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Feasibility of Using Data From Sensors Embedded in Smartphones to Measure Angles and Distances

Análise da Viabilidade do Uso de Dados Provenientes de Sensores Presentes em Smartphones Visando a Mensuração de Ângulos e Distâncias

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Abstract: Smartphones have become communication and information retrieval tools, but as part of their functionality they also contain a variety of sensors to determine their orientation and location. This research aims to evaluate the capacity of the embedded sensors: gyroscope, accelerometer and magnetometer, and the camera sensor, with the purpose of indirectly determining values of angles and distances, basic elements for the determination of positions by positioning techniques. The tests consisted of measuring some points in an internal environment and in an external environment. These were collected using a total station and with the application developed for comparison purposes. The results showed that, for the distances evaluated, the differences obtained between the data measured by the total station and by the application were a maximum of 1.54 meters and a minimum of 0.09 m. The measurements of the vertical angles showed, on average, approximately 2.09 degrees of discrepancies between the data compared to the total station data. The horizontal angles showed the greatest differences between the values measured with the application and the total station, which ranged from 4.83° to 69.32° evaluated indoors. These observed discrepancies increased with the increase of the measured and calculated angle, thus verifying a problem mainly in relation to the determination of the horizontal angles.
Keywords: App. Smartphone Sensors. Determining angles and distances.

Resumo: Os smartphones se tornaram instrumentos de comunicação e de recuperação de informações, mas como parte de sua funcionalidade eles também contêm uma variedade de sensores para determinar sua orientação e localização. Essa pesquisa tem como objetivo avaliar a capacidade dos sensores: giroscópio, acelerômetro e magnetômetros, e o sensor da câmera, embarcados com o propósito de determinar indiretamente valores de ângulos e distâncias, elementos básicos para a determinação de posições por técnicas de posicionamento terrestres. Os testes consistiram na medida de pontos em um ambiente interno e em ambiente externo. Com a finalidade de estabelecer um parâmetro de comparação, estes foram levantados com a utilização de uma estação total e com o auxílio do aplicativo desenvolvido. Os resultados mostraram que, para as distâncias avaliadas, as diferenças obtidas entre os dados medidos pela estação total e pelo aplicativo foi de no máximo 1,54 metro e no mínimo 0,09 m. As medidas dos ângulos verticais apresentaram em média, aproximadamente 2,09 graus de discrepâncias entre os dados comparados com os dados da estação total. Já os ângulos horizontais apresentaram as maiores diferenças entre os valores medidos com o aplicativo e a estação total, sendo estas variando de 4,83° até 69,32° avaliados em ambiente interno. Estas discrepâncias observadas aumentaram conforme o aumento do ângulo medido e calculado, verificando-se assim um problema principalmente em relação à determinação dos ângulos horizontais.
Palavras-chave: Aplicativo. Sensores de Smartphone. Determinação de ângulos e distâncias.

1 INTRODUCTION

Over the years, hundreds of app's (application programs) have been designed to access this hidden information, turning smartphones into measurement platforms and generally at low cost (ODENWALD, 2019). A modern smartphone allows measuring different physical quantities directly from its embedded sensors (DAPONTE et al., 2013). Some examples of sensors that come embedded to the most modern smartphones are accelerometer, digital compass, gyroscope, GPS, microphone and camera, which are enabling the emergence of new sensing applications (LANE, 2010).

With the advent of these devices, the programming process for using data from these sensors has been facilitated. Now phones can be programmed to support new disruptive sensing applications. Most smartphones available on the market have open and programmable platforms. In addition, it is possible to use programming interfaces from reliable platforms that allow access to the sensors available on the devices (LANE, 2010). This factor allowed the development of several applications aimed at different purposes, such as the health sector, environmental monitoring, safety, transportation, among others.

In the geodetic sciences, some studies have already been developed in the context of the use of smartphones for different applications such as: geographic information systems (GIS) (CONTI, 2015); photogrammetry (as applications developed for aerophotogrammetric flight planning); monitoring of structures (PERES, 2015) and GNSS surveys (Global Navigation Satellite System) (HWANG, 2012). For the development of these applications, it is necessary to use raw data from different sensors on smartphones.

Within the context of using data from the sensors of smartphones to measure angles and distances, Kuhlmann et al. (2021) presented a study on the accuracy of the data, especially with regard to the sensors that allow obtaining the orientation of the smartphone: the magnetometer, the accelerometer and the gyroscope. From the sensors it is possible to obtain the device orientation angles. These authors presented a comparison between the different models of smartphones on the market, and consequently the different types of sensors embedded in each of these devices.

