HuddleLamp - Interim Report

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1 Introduction

> "Science fiction writers foresee the inevitable, and although problems and catastrophes may be inevitable, solutions are not." (Isaac Asimov)

For an idea to be envisioned and come to fruition someone has to dream it first. People that dream the biggest and challenge the boundaries of our imagination are science fiction writers and moviemakers. Various technology advances and human feats were shown, or animated in the movies were then made into reality by various companies. I.e. smart watches were a popular gadget for various detective movies especially James Bond Movies. Smartphones was also popular in movies like matrix, and James bond movies. Another gadget that was very popular in a lot of mainstream movies was an interactive table, like the one in Star Trek. Where a lot of people can collaborate and contribute sitting around a table. Even though the idea was exciting and intrigued a lot of people, this has not been as popular as the other gadgets because of the high production cost which lead to even higher retail price of this product.

HuddleLamp [8] is a project to compete with the fact that interactive tables are quite expensive; making it is inaccessible for some everyday consumers such as schools, public libraries, community centers etc. HuddleLamp aim to use the multitude of unused tablets and smartphones, which people have lying around and create an ad-hoc interactive table by using a novel sensing and detection method to deduce where the devices are and what they should be shown.

HuddleLamp proposes to use some of the cheaper off-the-shelf products like a webcam, and a lamp to create a cheaper interactive table that anyone could use. HuddleLamp proposes to use a hybrid sensing approach that uses RGB and depth data, that can be obtained from sophisticated webcams, which can detect and identify mobile displays on tables and track their positions and orientations [8]. The project devised a way that multiple devices can interact with each other in such a way that they all serve as one seamless multi-device user interface.

Some of the main advantages of HuddleLamp were the face that you seamless, ad-hoc way of adding devices to the UI. Using HuddleLamp, users can add or remove displays and reconfigure them in space without the need of installing any software or attaching markers. Placing them below the camera implicitly does the setup and pairing of devices. Opening a URL on the device and making it visible to the camera adds the new device to the "Huddle". The camera also tracks the hand movements of the user, enabling interactions between the devices.

The simplicity in adding a device to the table means users are not constrained by having specific devices or requiring them to download particular apps. This also means collaboration can occur on tables that are cluttered with other objects likes pens and pencils. There are 2 main components that's required for HuddleLamp; a camera, they suggest Creative Senz3D camera, and a desk lamp, both are relatively inexpensive components compared to an interactive table.

