Location of Visually Impaired in Indoor Environments through Data Fusion of Wireless Network and the Inertial Sensor

Localização de deficientes visuais em ambientes internos através da fusão de dados da rede sem fios e do sensor de inércia

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ABSTRACT

Wireless sensor networks have been presented as an alternative to location and navigation systems for the visually impaired in environments where GPS is not effective. However, dealing with the information obtained from these sensors for this purpose may present some challenges. The difficulties described by several authors are related to the oscillation of the signals, which are susceptible to numerous interfering agents such as the scene itself, the presence of people, etc. Therefore, this paper proposes to apply a data fusion of wireless networks with inertial sensors in an experiment protocol to allow its use in the indoor location of visually impaired persons with greater reliability. The methodology adopted was to construct a database obtained from several readings of the wireless sensors and inertial devices, to construct a reference curve and to compare the data of the test readings to this curve and indicate through three models (raw data Moving average and weighted average) reliability in indoor location. The results show that RSSI with SNR and magnetometer with gyroscope provide high error rates with raw and isolated data, but when associated, they show a more efficient location, decreasing the error rates observed in isolated mode. The data obtained from the fusion were submitted to the moving average and the weighted average, presenting respectively a reduction of the variations and a smoothing. In meters, the error margins between the actual position and those indicated by the system were 1,200 m, 0,300 m and 0,148 m in each meter traveled.

Keywords: Visually impaired, Sensors, Wireless network, Localization, Indoor environments.

RESUMO

As redes de sensores sem fios têm sido apresentadas como uma alternativa aos sistemas de localização e navegação para os deficientes visuais em ambientes onde o GPS não é eficaz. No entanto, lidar com a informação obtida a partir destes sensores para este fim pode apresentar alguns desafios. As dificuldades descritas por vários autores estão relacionadas com a oscilação dos sinais, que são susceptíveis a numerosos agentes interferentes tais como a própria cena, a presença de pessoas, etc. Portanto, este artigo propõe a aplicação de uma fusão
de dados de redes sem fios com sensores inerciais num protocolo experimental para permitir a sua utilização na localização interior de pessoas com deficiências visuais com maior fiabilidade. A metodologia adoptada foi a de construir uma base de dados obtida a partir de várias leituras dos sensores sem fios e dispositivos inerciais, construir uma curva de referência e comparar os dados das leituras de teste com esta curva e indicar através de três modelos (dados brutos Média móvel e média ponderada) a fiabilidade em localização interior. Os resultados mostram que RSSI com SNR e magnetômetro com giroscópio fornecem altas taxas de erro com dados brutos e isolados, mas quando associados, mostram uma localização mais eficiente, diminuindo as taxas de erro observadas em modo isolado. Os dados obtidos a partir da fusão foram submetidos à média móvel e à média ponderada, apresentando respectivamente uma redução das variações e um alisamento. Em metros, as margens de erro entre a posição real e as indicadas pelo sistema eram de 1.200 m, 0.300 m e 0.148 m em cada metro percorrido.

Palavras-Chave: Deficientes visuais, Sensores, Rede sem fio, Localização, Ambientes internos.

1 INTRODUCTION

Several applications in wireless sensor networks require sensor localization technologies to generate information on the location of static and mobile objects, animals and humans. Its applications range from monitoring activities, recording and reporting events found during a navigation, to detecting dangerous situations (Kok et al., 2013).

Another useful feature of Wi-Fi location information is to help mobile nodes stay connected to a network. The mobility of the nodes can lead to the deterioration of the quality of an established connection, causing frequent changes of routes, producing delays of the packages. This occurs because a mobile node can not immediately begin transmitting data when it enters a network. For this channel to be used, it is necessary to wait for a certain time before it can be fully integrated (HE et al., 2017).

Many indoor radio frequency localization systems adopt RSSI as one of the parameters for real-time location. However, many papers show that there is not much reliability of RSSI for this indoor localization task when used in isolation (KUO et al., 2010).

In this work, it is intended to calibrate and map the RSSI and SNR at a distance and to map the same locations with information obtained by the magnetometer and gyroscope sensors, performing a series of experiments and presenting the results of the tests to indicate, based on the observations, the
viability of data fusion for indoor location.

The remainder of this paper is organized as follows: in Section II, the related work is summarized. In Section III, a brief introduction to the RSSI, SNR, magnetometer and gyroscope technologies is described. In Section IV, experiment settings are displayed. In Section V, the reliability of the isolated and fused data for internal location is investigated and the observations are discussed. Finally, Section VI gives the final observations.

