.

Figure 6 shows that increasing the distance between receivers greatly improve the accuracy of the system. The error detection system also contributed in improving the accuracy especially for distances at 2 to 5 meters. An interesting aspect of implementing this towards the gameplay is to let the players decide upon the distance that they want to use as part of strategic decision where more distance promises better accuracy but also requires better range estimation and effort to construct the formation.

C. Error Injection

In order to learn the contribution of the error detection system in reacting towards an erroneous data reading, an error injection experiment is done with the three player setting explained earlier and the target located at 7 meters form the centre of the triangle. Simulated readings of distance are supplied to the player receivers introducing errors from 0 to 3 meter with a 0.5 meter step throughout the range. The range 0 to 3 is chosen due to the findings from the estimated distance experiment that shows that the average inaccuracy is around 2 meters. Error detection system output are compared with a system that has a similar calculation steps though without the error detection portion of the system.

Results from this experiment as shown in Figure 7 indicate that the error detection solution proposed reacted better with erroneous data in terms of accuracy compared to calculations without correction. With error introduced at 2 meters, the system without self-correction displayed 58% accuracy while with self-correction, 70% rate of accuracy is achieved. At 3 meters of error introduced, the accuracy dwindles to 29% and 54% for without correction and with correction respectively and this made location determination of the target even harder. An initial test in the environment to check whether the error recorded is beyond 2 meters should be made prior to playing the game to ensure the game to be playable in the space.

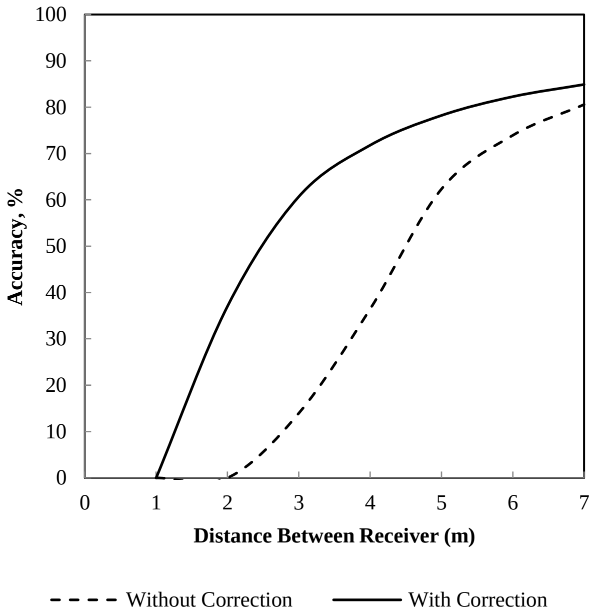

Figure 6: Distance between receivers and accuracy

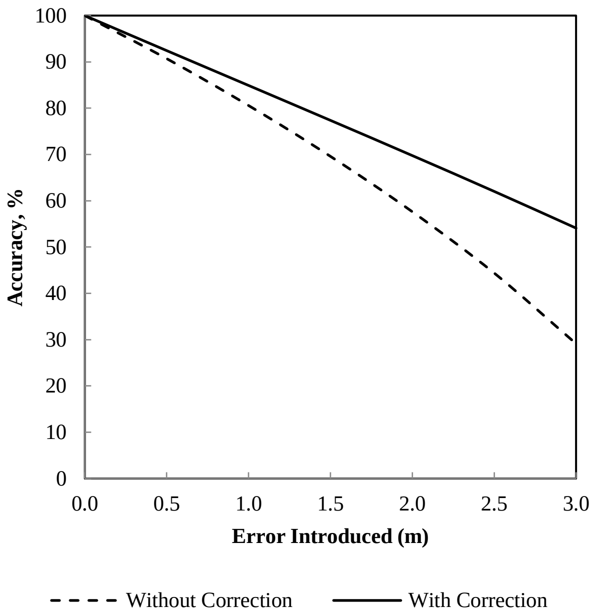

Figure 7: Error introduced and accuracy

D. Game Simulation

A simulation of the proposed game is done for the purpose of collecting data to measure the overall effectiveness of the proposed solution. The simulation involves 4 people; 3 players and 1 target. In the simulation, the target however does not move freely until the output is generated. The simulation is first done with calculations without correction and is later repeated for the system with self-correction. The target is positioned at 7 meters from the players with a 30 degrees angle with respect to player A. Distance and direction calculation is done from various angles and player distance setup with high number of repetition.

Table 1 summarizes the results obtained from the game simulation practice. The amount of distance readings accepted by the system with correction is only 42.86% where more than half of the readings are rejected. For direction calculation in the system without correction, only 52.38% of its data is accepted as the distance data supplied could not be used for angle calculation as it does not satisfy the triangle inequality where any two sides added should be more than the third side. This enforces recalculation to be done however the amount of correction obtained through this method is minimal as it only captures cases with extreme amount of errors only. Distance and direction accuracy of the system without correction is 61.22% and 65.20% respectively. With self-correction process, the distance accuracy achieved an impressive 91.80% while direction accuracy is at an acceptable percentage of 78.48%. Although Wi-Fi localization data is unstable, with adequate error detection system and good environment choice it could still provide reasonable accuracy to be used as game input.

Table 1
Game Simulation Statistics

Results	Without Error Detection	With Error Detection
% Distance Accepted	100.00%	42.86%
% Direction Accepted	52.38%	47.62%
Average Distance	4.29 m	6.43 m
Average Direction	40.44°	36.46°
% Distance Accuracy	61.22%	91.80%
% Direction Accuracy	65.20%	78.48%

VI. CONCLUSION

Wi-Fi localization offers an attractive potential as a game input medium however multipath fading issue has made Wi-Fi localization accuracy to suffer greatly. A proposed framework which consists of a gameplay design that enables collaborative uses of Wi-Fi antennae which are ubiquitously available nowadays and provides the capability to self-correct its calculation is presented. In order to utilize Wi-Fi localization, the systems need to be ready for erroneous readings to occur and possess the intelligence to handle it either by ignoring outliers, crosschecking, using the average of multiple readings and implements optimization. The error detection system significantly improves the overall accuracy with respect to the relative distance and direction accuracy. However, it still largely depends on the environment where the games are played. An area that has many factors for signal occlusion or multipath fading that could introduce discrepancy for the distance calculation for more than 2 meters might provide a substandard gaming experience. Nevertheless, it is important to note that the proposed solution in its current state is only suitable to be applied to a particular game as discussed earlier. For future works, a full game of the proposed solution should be played and accuracy of moving players should be evaluated. This presents a challenge as the calculation need to be completed close to real time and location information should always be made available to the players. Useful information could be obtained from a real game play-through to further improve the system. The gameplay proposed could be evolved by populating the arena with barricades for players to hide. Situations where players could not see each other visually but able to observe them in the radar creates a unique experience and offer possibilities to play First Person Shooter (FPS) games or laser tag with availability of radar to know the location of friendlies or foes. The biggest concern faced here is the choice of material and the dimension for the barricades must not introduce more multipath fading or signal occlusion. Issues such as the influence of signal congestion towards accuracy when playing the game with many players should also be investigated further to measure the scalability of the system proposed.

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