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TRACKING PEOPLE IN CLOSED SPACES TO LINK WITH METAVERSE

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ABSTRACT

The need to know the location and track people has become an important aspect of our daily lives, and although the global position system (GPS) has dominated outdoor location, in terms of indoor signal it is blocked and distorted by buildings, which affects its performance. Much of the technology that has emerged makes use of location, such are the applications that you have to do with the internet of things (IoT). In this work, an indoor people tracking system is proposed using the inertial navigation method to access different areas. Through an IMU device, the values of its sensors are obtained, which are transmitted to a computer in a virtual world, and the location of the person inside a building is disclosed. Thus, communication is established between the real world and a metaverse. Where movements of a person are represented in a virtual world.

Keywords: *RFID, Location, Inertial Navigation, IMU, Metaverse.*

1. INTRODUCTION

The way people communicate and relate to each other has changed over time and is closely related to the advancement of technology. The emergence of the internet has changed many aspects of daily life and enriched human interaction, communication, and the social sphere, provoking the search for new forms of communication and leading to the emergence of new technologies such as Virtual Reality (VR) and Augmented Reality (AR) [1], which focus on immersing the user in virtual worlds emulating the real world [2]. So now, it sought to have a better and more natural interaction through the interaction in virtual worlds, proposing the development of a metaverse [3]. Which is a fully immersive virtual world in which we can interact in multiple ways [4] [5], impacting areas such as education, economics, social interaction, etc [6] [7].

Metaverses provide a great challenge, due to the existing problems with building fully immersive virtual worlds. Where one of the troubles is the tracking of people; allowing the metaverse to go beyond an individual sitting in front of a camera; with the perspective of making the virtual universe more interactive.

Inertial navigation is one of the techniques for which no additional infrastructure is needed, as it uses an IMU device that incorporates sensors inside the machine in order to obtain the location [8]. The only drawback of the inertial navigation technique lies in the measurement errors that the sensors inside the IMU device have.

It was only a matter of time before tracking systems became widespread inside. Which has rapidly grown to become an area that has yet to be solved compared to outdoor global positioning system (GPS) [9], [10]. And while the outdoor location has dominated the market, when used for indoors its signal is lost or distorted in specific locations such as buildings, houses, tunnels, etc. This makes interaction within a virtual world difficult.

The presented work aims to carry out a system for locating people in closed spaces with an impact on the metaverse due to greater interactivity with the virtual world.

2. RELATED WORKS

In the reviewed literature some articles have worked with inertial navigation systems. In a project, an inertial navigation system was presented where high precision and stable performance are achieved by the readings of the intensity of the Wifi signal (RSSI), the signals of an IMU, and the use of a particle filter. at follow-up [8]. L. F. P. Carlos A. Gómez R. in 2018, designed a model using WiFi using the deformation of the earth's magnetic field for the location of a mobile device, without requiring external assistance [9]. The location method using inertial navigation is based on the measurements that we will obtain from the IMU device, without the adequate calibration of the sensors inside the IMU, the measurements will be erroneous, being the accelerometer the one that presents more errors in the long term and which needs a more robust calibration [11]. The main aspect of the accelerometer is based on the force that gravity exerts on it, requiring stationary detection methods with which we will avoid the false stop of movement in the accelerometer [12]. The most used filter is the Kalman; after using quaternions and projecting the sensor readings onto an Earth-centered inertial reference frame, they combine a classical peak-valley detector with a set of SVMs (Support Vector Machines) and a standard deviation-based classifier [13].

In another study, a combination of the ultra-wideband (UWB) technique with inertial navigation is proposed, inheriting the advantages of both components [14]. Apart from the IMU, a filtering method is needed for location estimation [15].

To adjust at key points and avoid errors, RFID technology was used. The N.C.S.S.D.e. a. Fescioglu-Unver in 2015, presented an overview of RFID technology and its characteristics [16]; while M. E. H. W. Y. Liu in 2019, points out that RFID allows the emergence of intelligent asset management processes [17].

Undoubtedly, the metaverse promises to change the world [18], with a future perspective of entering different fields and with varied technology where different specialists are immersed [19]. Being the follow-up of people indoors is a response to greater interactivity with avatars [20].

3. APPLIED RESEARCH METHOD

For the methodology of this work, DOE (experimental-oriented design) was used, which is based on statistics to plan, perform, analyze, and interpret controlled tests and assess the factors that intervene in a parameter or group. See figure 1. Three aspects of the process are analyzed: the controllable input factors, the uncontrollable input factors, and the responses or output measures.

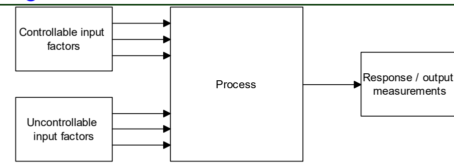

Figure 1: DOE process diagram

The benefits of using DOE are the reliable information that intervenes during the process, its interaction obtained through statistics in the field in real cases, process improvement based on the main output response, and cost reduction.

3.1 Inertial Navigation

It is an estimation technique, where inertial sensors allow us to know the acceleration in the 3 axes, position, and orientation of a device. It is also required to know the time; Any error in the estimation of these variables accumulates in an integration process, which increases the error over time, so the system is frequently adjusted using external references. Where RFID is useful.

An IMU (inertial measurement unit) is an electronic device that uses sensors to obtain acceleration in a Cartesian plane X, Y, and Z. In this way, through movement sensors, rotation sensors, and a computer, the position is obtained, orientation and speed.

