**Minimap Indoor Localization System**

**Technology Selection**

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Team North Star

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**Surveyed Solutions**

In this section, the team will explain four contending solutions for an indoor localization implementation, along with the results from similar projects and studies and associated advantages and disadvantages of each. The surveyed solutions are location trilateration methods using Wi-Fi Access Point Received Signal Strength Indication (RSSI), Wi-Fi Access Point Time-of-Flight (TOF), Bluetooth Low Energy 4.0 (BLE), and Ultrasonic Time-of-Flight (TOF).

**Wi-Fi Access Point Received Signal Strength Indication (RSSI) Trilateration and Fingerprinting**

A Wi-Fi capable device has the ability to detect available nearby Wi-Fi access points. Through this detection, the Service Set Identification (SSID) and Received Signal Strength Indication (RSSI) information can be gathered from all readable Wi-Fi access points within a given range. Given three or more accessible Wi-Fi access points with known positions, a Wi-Fi capable device would be able to use the signal strength values from these Wi-Fi access points and triangulate a position.

The main problem with this technique is that Wi-Fi signal strength does not linearly correlate to the distance between the source and the receiver. Furthermore, indoor environmental factors cause Wi-Fi access point signal propagation to be affected by reflection, refraction, and the multi-path propagation effect.

To overcome this, an RSSI map is created which describes the RSSI values from each access point. The RSSI values as received by the device is then matched against this map in a process called RSSI fingerprinting. The fingerprinting match results in an estimated location.

**Results**

The following is a table presenting various leading commercial and research-based Wi-Fi indoor localization systems as of April 2012 (Filonenko, et. al. 2012).

|  |  |  |
| --- | --- | --- |
| **System** | **Best Accuracy** | **Mobile Capable** |
| Skyhook (Wi-Fi) | 10 m | Yes |
| Navizon (Wi-Fi) | 20 m | Yes |
| Gaussian Processes for Signal Strength-Based Location Estimation (Ferris, 2006) | 2 m | Yes |
| Ekahau | 1 m | No |

**Advantages**

RSSI trilateration has a hardware requirement of four or more Wi-Fi access points for the project as described. RSSI is exposed in the Android Level 1 SDK and is thereby compatible with all versions of Android. Furthermore, all Android smartphones and tablets are Wi-Fi enabled.

**Disadvantages**

Pure RSSI trilateration is not accurate enough to meet the project requirements. Accuracy is improved using an RSSI fingerprinting technique, but requires the implementation of advanced techniques such as the Bayesian filtering of Gaussian processes likelihood models and fuzzy logic or machine learning techniques. Accuracy refinement calculations using these advanced techniques would require ample processing power and would not be able to run on mobile devices.

It is an additional concern that these refinement techniques will be difficult for the team to implement properly as the team members have limited experience within this field.

The creation and calibration of the RSSI fingerprinting map must occur in the same environment that the system is used. Additionally, RSSI is not exposed in the iOS SDK.

**802.11 Time-of-Flight (ToF) Trilateration and Fingerprinting**

By measuring the time required for an IEEE 802.11 MAC packet to travel between two WLAN nodes, the distance between the two devices can be derived as the time-of-flight linearly correlates to distance with the speed of light as the constant. Due to the short packet travel time, the clocks of the devices must be synchronized with nanosecond precision. Hardware configuration limitations make this a nontrivial task, such that a TOF fingerprinting technique similar to an RSSI fingerprinting technique might also be used (Koenig et. al. 2011).

**Results**

The following is a table presenting various leading research-based 802.11 TOF systems as of April 2012 (Filonenko, et. al. 2012).

|  |  |  |
| --- | --- | --- |
| **System** | **Best Accuracy** | **Smartphone Capable** |
| Goodtry | 4 m | No |
| Multipath Mitigation for Indoor Localization Based on IEEE 802.11 Time-of-Flight Measurements | 0.7\* m | No |

*\* within a static, controlled environment*

Direct control of the WLAN card in an Android smartphone is limited in the SDK and has been proven difficult to configure for time synchronization. Muthukrishnan et. al. presented a failure to configure clock synchronization beyond a millisecond level (corresponding to 300 m accuracy) for various 802.11 network cards using the Network Time Protocol (NTP), time measurement at the network layer (TCP/IP) level, time measurement at the data link layer level, and time measurement at the firmware level.

On the other hand, Hoene and Willmann (Goodtry) successfully developed an open-source tool that overcomes the clock resolution and control constraints of 802.11 cards to implement a time-of-arrival trilateration system capable of four meter accuracy. Hoene and Willmann accomplished this on PC devices running a GNU/Linux operating system. Koenig et. al. was able to achieve 0.7 m accuracy in a static, controlled environment using Linksys WRT54GL v1.1 access points and an Asus EEE-PC 902go Netbook running Ubuntu 10.10.

