Deterministic indoor detection from dispersions of GPS satellites on the celestial sphere

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Abstract. This paper suggests a deterministic scheme to detect whether a mobile device is located indoor or outdoor by comparing visible satellites information from GPS and the medium earth orbit information of the GPS satellites. As positioning methods which used indoor and outdoor is significantly different, the mobile device should alter the positioning method according to its environmental situation. Unfortunately, there are few prior researches on how to determine the trigger points for the transition of the positioning methods. This paper proposes a passive, low-power and deterministic indoor/outdoor detection scheme compared by sensor and learning based one. And the performance evaluation section shows the test results by the category of availability, accuracy, latency, and power consumptions. Finally, the paper concludes with some limitations and future works.

1. Introduction

Determining an absolute or relative position of a mobile device is an essential technic for the most location based services. Global positioning system is the basic approach to obtain locations of the mobile device when it is outdoor. As the GPS receiver should secure at least four line-of-sight signals from the GPS satellites, the GPS receiver cannot calculate its location or make quite errors when it is in building or underground. Indoor positioning methods like wireless positioning system might be useful for the mobile devices located indoors. However, utilizing both indoor and outdoor positioning system simultaneously will cause heavy battery drains, especially when the service needs to track the mobile device continuously. The ideal solution is to select the appropriate positioning method according to the situation of the mobile device. To achieve the goal there should be an indoor/outdoor detection. I/O detector is one approach to the detection of in/outdoor using light intensity sensor, geo-magnetism sensor, and cell

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tower RSSI variation. I/O detector adopts basic machine learning mechanisms to classify the status of mobile devices by aggregating various sensor data. We will discuss the limitations of the learning based approach and the needs of deterministic approach in Section 2. Section 3 will describe the system design of the proposed deterministic indoor detection technic and Section 4 will show the evaluation results. Finally, Section 5 will conclude the paper with applications and future works.

2. Background and motivation

2.1. Learning-based indoor detection

I/O detector is the latest and representative method of learning-based indoor detection. The learning based mechanism observes the significant changes on the sensor values when a mobile device is located indoor or outdoor. The sensors may be a light intensity sensor, a geo-magnetism sensor, a temperature sensor, a humidity sensor and so on. The aggregation of such sensor values will be helpful to improve the quality of the detection mechanism. After setup the system, the learning phase should be followed for various indoor and outdoor situations like rooms with many windows, standing near walls, underground, etc. And then the detector can classify whether the mobile device is indoor or not using the trained binary classifier. As many as training data provided and as clear as the sensor data distinguished, the learning based indoor detector will show high precision and recall for a specific situation to be classified.

2.2. Limitations in learning-based approach

The learning based indoor detection mechanisms have some limitations when it applied in a commercial location based services. In many cases, the sensor reading value is ambiguous and the vague condition may cause the false positive or false negative output results. And for the sensors that need to track the variation of the sensing value, the initial state should be referred. For example, in the cell tower RSSI monitoring method, if we define the increasing RSSI as a transition from the indoor to the outdoor, the system should know whether it was indoor or outdoor when it was powered on, as the RSSI can also vary by the distance from the cell tower even if it moves outdoor. Furthermore, some sensors like temperature and humidity sensors need to be trained over long time period as that kind of sensing value may vary by the seasons. The temperature of indoor in winter might be higher than the temperature of outdoor in summer. In that case, the training data should be supplied over the whole year. Geographical charac-

teristics and national regulations also can be obstacles to adopt the learning based indoor detection mechanisms.

2.3. Needs to deterministic approaches

To detect whether a mobile device is located indoor or outdoor without prior knowledge or training, a novel deterministic approach must be developed and the approach will satisfy the following criteria.

- Deterministic detection method

The decision should be made by the combinations of given conditions excluding statistic or probabilistic factors. By doing so, the method will be applicable without any temporal and geographical restrictions. GPS could be a candidate solution as the orbits of satellites are fixed and the satellites revolve around the earth twice per a day.