3.2 Inertial Navigation

The most important advantage of inertial navigation lies in the fact that the mobile device can work completely autonomously. There is no need for external sensors or any other device from which to obtain data.

3.3 Basic principles of inertial navigation

Inertial navigation is based on Newton's laws of motion. Acceleration is the most important quantity in a linear system because both the velocity v and the displacement s can be derived from the acceleration by the process of integration. In contrast, velocity and acceleration can be estimated by the differentiation of displacement. See equation (1).

$$v = \frac{ds}{dt}; \qquad a = \frac{dv}{dt} = \frac{d^2 s}{dt^2} \tag{1}$$

Integration (see equation 2) is the process of adding all the rate of change that occurs within the limits being investigated.

$$v = \int a\, dt; \quad s = \int v\, dt = \int \int a\, dt\, dt \tag{2}$$

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An inertial navigation system is made up of a detector and an integrator. It detects acceleration, integrates it to derive velocity, and then integrates it to derive displacement. To obtain a position, the coordinates of that point are necessary. In general, three coordinates are required, one for each direction of movement in the Cartesian axis system. So, when we describe the motion of an object, we use a frame of reference. Whereby we compare the movement from an arbitrary reference to an endpoint. It is normally defined by specifying the position of the reference point and the direction of the axes. An inertial reference frame is fixed or a constant speed with respect to another inertial frame used in which the laws of inertia are valid.

Accelerometers measure static acceleration such as gravity, and dynamic acceleration such as vibrations and movement. They can measure it in one, two, or three axes. The measurement provides the following parameters: Vibration Acceleration, Vibration Velocity, and Vibration Variation.

To obtain correct measurement data, certain criteria must be applied, such as the calibration of the accelerometer and the gyroscope. To calculate the angle of inclination, the only force that acts on the sensor, which is the force of gravity, is considered. Thus, the values that we obtain in the components of the accelerometer correspond to gravity; the angles of the resultant will be the inclination of the sensor plane since gravity is always vertical; that is, it is assumed that we are in an X-Z plane and tilt the IMU through an angle θ. See Figure 2.

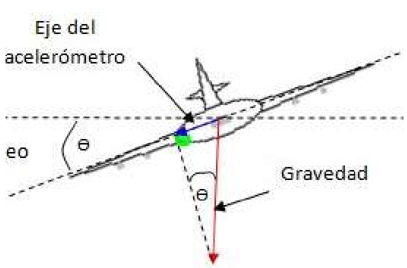

Figure 2: Pitch with angle [4].

This is how the angle is calculated in a 2D plane, but to calculate the angles of inclination in a 3D space in both X and Y we use the formulas (5) and (6):

$$\theta_x = tan^{-1}\left(\frac{a_x}{\sqrt[2]{a_{x^2} + a_{z^2}}}\right) \quad (5)$$

$$\theta_y = tan^{-1}\left(\frac{a_y}{\sqrt[2]{a_{x^2} + a_{z^2}}}\right) \quad (6)$$

With equations (5) and (6) the angle of inclination was calculated if we wanted the angle of rotation; Then the rotation angle is calculated using the IMU gyroscope, to calculate the angle the speed is integrated, and the initial angle is found using equations (7) and (8):

$$\theta_x = \theta_{x_0} + \omega_x \Delta t \quad (7)$$

$$\theta_y = \theta_{y_0} + \omega_y \Delta t \quad (8)$$

This is how the angle is calculated in a 2D plane, but to calculate the angles of inclination in a 3D space in both X and Y we use the formulas (5) and (6).

It must be considered that it refers to the angle at which the X axis rotates. Because exact measurements are not obtained, an error called Drift is generated. One of the best filters to remove drift is the Kalman filter, but it requires good computational processing power, making it difficult to implement on some platforms with low processing power. The complementary filter is a widely used and well-accepted alternative to the Kalman filter. The complementary filter combines the angle calculated by the gyroscope and the angle calculated by the accelerometer.

The need to combine both readings is since, if only the accelerometer is used, it is susceptible to accelerations due to the movement of the IMU or to external forces, but in long times the angle does not accumulate errors. Unlike working only with the gyroscope, although it is not susceptible to external forces, over time the drift is very large and therefore it is only recommended to use it for measurements of relatively short times.

The equation to calculate the angle using the plugin filter is:

$$angle = 0.98(angle + \omega_{gyroscope} dt) + 0.2(angle_{accelerometer}) \quad (9)$$

The angle of the accelerometer goes through a low pass filter, damping sudden variations in acceleration; the angle calculated by the gyroscope has a high pass filter avoiding problems caused by fast rotations. They can be tested with values other than 0.98 and 0.02, however, they must always add up to 1.

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Inertial positioning is based on the simple principle that position differences can be determined by Eq (10) in a well-defined and stable coordinate frame.

$$\Delta P(t) = P(t) - P(t_0) = \int_{t_0}^{t}\int_{t_0}^{t} a\,(t)dt\ dt \qquad (10)$$

Where:
• It is the starting point of the trajectory
• It is the acceleration along the trajectory obtained from the measurements of the inertial sensor in the coordinate frame prescribed by *P(t)*.

3.4 System overview diagram

The structure of the location system is divided into blocks. The first block consists of the IMU device and the passive tag for radiofrequency identification, and the data from the sensors is captured for later sending. The readers are connected to a development card, which sends the data through a radio frequency module. In another block, the central computer collects the data from the readers and IMUs, and a filter is applied to estimate the location and information of the person using the device. Once the location is obtained, it shows the location in the virtual world. See figure 3.