2 RELATED WORKS

The determination of indoor location can be done in several ways. Some approaches are briefly discussed in this paper.

The approach adopted by Nebel and his co-authors to determine the location is the Global Positioning System (GPS). The authors have done a study on the low intensity of the GPS signal in indoor environments and the impact on the location identification function. The results presented indicate an improvement of the accuracy of the location in 1.60 meters, however, due to the sophistication of the algorithms, the time demanded for the information delivery was higher than expected when the GPS outdoor (NEBEL et al., 2010).

The technique of pedometry was treated in the work of Gharghan (GHARGHAN et al., 2016). In this work, a portable electronic device was created to count each step that a person performed and sent them to a central through a Wi-Fi network so that an algorithm processed the data received and returned to the portable device its location. The results showed an absolute error rate of 0.208 m for each meter traveled. The authors have indicated that this method is highly dependent on network density and path length and thus prone to errors.

The localization technique through a set of weighted samples was studied by Levstek (LEVSTEK et al., 2017). In this paper, the authors used methods of representing the distributions of landmarks where new measures are incorporated into the data set to filter the previous location prediction and update the location information. The objective of the study was to determine mobile and personal asset locations in mining environments. However, it was evidenced after testing that this estimate suffers from rotational and translational errors, even if a map of the environment and sensory information is provided.

Kuo and his co-authors developed in their study an RFID tag model to be
used in an industrial environment for locating steel coils. In these scenarios, noise and interference levels cause a loss of confidence in the information indicated by RFID tags. In this way, the authors proposed the construction of a label with an antenna structure based on the monopolar principle. The tests performed by the authors demonstrate that the built label presented a performance superior to the traditional labels. The results of the study indicate that, although the model was superior to models already available in the market, its communication range is still short (1.5-2.5 m) (KUO et al., 2010).

Kok and his co-authors dealt with the construction of an indoor mapping using information about the Earth's magnetic field (Kok et al., 2013). The main idea was to mark a scenario with the periodic measurements of the magnetic oscillations and to submit them to a learning process. As a resource, MEMS devices, which associate magnetometers, accelerometers and gyroscopes, were used to obtain position, orientation and direction information. The results obtained by the authors indicate that the accuracy of the observed location obtained an accuracy of 0.300 meters when approaching a marked point and after 42 seconds, the distance reduces to 0.200 meters due to the application of means to the values previously perceived.

He and his co-authors addressed the Time of Arrival (TOA) application in localization and simulation. The authors implemented a complete prototype based on the asynchronous arrival time difference (A-TDOA) technique in hardware. The choice of authors by A-TDOA was due to the need to not synchronize clocks between a target and anchor nodes. The implemented system was tested in indoor and outdoor radio environments. The obtained accuracies are 0, 207 m and 0,152 m in an area of 5 m x 5 m. The comparison with related works shows a very strong approximation with the actual positions of the markers (HE et al., 2017).

Benedetto and his co-authors used the Signal-to-Noise Ratio (SNR) in a study on the influence of scenario interference on the wireless signal (BENEDETTO et al., 2013). The SNR developed by the authors adopted algorithms that calculated the estimates of signal values and the attenuations to which they were submitted along a path. With this connectivity information, a one-to-one mapping (fixed nodes and the mobile node) was constructed and a relation of the distance between them was made by signal quality. The results presented by the authors showed that it is possible to predict the propagation and behavior
of the signals in indoor environments in an approximate way, however there are a great number of problems to be treated as the influences of the obstacles that require a training phase to improve certainty about landmarks.

Toh and their co-authors applied the association of ultrasonic perception to a mobile node to measure the distance between the network nodes and to explore the propagation time of the signal. The results presented by the authors indicate that the transmission range of an ultrasound signal is small, since it can not propagate more than the radiofrequency wave. Although the ultrasound-based location approach can achieve high accuracy, it is not suitable for wireless sensor networks over long distances, but its use may be interesting at specific points such as in curves or to cross a door (TOH et al., 2016).

A mechanism based on accelerometer and gyroscope bound to a network node is shown in Liu's work (LIU et al., 2015). The authors performed an integrated and practical method for inertial hybrid localization to mitigate inaccuracy in wireless location results and improve reliability in the absence of radiofrequency signal. The tests consisted in monitoring a trajectory between a base node and a mobile station and in the places of greater oscillation of signal of the wireless network, information was obtained from sensors IMU (magnetometer). The results showed that the margins of errors perceived by the typical wifi location were reduced with the inclusion of the IMU markers. However, the authors indicate that the magnetometer also suffers interference and that it is important to deepen the discussion in the inclusion of other models of sensing.