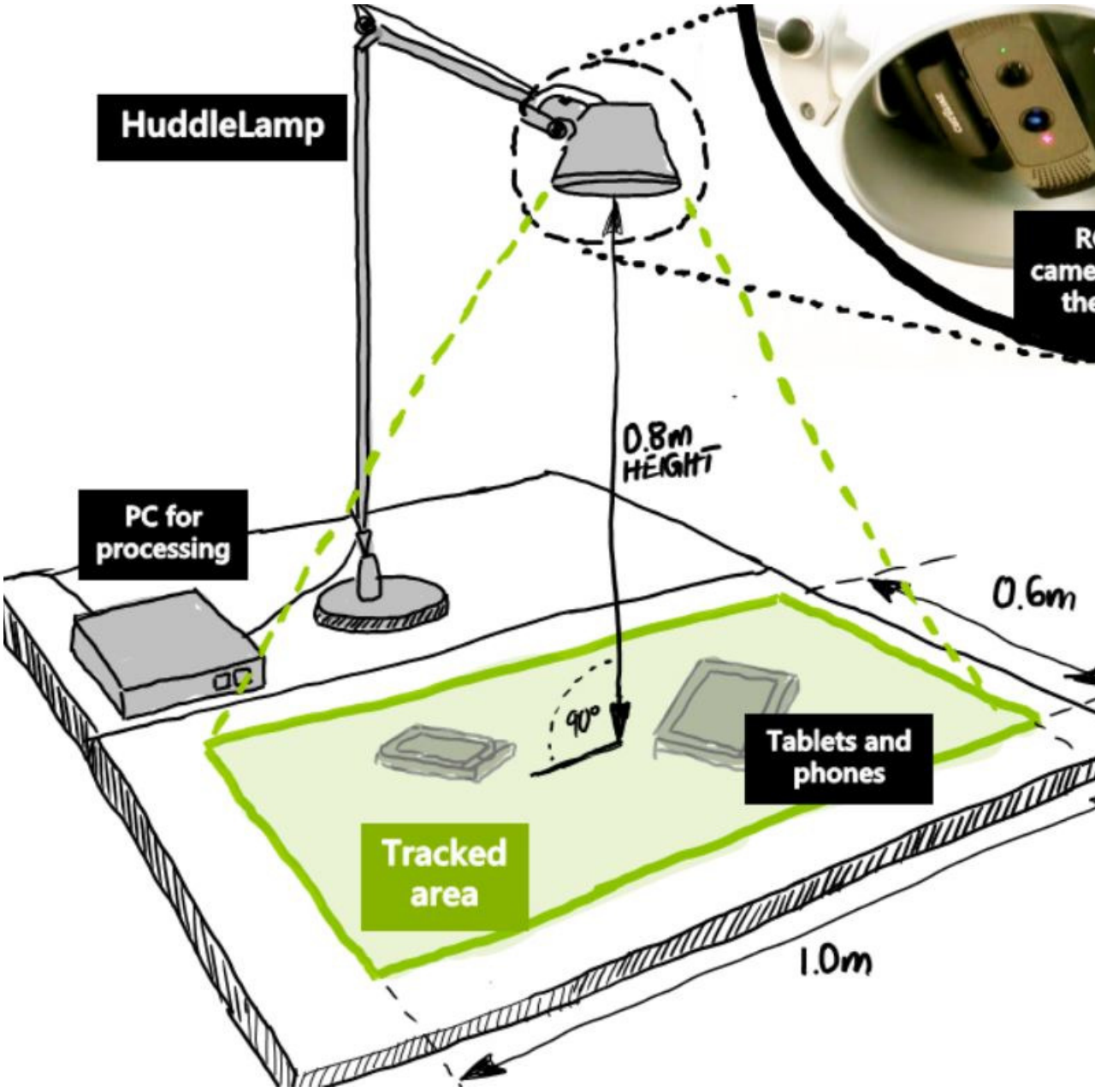

Figure 1: HuddleLamp Configuration

However there are some deficiencies in this improvisation to make an interactive table. At the time of writing, the project has not release a public version of their software. The developer's version requires you to connect a computer with the webcam, which does most of the grunt work in term tracking devices. In this architecture of HuddleLamp, this does all the resource intensive tasks so if it's not a really powerful computer, there are lagging experiences by the users. The fact that to set this interactive table up you need to connect a lamp up to a computer means that the whole setup is not very portable. The size of the interactive part of the table is constrained by how high up the camera is, from the surface of the table. The use of camera means users' arms and hands can sometimes impede the detection and tracking of devices during moving or touching the devices.

For these reasons, I propose to create an app, which can communicate and collaborate with other mobile devices running the same app nearby. I envision using Bluetooth Low energy technology that came to the fore over the recent years and the advancement done by Apple in iBeacon technology[6], and creating an indoor positioning algorithm around a table.

This solution can clearly get rid off the camera used by HuddleLamp to make the whole system much more portable. I want to place 3 iBeacon nodes around the table and use trilateration algorithm. Its similar to algorithms used in movies for tracking people using the phone signals. The web architecture implementation would ensure that all the devices would have a synchronised data showing ensuring collaboration between the devices.

This idea in turn has several challenges that need to be overcome. The main challenge is the fact that Bluetooth technology is not designed exact positioning. Even though the idea is theoretically possible and also there exist libraries, which helps in this scenario. Advanced, sophisticated algorithms needs to be created which can factor the error that is prone to show up. Bluetooth signal is just a 2.4 GHz radio wave and as such is susceptible to factors like absorption, diffraction, interference and multipath propagation. Therefore to achieve more than 5-6m accuracy using trilateration, you need really advanced noise cancelling algorithms.

