Localization and Human Mobility

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Abstract

The objective of this study is to offer a comprehensive review on Internet of Things (IoT) localization approaches and technologies. The study begins with the current localization methods and analyses comparisons in terms of their accuracy, cost, benefits, and drawbacks. In addition, the research compares several detection strategies in terms of accuracy and cost. Finally, localization methods and algorithms are provided, such as Angel of Arrival (AOA), Time of Arrival (TOA), and Received Signal Strength (RSS). The research includes ideas, requirements, and specifications for each technique category, as well as advantages and disadvantages for the examined methods and comparisons between them.

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Chapter 1

Introduction

Localization refers to the process of pinpointing the actual region or geographical position of an object. There are two main categories of localization namely outdoor localization and indoor localization. In this report we discuss the technologies that are used in the localization process and some of the techniques that are implementetd to decrease the error in the accuracy measurments of the localization process.

Chapter 2

Outdoor Localization

2.1 Technologies used in Outdoor Localization

In the literature, four main system categories can be used for localization. in this section we will discuss each of these systems and what are advantages and disadvantages for each system.

2.1.1 Global Positioning System (GPS)

The first category is the GPS that is considered the standard system for outdoor navigation worldwide.[6]

How does it work?

GPS satellites circle the Earth twice a day in a precise orbit. Each satellite transmits a unique signal and orbital parameters that allow GPS devices to decode and compute the precise location of the satellite. GPS receivers use this information and trilateration to calculate a user's exact location. Essentially, the GPS receiver measures the distance to each satellite by the amount of time it takes to receive a transmitted signal. With distance measurements from a few more satellites, the receiver can determine a user's position and display it electronically. To calculate your 2D position (latitude and longitude) and track movement, a GPS receiver must be locked on to the signal of at least 3 satellites. With 4 or more satellites in view, the receiver can determine your 3D position (latitude, longitude and altitude). Generally, a GPS receiver will track 8 or more satellites, but that depends on the time of day and where you are on the earth.[8]

What are some of the Advantages?

The high accuracy localization is considered the main advantage of GPS localization systems. GPS-enabled smartphones are typically accurate to within a 4.9 m (16 ft.) radius under open sky. High-end users boost GPS accuracy with dual-frequency receivers and/or augmentation systems. These can enable real-time positioning within a few centimeters, and long-term measurements at the millimeter level.[9]

What are some of the Disadvantages?

It requires Line-of-Sight (LoS) to the satellites. Thus, it neither works well in urban regions nor indoors. In addition, it drains the phone battery quickly when GPS is enabled.[22]

2.1.2 Wireless Fidelity (WiFi) Positioning System

The second category is a WiFi-based system that utilizes WiFi signals received from Access Points (APs).

How does it Work?

The most common and widespread localization technique used for positioning with wireless access points outdoor is based on measuring the intensity of the Received Signal Strength Indedicator (RSSI). Another technique is called fingerprinting. Location fingerprinting has two phases: 'training' and 'positioning'. The objective of the training phase is to build a fingerprint database. In order to generate the database, Reference Point (RP) must first be carefully selected. Generally, the data acquired are the Signal Strengths (SS) measured by the Mobile User (MU). Locating a MU at one RP, the received SSs of all the APs are measured. From such measurements the characteristic features of that RP are determined, and are then recorded in the database. This process is repeated at another RP, and so forth until all RPs are visited. In the positioning phase, the MU measures the SS at a place where it requires its position. The measurements are compared with the data in the database using an appropriate search/matching algorithm. The outcome is the likeliest location of the MU.[15]

What are some of the Advantages?

The advantage of this system is that it takes advantage of the widespread use of WiFi technologies and the existence of the WiFi receivers on most mobile phones.

What are some of the Disadvantages?

The weakness of this system is the lack of availability of WiFi AP outdoors.

2.1.3 Sensor Positioning

The third category relies on sensors deployed in smartphones, such as the compass, gyroscope, and accelerometer sensors.

How does it Work?

Motion sensors (accelerometers), rotation sensors (gyroscopes), and occasionally magnetic sensors (magnetometers) to continuously calculate by dead reckoning the position, the orientation, and the velocity (direction and speed of movement) of a moving object without the need for external references. With the development of technology, other methods can also be used for relative positioning. The speed of movement can be measured by number of rotations of the wheel (speedometer), Doppler spectrum of a received RF signal, the number of steps that a pedestrian walks (step counter), or similarities between the consecutive pictures taken by a camera.[30]

What are some of the Advantages?

This system category doesn't need extra equipment. This system category results in acceptable localization accuracy.

What are some of the Disadvantages?

The required sensors are not available in low-end phones. Besides, sensors with low cost are usually noisy and results in low accuracy in positioning.