Studies in the area of distance measurement were carried out by Salih and Malik (2012) in which a methodology for measuring distance from a single photo was presented. In this research this method was used, with the aim to obtain distances from a single image. So, the multiple images method was not used. In addition, the author Odenwald (2019) presented free and paid applications, with the purpose of measuring distances, but all based on the principle of measurement by coordinates obtained from GNSS data.

As shown, several applications have already been developed for measurement purposes. However, no studies were found showing applications for the purpose of measuring angles and distances at the same time, on free platforms, which also aim to evaluate the feasibility of using smartphone's sensors. It should also be noted that the simultaneous measurement of angles and distances is the most practical way to obtain two-dimensional and three-dimensional coordinates from a single station. Using just measurements of angles or just measurements of distances require the occupation of two or more station points to obtain the coordinates.

On this context, this paper proposes the development of an application on a free platform, which allows accessing data from different embedded sensors in the smartphone, with the objective of making the indirect measure of angles and distances through this application, and the determination of local coordinates, without using GNSS (Global Navigation Satellite System). To verify the feasibility of the application, measurements will be made with the total station located in the same positions where the measurements will be made with the developed application.

The use of a satellite positioning system presents limitations of use especially in urbanized and indoor environments, and in this case alternative methodologies such as the one proposed in this paper become more viable depending on the application.

Historically, smartphones have integrated depth sensors and augmented reality. The first smartphone equipped with ToF (Time of Flight) camera and augmented reality features launched in the consumer market was in 2016. In 2020, an American company launched the iPad Pro 2020 and the iPhone 12 on the market with the presence of LiDAR sensors (COSTANTINO, 2022).

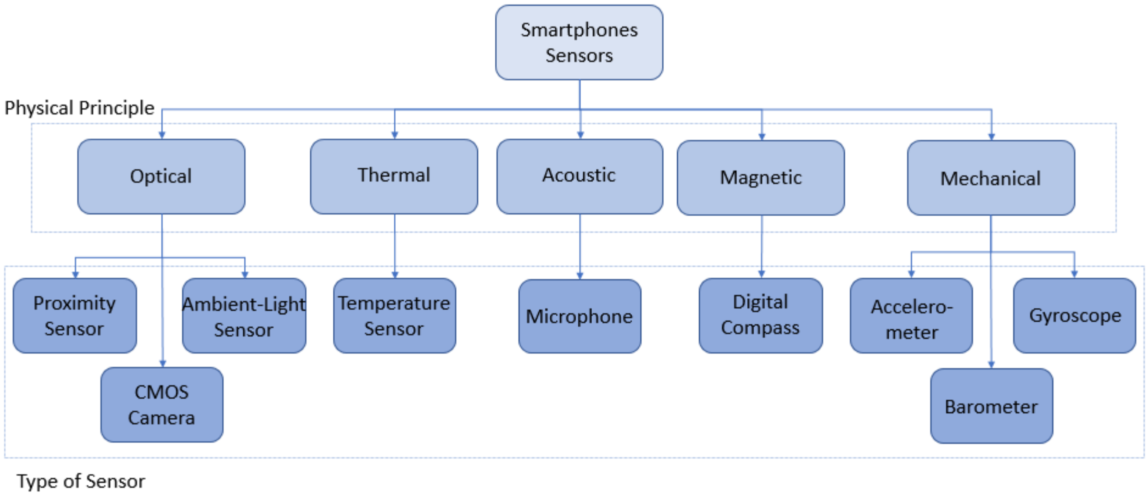
This LiDAR sensor is a new kind of sensor embedded in smartphones that measures depth and detects objects in three dimensions. It is important to emphasize that from a survey using a laser scanner, scans of hundreds and thousands of points are obtained for the 3D reconstitution of an environment or an object, which requires devices with a high operational capacity so that processing is possible and analysis of these data.

In addition, as it is a recent technology (it started after the year 2020), the values of cell phones that contain this sensor are still very high, difficult to access. The software and programming tools still do not have adequate and easily accessible tools to use the raw data coming from this sensor. Due to these limiting factors, this sensor has not yet been used to obtain distances in the proposed application in this paper.

2 SENSORS

Daponte (2013) classifies the sensors according to their physical principle of operation (Figure 1).

Figure 1 – Classification of Smartphone Sensors.



Source: Adapted from Daponte (2013).

Magnetic and mechanical sensors are based on a technology known as MEMS (Micro Electro-Mechanical Systems), which are sensors that contain microelectronic and micromechanical structures. MEMS technology is used for the development of sensors, such as the accelerometer, the gyroscope and the magnetometer, which have three axes. The main advantages for using these technologies are the low cost of this system, the size (few millimeters), and the high performance.