Over the course of this project I wish to investigate into the possibility of using BLE technology for accurate positioning. Evaluation will be predominantly through comparison with HuddleLamp, and creating my own tests to compare with the HuddleLamp implementation.

Another big challenge that has to be overcome is the lagging experienced by the users of the HuddleLamp. Some of the main culprits for the lagging in the HuddleLamp project were the processing power of the computer used and the delay of transferring information through the web sockets. Using the power of cloud computing and scalable cloud applications like Heroku should ensure that the lagging would stay to a minimum.

One of the big advantages of the hybrid sensing system employed by HuddleLamp was the ease to track the mobile devices on the table. This is another aspect that I would require to replicate using BLE technology. I have decided to overcome this by using the sensors like accelerometer and compass on the

devices and dead reckoning. Dead reckoning is the process of calculating one's current position by using a previously determined position, or fix, and advancing that position based upon known or estimated speeds over elapsed time and course. [1]

2 Background

There are a lot of very important decisions that needs to be taken before the implementation of the product. There are a wide choice of options for each aspect of product such as positioning, implementation language, benchmarking. Over the course of this section we will go through some of the similar work done by other research labs. Also go through some of the options that need to be narrowed down, where we will see the advantage and disadvantage for the choices and then pick the method we will be implementing.

2.1 Related Work

Interactive table is by no means a new idea. A lot of research has been undertaken to find a simple suitable solution for the problem.

2.1.1 LightSpace

One of the companies that do a lot of research into this area is Microsoft. One of their researches is into a system called LightSpace. LightSpace is a small room installation designed to explore a variety of interactions and computational strategies related to interactive displays and the space that they inhabit [11]. This was a research that investigated into touch sensitive interactive displays which was built using cameras and projectors to simulate a fully virtual 3D environment. As you can see from FIGURE 1 LightSpace is not a portable design, aimed at turning a whole room into an interactive space. It is a more sophisticated implementation with larger set of use cases. Including picking and dropping virtual object. It gives a more augmented reality environment. There are other limitations to LightSpace, like it can only emulate interactive display features on flat, static shapes that are designated beforehand.

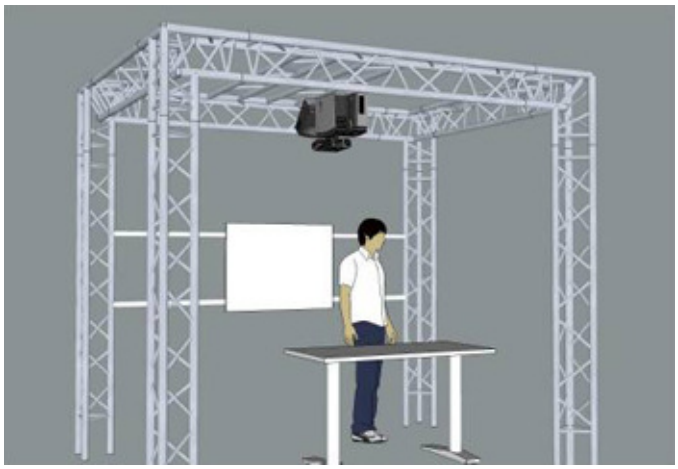

Figure 2: LightSpace Configuration

2.1.2 Beamatron

Another research undertaken by Microsoft is Steerable displays [12]. It uses a motorized platform to orient a projector to display graphics at any point in the room. It is quite similar to the LightSpace research we discussed previously, however the Beamatron can project graphics in the user's hand, and follow the user as they move about the room. It uses a depth camera to calculate the live changes in the room such as following a user's hand. It discusses how we can move 2D graphics using gestures.