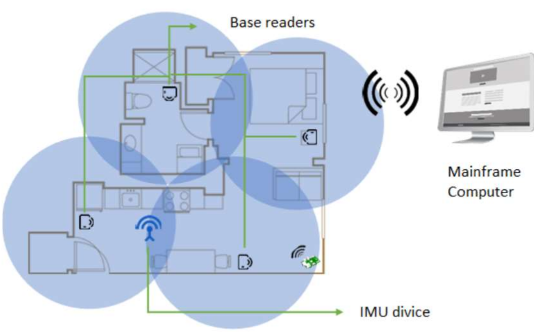

Figure 3: General diagram.

When the particulate filter finishes estimating the device's position, the position data is passed to the virtual world; where the position of the person who has the device is shown. As the device changes position, the data will change accordingly if there is a new reading on the RFID sensor it is confirmed to reset the initial position, otherwise, the position is recalculated from the data obtained from the orientation towards the filter of particles, obtaining a new estimate of the position. See figure 4.

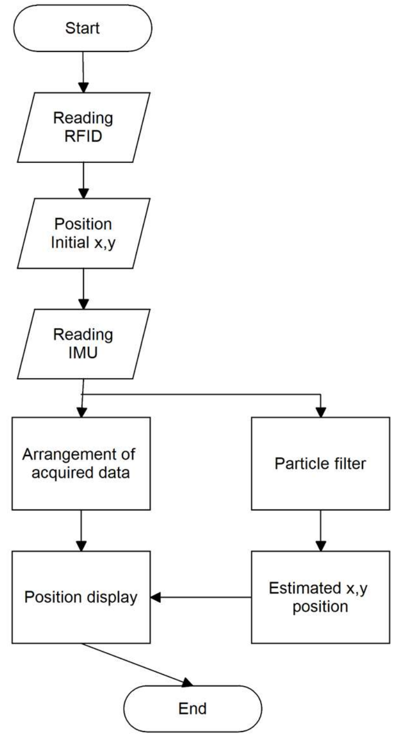

Figure 4: System architecture block diagram

4. MATERIALS

4.1 System overview diagram

The RFID (Radio Frequency Identification) emits a signal to initiate communication through tags that are captured within the reading range and said information is transmitted, which is captured and decoded by the RFID reader. This initializes a position and corrects it if necessary.

4.2 Micro-BIT Accelerometer

It is a 4x5 cm programmable IMU card. See figure 5. The sensors that interest us are the accelerometer and the magnetometer to calculate the position and orientation. The accelerometer is configured to measure values in the range of +2g to -2g. These values are scaled in the range of 0 to 1024.

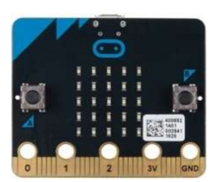

Figure 5: Micro: bit accelerometer.

The micro: bit (IMU) measures movement along three axes (See figure 6):

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• X: tilt from left to right.
• Y: Tilt forwards and backward.
• Z - moving up and down.

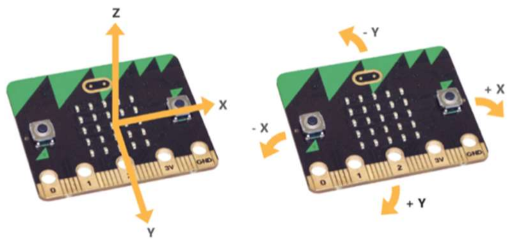

Figure 6: Micro: bit accelerometer axes.

The BBC Micro: bit accelerometer obtains the measurements of each axis as a positive or negative number indicating a value in milli-g's. Acceleration measurements can be accessed one at a time, or all three values can be obtained at once. Figure 7 shows the general magnitude and orientation with only two axes X and Y.

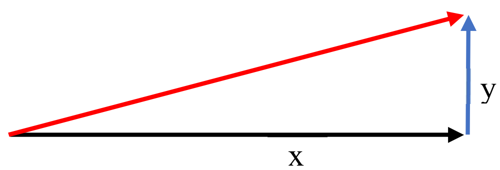

Figure 7: Calculate the magnitude (length) of the results using the Pythagorean rule.

The same principle applies to a 3D accelerometer. So, the overall magnitude of the resulting acceleration vector is:

$$aceleracion = \sqrt{x^2 + y^2 + z^2} \qquad (11)$$

Now, if you hold the accelerometer still, this will give an acceleration of about 1 g's, regardless of what orientation the BBC micro: bit is in, and it changes when you move. Another main component for inertial navigation is the compass which measures the strength of the magnetic field in each of the three axes.

4.3 Micro-BIT Accelerometer

Figure 8 shows the flow diagram of the accelerometer. The accelerometer returns a value in the range 0-1024 for each axis, which is then scaled accordingly.

Before using the compass, it must be calibrated, otherwise, the readings may be incorrect. Compass calibration will pause any program until calibration is complete. Calibration consists of a little game to draw a circle on the LED screen by rotating the device. This reads the magnetic field in two dimensions and outputs the values. The stronger the field, the higher the number. If you want to know the direction, you need to calculate and convert it to degrees. This provides the compass heading, as an integer in the range 0 to 360, which represents the angle in degrees, clockwise, with north as 0. See figure 9. Needs to be calibrated the device before using the compass. Figure 9 shows the flow diagram of the compass.