The gyroscope is a device that determines orientation through angles. It has applicability in sectors such as aviation, computing, robotics and in mobile devices such as video games and cell phones. There are several types of gyroscopes, among them: gyrostat, Fiber-Optic Gyroscopes (FOG), Dynamically Tuned Gyroscopes (DTG), London Momentum and MEMS. The MEMS-type gyroscope uses the Coriolis effect to explain the direction and change of this direction, so the application works (PASSARO et al. 2017).

Used together with the gyroscope to define the rotation of the pulse, there is the accelerometer, which is an electromechanical device that measures the acceleration force. The most common type of accelerometer found on smartphones is one that contains three axes and a capacitive principle.

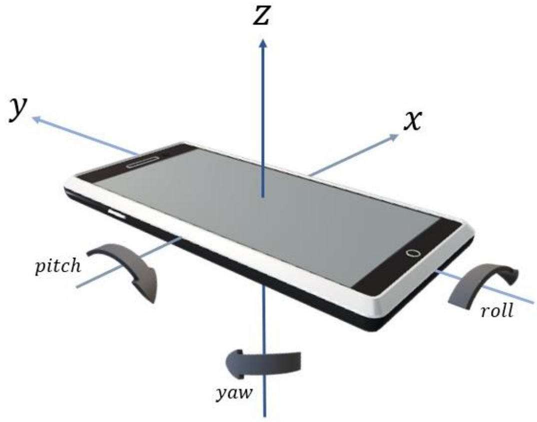
In addition to the gyroscope and the accelerometer, there is the magnetometer. The magnetometer estimates the strength of the earth's magnetic field. The digital compass, for example, is based on this three-axis magnetic sensor (DAPONTE, 2013).

These so-called MEMS sensors allow obtaining information related to the orientation of smartphones. The three axes of these sensors, as seen in Figure 2, provide the roll, pitch and yaw angles. The roll measures 0° when the device is leveled, increases 90° when the device is tilted upwards on the left side and decreases to -90 ° when the device is tilted upwards on the right side (MIT, 2020).

The pitch measures the slope, being 0° when the device is leveled, up to 90° when the device is tilted so that its top is pointing down, and up to 180° as it is turned. Likewise, as the device is tilted down, the angle decreases to -90° and then to -180° as it is rotated all the way.

The yaw also corresponds to the magnetic azimuth, and measures 0° when the top of the device is pointing towards magnetic north, measures 90° when it is pointing east, 180° when it is pointing south, and 270° when it is pointing west. These measures assume that the device itself is not moving.

Figure 2 – Axes of MEMS sensors.



Source: The Authors (2022).

Another important sensor that will be used to carry out this research is the digital camera. smartphone cameras are basically composed of sensors, lens, auxiliary circuits and, in some cases, a lighting system for photos (flash). The big difference between cellphone cameras and others is the need for low cost and small size (MORIMOTO, 2009).

While sensor availability varies by device, it may also vary between the operating system versions of the device being used. That is why it is important to know which operating system and which version is being used to verify whether or not it is possible to use data from certain sensors. Smartphones have an operating system whose main function is to manage all the applications and hardware processes of a device.

There are some application development platforms, the so-called "frameworks." These frameworks allow accessing various types of sensors. Some of them are hardware based while others are software based. Hardware-based sensors are physical components built into a mobile device or tablet. They derive data by directly measuring specific environmental properties such as acceleration, geomagnetic field strength or angular change. Software-based sensors are not physical devices, although they mimic hardware-based sensors. These derive data from one or more hardware-based sensors and are known as virtual or synthetic sensors. The linear acceleration sensor and the gravity sensor are examples of software-based sensors (KUHLMANN et al., 2021).

In this research, a platform called MIT App Inventor will be used to access sensor data. This platform provides guidance data from software-based sensors. MIT App Inventor is an environment that uses a block-based visual language to allow users to create applications for mobile devices. The creation of a project in "App Inventor" consists of a set of components and blocks of programs that provide functionality to these components, which are items visible on the phone, such as buttons and text boxes, and non-visible items, such as sensors and the database (TURBAK, 2014).

3 ALGORITHM FOR CALCULATING DISTANCE

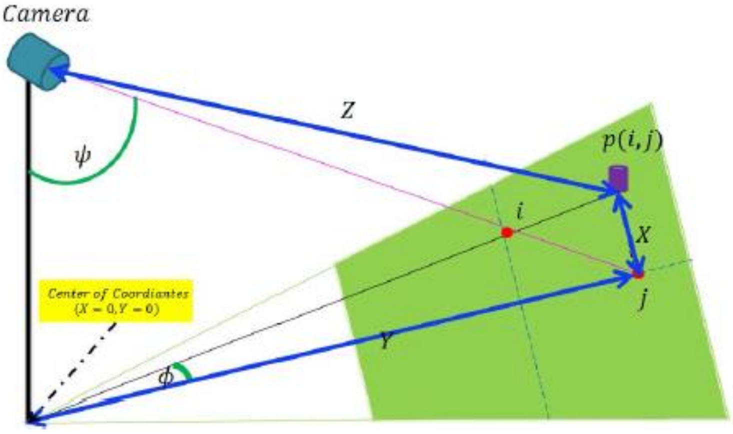
Salih and Malik (2012) presented a method for calculating the depth and geometry of an object in a photo from a single 2D image. In this article, this methodology presented by these authors will be used to calculate the distance between the smartphone and a certain point measured in the photo.

