WhereAReYou? An Offline Bluetooth Positioning Mobile Application

SPCL-2013 Project Report

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ABSTRACT

The increasing use of social media and the integration of location services to this services suggests that users like to know the location of others while interacting with them. However, if the user has no Internet connection this interaction is not possible. This paper presents WhereAReYou?, an offline Bluetooth positioning mobile application that predicts the relative location of mobile devices in the surroundings without an Internet connection. Unlike existing positioning systems, by using Bluetooth and simple movements from the user we are able to reduce the infrastructure to only two paired mobile devices while staying offline. A quantitative evaluation of the project shows an accuracy for the cardinal direction of 100% on the outside and less than 50% on the inside. The same evaluation shows a low accuracy of the distance between devices, in both scenarios, with a difference of up to 6 meters. A qualitative evaluation for this project shows that the users are in general satisfied with the predicted relative position given by the application.

INTRODUCTION

The increasing use of social media in the last years shows the importance for people to stay in touch with each other. The integration of location services to social media applications, like Facebook or Twitter, suggests that people also like to know the location of others while interacting with them. However, without an Internet connection this interaction is not possible. The existing applications use either the Internet, location technologies like GPS, centralized servers to store known positions of beacons and devices or a combination of the previous in order to calculate the position of a mobile device in the room. If any of the resources are removed from the infrastructure these systems will not work correctly.

This paper presents WhereAReYou? an offline Bluetooth positioning mobile application that calculates the relative location of paired mobile devices in the surroundings without the need for centralized servers or an Internet connection. Using the RSSI values provided by Bluetooth and the Multibreakpoint Path Loss Model [10] we predict the distance between devices and with simple physical movements from the user we can also predict the cardinal direction of the paired mobile device. Putting these two values together we can present the relative position of the paired mobile device to the user, as seen in the next picture.

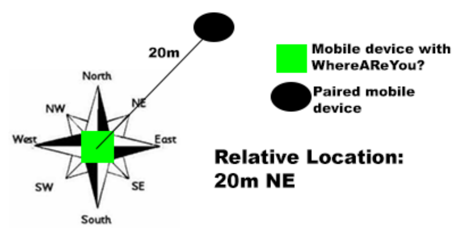

Figure 1. Relative location between a device with WhereAReYou? and a paired mobile device.

The results of the application are evaluated in two ways. The first is a quantitative evaluation applied in two environments, indoors and outdoors. This evaluation shows that the accuracy of the application is greater on the outdoors than indoors, and also shows that the predicted distance could be more accurate. The seconds is a qualitative evaluation where five subjects where interviewed about the predicted relative position of the paired mobile device. This evaluation shows that the subjects where in general satisfied with the predicted relative position of the paired mobile device.

The rest of the project has seven sections. The Research Method section explains the methodology for this project. The Related Work section presents examples of existing systems to locate mobile devices. The Background section explains the different approaches taken to locate mobile devices in this project. The WhereAReYou section gives the final design and the Discussion section discusses the final approach. The Evaluation section presents the qualitative and quantitative evaluation and its results. Finally the future work is presented.

RESEARCH METHOD

This project followed an iterative design with two iterations.

First iteration. It focused on developing a fast prototype to evaluate the reaction of the users. When the prototype was finished a questionnaire was applied to five subjects. This questionnaire consists of two parts. The first part has 5 questions regarding the need of the users for an application like WhereAReYou. The second part consists of a scenario

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where the subject had to find a friend in party they were at, but lost each other. For this part the subject was asked to use the prototype and after using it three more questions where asked.

Second iteration. It focused on developing a proof-of-concept prototype of the application with the knowledge acquired from the first iteration. Towards the end of the second iteration, when the proof-of-concept prototype was ready, the results where evaluated with a qualitative and a quantitative evaluation. The quantitative evaluation consists of testing the application in the outdoors and indoors. The qualitative evaluation consists of a similar scenario to the one in the first iteration with three questions regarding the general thoughts from the subject, the accuracy of the application and the acceptable margin of error for the relative location.