Successful time-of-flight implementations have used a PC running a Linux operating system, but there are no known successful implementations running on an Android device.

**Advantages**

The time-of-flight linearly correlates to the distance between the source and the receiver. The processing power required for time-of-flight trilateration should be minimal enough to be computable on a handheld device (if not using a TOF fingerprinting technique).

**Disadvantages**

The clock synchronization precision required to achieve accurate results within an indoor location is not achievable on unmodified Android devices.

Achieving such precision in clock synchronization has proven difficult even for teams with the necessary computer and/or electrical engineering backgrounds to configure IEEE 802.11 cards at the firmware levels.

**Bluetooth Connectivity and Received Signal Strength Indication (RSSI) Trilateration and Fingerprinting**

Given a space consisting of evenly distributed Bluetooth beacons, the location of a Bluetooth-enabled device can be determined based upon which Bluetooth beacons are within connectivity range. The accuracy of the device position depends upon the range of the Bluetooth beacons and the number of Bluetooth beacons.

Increasing the number of Bluetooth beacons to gain sub-meter resolution based on pure connectivity would require too many Bluetooth beacons. However, received signal strength can also be measured to provide a stronger estimation. In addition, the same aforementioned Wi-Fi RSSI fingerprinting techniques can be applied to Bluetooth RSSI to achieve an even higher level of precision (Zhang et. al., 2013). Therefore, high accuracy can be attained through a balance between the number of Bluetooth beacons and the number of advanced fingerprinting techniques applied.

**Results**

The following is a table presenting various leading commercial and research-based Bluetooth indoor localization systems as of April 2012 (Filonenko, et. al. 2012).

|  |  |  |
| --- | --- | --- |
| **System** | **Best Accuracy** | **Smartphone Capable** |
| Bluetooth Direction of Arrival | 72 cm | No |
| Nokia High Accuracy Indoor Positioning System | 20 cm | Not yet |
| A Comprehensive Study of Bluetooth Fingerprinting-Based Algorithms for Localization (Zhang et. al., 2013) | < 1 m | No |

**Advantages**

Bluetooth beacons are small and less expensive as Wi-Fi access points, thereby allowing them to be placed within the space of operation. This allows the areas for the highest precision (areas closest to the signal sources) to be in the space of operation as opposed to on the boundaries. The level of precision can be adjusted by the range of the Bluetooth beacons used and the number of Bluetooth beacons used. The also allows the system to be scaled up or down without a loss of precision.

Bluetooth trilateration is very simple to implement and would ensure an early working prototype. Bluetooth fingerprinting can also be added to Bluetooth trilateration, whereas Wi-Fi fingerprinting would typically replace Wi-Fi trilateration. This is because Wi-Fi trilateration is based off of RSSI only and cannot ensure an accurate location due to the multi-path effect, whereas Bluetooth localization based off of connectivity does ensure an accurate location and Bluetooth fingerprinting can only improve the precision.

Bluetooth 4.0 features very fast connectivity latency. Bluetooth 4.0 connectivity can be established within several milliseconds (Bluetooth, 2009).

Bluetooth is common in iOS and Android devices and is exposed in both the iOS and Android SDKs, allowing for a cross-platform solution.

**Disadvantages**

Bluetooth beacons have a shorter range than Wi-Fi access points and therefore more are required to ensure a location calculation for every location within the space of operation.

Bluetooth beacons on the market are based off of Bluetooth 4.0 and Bluetooth Low Energy (BLE) which are new specifications. This will required recently released iOS or Android devices.

The only disadvantage for the Bluetooth connectivity, trilateration, and fingerprinting solutions is the required budget. However, the number of Bluetooth beacons required can be reduced with a minimal loss of precision by applying fingerprinting techniques.

**Ultrasonic Trilateration**

Ultrasonic trilateration involves the propagation of sound waves with a frequency greater than 20 kHZ between multiple sources and/or receivers in order the use the differences in the time of arrival to determine the distance between the sources and receivers and thereby locating the device. Ultrasonic trilateration has successfully been demonstrated using mobile devices as both the source and the receiver. Using the former technique, four microphones at the corners of the space of operation receive the ultrasonic wave emission from a mobile device. A central server connected to each of the microphones records the time of arrival. Using the latter technique, four speakers at the corners of the space of operation emit ultrasonic waves and the mobile device records the time of arrival of each chirp.