The method proposed by Salih and Malik (2012) works for cameras that face downwards with a known angle of inclination and height. The camera is installed at a known height (h) from the floor and has a tilt (inclination) angle (θ). The camera's field of view is (FOV_h) in the horizontal direction and (FOV_V) in the vertical direction. The above parameters restrict the geometry of the image and control how large or small the viewing area can be. The calculation of depth and geometry is performed using triangulation, so the angle of inclination can be defined by Equation 1.

$$\theta < 90 - \frac{FOV_V}{2} \tag{1}$$

In Figure 3, an object located in the image is considered as the point p (i, j). The location of this object can be completely described by the height of the camera, as well as the vertical angle (Ψ) and rotation angle (Φ). These two angles are calculated using equations (2) and (3), respectively, where W and H are the width and height of the image.

Figure 3 – A Trigonometric model for three-dimensional determination of the coordinates of a point located at the position p (i, j).



Source: Salih e Malik (2012).

$$\Psi = \theta + \left(\frac{H}{2} - j\right) \times \left(\frac{FOV_v}{H}\right) \tag{2}$$

$$\Phi = \left(i - \frac{W}{2}\right) \times \left(\frac{FOV_h}{W}\right) \tag{3}$$

The values ($\frac{FOV_v}{H}$) and ($\frac{FOV_H}{W}$)) are the angles in the respective vertical and horizontal direction. These angles are calculated due to the displacement of a pixel in the vertical or horizontal direction. Given the angles (Ψ) and (Φ) and assuming that the center of the coordinates is directly below the camera, the absolute location of the ground (X, Y) and the absolute depth of the field (Z) for the image point p (i,j) can be calculated using equations (4), (5) and (6), respectively.

$$Y = h \times \tan(\Psi) \tag{4}$$

$$X = Y \times \tan(\Phi) \tag{5}$$

$$Z = \sqrt{h^2 + Y^2 + X^2} \tag{6}$$

The methodology presented by the authors Salih and Malik (2012) was used in this research only to obtain the distance between the point in the image and the object. With this information and the data obtained by the sensors of the angular measurements, it is possible to obtain the three-dimensional coordinates of the measured points.

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4 MATERIALS AND METHODS

4.1 Materials

The materials used for this research were:

a) The application development platform: MIT App Inventor;

b) A smartphone that contains the following sensors: camera, gyroscope, accelerometer and magnetometer – smartphone Xiaomi Redmi Note 8;

c) TS15 total station;

d) Support developed for the smartphone (Figure 4).

Figure 4 – Support developed for taking measurements with the smartphone attached to a base.

Source: The Authors (2022).

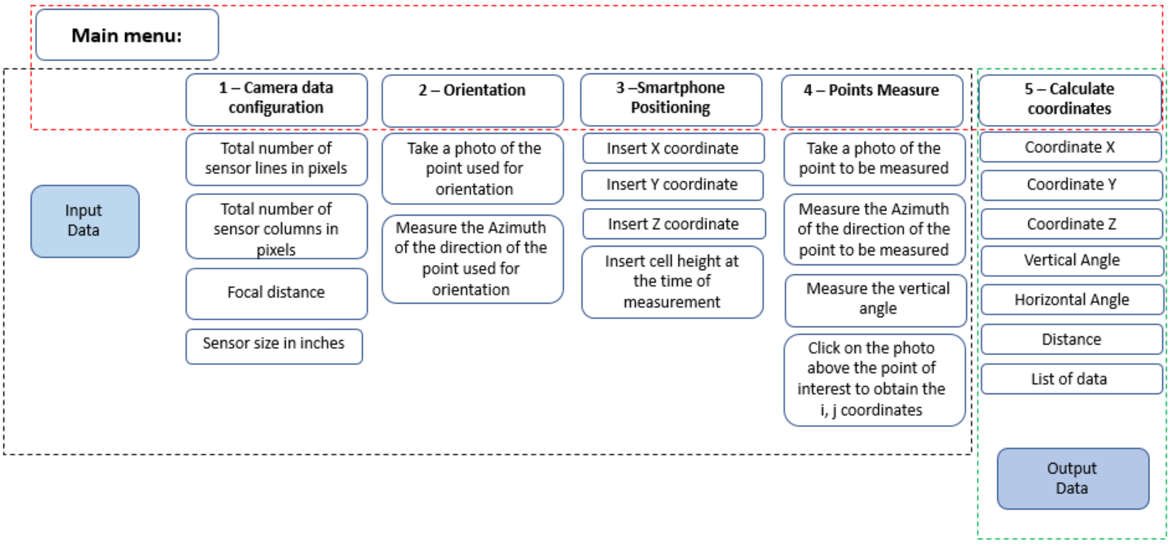
The support developed allowed the smartphone with the application program to be installed in the same position as the total station, in order to ensure that the measured data were taken from the same position. The support consists of a leveling base, a cell phone holder normally used for pinning smartphones in vehicles and a prism holder, adapted for the cell phone.