2.1.4 Cellular Positioning Systems

The fourth system is a cellular-based localization system. There are plenty of localization systems that depend on cellular signals for both indoor and outdoor environments.

How does it work?

Fingerprint-based cellular localization techniques consist of two main phases: offline and online [12]. The basic idea of the offline phase is capturing the signatures representing cellular signals received from different Base Stations (BS) towers within the area of interest, and those signatures are called fingerprints. Later, during the online phase, the cellular signal received by the user is matched with the already pre-defined fingerprints. Finally, the best match will be used to locate the user.

What are some of the Advantages?

cellular localization capabilities shine well in populated areas where cell towers are more densely located. Cellular methods thrive in buildings, cities and densely-populated areas.[7]

What are some of the disadvantages?

The biggest disadvantage associated with cellular locating technology is geographical coverage. For subscribers in rural areas or people who travel away from home, cellular networks are not always a reliable ally.[7]

2.2 Increasing the Accuracy of the Localization

From the previous section we can see that the previously discussed technologies are not perfect, all of these technologies suffer from problems that can affect the accuracy of the localization. In this section we will discuss two different techniques that are used to increase the accuracy of localization.

2.2.1 The GloCal Method

Proposed in 2014 by (Wu, et. al)[28] this method works on decreasing the average error in the GPS positioning.

How Does It Work?

GloCal characterizes and exploits user mobility to attain local position information. Analogous to conventional dead reckoning techniques, GloCal leverages various sensors to infer user walking characteristics Specifically, GloCal uses accelerometer to identify user walking steps and gyroscope to estimate moving directions. Acceleration feature is further investigated to determine the accurate stride length of a specific user. The walking displacement is then derived by multiplying the step counts with the stride length. Provided that the displacement and direction are available, a user trajectory beyond the GPS is obtained namely a local coordinates. What the GloCal method does is that it applies coordinate transformation of the local coordinates to a global one. the GloCal method achieved 30% improvement on average error with respect to GPS.

2.2.2 The DeepFeat Method

Proposed in 2022 by (A.Mohamed et.al)[18] DeepFeat works on the mobile operator side, and it leverages many mobile network features and other metrics to achieve high localization accuracy.

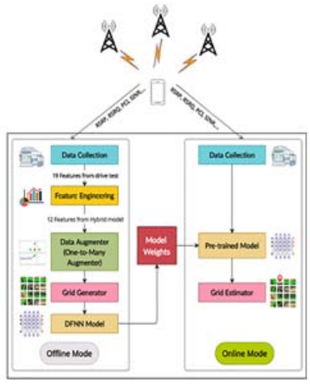

Figure 2.1: DeepFeat system architecture

How Does It Works?

Various Long-Term Evaluation (LTE) features are collected via intensive drive test in a large-scale area using the Data Collection module during the offline mode. The DeepFeat model includes a feature selection module, that differs from previously used selection modules. DeepFeat uses one-to-many data augmenter to extend the number of samples and reduce the noise impact. Finally, DeepFeat uses a Deep Feed-Forward Neural Network (DFNN) model, and the most influential collected features are used for training this model. During the online mode, the desired features are collected from the User Equipment (UE). Then, we use the weights of the trained model for the prediction. The mobile device location is then estimated using the trained model to predict the grid where the mobile device is located. using The DeepFeat Technique in small-scale area results in median accuracy of 13.179m. In comparison, the large-scale area results in median accuracy of 13.7m, which indicates that DeepFeat is a robust outdoor localization system even in a large-scale area.

Chapter 3

Indoor Localization

Localization within interior contexts such as supermarkets, airports, railway stations, and hospitals has become inevitable with the rise of the IoT. In grocery stores, customers can choose a cart equipped with a Personal Digial Assistant (PDA) screen equipped Radio Frequency Identification (RFID) tags; the cart's location is identified using a hybrid WiFi and RFID system; and once the customer wants to find the location of a product, they can browse through the PDA screen, and the directions to the target are provided[13]. Rather than handing out pamphlets to tourists at museums around the glob, roaming tourists may be managed by a Bluetooth and WiFi-enabled gadget. The gadget then directs visitors to a specific area of the gallery and provide information of an artefact.

Bluetooth beacons can lead students to the locations of books in libraries. The student might use a mobile device to access his position to the network and recommend him. The precision of the position is within meters, ensuring that the scholar is close to the relevant book shelf[10]. It is crucial in clinical institutions to supervise some patients' movements, primarily those suffering from mental impairments such as Alzheimer's; RFID technology can help with this[3]. RFID tags may also be implanted on various areas of the body, allowing patients who require home-healthcare to know if they are sitting, sleeping, walking, standing, or collapsing, which demands close monitoring and prompt response[24].