The smartphone-as-a-source technique would be difficult to scale to both large rooms and multiple concurrent users. The smartphone would require a speaker powerful enough to emit sound across a room. With multiple smartphones attempting location concurrently, cooperative synchronization and unique signal patterns would be required in order to ensure that each signal was received without interference from another signal.

The smartphone-as-a-receiver technique requires precise time synchronization between the smartphone and the speakers. Such time synchronization does not need to meet the level of precision required for 802.11 ToF trilateration, but should still be accurate within microseconds. This technique also requires advanced signal processing in order to determine the time of arrival for each ultrasonic wave, due to the fact that the signals are not guaranteed to arrive independent of each other unless additional cooperative synchronization is established.

**Results**

The following is a table presenting various leading research-based Ultrasonic trilateration systems as of April 2012 (Filonenko, et. al. 2012).

|  |  |  |
| --- | --- | --- |
| **System** | **Best Accuracy** | **Smartphone Capable** |
| The Bat | 3 cm | No |
| The Cricket | 3 cm | No |
| Lok8 (Filonenko, et. al. 2012) | < 1 m | Yes |

**Advantages**

Ultrasonic ToF trilateration shares the advantage of a linear correlation between time-of-flight and distance with 802.11 ToF trilateration, but does not require such a high level of clock synchronization precision due to the fact that sound waves slower than electromagnetic waves.

The emission and reception of ultrasonic waves can be performed by most iOS and Android devices. These features are also possible to implement through both the iOS and Android SDKs.

**Disadvantages**

Ultrasonic ToF trilateration requires time synchronization with devices that do not have built in timing features, i.e. microphones and speakers. Furthermore, this time synchronization would require microsecond-level precision for accurate results. Advanced signal processing or cooperative synchronization would be required as more location-requesting devices are added to the system. A custom method must be created in order to identify the source and/or receiver, as opposed to using a Wi-Fi access point SSID or Bluetooth device ID.

Ultrasonic ToF trilateration requires powerful speakers or high-quality microphones in order to be operable in the specified space, which would increase the required hardware cost higher than any other proposed solution. The speakers/microphones on the perimeter of the space of operation would need to be either all wired to a central computer and wired to individual computers. The amount of wires required for the former solution adds to the required budget as well as the amount of initial setup required to install the system.

Furthermore, other research teams expressed health concerns over the prolonged exposure of humans to constant ultrasonic noise.

**Other Considered Solutions**

**Near-Field Communication (NFC)**

NFC has a maximum working range of fewer than twenty centimeters which would not make it a viable candidate for indoor localization.

**Radio-Frequency Identification (RFID)**

RFID passive and active tags within the 902-928 MHz frequency range have a maximum working range of twelve meters. As RFID readers are not built into smartphones, an RFID reader would have to be purchased for each device in use (around $200 each), making an RFID solution the most expensive solution proposed.

**Comparison of Solutions**

The following is a table of the surveyed solutions and a team-assigned rating of each solution on a ten-point scale in terms of accuracy, hardware cost, and ease of implementation.

[ 1 = worst ; 10 = best ]

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| System | Accuracy Rating | Hardware Cost | Ease of Implementation | Overall Score |
| Wi-Fi RSSI Trilateration | 1 | 9 | 8 | 5.1 |
| Wi-Fi RSSI Fingerprinting | 3 | 9 | 5 | 5.5 |
| 802.11 ToF Trilateration | 4 | 8 | 2 | 4.8 |
| 802.11 ToF Fingerprinting | 5 | 8 | 1 | 5.1 |
| **Bluetooth 4.0 Connectivity** | **9** | **1** | **10** | **7.3** |
| **Bluetooth 4.0 Trilateration** | **8** | **5** | **9** | **7.5** |
| **Bluetooth 4.0**  **Fingerprinting** | **8** | **5** | **5** | **6.5** |
| Ultrasonic Trilateration | 10 | 1 | 2 | 5.7 |

**Selection of Technology Solution**

After reviewing possible indoor localization solutions, the team has determined that the best solution to implement is a Bluetooth-based trilateration and fingerprinting system.

**Selection Justification**

A Bluetooth-based system has the advantages of higher accuracy, better scalability, and a lesser difficulty of implementation. Bluetooth beacons have an indoor range comparable to that of Wi-Fi routers, but with much lower latency and at a competitive cost; a Wi-Fi-based solutions rated favorably in terms of hardware cost solely because the team has been already provided with Wi-Fi access points.

Bluetooth is designed to work and communicate with mobile devices, allowing the team to potentially create a cross-platform solution that works for both iOS and Android devices. Bluetooth support is built directly into both the iOS 7 and Android 4.3 SDKs along with numerous usage examples and documentation.