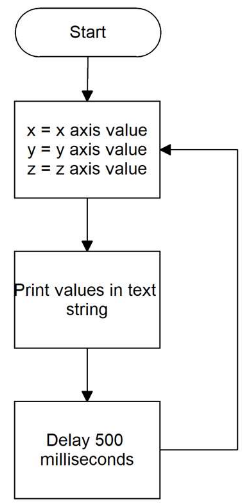

Figure 8: Accelerometer flow chart

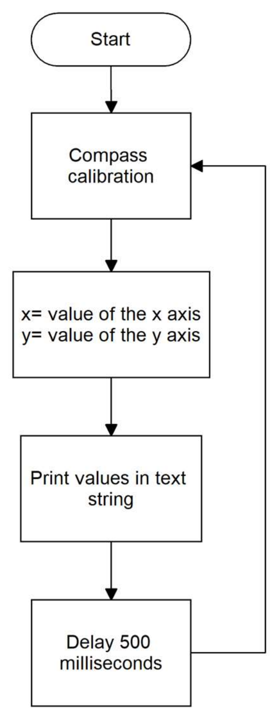

Figure 9: Compass Flowchart

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This angle is with concerning the North, but there is a difference between geographic north and magnetic north, this difference is known as magnetic declination. The value of the magnetic declination depends on the location where we are, in the case of this project the magnetic declination is + 4.17°. Finally, the angles coinciding with the cardinal points are selected, establishing a limit between each of their angles. See figure 10. The magnetometer data will be correct if it is not affected by external magnetic fields, as well as metals that interfere with the magnetic field of the device.

$$\theta = atan(my/mx)$$

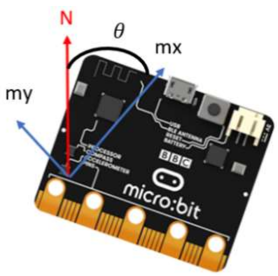

Figure10. Calculation of the angle of the IMU.

4.4 Particulate filter

The project estimates the location by using a particle filter, which is based on a recursive Bayesian estimator. Discrete particles are used to approximate the posterior distribution of the estimated state. Using these two steps, the position of the device is estimated, taking new samples each time, the device moves, in this way the new estimated position is calculated.

To carry out the particulate filter, an object is created that allows state estimation for a simple system with three variables. The filter obtains the magnetometer data from the IMU device in its three axes, then in the next step, the particle filter is initialized with a known mean and covariance, or particles uniformly distributed within the defined limits, as well as the initial state.

Before performing the estimation, first, the trajectory data is linked for the filter to follow and a vector is created to store the predicted and estimated position, as well as the noise amplitude. Once the trajectory data is obtained, the first prediction step is created and executed, and using the particles under evaluation, the next state is estimated. Then the values of the IMU device are obtained again to be used in the next step and correct the predicted current state. With the data obtained from the IMU, the previously predicted state is adjusted, and the position estimate is corrected. See figure 11.

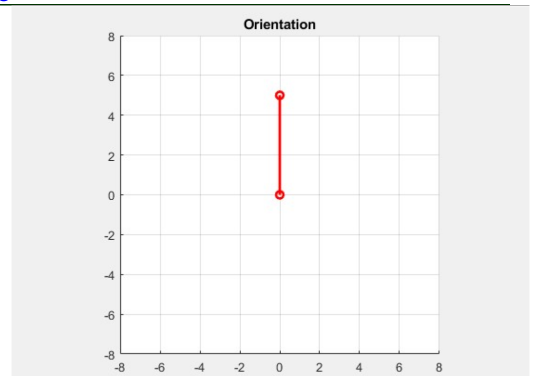

Figure 11: Orientation estimation filter

The estimate is not an exact assumption, but an approximate one that we give to a value x, considering a base reference or data set. The estimation states are based on probability theory, with which we can make data estimates and predict future observations through Bayesian statistics.

Applying the Bayes theorem, the subsequent pdf is given by:

$$p(x|z_{1:k}) = \frac{p(z_{1:k}|x)p(x)}{p(z_{1:k})} \propto n \times p(z_{1:k}|x)p(x) \quad (11)$$

$p(x|z_{1:k})$= the later pdf.

$p(z_{1:k}|x)$ = the similar function.

p(x) = the prior distribution.

Building on the concepts of Bayesian statistics, a particle filter is a technique for implementing the Bayesian recursive Monte Carlo filter. What you are looking for is to represent the posterior density by a set of particles with associated weights, and compute estimates based on these samples and weights. Recursive filtering implies a previous description of the knowledge.

Dynamic system model:

Evaluates the evolution of the state of the previous system with the following system.

Measurement model:

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Describe how the measurements are related to the state of the following system.

Recursive estimation involves two steps:

• Prediction: Based on the measurements, the previous state is used to infer the current state depending on a given system model.

• Correction: With the current sensor measurements and predictions, the state estimate is corrected. See figure 12.

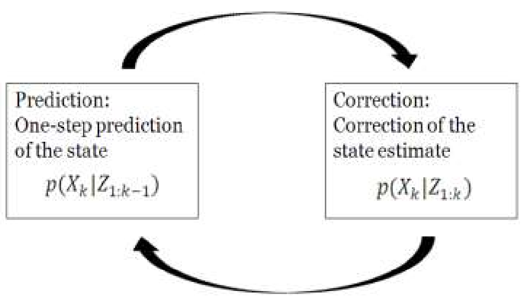


Figure 12: Recursive estimation steps.

4.5 Particulate filter

The particle filter starts with the initialization of the main state, in one cycle, and will make sure to take into account enough particles in the region of high similarity. Measurements are then obtained, and sampling is continued. The estimate is extracted for resampling. See figure 13.

Step 1.

Initialization

- K=0
- For i=1, . . ., N sample $x_0^i \sim p(x_0)$
- And set K=1;

Step 2.