RELATED WORK

In this section examples of existing systems and application to locate people are presented.

RADAR. Radar[2] is an in-building radio-frequency system to locate and track users inside building. It gathers the RSS from a device at multiple receivers with known locations and triangulates the user's coordinates. It relies on data collection from the received signal strengths in the multiple receivers, so this has to be done before the system can work properly.

Cricket Compass. This paper[5] presents a systems that uses RF and ultrasound signals to calculate the position of devices in the room. It combines RSSI and Angle of Arrival (AoA) calculated by multiple transceivers in a ”V” shape in the mobile device. It uses beacons in the ceiling and the Cricket Compass is attached to a mobile device in order to determine its position.

Tracking the Location of a Mobile Node in Wireless Sensor Network. This paper[1] presents a way to track the location of mobile nodes in a wireless sensor network by placing sensor nodes in known locations either by having known coordinates or by using GPS. By using mathematical formulas like Heron's Formula and the Signal Propagation Model the mobile nodes calculate their own positions with received location references from the static nodes.

Positioning with Bluetooth. This paper[3] presents two main methods to position a device using bluetooth, the direct and indirect method. With the direct method the device must be programmed and it can operate standalone. The client asks the device for a positioning service and proceeds to ask for its position. If the device has no positioning service it proceeds to the indirect method where the client will look for the device in the location server with its unique address and retrieve its position.

WLocator. This paper[6] presents a systems based on WiFi for indoor positioning. It is able to support other detectable signals like Bluetooth and RFID tags to improve accuracy, although only devices that are considered to be static are used. This system maps fingerprints of RSSI's at given locations to known locations or landmarks, like ”TV room”.

FriendFinder AR. FriendFinder AR[7] is an Android Application to locate friends from the contact list in your mobile device. It uses GPS to determine the location of the mobile device and then it is shared temporarily with the people you desire. The location is used to display the people in either a map or an AR view.

Wikitude. Wikitude[8] is a Mobile AR Browser that integrates with social media networks like Twitter and Facebook and displays it in an AR view. The social networks store the geolocation at the time of the user interaction with it and Wikitude retrieves that geolocation to use it as an input to the user's screen. This geolocation is obtained by GPS.

Whether it is for locating people or pointing out landmarks, all of these positioning systems rely either on connection to the Internet, GPS, a central server or different nodes with a known location, as seen in the next picture, which is the main difference between these and our system.

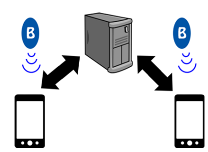

Figure 2. Other positioning systems

WhereAReYou? does not rely on infrastructure other than two paired mobile devices, one of them with the application installed. With Bluetooth and simple physical movements from the user, we can determine the relative position of the paired mobile device to present to the user, all of these without and Internet connection or centralized servers.

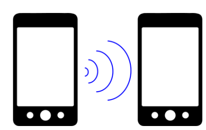

Figure 3. WhereAReYou?

BACKGROUND

In this section we present the background of the project and the decisions made along the way. Since the beginning the main idea of this project was to develop an Android application that allows the users to locate people in the surroundings when having an Internet connection is not possible. With this idea in mind we faced three important challenges. The first regarding a way to predict the cardinal direction of the paired mobile device, the second was the technologies to predict the distance between devices and the third was the presentation of the data.

Predicting cardinal direction

To find a way to predict the paired mobile device cardinal direction we evaluated two methods. The first method involves the user acting as a shield for the RSSI readings by placing the device in the chest area and turning around. The second method also involves the user turning around but this time taking a step forward at different cardinal directions. After evaluating both methods we decided to implement the first method since it provided a better accuracy than the second method.