Huang and his co-authors dealt with the localization of mobile nodes through triangulation and trilateration (HUANG et al., 2009). In this study, triangulation was used to estimate the global location of each node in terms of distance and direction between each node and a particular central node. The trilateration uses this prior knowledge of the global location of the nodes to indicate the distance between a static node or another or a moving node and the static nodes within a certain degree of certainty. The results showed that to obtain a location with error margins less than 0.50 cm, it is necessary to apply other sensing models and positioning update algorithms because the network system is affected by many factors such as multiple path fading and obstructions of the signs.
3 DESCRIPTION OF RSSI, SNR, MAGNETOMER AND GYROSCOPE

Unlike all of the location approaches discussed above, RSSI associated with the SNR, magnetometer and gyroscope represents the relationship between the data obtained from Wi-Fi networks and the inertial sensors. The association of the RSSI to the SNR deals with a transmission and received signal strength of the network and the attenuations to which these signals were submitted along a path (BENEDETTO et al., 2013), (NEBEL et al., 2010). The association of the magnetometer with the gyroscope deals with the reinforcement of location by magnetic compass and the reference identification of direction by the gyroscope (KOK et al., 2013), (LIU et al., 2015).

The association of RSSI and SNR is used to calculate the separation distance between a transmitter and a receiver on a direct line of sight. If there is a direct path between two nodes placed in an environment in which no signal interference occurs, the received signal power, $Pr$, is related to the distance, $d$, between the transmitter and receiver nodes in the law of the inverse square (Kok et al., 2013).

$$Pr \propto d^{-2}$$ (1)

Equation (1) expresses the ideal relationship between RSSI and relative distance. In the real world, many factors influence the value of the received signal strength, such as reflection, refraction, diffraction and scattering of waves caused by nearby objects, which are treated by the SNR.

Signal-to-Noise Ratio (SNR) is obtained by the power ratio of a signal (meaningful information) and background noise (unwanted signal) (HUANG et al., 2009), by the formula:

$$\text{SNR} = \frac{\text{signal}}{\text{noise}}$$ (2)

The application of the SNR takes into account the attenuations and impacts caused by sources such as wooden walls (6dB), office partitions with glass (4 dB), concrete walls (18 dB), and human body (3 dB).

Due to the multi-path fading and non-uniform propagation of the radio signal, the received power can decay at a faster rate. This transfers the relationship between $Pr$ and $d$ to:

$$Pr \propto d^{-\gamma}$$ (3)

Here $\gamma$ denotes the loss exponent. Another factor that affects the power...
received and therefore affects the prediction of location is the antenna polarization. To obtain the maximum power received, the antenna of the receiving node must be set in the same orientation as the transmitting node (Gharghan et al., 2016). The loss due to misaligned antenna polarization, L, can be expressed as:

$$L = 20\log(\cos \theta)$$

The association of the magnetometer with the gyroscope is used to indicate the direction and special orientation, using as reference the terrestrial magnetic field. The absolute (inertial) position of the sensors relative to ground is perceived by the x, y, z axes through the reference system RPY (roll-pitch-yaw). The x-axis points to the nominal direction (front), y (pitch) is orthogonal to the x-axis and points to the left-hand side and the z-axis (yaw) points upwards, as shown in Figure 1 (IBARRA-BONILLA et al., 2011).

![Figure 1. RPY System Axes](image)

The objective of the experiments is to investigate if the association of RSSI, SNR, magnetometer and gyroscope is reliable and therefore feasible to be used for indoor localization.

The sensor platform used for the perception of Wi-Fi signals is the Arduino ESP8266, which uses the 802.11 radio system. The proposed distance estimation model is:

$$d = 10^{\frac{(txPower - RSSI)}{10n}}$$

In equation 5, RSSI is the radio signal strength indicator, measured in dBm, n is the signal propagation constant or exponent, with a range of 2 to 4, d is the relative distance between the communication nodes, and txPower is a Signal strength received in dBm. This value of txPower is obtained with the value of RSSI measured the distance of separation between the receiver and the transmitter is one meter).

The sensor platform used to obtain inertial information is the Arduino GY-
80, which offers 3 axes of gyroscope L3G4200D, 3 axes of accelerometer ADXL245, 3 axes of magnetometer HMC5883L and a pressure and temperature sensor BMP085. The HMC5883L magnetometer is a digital compass and measures the Earth's magnetic field. The L3G4200D gyroscope has the capability for 3 axes and 3 sensitivity levels, used to calculate the viewing angles.