Sampling Step

- For i =1, . . ., N sample $\tilde{x}_k^i \sim p\left(x_k \mid x_{k-1}^i\right)$
- And set $\tilde{x}_{0:1}^i = (x_{0:k-1}^i, x_k^i)$
- For i = 1, . . ., N. Assess important weights
- sample $w_k^i = p\left(y_k \mid \tilde{x}_k^i\right)$
- $\widetilde{w}_k^i = w_k^i \,/\, \sum_{j=1}^N w_k^j$,
- Normalize important weights

Step 3.

Resample Step

- Resample replacing N particles: $(x_{0:k}^i; i = 1, \dots, N)$
- To put: $(\tilde{x}_{0:k}^i; i = 1, \dots, N)$
- According to normalized importance weights, $\tilde{x}_k^i$
- Set K → k + 1

Return to sampling as the next measurements arrive.

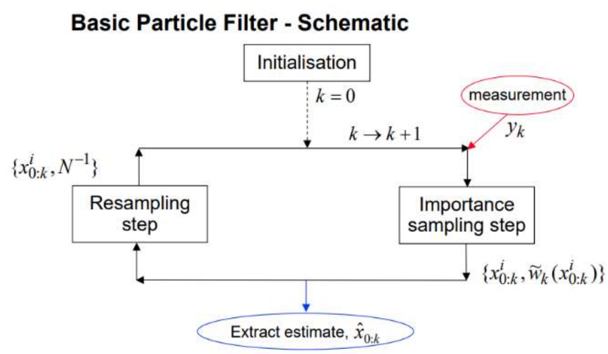


Figure 13: Particle filter diagram.

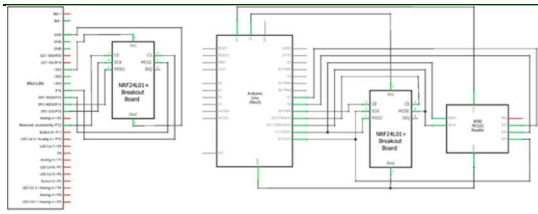
4. SYSTEM ELECTRICAL DIAGRAM

The electrical diagram of the system is presented, where the connections of the circuits between the devices are shown. The system is divided into three modules as shown in figure 14.

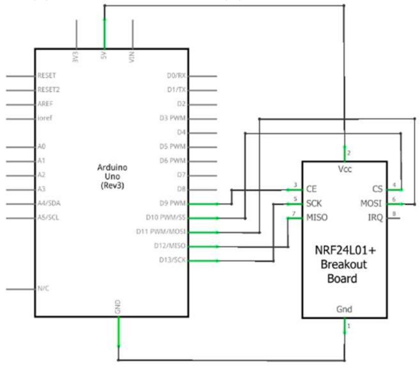
Figure 1(a) shows the IMU module, which is made up of the BBC: Microbit card and the wireless communication device.

In Figure 1(b) the RFID device is shown; An RFID reader is incorporated into the Arduino Uno card and the wireless communication device.

Figure 1(c) shows the data receiving module, corresponding to the wireless communication module. Which only has the connection of the Arduino Uno card to the wireless communication device and connects through SPI.



(a) Module IMU (b) Module RFID



(c) Data receiving module

Figure 14. Electrical diagram of the system.

Tables 1 and 2 show the total voltage and amperage consumption values of each module.

Table 1: Consumption Voltage of the modules

Voltage	Maximum	Minimum
Module IMU	5v	1.9v
Module RFID	12v	5v
Module Data reception	12v	5v

Table 2: Total consumption of the modules.

Amperage	Maximum	Minimum
Module IMU	315 mA	315 mA
Module RFID	541 mA	74 mA
Module Data reception	515 mA	61 mA

5. RESULTS

The experiments carried out in the project will be presented to evaluate its performance. In the same way, the efficiency of the implemented algorithms is estimated, and the location of people indoors will be verified with the corresponding use of the virtual location.

First test

The first tests carried out are aimed at validating the different stages of the location system and the system in general. The place where the different tests were carried out was the first floor of a residential home.

In this test, the real ranges that are obtained with the signal of the radiofrequency modules were verified, to find the limitations in the propagation of the signal. For this, samples were taken of the signal received through the different rooms. The radio frequency modules are NRF24L01 and, although the IMU device has a built-in radio, it is not robust enough. The signal range test was carried out while people were inside, so the aim was to obtain results as close to a real scenario, that is, people hinder the propagation signal. Figure 15 shows the architectural plan of the place where the tests were carried out, marking the location of the transmitter and receiver modules on the map.

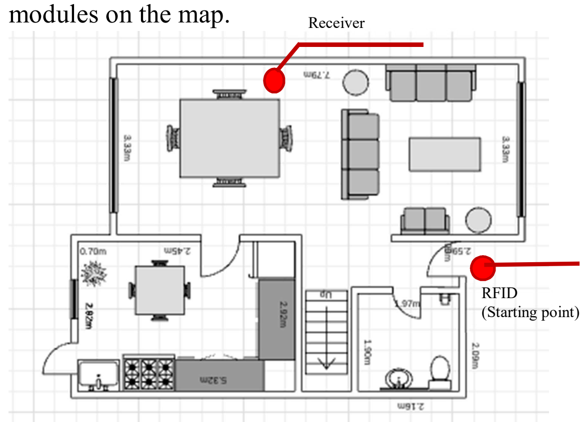


Figure 15: Plan of the ground floor.