- Minimize additional power consumptions

The battery life is a insistent problem of most mobile devices. Location-based services already consume numerous powers to detect the location of the mobile device. As a result, the method should minimize the power consumption itself or work passively by other fundamental operations.

- High availability and accuracy

Besides the deterministic and low power operation, the method should be applicable in most indoor/outdoor conditions and the detection result should show over 90% accuracy compared by the learning based approach. The detection latency also needs to be minimized.

3. System design

To develop the deterministic, low-power, and accurate indoor/outdoor detection system, this paper proposes to use GPS visible satellites information from GPS chipset in a mobile device and the medium earth orbit information of the GPS satellites from NASA. By plotting the information on the celestial sphere, the system could detect obstacles which are hiding the GPS signals. And the detected obstacles will be used to determine whether the location is indoor or outdoor.

3.1. GPS visible satellites

Generally, GPS chipset consists of GPS frontend and GPS baseband. The signal from a GPS satellite is received by GPS antenna and processed to digital data in GPS frontend. The digitized GPS signal is handled in GPS baseband. After complex calculation of FFT/IFFT, the GPS chipset finally

get the pseudo ranges and azimuth/elevation of each visible GPS satellites. The most appropriate four satellites are selected to calculate location by trilateration. However, the information about unselected remaining satellites are still quite important as they let us know which direction is open to see the sky. NMEA 0183 is a protocol specification between a GPS chipset and a host system. Application layer protocol of NMEA consists of several sub-messages like GPGGA and GPSV. GPGGA message contains information about fix time, longitude, latitude, altitude, HDOP and etc. GPGSV message contains azimuth and elevation of all GPS satellites from which currently the GPS module can receive the signal. Furthermore, the GPGSV message is available when the GPS chipset does not fix the location. After getting azimuth and elevation from GPGSV message, each satellite can be plotted on the celestial sphere like figure 1.

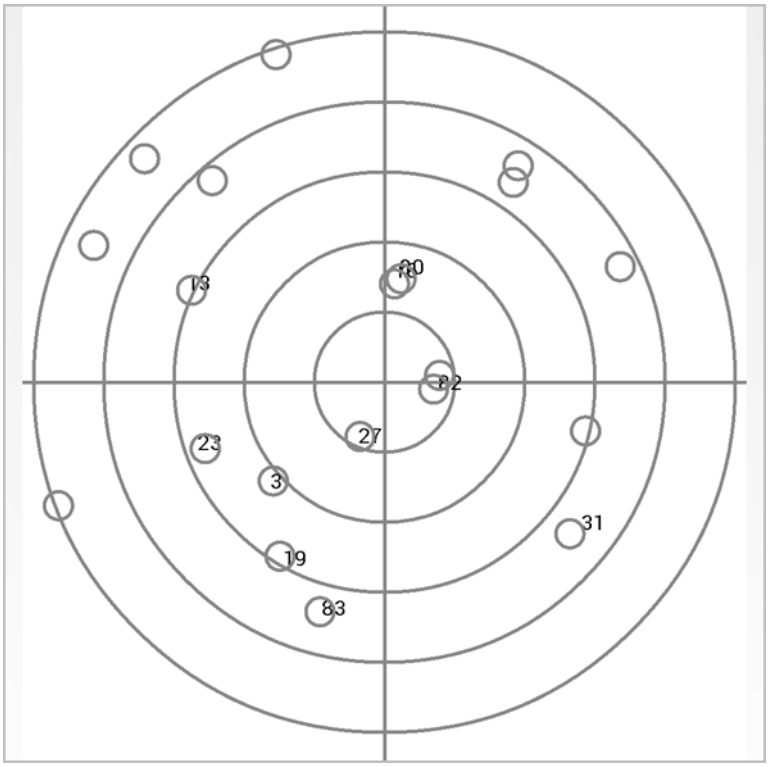


Figure 1. The celestial sphere is illustrated which the position of GPS satellites are noted on. Circles are actual satellite locations and the numbers are the satellites which can have line-of-sight signals. Circles without mapped number mean there exist obstacles by the direction to those satellites.