2.1.3 ConnecTable

ConnecTable is one of the earlier concepts for interactive table using multiple devices [10]. It's a mobile, context aware information appliance, which uses a pen-based interaction. It also has the capability of extending its display area to merge multiple ConnecTable together to form one large display. There are primary mode of interaction with ConnecTable is the pen based method. Sensors are also building onto the ConnecTable, allowing the interpretation of physical actions in the real world, mapped to an action on the table depending on the software used. ConnecTable is a Roomware component. Roomware is a concept where lots of multiple objects in a room could interact with each other in a way that they would be able to provide information of what is happening in the room.[9]

2.2 Radio Frequency Signal

One of the biggest decisions that need to be taken for our implementation is the type of Radio Frequency signal (RF) we are going to use for our positioning. There are quite a few mainstreams RF widely used, such as Wi-Fi, Near Field

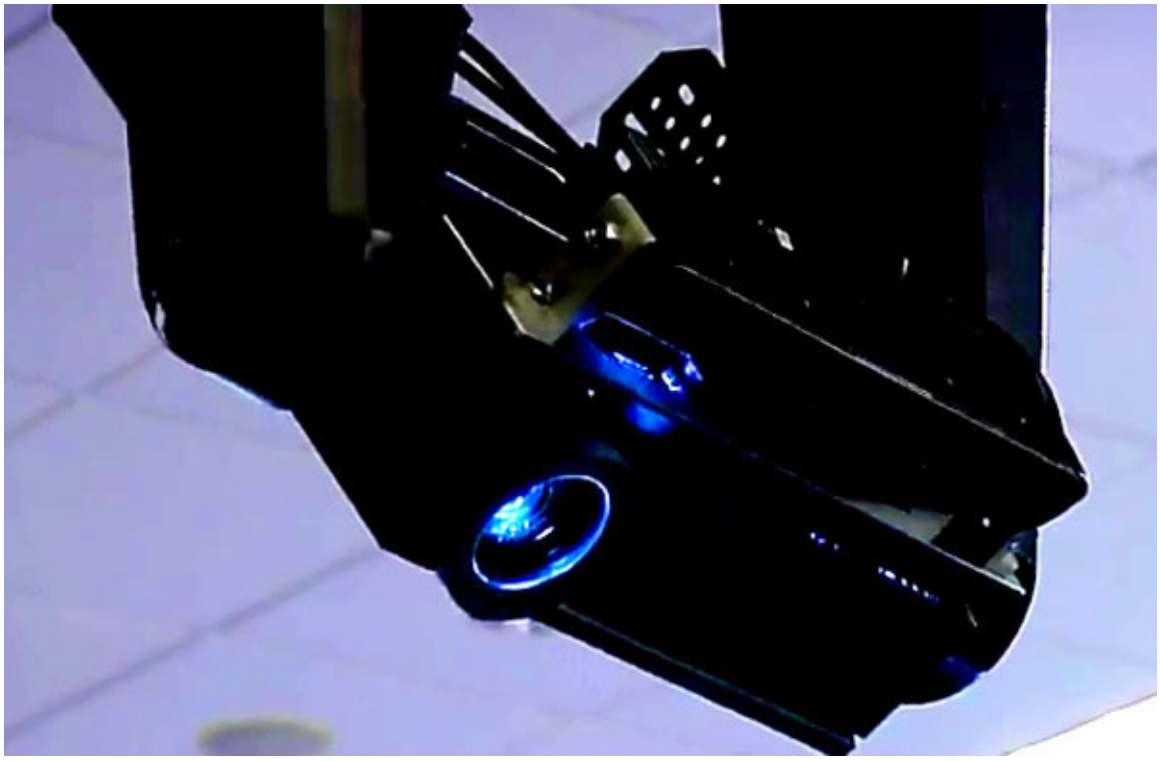

Figure 3: Beamatron Configuratio

Communication (NFC), Bluetooth, Bluetooth Low Energy (BLE) also known as Bluetooth smart. In this section we are going to look at the advantages and the disadvantages of these RF signals.

2.2.1 Wifi

Wi-Fi is one of the most used RF signals out there. It is used for computer networking using 2.4 GHz UHF and 5 GHz SHF ISM radio bands. The services provided are also numerous, from consulting web pages to watching on demand video sequences.