As shown in figure 15, it is made up of three rooms with an extension of 53 square meters and the range of the NRF24L01 module is more than enough to cover the required area. The location area is made up of several tables and everyday objects. People are in this area throughout the day, so there may be variations in the signal. The receiver is in a position that allows obtaining the optimal signal from the transmitter module, taking into account the morphology of the plant. Comparing the distances offered by the manufacturer of the NRF14L01 module (between 10 and 20 meters) with the real distances obtained in the test, we can see the radii of the reach of each signal in figure 16.

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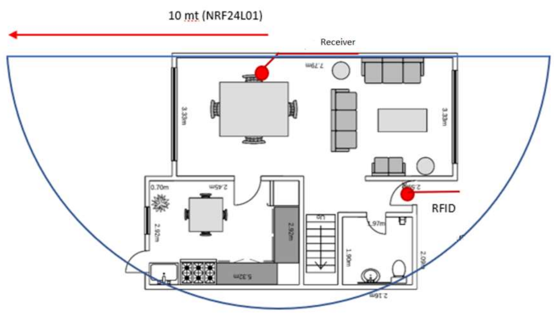

Figure 16: NRF24L01 scope.

The module's signal theoretically covers the entire area to be located. However, when testing the signal, there are places where variations occur, and the signal is diminished. Even so, the signal remains in constant communication with the receiving module, which continues to obtain data with little loss. The only case where the signal drops drastically until data is lost occurs when the signal is blocked by a gate, to the left of the starting point. The points where the signal is intact are marked in green, the loss of few data in yellow, and brown is the blocking of the door. See figure 17.

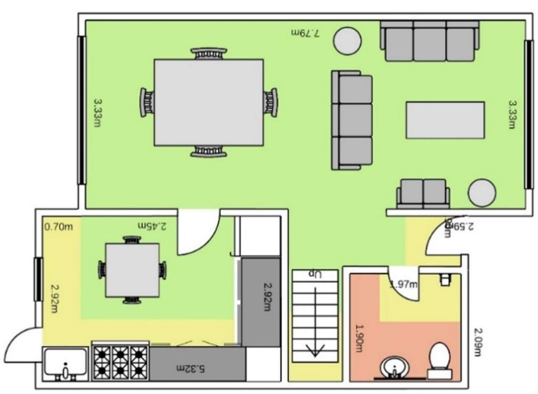

Figure 17: Signal status.

Second test

This test shows the connection from data acquisition through the serial port, across the software with the virtual graphical interface. See figure 18. This test is made up of three devices, which communicate with each other at a speed of 9600 bauds. Two transmitter modules and one receiver module are used. The two transmitter modules have the functionality to send the data of the IMU device, as well as the associated data in the RFID card, and establish the starting point in a two-dimensional plane.

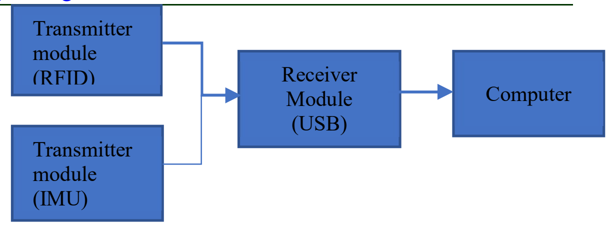

Figure 18: System connection diagram.

In the case of the receiver module, it is connected through the USB port of the computer. Data acquisition from the receiver module is by the serial port. Subsequently, the connection between the virtual reality software is using datagrams (UDP), with the address 127.0.0.1 and port 9090. Both programs are running continuously, as can be seen in figure 19.

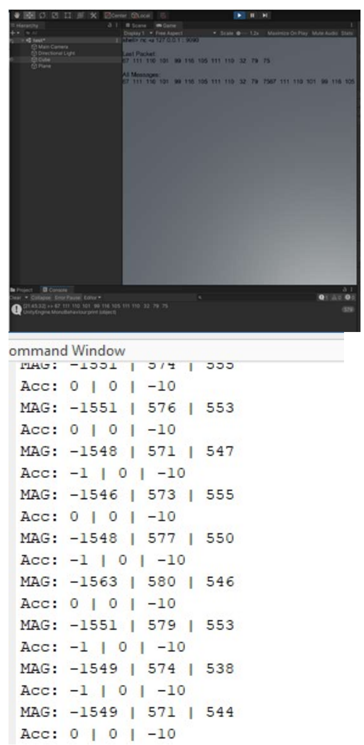

Figure 19: Connection between programs.

Third Test

The RFID module, in addition to being used as access control, establishes a starting point in the system. To carry out the control, first, the unique data of the RFID card is obtained, with which the data of the person to be located is associated. Through the Arduino IDE, the RFID card is programmed, and the data collected from the reader is sent to a receiver radio frequency module and reaches the virtual reality software. In figure 20, the access control works satisfactorily by providing the initial position, access to the various areas within the

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test area, as well as the time between sensing, going through data processing, until the reaction in the virtual world.

Figure 20: Access Control.

Fourth Test

The orientation of the IMU device is tested. Once the connection step between devices and software has been configured, the data to be processed is obtained. The data used in the orientation of the IMU device is that of the magnetometer, with which a compass is created that determines the orientation based on the cardinal points. The sensor chip that the IMU device has is from the LSM303AGR family, with a Gaussian dynamic magnetic range. In the virtual reality software, a two-dimensional plane is created in which we will point the orientation of the IMU device with the compass, as shown in figure 21. The IMU is attached to the foot, as it is the best position in which they do not appear bad readings.