3.2. Orbit information of GPS satellites

All artificial and natural objects revolving the earth orbit are tracked by NORAD and NASA, and the orbit information is announced publically on each week or month. GPS satellite constellation is located in the medium earth orbit, thus the orbit information of GPS satellites also could be found by online in format of two-line element sets. By using the orbital information, we can calculate the expected position of satellites at a given time. PREDICT is an open-source software to track the position of satellites from the orbital information. If we set the location of ground station to the current location and calculate locations of the GPS satellites for the current time, the software will produce azimuth and elevation information of all the satellites over the horizon. And then each satellite can be plotted on the celestial sphere at the same way to the Section 3.1.

3.3. Determining the condition

Till now, the maps of two celestial spheres are generated which have marks from the position of the GPS satellites. By comparing the two celestial spheres, the system can detect which GPS satellites are actually on the sky and which GPS satellites have line-of-sight signals from the current location. If a GPS satellite is positioned somewhere on the sky and the mobile device cannot receive a signal from that GPS satellite, there might be an obstacle between the satellite and the mobile device. As the GPS system is designed at least six satellites to be observed at any time and any location on the earth, the proposed system can know how many obstacles are near by the mobile device and can determine the mobile device is located indoor or outdoor from the information. The metric can be defined as the degree of open skies (DOOS). And this paper will evaluate the relationship between the DOOS and the detection accuracy in the next section.

4. Evaluations

In this section, the performance evaluation results will be described. The reference detection system is developed on android smart phone and the experiments are performed at the places near latitude 37.25 north and longitude 127.05 east.

4.1. Detection accuracy

The accuracy could be parameterized by the ratio of false positive and false negative. The false positive means the situation when the mobile device is actually located outdoor but the system results the mobile device is located indoor. The false negative means vice versa. Figure 2 shows the relationship

between the degree of open skies and the measured false positive ratio. Figure 2 also shows the relationship between the degree of open skies and the measured false negative ratio. If we set the DOOS threshold too tight, the ratios of false positive would increase. Otherwise, if we set the DOOS threshold too loose, the ratio of false negative might increases. So we need to find the optimal threshold value that minimizes both false positive and false negative ratio.