One of the biggest advantages of Wi-Fi is the fact that it's widely used. Almost all location has Wi-Fi now, which means the setup cost and maintenance cost of Wi-Fi would be cheap. It also has the ability to transfer complicated data between its Access point (AP) and the mobile devices, making it highly adaptable.

Wi-Fi has been used for indoor positioning before by various research groups. Two positioning techniques have been used for this research called Signal Strength Cartography and Wave propagation. Signal Strength Cartography is a reference-based system where you map the area offline with coordinates and the strength of the Wi-Fi signal. Then when you are trying to locate a device use the co-ordinates and the strength to work out where exactly the device is. There are two main steps for this mapping, an offline mapping step, which could be done either by simulation or manually using measurements, and an online positioning step, which could be done either using a probabilistic method or deterministic method.

Wave propagation approach is a mathematical attempt at finding the distance between the device and the transmitter by finding a relation between the distance and the signal strength. By using at least 3 AP we can use wave propagation and trilateration to work out the position of the device.

However there are various disadvantages of using Wi-Fi to work out positioning of the devices. There are usually only one AP per location, however we would require more than one, to get more accurate positioning of the devices. Wi-Fi works mainly by sending signals in channels, so having more than one Wi-Fi AP in a location could produce congestion in channels, which would create interference. Wi-Fi also has a higher power consumption. This is because of the larger range in which Wi-Fi sends out its signal.

There is hope for using Wi-Fi as the main Radio frequency for our product in the future after the Wi-Fi Standards agency brings out Wi-Fi -aware. Which is proximity based discovery system. Introduction of this system could mean that you don't require any extra AP, and the devices could interact with each other without any outside help.

2.2.2 Global Positioning System (GPS)

GPS is one of the most widely used features in our devices. Over the past few years the use of GPS has increased significantly due to the increasing social

network activity. Nowadays almost every app that we use through our mobile devices request for GPS access which shows how much it has come forward. GPS is a space based navigation system using the satellites. The Department of Defence of USA, using the 24 satellites already in orbit, initially introduced it.

GPS satellites transmit data continuously, which contains their current time and position. A GPS receiver listens to multiple satellites and solves equations to determine the exact position of the receiver and its deviation from true time. At a minimum, four satellites must be in view of the receiver in order to compute four unknown quantities (three position coordinates and clock deviation from satellite time).

The main advantage of GPS is that it's widely available. Almost all devices have a GPS receiver on it. It also has a very large range. However it is not a viable option for us because of the fact that the signal comes from outer space and our devices are usually indoors. GPS like any radio frequency signal is prone to absorption and diffraction by the roof and walls in the building. GPS also has high power consumption. GPS tends to be not very accurate, averaging ~10m which would make it unviable for our use.

2.2.3 Bluetooth

Classic Bluetooth, usually known as Bluetooth, was the codename for a project by Special Interest Group (SIG), collaboration between some major companies, like Ericsson, Intel, and Nokia. Bluetooth was invented for short-range wireless communication with devices. Bluetooth uses radio signals in the 2.4 GHz range to transmit data. This range is globally license free range; therefore there is no extra cost for deployment. Bluetooth is not targeted any specific application, therefore a multitude of applications has used Bluetooth in various different ways from transferring files to streaming songs.[2]

SIG is in charge of the specification of Bluetooth and creating a roadmap for it going forward. To standardise the form of communication through Bluetooth, SIG has defined a set of profiles that needs to be made available by the manufacturer. Devices usually only have a subset of these profiles enabled. Some of these profiles are:

- A2DP Advanced Audio Distribution Profile. Used for Streaming audio.
- HFP Hands-Free Profile. Used for hands free kit to make calls in cars
- HID Human Interface Device Profile. Provides support for input devices like keyboards, mice and game controllers.