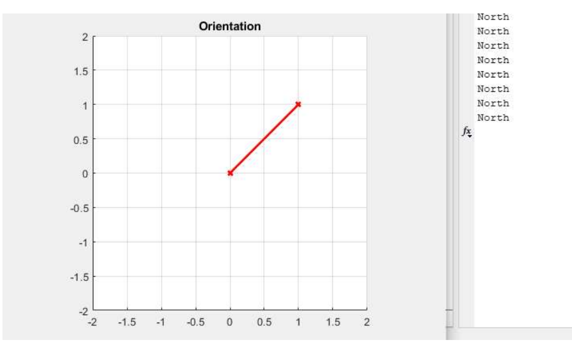

Figure 21: IMU orientation.

As can be seen in figure 21, the compass manages to obtain the correct orientation based on true north. The compass has reading errors when exposed to large magnetic fields, causing the reading value to decrease below the real ones. These magnetic fields generated by other devices need to be at a distance of approximately 5 centimeters from the device. See figure 22.

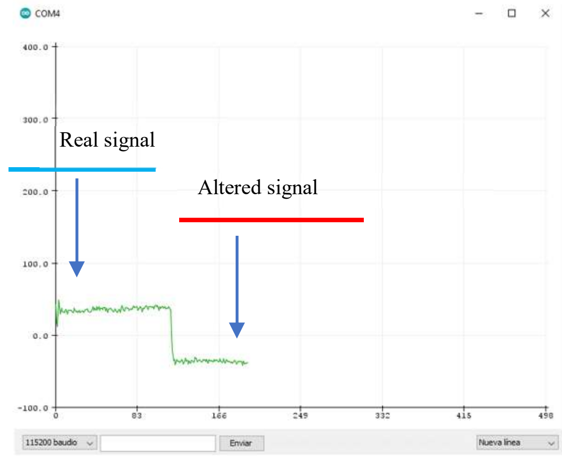

Figure 22: Distortion of magnetometer readings.

Tests were also performed to detect a person with a forward step. To define the step, first, the type of progress is distinguished between a step and a stride, the step being the distance between the heel of one foot and the heel of the other foot when walking; The stride is defined as the distance between two steps. The step is usually very different from one person to another, taking into account aspects such as height and gender. In this test, the advance of one foot in front of the other with an altitude of 10 cm above the ground is taken as a step, with an average step speed. With the data from the accelerometer, a pedometer is developed that can record the steps forward in a frontal way, the accelerometer detects the inclination in the X and Y axes that occurs when lifting a foot. The total acceleration of the IMU device is also measured, adjusting the sensitivity for recording one step forward, as shown in figure 23.

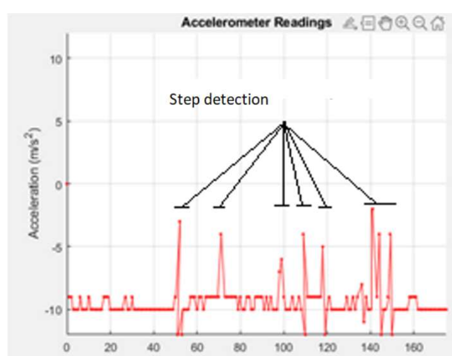

Figure 23: Pedometer.

As can be seen in figure 23, the steps are recorded with the configured parameters. Despite getting an optimal fit, the device is not immune to erroneous readings caused by a quick change in throttle or even a jump.

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Fifth Test

With the orientation defined and the connection of programs and devices, we proceed to join all the parts and test the operation of the system. First, use is made of the development of a three-dimensional environment where the IMU device is located. Taking into account the ground floor plan, the first transmitter module with the RFID is located at the entry point. Once the reader obtains a reading, the system will place its starting point in the position [0 0] and, from that point, the second transmitter module will send the sensor data to the receiving device, where the orientation of the reader will be obtained. device. Thus, each time a step forward is detected, the position of the device will be updated towards the direction indicated by the orientation, as shown in figure 24. It can be seen that the real position of the person corresponds to the virtual world. As the data is obtained from the IMU device, the current position is calculated through the position estimate made by the particulate filter. For this test, 100 samples were taken with which the average accuracy in the position is 89.3%, obtaining an error of 10.7% in the location, see figure 25. The error in the location by the particle filter is found within the acceptable range.

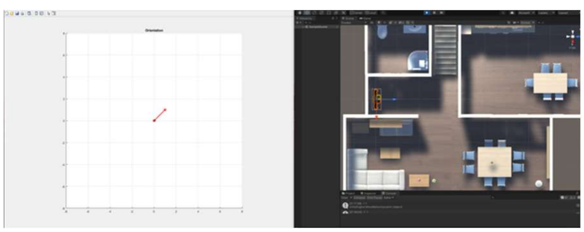

Figure 24: Virtual graphic interface.

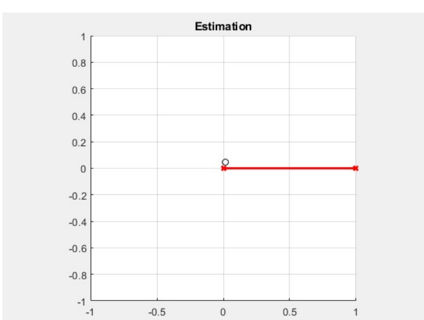

Figure 25: Particulate filter estimation.

In figure 25 the arrow indicates the orientation to which the person is heading and the blue circle is the position estimated from the data obtained from the IMU device. The estimated position does not vary much compared to the actual position of the device.

Sixth Test

In this test, the success rate of the estimation of the real position of the person concerning the virtual world is analyzed. To do this, the real distances traveled and the position of the receiver module is taken, compared with the distances estimated by the software. For this test, the plant is divided into 4 parts, as shown in figure 26. The second plant as part of the system would not provide more information than is obtained with the first plant.