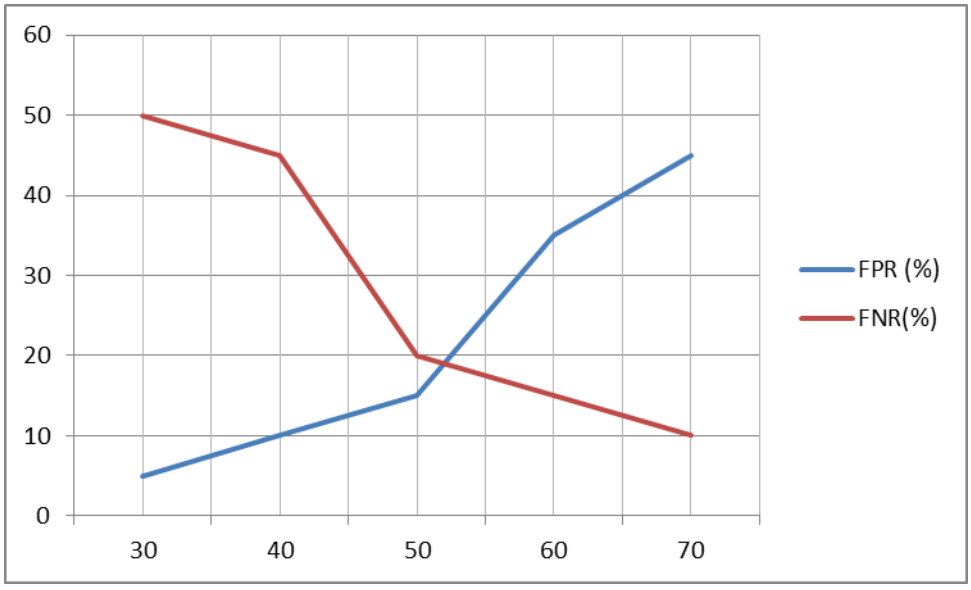


Figure 2. False Positive Ratio(FPR) and False Negative Ratio(FNR) according to the DOOS threshold of the proposed system. Both FPR and FNR are minimized at near 53 of DOOS.

4.2. Power-consumptions

Figure 3 shows the power consumptions when the indoor detection performs periodically. However, the result includes the power consumption of both GPS positioning and indoor detection. So if the positioning is already requested from other location based service, the additional power consumption of the indoor detection is negligible. Furthermore, the information concomitant with the positioning can be used to save more power of the location based service itself and filter out location errors caused by the multi-path, attenuation, and reflection of the GPS signals when it is located indoors. Figure 4 (a) illustrates the GPS position based location tracking service without the indoor detection, and the Figure 4 (b) shows the effect of the indoor detection. By filtering out fixed location from indoor, location errors of GPS were eliminated.

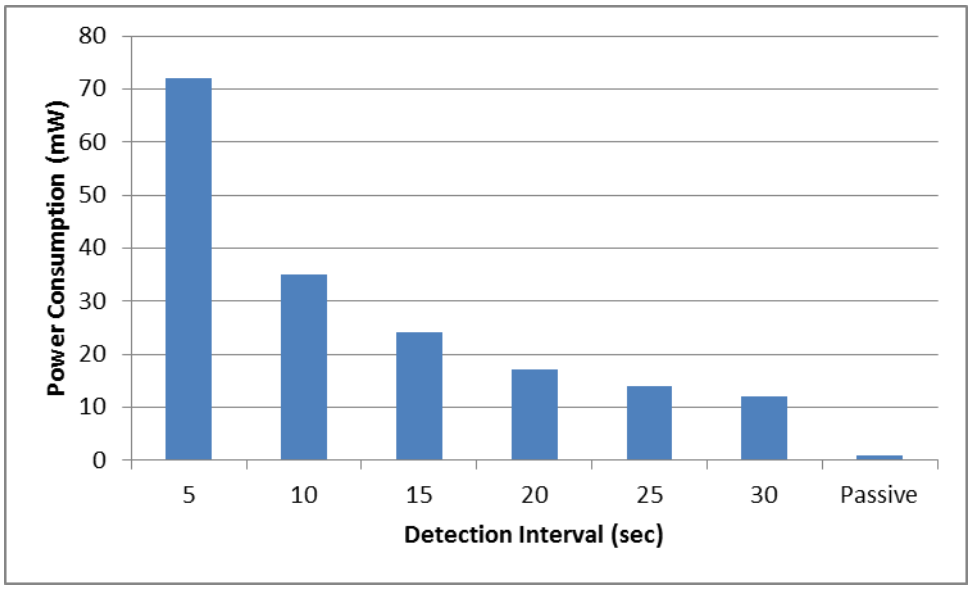


Figure 3. Average power consumptions according to the detection intervals. As the system could work passivly when other services use GPS, the power consumption might be measured extremely low.