3.1 Localization Systems Technologies

3.1.1 Satellite-Based Navigation

The most widely used technology for outdoor localization is the GPS. It does, however, necessitate Line-of-Sight (LoS) between the satellites and the handset. As a consequence, primarily caused by external walls of the building, it has become ineffective for interior location-based service. The

GPS may be used as the front-end of an GPS receiver by utilizing a steerable, high gain directional antenna. Pseudolites (i.e., pseudo satellites) are deployed as independent localization systems in areas where GPS signals cannot be received; these systems are comprised of pseudolites, transmitter and receiver antennas, target receivers, and reference. The basic idea is to receive the GPS signal and rebroadcast it via indoor transmitters[29].

3.1.2 Inertial Navigation System (INS)

Inertial Measuring Units (IMU) such as accelerometers and gyroscopes are used in INSs to define the location and directional movement of an item to an initial location, velocity, and angle. INS is recognized by its precision and resource utilization given that the inertial sensor is mounted to the surface of the object. However, INS may become vulnerable to distortion, necessitating the use of specialized filtering systems such as the Kalman filter[11]. Another disadvantage of employing INS is the expense and effort required to build the location sensor's network infrastructure. A unique initial location estimation approach has been proposed in [4] by integrating current WiFi routers and iBeacons.

3.1.3 Magnetic Based Navigation

At low altitudes, magnetic-based technologies are used for localization. A magnetic sensor receives the radiated fields from at least three reference magnetic stations, and the sensor's placement is computed via trilateration. At low frequencies, this technique is accurate; nonetheless, it is sensitive to conductive and ferromagnetic materials. Magnetic-based navigation systems often rely on disruptions in the Earth's magnetic field within surroundings; these disturbances arise owing to the ferromagnetic nature of metal structures within buildings[23].

Magnetic maps are developed by measuring the magnetic magnetic field at known places; these maps can estimate the position of an unknown target based on its magnetic measurement. This method is known as magnetic fingerprinting. Magnetic interference, on the other hand, might be severe and produce localization issues. Using multiple handsets along the same routes may result in different magnetic readings being recorded. The authors of [14] investigated localization using deep learning; accuracy was determined to be $0.8m$ in corridors and $2.3m$ in the atrium. Cameras and magnetic fields are integrated with neural networks to improve localization when the phone is upright; their proposed techniques [16] achieved more than 91% percent accuracy increase of $1.34m$.

3.1.4 Radio Frequency (RF) Based Navigation

The most widely used techniques for localization are those based on radio frequencies. It is advocated since it covers a larger territory with low-cost gear. This is reinforced by the fact that RF waves can permeate solids such as walls and human bodies. RF-based navigation technologies outperform alternative localization techniques such as infrared and ultrasonic navigation systems. These systems, however, should be avoided in hospitals and aircraft since they may conflict with current RF systems.

Since the radio frequency is less than $300GHz$, wireless technologies employed for interior localization can be classified. At the same time, the frequency of wireless technology determines its capabilities such as coverage, wall penetration, and resistance to barriers. Thus, there are three primary categories of wireless technology for diverse applications: long-distance, medium-distance, and short-distance technology.

In a Wireless Sensor Network (WSN), node position information is critical for several functions such as routing, clustering, and context-based applications. WSN is described as a network of nodes that detect the environment's fields and wirelessly communicate the acquired data[21]. These details are sent to the sink node, which is used to gather data. In WSN, knowledge about the position of nodes is vital since observations lacking position information are pointless.

An examples of localization in WSN is demonstrated using RSSI based on the ZigBee standard[17]. WSN may employ both range-based and free-range for localization[19]. It is further classified as accurate (lateration, trilateration) and approximate. WiFi, Bluetooth, ZigBee, Ultra-Wideband (UWB), and Radio Frequency Identification (RFID) are a few examples of RF-based navigation systems.

WiFi Technology

Most large communal environments, such as colleges or business buildings, have already deployed WiFi hotspots that offer network access point coverage throughout the building. WiFi technology is used in a variety of devices, including personal computers, video game consoles, cellphones, digital cameras, tablet computers, and digital music players. That infrastructure cost may be quite minimal, and WiFi has expanded from a reception range of roughly $100m$ to about $1km$. Furthermore, WiFi localization based on fingerprinting RSS might be used in conjunction with other RF localization methods, such as RFID[27]. WiFi covers a larger area than Bluetooth and has a higher throughput, making it more practical to use. RADAR[2], HORUS[2], and COMPASS[2] are examples of commercial WiFi-based navigation systems.

ZigBee

ZigBee is an IEEE 802.15.4 standard-based specification. It operates in the 868MHz band in Europe, the 915MHz band in the United States and Australia, and the 2.4GHz spectrum in other locations. ZigBee is a wireless mesh network protocol that allows for long-distance communication between devices. When compared to WiFi standards, it has a low cost, a modest data transmission rate, and a short latency time. The RSS technique is used by the technology to quantify the distance between two or more ZigBee sensor devices[25]. The scanning of Access Point (AP)s via the WiFi interface consumes a lot of electricity. To mitigate this impact, the author in [20] proposed ZIL, an energy-efficient indoor localization utilizing ZigBee in which the ZigBee interface is utilized to gather WiFi signals.