The work necessary to implement a Bluetooth-based system is well-understood by the team. The team has the needed expertise to successfully implement a working Bluetooth-enabled trilateration system. Furthermore, this will allow the team to focus more time on exploring more advanced techniques, such as fingerprinting.

**Bluetooth System Specification**

**Bluetooth Beacons (Initial Survey)**

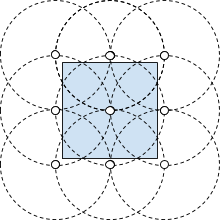
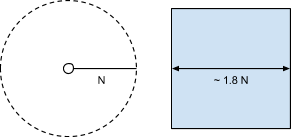
|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Maximum Range** | **Unit Price** | **Website** |
| Stick-’n’-Find | 30 m | $20 ($390 for 20) | [https://sticknfind.com](https://www.sticknfind.com/default.aspx) |
| Estimote | 50 m | $33 ($99 for 3) | <http://estimote.com> |
| Tod | 100 m | $38 ($380 for 10) | <http://todhq.com> |
| Roximity | ? | $10 / month (or inquiry) | <http://buyibeacons.com/> |
| Adomaly | ? | By inquiry | <https://adomaly.com/> |

It is important to note that accuracy will change inversely-proportionally with each beacon’s maximum range.

**System Example**

This is an example setup for explanation purposes only.

Using a system of nine beacon beacons with a range of N meters, a square space in which at least three beacons are in range can be created, measuring at roughly 1.8 N in length.

Using the estimated maximum range of candidate Bluetooth beacons, nine Estimote beacons could cover a 90 X 90 m to 126 X 126 m square. Nine Tod beacons could cover a 180 X 180 m square. Other configurations are possible and other Bluetooth beacons may be considered.

Compare this to a Wi-Fi-based solution which would have a similar setup based on the range of the Wi-Fi access points used. In contrast with Wi-Fi access points, Bluetooth beacons are small and can be unobtrusively positioned within the interior of the operational space.

**Android 4.3 SDK**

The received signal strength indication (RSSI) of Bluetooth Low Energy (BLE) devices can be read in the Android 4.3 SDK by using the BluetoothAdapter.LeScanCallback() function which provides the RSSI of BLE devices within range.

**iOS 7 SDK**

The received signal strength indication (RSSI) of Bluetooth Low Energy (BLE) devices can be read in the iOS 7.0 SDK by using the following delegate method from CBCentralManger:

- (void)centralManager:(CBCentralManager \*)central

didDiscoverPeripheral:(CBPeripheral \*)peripheral

advertisementData:(NSDictionary \*)advertisementData

RSSI:(NSNumber \*)RSSI {

}

**Conclusion**

Bluetooth 4.0 and Bluetooth Low Energy (BLE) is emerging as the best solution for indoor localization. With the introduction of iBeacons into the iOS 7 SDK by Apple, and BLE support in the Android 4.3 SDK by Google, the penetration of Bluetooth into the consumer-facing indoor localization market is taking shape.

As an open-source project, this project may help shape the future of indoor localization rather than replicate what others have already accomplished.

For this reason and all of the aforementioned reasons, the team has selected a Bluetooth-based system to achieve indoor localization.

**References**

Bluetooth, S. I. G. "Bluetooth specification version 4.0." *Bluetooth SIG Standard* (2009).

Ferris, Brian, Dirk Hähnel, and Dieter Fox. "Gaussian processes for signal strength-based location estimation." *In Proc. of Robotics Science and Systems*. 2006.

Filonenko, Viacheslav, Charlie Cullen, and James D. Carswell. "Asynchronous ultrasonic trilateration for indoor positioning of mobile phones." *Web and Wireless Geographical Information Systems*. Springer Berlin Heidelberg, 2012. 33-46.

Hoene, Christian, and Jörg Willmann. "Four-way TOA and software-based trilateration of IEEE 802.11 devices." *Personal, Indoor and Mobile Radio Communications, 2008. PIMRC 2008. IEEE 19th International Symposium on*. IEEE, 2008.

Koenig, Stefan, Mark T. Schmidt, and Christian Hoene. "Multipath mitigation for indoor localization based on IEEE 802.11 time-of-flight measurements."*World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2011 IEEE International Symposium on a*. IEEE, 2011.

Zhang, Li, et al. "A Comprehensive Study of Bluetooth Fingerprinting-Based Algorithms for Localization." *Advanced Information Networking and Applications Workshops (WAINA), 2013 27th International Conference on*. IEEE, 2013.