4.2 Methodology

4.2.1 DEVELOPMENT OF THE APPLICATION

The first step of the methodology consisted in the elaboration of the application that was called MEDIDAS. The development of this application was divided into parts to facilitate data entry and exit. Figure 5 shows the parts of the developed application. In the first screen of the application there are steps 1, 2, 3, 4 and 5 that must be followed to obtain the measurements of the points of interest.

Figure 5 – Flowchart of the application.



Source: The Authors (2022).

In Figure 5, it is also possible to verify all the data that will be necessary to be inserted in each step of the application. In the first step, for example, the user must enter data from the camera of the cell phone used, such as the focal length, the size of the sensor, etc. The application allows these data to be saved. So, this is a procedure that does not need to be repeated to measure different points, it is necessary to enter this data only once.

For the cases of devices that have multiple cameras on the cell phone, such as front and rear camera, it is necessary to enter data only from the main camera of the device, which usually is the rear camera, that will be used to measure the points. The graphical interface of the main screen of the application and the first stage presented can be seen in Figure 6.

Figure 6 – Graphical Application interface.

Source: The Authors (2022).

It is important to highlight some necessary precautions for carrying out the measurements using the developed application. Thus, before starting measurements with the application, it is necessary to perform a calibration of the smartphone's compass. This calibration can be done using the compass application available on smartphones that have a magnetometer sensor attached.

Another precaution that must be taken is the positioning of the cell phone to obtain the horizontal angle measured between two directions. The horizontal direction is obtained by using the magnetometer sensor. This should be measured with the cell phone in a horizontal position, facing the direction you want to observe. In addition, it is necessary that between the measurements, a few seconds of waiting are given so that the sensor is stabilized in the new position.

The measurement of a first point is carried out, which will serve to guide the other measures. For this, on the second screen of the application, (2-orientation), you must take a photo of the point that will serve as a reference for the other measurements. Then, position the phone horizontally and click on the button to obtain the horizontal direction between the device and the observed point. Finally, you must save these measurements made by clicking on the button: “save.”

With the smartphone properly oriented, you must fill in the requested data on the third screen of the application (3-cell positioning), in this screen the coordinates (X, Y and Z) adopted for the point where the equipment is parked must be entered and the height of it. The height should be measured, with a measuring tape, from the floor to approximately the height of the cell phone's main camera. As in the previous step, it is necessary to click on the “save” button to save the data entered.

Once the equipment is already oriented and the information about the position of the cell phone is already inserted, step 4 of the application is carried out, where the point measurements will be effectively performed. In this step, rotate the device slowly to the approximate direction in which the point to be measured is. When the cell phone is positioned towards the point, a photo of the target must be taken so that it is approximately in the center of the photo. The user must click on the photo, in the approximate position where the target is (Figure 7).

Figure 7 – Indication of the approximated position of the measured and Smartphone in horizontal positioning.

Source: The Authors (2022).

The cell phone must be in a horizontal position (Figure 7), and the user must wait a few seconds for the sensors to stabilize, and then measure the horizontal direction between the device and the observed point. After this measurement, it is necessary to click on save, to store the measured data.

After performing each of the steps, it is necessary for the user to save the data entered, in order to ensure that the application calculates the coordinates of the observed points in a correct and updated way. If the new measurement is not saved, the application will calculate the coordinates, based on previously measured data.

Finally, to obtain the coordinates of the measured point, it is necessary to click on the button “5 - Calculate coordinates” and click on the button “calculate”. If the user wants to save these coordinates, click on the “save” button, and they will go to a list created in the application itself, which can be shared by email, if the user wants to work with this data later.

If the user wishes to use the same reference point for the measurement of a new point, it is possible to go back to the button “4 - measurement of points” and perform the measurement of one more point, proceed to button 5 to calculate and add new point to the list of measured points.

The ".aia" file with the application code created, is available in Sampaio (2022).