The experiments were carried out in a corridor composed of a wooden wall and concrete on one side and an open side with presence of high vegetation but not closed. A node was used as a base station connected directly to a notebook to collect the data to be submitted to the evaluation processes. The other node was mounted on a mini protoboard. Both nodes operated with full battery. There were no additional obstacles in the way of communication between the two nodes during the experiments. As a result, a good portion of the signal was propagated on a line of sight.

3. Experiments

In order to perform the experiments, a protocol was defined, ranging from the construction definition of the devices to the submission of the collected data to a set of techniques, as shown in Figure 2.

![Experiment protocol](image)

3.1. Construction of Physical Devices

For the realization of the experiments, two devices were constructed: slave and the master. The slave device is attached to the scenario has a Wi-Fi network node with the function of generating signals with its ID and RSSI. The master device is mobile, connected to a mini computer and has the function of collecting the perceived information of the slaves devices and indicate the distance between them, besides perceiving the places registered by the inertial sensors. The master
and slave devices adopted for collecting are presented in Figure 3.

Figure 3. (a) slave device, (b) master device

In the slaves devices a programming in language C was embarked for the emission of the information about the own network node.

In the master devices, a programming in language C was embarked to capture the IDs and RSSIs of the slaves nodes and the realization of the calculation of the SNR and the relative distance between them. The programming also performs the reading of the IMU (magnetometer and gyroscope) sensors to perceive each inertial address.

The information captured from the slave nodes is submitted to a BubbleSort-based sorting method so that the node with the strongest signal. This operation is useful in navigation, since each slave node represents a point in a route.

The information captured from the IMU sensor is subjected to a position-by-proximity grouping method (considered as a 0.50 cm variation for all directions) to create a record of a location.

3.2. Data Collection

The formal definition of data collection is important in order to standardize the process.

Initial tests where the mobile node was placed at the waist and at the head of the tester user, kept at a distance of one meter from a slave node showed different values. For this reason, it was defined for this experiment that the Wi-Fi network sensor and the inertial sensor will always be placed at the height of the head of user in a wearable mobile device to decrease the variation of their RSSI values (Figure 4).
Once position of the sensors on the user was defined, the maximum distance between nodes was verified. The user moved away from the initial slave node until it was no longer perceived. The distance reached was 38.2 m.

RSSI is measured as an integer value and can be converted to its corresponding dBm value by subtracting a constant (the default value is 45) (BENEDETTO et al., 2013). Since an RSSI value can not be a decimal or a fraction, it can not provide enough resolution to distinguish changes more refinedly over distances. Despite this limitation of RSSI, its application may provide a resolution that distinguishes distances that are large enough to cause at least one unit change in dBm of the signal power at the receive node.

The magnetometer sensor indicates the direction and direction of a registered position and when associated with the gyroscope, it improves the level of accuracy on the observation angulation. Locations can be registered and measured to a decimal or fraction, providing sufficient resolution to distinguish positions with very short distances (less than 0.1 cm).

Due to perceived oscillations in each of the sensors (Wi-fi and inertial), each location identifier is registered through the weighted average of 50 values read.

3.3. Verification of Location Realability

To verify that the Wi-fi network fusion and the inertial address mappings can reliably determine the position of indoors markers, their results were observed in isolation and after the fusion to compare the results in relation to observed distances.

For the experiments performed, the RSSI, RSSI with the SNR was tested every 1.5m and each test lasted 10 seconds. The value of RSSI validated at each place is obtained by calculating the average of all values received during this time. The black line represents the real positions, the red line represents the RSSI and the blue line represents RSSI with the SNR. All data sets sampled during the
The experiments performed to deal with the inertial data obtained from the magnetometer and gyroscope followed the protocol: The places were recorded every 1.5m and place site represents an average of 50 readings. The black line represents the actual positions; the red line represents the data read from the magnetometer associated with the gyroscope. All data sets sampled during the experiment are displayed in Figure 6.

3.4. Establishment of the Reference Curve

This line is the first reference curve. Based on the discrete data sets collected and assuming that $x = (-10) \log_{10} (d)$, a linear relationship between RSSI and $x$ can be established by formula $\text{RSSI} = nx - txPower$. The linear relationship between RSSI and $x$ forms the second reference curve, illustrated by the blue solid line in Figure 5.

The experiments performed to create the reference curve of the inertial data followed the same distance as the one adopted in the experiments on the Wi-fi
data (1.5m), however, in each test 50 readings were collected for each registered place. The value of RPY (x, y, z) validated at each location is obtained by calculating the average of all values received during this time. All data sets sampled during the experiment are displayed as red asterisks in Figure 6.