Bluetooth

Bluetooth is created to encourage devices to communicate wirelessly across short distances. Bluetooth uses radio waves with frequencies ranging from 2.402GHz to 2.480GHz to communicate. If it has qualities such as low transmission power, battery life, secure and efficient communications, and an easily accessible solution. The new Bluetooth Low Energy (BLE) can cover a range of $70 - 100m$ and offer $24Mbps$ while using less power[31]. As a result, Bluetooth is unsuitable for large-area localization. Using the RSS trained Neural Networks (NN) trained in [1], and they may be used to detect user location based on online RSS measurements.

Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) systems rely on RFID tags' backscattering communication, as well as RFID readers and middleware to process the signal created between the tags and the readers[26]. RFID tags are classified as either active, passive, or semi-active. Active RFID tags have a built-in battery included within their electronics. Active RFIDs operate at Ultra-High Frequency (UHF) and Super High Frequency (SHF), with detection spans of 100m. Consequently, active RFID may be used for long-range localization and object tracking[5]. Active RFID technology, on the other hand, is unreliable for sub-meter localization precision and is not widely available on most portable user devices. Passive tags lack internal batteries and instead reflect the signal received from the base station. Passive RFID is widely utilized for a variety of applications owing to its multiple advantages, including low cost, reduced size, and ease of manufacture compared to active RFID, which requires only a tag chip and an antenna. Passive RFID is helpful for sub-meter detections and has a detection range of 10m[5].

Table 3.1: Localization Techniques Performance Overview

Technology	Technique	Method	Accuracy (m)	Cost	Coverage	Pros	Cons
Satellite	Trilateration	TOA TDOA	$3-5$		Floor level	Lower power consumption	
Inertial	Dead Reckoning	—	2	Low	Floor level	Cheap	Accumulative errors
Magnetic based	Trilateration	—	2	Low	Floor level	Cheap	Requires mapping
WiFi	Proximity Trilateration Angulation Fingerprinting RSS-Propagation Model	APID RSS TOA TDOA AOA	10 (proximity) $1-5$	Low	Floor level (around 35)	Good accuracy Low cost WiFi signal can penetrate walls No need for additional infrastructure	RF interface with devices operating at $2.4GHz$ Fingerprinting requires a huge effort
ZigBee	Proximity Trilateration Fingerprinting RSS-Propagation Model	APID RSS	$3-5$	Medium	Floor level	Low Cost Low power consumption	Requires special equipment
Bluetooth	Proximity Trilateration Fingerprinting	APID RSS TOA	$2-5$	Low-Medium	around 10	Good accuracy No need for additional infrastructure Low power consumption	RF interface Limited coverage and mobility
RFID	Proximity Trilateration Fingerprinting RSS-Propagation Model	APID RSS	$1-5$	Low	Room level	Cheap Realtime localization	Low accuracy Response time is high

Chapter 4

Conclusion

Indoor localization systems and wireless technologies were reviewed. This study attempts to provide a thorough understanding of localization techniques and technologies utilized in indoor contexts. The survey provides an overview of localization system technologies such as satellite navigation, inertial navigation systems, magnetic navigation, sound-based technologies, optical-based technologies, and radio frequency-based technologies. The paper also looks into approaches for detecting localization, such as proximity-based techniques, scene analysis, triangulations, and dead reckoning. Finally, the study discusses the most widely used localization techniques and approaches, such as Angel of Arrival (AOA), Time of Arrival (TOA), and Received Signal Strength (RSS). Choosing a localization method is influenced by a variety of criteria, including cost, available resources, environment type, and desired precision; the most powerful strategy is one that provides high accuracy with minimal processing.

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Acronyms

AOA Angel of Arrival . . . . I, 13

AP Access Point 11

APs Access Points 4

BLE Bluetooth Low Energy 11

BS Base Stations 5

DFNN Deep Feed-Forward Neural Network 7

GPS Global Positioning System 3, 4, 6, 8, 9

IMU Inertial Measuring Units 9

INS Inertial Navigation System 9

IoT Internet of Things . . . . I, 8

LoS Line-of-Sight 4, 8

LTE Long-Term Evaluation 7

MU Mobile User 4

NN Neural Networks 11

PDA Personal Digial Assistant 8

RF Radio Frequency 10

RFID Radio Frequency Identification 8, 10, 11

RP Reference Point 4

RSS Received Signal Strength . . . . I, 10, 11, 13

RSSI Received Signal Strength Indedicator 4, 10

SHF Super High Frequency 11

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