4.2.2 CARRYING OUT MEASURES IN INTERNAL AND EXTERNAL ENVIRONMENT

First, for preliminary evaluation of the application's operation, tests were carried out at the Laboratory of Geodesy Applied to Engineering (GEENG) at the Federal University of Paraná (UFPR). These tests consisted of measuring some points in the laboratory, using the MEDIDAS application.

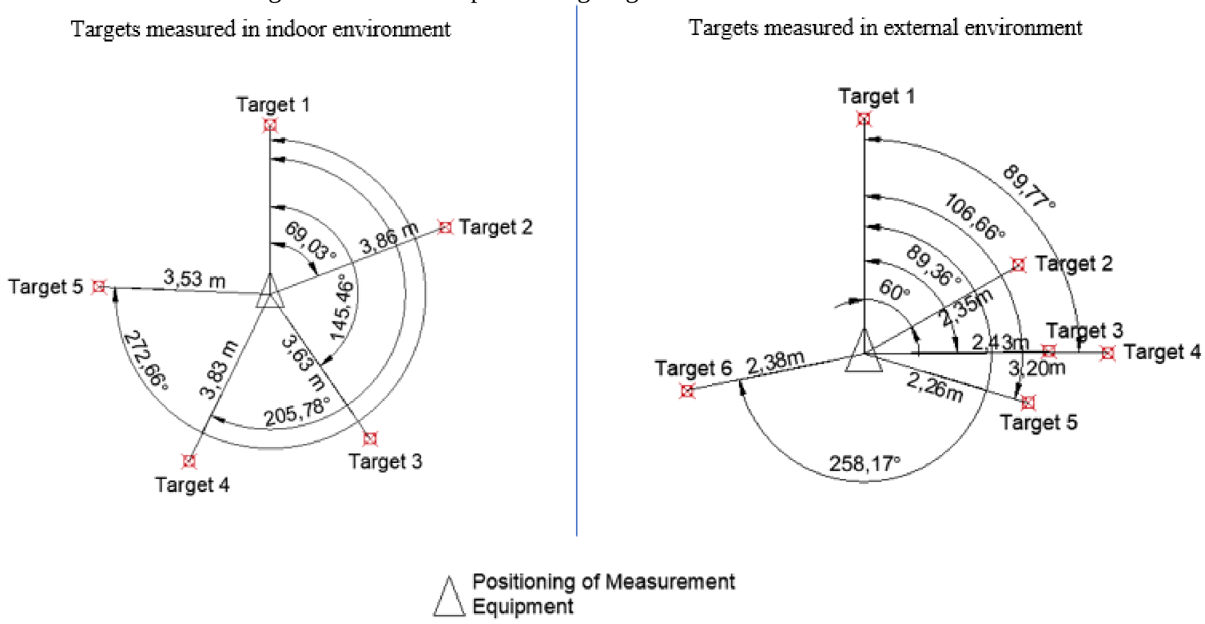
For this, it was used a smartphone that was placed on the support developed in the laboratory, as shown in Figure 8. Some targets were distributed on the laboratory floor, and these were used to carry out these measurements. In Figure 8, it can be seen how these targets were arranged, and how the mobile device was positioned in relation to these points.

Figure 8 – Tests with the application at GEENG.

Source: The Authors (2022).

Figure 9 presents a sketch for a visualization of how the points were distributed around the place where the measurement equipment was installed. Target 1 was used to orient the measurement equipment, and from this point on, the other targets were measured. With the application, 5 sets of measurements were made for each point. In relation to vertical angles, this angle was measured in the same position that the photo was taken, with the same inclination of the smartphone.

Figure 9 – Sketch of positioning targets in an indoor environment.



Source: The Authors (2022).

Subsequently, the same experiments were carried out in an external environment, on the UFPR campus, as can be seen in Figure 10.

Figure 10 – Testing with the application in an external environment.

Source: The Authors (2022).

For the experiment carried out in an external environment, five targets were distributed around the installation position of the measurement equipment. The positioning of the points can be seen in Figure 9.