Bluetooth is aimed at applications that require short-range communication typically few meters. The actual range an application make depends on the Bluetooth Class the application has and also external circumstances like absorption, diffraction etc. Bluetooth devices are separated out into 3 different classes with separate transmission power. The full picture is shown in Table 1.

Class	Max Power Output	Max Range	Power Level Control
1	100 mW	100 m	Mandatory
2	2.5 mW	10 m	Optional
3	1 mW	1 m	Optional

Table 1: Bluetooth Power class

Due to the different profiles and more than sufficient range and relatively low power consumption, Bluetooth shows considerable potential to be used as our Radio frequency signal for our positioning. However they're some aspects of it, which makes it difficult for Bluetooth to be used. The main problem is the security constraints of Bluetooth, which requires the devices to go through a pairing process with each other.

In Bluetooth technology a device could take either the master role or the slave role. Before the devices can communicate with each other they have to discover each other and specify which profile they are going to use. Pairing is done by:

1. Master devices continuously broadcast "inquiry messages"
2. These messages will be picked up by nearby devices that are "discoverable"
3. These devices will respond with a message containing their name, profiles they support and other technical details.
4. Using these details the master device can establish a connection with the correct profile

2.2.4 Bluetooth Low Energy (BLE)

BLE is a relatively new technology, which came out in 2010 with the new specification for Classic Bluetooth 4.0. BLE was introduced for devices that are predominantly used for monitoring and control, like sensors values and control commands, where there is no need for large amount of data transfer.

2.2.4.1 Modes

One of the biggest improvements introduced for BLE that is not there for Bluetooth is the addition of the new mode. This new mode takes away the necessity for pairing to exchange data. In this "broadcast" mode the device can send data in the advertisement channel. There are 4 different modes in BLE[2] :

Central : Similar to the Bluetooth master role, can have multiple connections.

Peripheral: A device can only have one active connection with the central mode

Broadcaster : Where you send data in the advertisement channel

Observer: Where you listen to the advertisement channel

2.2.4.2 Scanning

Another big improvement BLE has brought is the ability to discover other devices in two different modes. BLE enabled devices can now passively and actively scan for connectable devices.

- Passive scanning - a central device listens to the advertising channel passively to capture all the packets transmitted by connectable devices
- Active scanning - a central device listen for advertisement packets and when it receives the packet, it checks whether the sender is connectable through looking at the mode. If it is then a scan request packet is send to gain more information.

Devices may advertise as seldom as once every 10 seconds or as fast as every 20 millisecond.

2.2.4.3 Range

Similar to the Classic Bluetooth, the range of BLE is determined by the transmitting power and the interference that it might experience. BLE has a transmitting power up +10dBm, which gives it a range of 300m theoretically. However BLE usually use a power of 0dB or less which gives it a range of about 50m[link 9]. Even though BLE is meant to have low-energy consumption, it has a bigger range than Classic Bluetooth under maximum power due to smaller packet size.

2.3 Positioning algorithms

2.3.1 Ecolocation

Ecolocation is a RF based location algorithm [4]. It uses the sequence of received signal strength RSS from nearby reference nodes with known locations, to find the location of the unknown node. By ordering the reference nodes by their distance we are able to map different regions of the space to their unique signature.

Training phase During the training phase, we divide the area (the table), where the device is going to be, into segments. We go through these segments and detect the RSS signal from all of the reference nodes and store them to a database.

Online phase Online phase is when an unknown device in in the area and we want to know its location. The device collects the RSSI information from the reference nodes and compares it to the stored information in the database, to get best match or get geometric median of the K-closest values, to work its location.

2.3.2 Trilateration

Trilateration is one of the oldest and most recognisable methods of estimating location of an object. We use a minimum of three reference nodes and the

distance between them and the device to work out the position of the device. The reference nodes are used as centres of circles and the distance is used as the radius of those circles. The point of intersection of those three circles is the relative or the actual position of the devices depending on whether the location of the reference nodes is known. In most cases of position systems the reference nodes are beacons or access points. The distance can be measured using RSS or time of flight (TOF), time taken for the signal to reach the device. These measurements combined with the coordinates of the beacons can form the basis of trilateration.