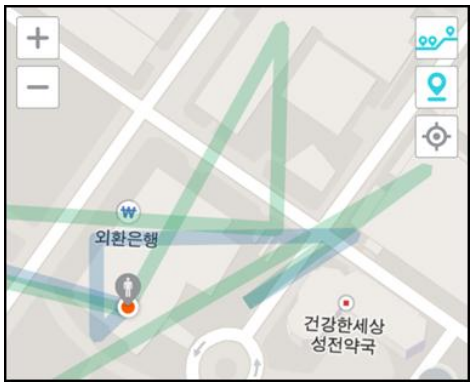
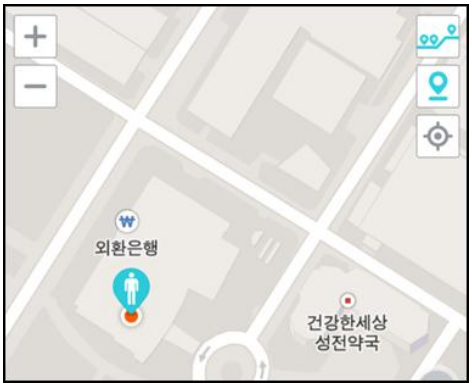


Figure 4. (a) The location from GPS shows quite errors while staying indoors.



(b) There are no need to use GPS while staying indoors.

4.3. Availability

To evaluate the availability of the indoor detection system, we selected fifteen locations mixed indoor and outdoor and numbered the location from 1 to 15. Figure 5 shows the ratio of false positive and false negative on each

location. The result implies that the detection system can be applied generally over various indoor and outdoor conditions.

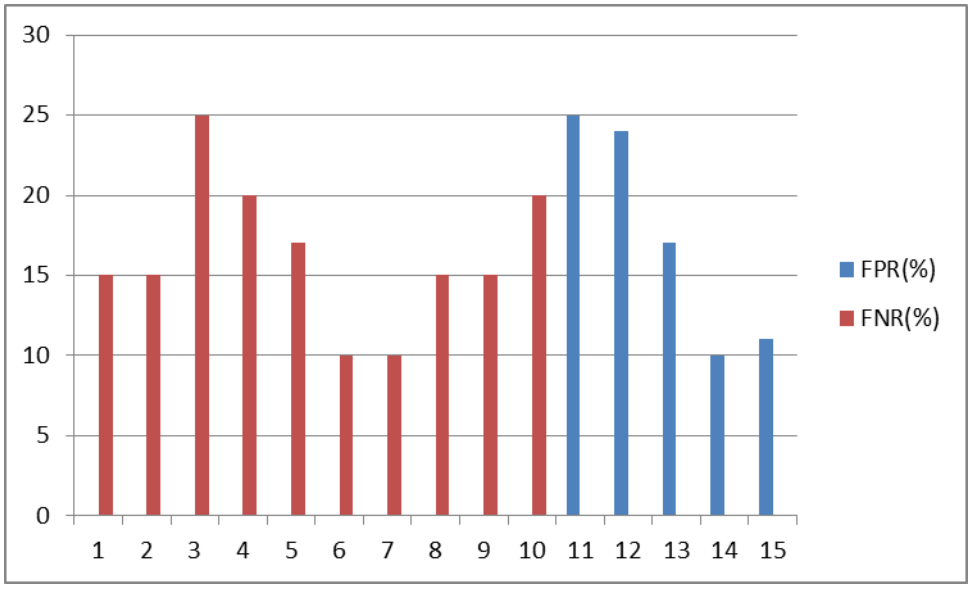


Figure 5. Measured false positive and false negative ratios by the fifteen identical locations. The ratios vary by the charicteristics of the specific location.

5. Conclusion

The global positioning system is an essential part to most location based services. However, the GPS cannot be utilized when the mobile device is located indoor, and even worse, the location from GPS when it is indoor could show quite errors by the distortion of the GPS signals. So it may very helpful if we can know the mobile device is located indoor or outdoor exactly and with less additional costs. The deterministic indoor detection method which this paper propose shows a low-power operation, high availability, and high accuracy by utilizing concomitant information generated while locating from GPS. It's deterministic nature can make it possible to be applied in most indoor and outdoor conditions. Performance evaluation results support that the proposed method can meet the design criteia discussed in Section 2.3. By adopting the indoor detection to the location based services, the service could save power and reduce location errors.

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