The mean value of the data collected at each point is represented by the dotted black line in Figure 7, forming the reference curve.

![Figure 7. Establishment of the reference curve](image)

As can be seen in Figure 6, there is a deviation between the two reference curves. The distinction demonstrates that accurate RSSI values cannot be obtained when two communication nodes are too close to each other.

### 3.5. RSSI Reliability Check

To prove or disprove the reliability of the RSSI, SNR and inertial sensor data for indoor location, an experiment was performed, processing the data obtained to compare with the reference curve.

It was applied as a verification protocol that, if the processed result falls within the reference curve or is very close to the reference curve, the fusion is reliable and the corresponding distance is calculated.

The user has moved from the end of the radio transmission range to the base station in a rectilinear manner. The reason the motion starts from the maximum radio transmission range is that it can align the distance traveled during all the experiments (38.2m). Since the movement of humans is slow, the walking speed can be considered uniform (low variation of acceleration, which was neglected in this study). As a result, for each pair of data sets, the time can be transformed to the corresponding distance. The transformation is expressed as:
\[
d(i) = \frac{R}{t_{\text{max}} - t_{\text{min}}} t(i) \quad i \in [1, n]
\]

Here, \(n\) is the total number of data sets, \(R\) is the maximum radio transmission interval, and \(t_{\text{max}}\) and \(t_{\text{min}}\) are the beginning and end of the experiment. Equation (6) establishes the relationship between each RSSI and its corresponding distance during the mobility experience.

Before verifying the reliability of RSSI for internal location, some mathematical methods were applied to process the collected data.

a) Raw data: The first and obviously simplest method to test the reliability of the RSSI with SNR and the gyroscope magnetometer for location is to use the raw data directly.

In this approach, it was observed that there was a very high Wi-Fi signal fluctuation during mobility. Furthermore, for a given RSSI value, there were multiple corresponding distances. Even worse, the difference between these distances was great. For example, the RSSI value of -72 dBm immediately indicated a distance of 12.0 m and 30.0 m (Figure 6). Therefore, RSSI raw data is absolutely weak in determining the distance of a mobile node in an indoor environment.

For the perceived data from the inertial sensors, a slightly smoother fluctuation than that presented by the Wi-Fi sensor was perceived. However, there were also readings with diverging values to represent the same point (Figure 8). Therefore, the raw magnetometer data with gyroscope is also weak in determining the position of a mobile node.

b) Moving Average Method: To reduce signal fluctuation, the moving average method was applied. The moving average method uses for each
collection point the average of 50 previously read data. The moving average method presented a smoother RSSI curve when compared to the raw data, as shown in Figure 9.

![Figure 9. Using the moving average method for location](image)

c) Weighted Average Method: changing the RSSI value should be a gradual but constant process. As a strategy, instead of giving the same weight to all previous datasets, a different weight was applied to the collected samples to allow a more accurate estimate of the RSSI. The weighted average method assigned a greater weight to the sample that were closer to the target, where the RSSI value was evaluated. However, as shown in Figure 10, the result does not show significant changes from the moving average method due to the strong fluctuation of the signal.

![Figure 10. Weighted Average Method for Location](image)

The trajectory of the RSSI values processed by the weighted average method is the one that best fits the reference curve. This indicates that RSSI values manipulated by the weighted average method are able to more realistically determine the distance as a whole. However, for each RSSI sample, the distance it gives is far from the actual position.

The graph in Figure 11 shows a comparison of the application of the three techniques in the same RSSI plane x distance relative to the real location.
According to the observations, the raw RSSI does not adjust to the value given by the reference curve, and as this value is submitted to other approaches such as moving average and weighted average, it adjusts to the reference curve.

Even having presented a decrease in the distance error margin between the slave node's real position and the information indicated by the system, two factors were still perceived. The first factor is related to the accumulative error margin, which makes the system unreliable for displacements with distances greater than 10 meters (mean error of 1.88 meters). The second factor is related to sensitivity to radio frequency noise, which can cause sudden changes in read RSSI values.

4. CONCLUSION AND FUTURE WORK

In this work, the reliability of the data fusion of Wi-Fi networks with the data of inertial sensors for interior location was investigated. First, a statistical reference curve was established using a series of samples. Then, a series of experiments was carried out. Based on the collected data sets, three location estimation techniques were used through RSSI and SNR. Even with the decrease in the error margins between the real location and the one informed by the system, the RSSI still shows significant fluctuations in relation to the reference curve, not being indicated to be adopted as the only input in determining the location of a given mapped position in an indoor environment.
REFERENCES