Predicting the distance

For the prediction of distance between devices the determining factor is that this application is intended to be used without an Internet connection and this lead us to explore peer to peer short range radio technologies. The first choice was Wi-Fi Direct but we quickly came to realize that the RSSI measurement for the Android Wi-Fi Direct API is not available. This made us turn to Bluetooth and leave Wi-Fi Direct for future development of the application, like the exchange of information to complement the Bluetooth RSSI readings. After the decision of making Bluetooth the main technology, we started to look for the best way to predict distance between devices using the RSSI readings and the method we decided for is the application of the Simple Path Loss formula. When testing this formula in a controlled scenario we came to realize that the RSSI readings vary a lot so we decided to apply a Mean Filter[11] to smooth the readings and have better data to work with. For this filter a weighted average with a sliding window of 7 was used.

Presentation of results

For the presentation of the data the first thing the challenge was to do it in a way that it was easy and natural for the user to understand. After evaluating different approaches like using the vibrations and sound of the phone, we decided for Augmented Reality through the integrated camera in the user's phone. We thought this was the perfect choice to present the calculated data to the user because we could do it in an easy, natural and intuitive way. By integrating Augmented reality to the process of the calculation we can control the user's movements. It also makes the process of the calculation more interactive and help the user to not feel lost during it. There are several tools for developing using Augmented Reality and the one that we decided fitted the best with this project is the MetaioSDK[9]. The main reasons for this decision are the support it provides to developers, the documentation of the SDK and that the scope for this SDK is wide and very open.

WHEREAREYOU

This section focuses on a more detailed explanation of the design as well as the contributions of WhereAReYou?. First we address the flow of the application, then the process of predicting the distance and finally the process of predicting the cardinal direction.

Flow of application

The complete flow of the application is as follows. First, the user has to select if the the environment is indoors or outdoors, then the user has to select a nearby paired mobile device from a list in the initial screen. After the mobile device is selected the augmented reality view is shown. In this view the user is asked to look for and click on eight red crosses, one at a time, which are displayed at different cardinal directions starting at north and ending at north-west in a clockwise motion as seen in figure 4.

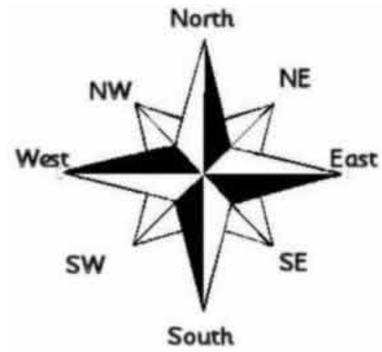

Figure 4. RSSI readings are taken in this cardinal directions

This method was selected because of the way the Bluetooth RSSI readings are obtained, this procedure has to be very restricted and controlled. When clicking on a cross the user is asked to stand still and wait for the next cross to appear. When the time comes to turn, the phone vibrates. Every time the user clicks on a cross the application stores the necessary RSSI readings from the selected paired mobile device at the present cardinal direction. After taking readings at all eight cardinal directions the distance and cardinal direction of the paired mobile device are predicted and presented to the user through the augmented reality view.

Distance

Once all the readings at all the different cardinal directions are taken the application proceeds to do to apply two times the same mean filter. Applying the mean filter only one time would still give results with low accuracy when predicting the distance between devices so after the second mean filter the results are more accurate without loosing the important data produced by the user when turning around, as seen in figure 5.

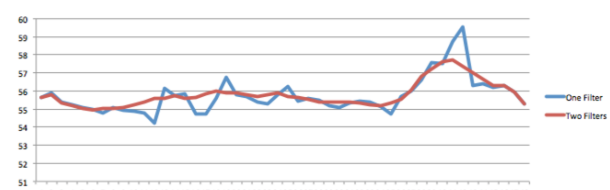

Figure 5. Comparison between applying fitter 2 times (red line) and 1 time (blue line)

After the mean filters are applied the application proceeds to do an average of the RSSI readings at each cardinal direction. With these averaged values the distance between devices is predicted using the Simple Path loss equation:
$DBm_i = DBm_0 + 10n * Log10(d_i/d_0)$
Where DBm_i is the RSSI in DBm, $DBm_0 = 55$ is the initial RSSI reading at initial distance $d_0 = 1$, d_i is the distance for the present reading and n is the Path Loss Exponent. The value for n depends on the environment the user is present in, $n = 2.0$ for outdoors and $n = 2.3$ for indoors.