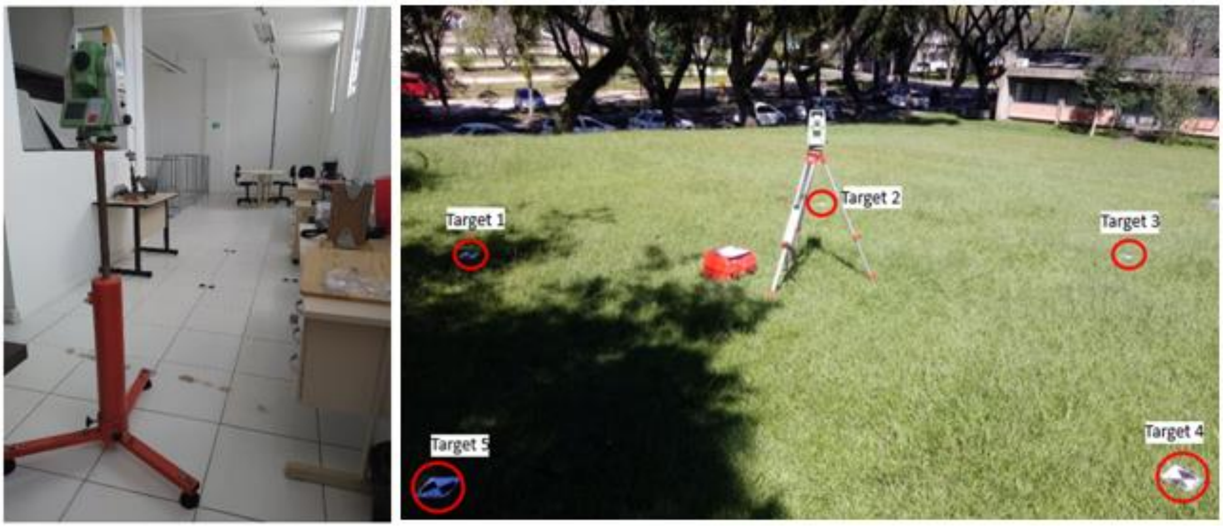
To carry out the measurements, a smartphone was used, which was placed on the developed support. In this way, it was possible to install this equipment on the tripod in the same position (centering) that the total station was installed, to perform measurements that would allow to check the results obtained (coordinates).

For preliminary assessment of the operation of the application, experiments were carried out in an internal and external environment. The experiments were carried out in these environments in order to evaluate the operation of the magnetometer sensor, since it is influenced by the magnetic field, which is affected by interference depending on the place where the experiment is being carried out.

4.2.3 PERFORMING THE SAME MEASUREMENTS PERFORMED WITH THE APPLICATION USING A TOTAL STATION

To verify the data collected with the application, the same measurements were performed with a TS15 total station (Figure 11). Measurements were taken for the same targets and in the same positions in which the cell phone was placed. For this case, as it is a high precision measuring equipment (angular precision of 1” and linear precision of 1mm + 1ppm), 3 series of readings were performed.

Figure 11 – Survey with TS15 Total Station.



Source: The Authors (2022).

5 RESULTS

As shown in the methodology, 5 sets of repetitions were taken to measure each target with the application, both indoors and outdoors. The differences found between the data measured by the application and the total station is shown in Table 1 and 2. In Table 1 it is possible to verify that the largest differences refer to the horizontal angle measurements, with the largest discrepancy (69.32°) being obtained for point 6. As for the distance and vertical angle measures, the largest differences found were 0.81m and 2.88° respectively.

Table 1 – Difference between data raised with the total station and with the application - internal environment.

Target	Horizontal angle (°)	Distance (m)	Vertical angle (°)
2	4.83	0.29	2.29
3	16.38	0.17	1.82
4	17.01	0.81	2.82
5	23.50	0.73	2.88
6	69.32	0.11	2.46

Source: The Authors (2022)

In Table 2 it is possible to verify that the largest differences are also to the horizontal angle measurements, with the largest discrepancy (29.39°) being obtained for point 4. As for the distance and vertical angle measures, the largest differences found were 1.54m and 2.38° respectively.

Table 2 – Difference between data raised with the total station and with the application - external environment.

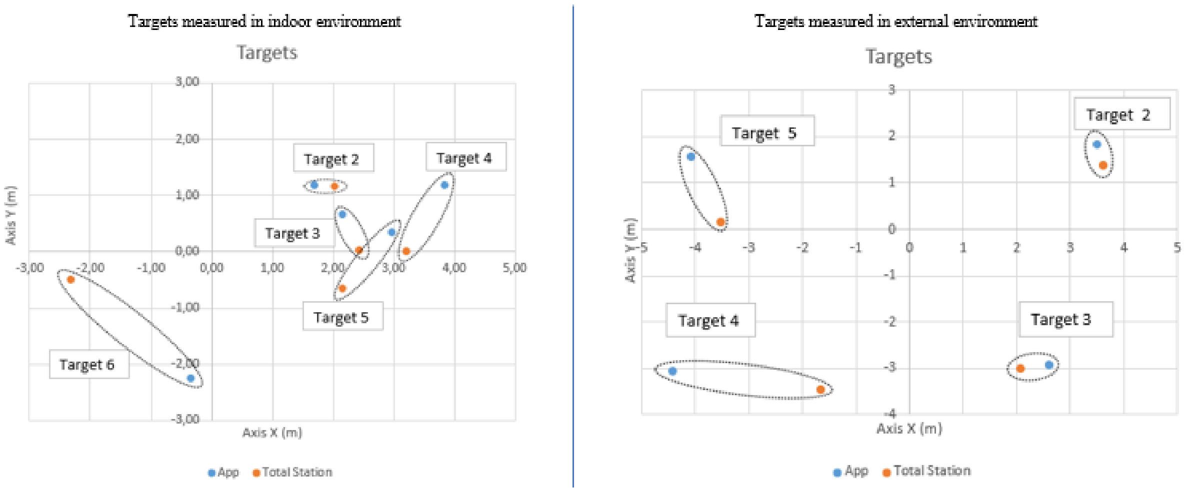
Target	Horizontal angle (°)	Distance (m)	Vertical angle (°)
2	6.82	0.09	0.58
3	7.18	0.27	2.38
4	29.39	1.54	1.71
5	18.57	0.85	1.86