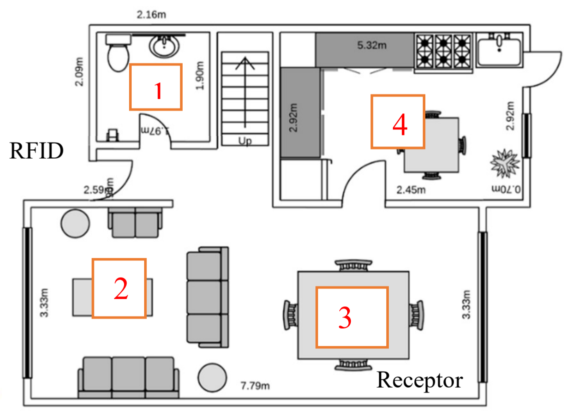

Figure 26: Plant Division

This test focuses on evaluating the performance of the system in terms of tracking the person through the various rooms and their corresponding representation in the virtual world. For the test, 100 samples were taken in each of the different rooms, with variations in the intensity of the signal as shown in Table 3. It was observed that the number of hits increased as the number of samples increased. However, this is minimal, so, to display the results, the minimum value of 20 samples was chosen, since there is not such a large variation that it harms the success rate and, practically, a success rate would be obtained. equal to the maximum number of samples proposed.

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Table 3: Location success rate.

N° de Muestra	Cuarto 1	Cuarto 1 (Cuarto cerrado)	Cuarto 2	Cuarto 3	Cuarto 4
1	83.5%	80.2%	83.1%	87.7 %	82.1%
2	84.3%	82.7%	90.1%	89.0 %	80.7%
3	79.9%	62.4%	87.7 %	95.1 %	81.3%
4	88.9%	85.9%	94.8%	80.3 %	77.5%
5	92.2%	77.9%	79.1%	98.4 %	90.7%
6	90.7%	65.7%	92.5%	71.1 %	84.1%
7	96.4%	89.6%	88.3%	98.2 %	76.4%
8	78.8%	90.5%	94.3%	92.5%	73.8%
9	83.2%	89.4%	66.2%	84.2%	88.6%
10	91.3%	79.9%	91.4%	96.6%	86.7%
% Aciertos	86.92%	80.42%	86.75%	89.31%	82.19

Figure 27 shows how the hit rate does not vary too much for the location in different rooms, both in room 1 with the door open and the door closed with a decrease in the signal. The overall success rate of the system is around 85.1% of success in locating a person in indoor environments. Therefore, it can be said that the system complies with a more than satisfactory localization, with an error of 14.9%.

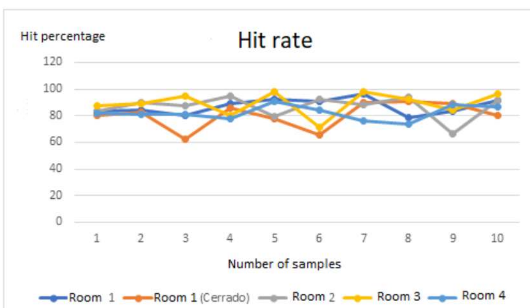

Figure 27: Success rate graph.

5. DISCUSSION

The implementation of indoor localization systems focused on virtual spaces can highly improve the immersion of users within virtual worlds. It manages to emulate with great similarity almost real experiences in a virtual environment.

The presented analysis of the results shows the evaluation of the system's performance in tracking a person. The indoor localization, based on the simulation of a virtual scenario, is able to track a person through multiple rooms, through changes in the parameters of the IMU device and the different access points distributed in the localization area.

The analysis highlights the advantages of applying an indoor location system to visualize the tracking of a person in a virtual world. The results of the tests performed on the location algorithm denoted the ability to correctly visualize the tracking of the user within the virtual world. Also, the analysis showed the efficiency with which the localization algorithm has been able to estimate the position of the person to be tracked within the rooms with a more than acceptable accuracy compared to the systems reviewed in related works based on the inertial navigation technique.

In addition, the analysis indicated the considerations that an indoor location system should take into account for the site where it is desired to implement such systems. This means that a location system has several significant limitations for its proper functioning within particular spaces. Depending on characteristics such as the total area to be covered, the number of simultaneous users to be located, and the complexity of the design of the virtual space, are factors that influence the performance of the system.

Comparison with other location systems based on inertial navigation reveals that it has a similar accuracy, with the advantage of a significant size reduction; so it is ideal for systems that use metaverse.

7. CONCLUSION

In this paper, an indoor people tracking system was proposed for use in the metaverse using the inertial navigation method to access different areas. The proposed location system is designed to have the best features present in indoor location systems, i.e. having good location coverage, low cost, satisfactory location, and size reduction.

It is necessary to take into account that the system has been initially designed for the location of a single user since in the Metaverse there is normally only one person, however, this does not mean that the system cannot support more users.

For this purpose, tests were performed in each of the stages, demonstrating that the proposed system achieves similar performance in the indoor location of people than the systems reviewed in the state of the art. It also observed the different limitations in the calculation processing that the development board has as well as the visual complexity of the virtual space that is developed. These are two important points to take into consideration because they affect the performance of the system when tracking a person.

We also present a tracking algorithm that achieves tracking of a single subject across multiple rooms with an accuracy of better than 80 percent among other tracking systems using different localization techniques, as well as accuracy of better than 85 percent in terms of estimation. The results in this paper help identify the optimal aspects of indoor localization requirements for future systems that require tracking people in virtual spaces.

The development of metaverses should consider the development of projects that consider the monitoring of people, due to the implications that a future recreation of the realization in virtual space will require to increase user immersion.

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