Cardinal direction

The way we predict the cardinal direction of the paired mobile device is fairly simple, we simply take the highest RSSI values from the filtered list and its direction and the same is done with the lowest RSSI value of the filtered list. Because of the body acting as a natural shield [4] between devices making the signal strength to drop, the RSSI values would increase when the user is blocking the signal with the body and the lowest RSSI value would be when the mobile devices are in facing each other, this can be seen in the last picture. To complement this prediction, if the direction of the highest averaged value is not the complete opposite to the one from the lowest averaged value the user is notified that the cardinal direction of the paired mobile device may not be completely accurate. Finally, the predictions of distance and cardinal direction are presented to the user with a 3D Model rendered in screen.

As seen with the previous explanation of the whole process, with the selected methods to predict the relative position of the paired mobile device this application relies on the user. This also suggests that it does not matter if there are things blocking the line of sight between the devices as long as it remains constant. With WhereAReYou? the infrastructure for positioning devices is dropped from using central servers, using beacons and using communication technologies like Internet, to using 2 paired mobile devices with Bluetooth. The user does not have to be online and it does not matter if the paired mobile device has the application installed, the only requirement is that the devices need to be paired, and naturally in the same location.

EVALUATION & RESULTS

In this section we present results for the quantitative and qualitative evaluation of the application.

Quantitative Evaluation

This evaluation helped to determine the accuracy of the predicted values: cardinal direction and distance. This evaluation was done in two controlled open environments, one indoors and one outdoors. First we address the indoor evaluation, then the outdoor evaluation and at the end we address the duration time of the prediction process.

Indoors. The evaluation indoors was done in the first floor of the IT University of Copenhagen. The application was used 5 times at different distances and the paired mobile device was always heading north of the user.

Test #	Real orientation	Calculated Orientation	Real distance	Calculated Distance	Running time (mins)
1	West	Northwest	10	3.880	9
2	North	North	10	6.812	8
3	North	Northeast	15	5.332	10
4	North	North	20	8.745	9
5	North	Northwest	20	12.031	8

Figure 6. Indoors. Table of results before modifying parameters for predicting distance

As seen in figure 6, less than 50% of the times the predicted cardinal direction given by the application was accurate. The times the application was not entirely accurate it missed by one cardinal direction (Real direction: north-west, calculated: north). Also in figure 6, the calculated distance between devices is not accurate most of the times. After seeing this results we determined that the inaccurate predictions regarding the cardinal direction were caused by the environment, metal most of the time. We also determined that the same factors applied to the predicted distance, but we were not in peace with this results so we decided to modify the parameters used for predicting the distance.

Test #	Real orientation	Calculated Orientation	Real distance	Calculated Distance	Running time (mins)
1	W	NW	5	5.37	6
2	N	N	10	8.12	6
3	N	NE	20	19.95	7
4	N	NW	25	22.50	6

Figure 7. Indoors. Table of results after modifying parameters for predicting distance

Figure 7 shows the same type of behavior when predicting the cardinal direction but we also can see a big difference in the predicted distance. This results show a better accuracy and we are satisfied with them.

Outdoors. The evaluation outdoors was done in the surroundings of the IT University of Copenhagen. The application was also used 5 times at different distances and the paired mobile devices was placed in different cardinal directions.

Test #	Real orientation	Calculated Orientation	Real distance	Calculated Distance	Running time (mins)
1	Southwest	Southwest	5	4.822	8
2	Northeast	Northeast	5	7.582	9
3	North	North	10	29.054	8
4	Northwest	Northwest	10	20.077	8
3	S	S	8	10.124	5

Figure 8. Outdoors. Table of results before modifying parameters for predicting distance

As seen in figure 8, the application predicts with a 100% accuracy the cardinal direction of the paired mobile device. But when it comes to the predicted distance we see the same results as with the indoors evaluation so we decided to do the same thing, go back and modify the parameters used for predicting the distance.