Source: The Authors (2022)

In the experiments carried out, the X and Y coordinates calculated for the measured targets were also evaluated. In this way, it is possible to plot and spatially visualize the location of the points and check the difference between the positions of the targets measured by the total station and the application.

In Figure 12, the coordinates of the targets calculated from the measurements made with the application and from the measurements made with the total station were represented. In this figure, the blue dots represent the position of the targets raised with the application and in orange, the position of the targets raised with the total station. It appears that targets 6 and 4 are the ones with the greatest discrepancy in the coordinates.

Figure 12 – Differences between the measurements with Total Station and the application.



Source: The Authors (2022).

As a pattern can be observed in these differences found, techniques can be developed to minimize these differences, for example, applying a correction factor proportionally to the increase in the measured angle value. Another possibility is to increase the time for stabilization of the sensors between the intervals of the measurements in each target.

It is necessary that the data obtained for the horizontal angles be treated, since they present systematic errors due to the use of the magnetometer sensor to obtain this measurement.

Another factor that can be investigated to improve a gyroscope and accelerometer quality is to use the data coming from hardware sensors instead of software sensors. Finally, the question of obtaining horizontal angles from smartphone sensors deserves further study.

Both in experiments carried out indoors and outdoors, it was found that the discrepancies found for the distance values were on average 0.54 m. The average of the distance measurements carried out in the experiments was approximately 3.47 m due to the limitation of indicating in the image, the approximate position of the target being measured. This limitation due to the method used to determine the distances, could be calculate the distances from estimated coordinates that could be obtained using a map base inside the app. The measurements of the vertical angles showed, on average, approximately 2.09 ° of discrepancies between the measurements, which also proves their usability for the purposes of the application.

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6 CONCLUSIONS

Although the tests were carried out with a specific model of smartphone, they showed that it is possible to determine local coordinates of points using the sensors of a smartphone. The precision of the determined quantities and of the calculated coordinates is not yet comparable with traditional techniques, such as surveying techniques, but the advance in the development of sensors to help minimize these problems.

The results showed that for the distance determination, the differences obtained between the data were in general at most 1 meter, and that the quality of the determined distance worsens as the point moves away from the smartphone. The measurements of the vertical angles showed on average approximately 2 degrees of discrepancies between the measurements, which also proves its usability. The measurements obtained from the horizontal angles were those that showed the biggest differences between the values measured with the application and the total station.

It is necessary to treat these data obtained for the horizontal angles, since they present systematic errors due to the use of the magnetic compass to obtain this measurement. It is recommended that a calibration technique be applied to this sensor, for example.

For the calibration of sensors, D'elia et al. (2013) presents a proposal for a method with this purpose, more focused on accelerometer calibration, but indicates that this method can be used for different sensors. This consists of determining some parameters such as the scale factor matrix and the MEMS sensor displacement vector. As these sensors make measurements in relation to three axes, the calibration model incorporates the displacement and a scale factor for each axis and the symmetric factor in the transverse axis.

Another factor that can be investigated to improve the achievement of the horizontal angle is the use of the accelerometer sensor with the gyroscope to obtain these measurements.

From the analysis performed, it is concluded that, from the access to the data provided by the sensors present in smartphones, measurements of angles and distances can be performed using these data, making possible to determine the three-dimensional coordinates of points on a physical surface. It should be noted that the precision in determining the coordinates was not the factor sought in this work, but the possibility of determining them. It should be noted that studies are still needed to improve the measurements obtained for mainly the horizontal angles measured from the gyroscope.

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Authors' Contribution

The authors L. F. S. and A. L. B. I. developed the application. The author L. A. K. V. supervised the work and revised the text. The authors S. S. O. A., F. A. C. R. and L. I. B. M. helped in the execution of the tests and in the writing of the article.

Conflict of Interest

The authors declare no conflict of interest.

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