Test #	Real orientation	Calculated Orientation	Real distance	Calculated Distance	Running time (mins)
1	SW	SW	5	3.98	5
2	SW	SW	10	11.22	6
3	SW	SW	15	15.85	6
4	SW	SW	20	17.78	7
5	SW	SW	25	19.95	6

Figure 9. Outdoors. Table of results after modifying parameters for predicting distance

Figure 9 shows that the application still gives a 100% accuracy when predicting the cardinal direction of the paired mobile device, but it also shows a big improvement when predicting the distance between devices. This results, as with the indoors evaluation, show a better accuracy and we are also satisfied with them.

Duration of process. Since we started testing the application we noticed that the duration time of the predicting process took too long. We anticipated that the users would give a bad review over this and it may have resulted in a discontent attitude towards the application. To address this we review the design of the application and found that we were taking extra unnecessary RSSI readings at each cardinal direction. Because of this we lowered the amount of readings resulting in a drop in the duration time of 2 minutes in average as seen in figures 6 and 8.

From these results we can determine that the application can still have a better set up for indoor environments when predicting the cardinal orientation of the paired mobile device. And in greater need, the application needs a better approach for predicting the distance between devices.

Qualitative Evaluation

This evaluation helped to determine the acceptance of the application by potential users. It consists of a questionnaire applied to 10 subjects in a resembling environment where potential users would use the application, only smaller, a gathering of friends in an apartment of about 45 squared meters.

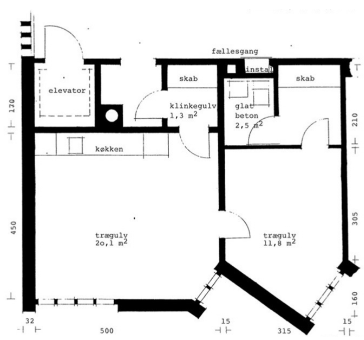

Figure 10. Apartment for qualitative evaluation

The subjects positioned themselves at any part of the room they wanted and the paired mobile device was positioned in other place. After using the application the subjects where asked the following questions:

1. In a scale of 1 to 5, 1 being the worst and 5 the best, What do you think about the application?
2. In a scale of 1 to 5, 1 being the worst and 5 the best, How accurate was the application?
3. First in meters then in cardinal points, What would be the accepted margin of error for the application?

With the first question the subjects where asked to rate the application. With a satisfying result for us, the averaged result for this questions was 3.9. For the second question the subjects where shown the real location of the paired mobile device and then they where asked to rate the accuracy of the prediction. With a bad result, the averaged result for this question was 2.3. For the third question the subjects where asked about the acceptable margin of error. Before they answered, they where shown picture 4 and explained that this are the only cardinal points the application can predict the paired mobile device being at and if the real location of the paired device is North, then NW or NE would be 1 point, W or E would be 2 points and so on. The averaged result for the acceptable margin of error regarding meters was 10.11 and the averaged result regarding cardinal direction was 1 point. It is important to mention that all the predictions made by the application during this test failed by 1 cardinal point and after the subjects where shown picture 4 and explained the limitations of the application they where asked in an informal way if they would change their answer for question number two and the majority answered positive with a higher number. Also in an informal way, they where asked to give their general thoughts about the application, leaving aside the accuracy, and the results can be seen in the Appendix with the complete results for this evaluation.

DISCUSSION & FUTURE WORK

In this section we discuss the technical challenges, limitations of WhereAReYou? and future work.

Bluetooth

The RSSI readings from paired devices vary with an enormous difference. Without some kind of filter or smoothing applied to the RSSI readings, working with the data would be pointless. As the data is inconsistent, the results would be inconsistent too. And even when applying the filter the results may vary because of the surrounding environment. Basically, if metal is present around the devices the accuracy of the readings drops dramatically.

Another drawback from Bluetooth is the time it takes to get the RSSI from a device. It is not certain, thus a lot of time can be spent just by trying to get one reading when multiple readings are needed to make an accurate relative position calculation.

Android & Bluetooth

One major drawback of the Android Bluetooth API is that the RSSI can only be read when a device is found and not when two devices are connected, in other words in the discovery process. This causes a battery drain since the application is constantly looking for devices and this action is the one that requires the most battery when using Bluetooth. The previous drawback also imposes another limitation. Same as the device using the application, the paired mobile device also has to be in discovery mode. This does not causes that much of a drain of battery in the device but the fact that the device is visible to all nearby devices can turn out to be a security threat or cause an unpleasant situation for the user.

Future work

As seen in the evaluation section, the calculated distance between devices is not very accurate and this needs to be addressed for a future version of WhereAReYou?. To increase the accuracy of the calculated cardinal orientation, instead of having eight reading directions more readings directions can be added, but this would increase significantly the time of use and this can result in changes to the method of getting the RSSI readings at every direction or decreasing the number of readings at every direction possibly causing the accuracy of the distance to drop even lower. Another next step for this project could be implementing a small protocol for communication between devices in the surroundings through Wi-Fi Direct where the location of other devices the user can not see are shared. Another important implementation for the future is the modification of the models displayed in the augmented reality view. The used graphics are generic from the MetaioSDK and they may not be pleasant for the users.

CONCLUSION

In this paper we presented WhereAReYou? an Offline Bluetooth Positioning Mobile Application that helps users locate paired mobile devices in the surroundings without an Internet connection. By using the signal strength provided by Bluetooth and simple movements from the user, we are able to determine the relative position of a mobile device. Because of its easiness, intuitiveness and natural feel for the user, the predicted position of the paired mobile device is rendered in an augmented reality view using the MetaioSDK. With promising results, we presented the quantitative and qualitative evaluation of the application. The quantitative evaluation applied to the predicted relative position of the paired mobile device, showing that the predicted cardinal direction being accurate and the distance not accurate. And the qualitative evaluation regarding what the subjects thought about WhereAReYou, showing that the users are in general satisfied with the predicted relative position of the paired mobile device.

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APPENDIX

Complete results for Qualitative Evaluation

Subject	What do you think about the application?	How accurate was the location given by the application?	What would be the acceptable margin of error for the cardinal direction? (In points)	What would be the acceptable margin of error for the distance?
1	4	2	2	10m
2	4	2	1	20%
3	4	3	1	5m
4	5	1	1	6m
5	5	3	1	10m
6	4	2	0	5m
7	2	2	1	30m
8	4	2	1	10m
9	4	3	1	5m
10	3	3	1	10m
AVG	3.9	2.3	1	10.11

Figure 11. Results for qualitative evaluation

General Thoughts:

1. I would recommend it if it worked correctly, it just needs to have the correct predictions. Maybe you can make it to have fewer steps.
2. The messages where shown long enough to read them.
3. Time could be decreased. Although since the first time I used it improved a lot.
4. The indoor button is not very clear whether it is on or off. You have a lot of steps to look for someone.
   (a) The messages are too quick I could not read them.
   (b) Add colors, more ”pretty”
5. The texts are not totally visible. They should be more like alerts with more color.
   (a) Not so intuitive at first. But after I got an explanation it was easy.
6. It is a great idea, especially for festivals.
7. Would not use it as it is right now because you have to go through so many steps to get the results. If I were in a crown I wouldn’t spend several minutes to find the person. Don’t see the purpose of it, of do it so many times. The app ”works”, it does not lag. It is responsive, ”fast”. The info that is shown is ok. The initial list is not clear maybe change the title to ”friends to look for”.
8. Useful app? very useful? funny and friendly user interface.
   (a) Too many steps until you locate the people.
9. Not enough information about how to proceed.
10. It is a great idea. Accuracy is important. Not really sure why I was doing the turning. If I was supposed to find the device in one direction why was I turning?
    (a) The menu interface was easy to figure out and how to get started.