2.3.2.1 Signal Based Position From previous work done for indoor positioning we know that many different signal characteristics could be taken into account to determine the position of the device. Some of these characteristics are:

Angle of Arrival (AoA)- Angle of Arrival compares the direction from which the different signals arrive at the devices. Using the received angle, we can determine it direction from which the signal came from. If we have multiple signals coming to the device, we can find the exact location of the device by looking at where the lines intersect. We need a minimum of two reference points and two angles to work out the correct position. There are many difficulties with the method; the device would need to know its own orientation to work out the correct angle. The sensor that detects the signal needs to be very advanced (more advanced than the ones usually found on a device.

Time of Arrival (TOA) - By using the time of arrival of the signal and the time of sending of the signal and the medium in which it travelled through we can work out the distance of the devices from reference nodes. This coupled with a database of known travelling time we can work out where the device is. This would however mean we would have to keep a database of results and wont be very portable.

RSSI - Based -Similar to trilateration, the device can use the Received Signal Strength Indicator (RSSI) to work out distance from the reference nodes. Any device with a proper network adapter can work out the RSSI value.

2.3.3 Filter Methods

Filter based positioning uses mathematical methods to estimate the positioning of the device, using some given observations from the system. The observation can be anything from distance to references, previous estimated position or sensor inputs such as a compass or gyroscope. This technique has been used for many different applications. Its very helpful because it allows us to incorporate many other sources of data that we could potentially has for the system. A good example of this is presented in [7], where they use ultrasound as the radio

frequency signal and combine it with odometer reading to get a better accuracy for their tracking ability.

A particle filter work by continuously generating thousands of particle at random during runtime. For positioning, these particles represent the location that the device could be. We can calculate the distance to the reference beacons for each particle. By using the observer value from the device we can eliminate and filter out those particles that are unlikely to be the correct location. We then use the remaining particles to calculate an estimate for the position of the device. The filtering is done by assigning weights to the entire particle depending on how reasonable the particle values are according to the observed value. Gradually, most of the particles will have negligible weight and therefore would not affect the estimation while some particles with significant weights will remain affecting the estimated value significantly. To avoid this problem we resample the higher weight particles while particles with negligent weights are discarded. During the initial step we uniformly distribute the particles around the map, later particles and discarded or saved depending on the filtering method. Two of the most commonly used filter methods are Kalman Filter [5] and Mote Carlo Filter[3].

3 Project Plan

Date	Target	Fall Back Milestone
30- Jan	• Finish Interim Report, • Finish research into frameworks • Identify the frameworks to be used • Learn the frameworks	
17 - Feb	• Implement the basic bluetooth listening app • use the app to get data for evaluation on distance • Start implementing trilateration	

1- March	• Finish implement trilateration • Get data by testing it on a grid to get the error in trilateration • Start adding dead reckoning information and start filtering methods • finished background for the full report	
15- April	• finish implementing filtering methods • get error rate adjust the filtering method to get it working • Start implementing the mobile app with a picture and moving on picture to get it working • finish evaluation of the full report including tables charts and diagrams	App that shows a fiteration method ie. a rectangle with dots to show the position of the app!
30-April	• Finish evaluation section for the report • Get background and evaluation checked by tutor	
15- May	• Finish moving picture app • Do other parts of the report	Moving picture app similar to where is waldo type app
30-May	• Finish the report • add gesture control to the app	gesture control app
15-June	• Be at a stage where report needs to proof read and checked • Finish the gesture control • final hacking session to get the app presentable	

30-June	• Everything should be finished	

3.1 Potential Extentions

There are various extensions I would like to do including:

- Finish the gesture controls
- Make it more of a platform so that people can create a workspace they want
- Have some in app workspaces like blank drawing page, casino games
- Have the ability for the picture app to import pics from library

4 Evaluation Plan

As you can see from the background research, a lot of companies and individuals have done various researches into creating an interactive table. A lot of research has also been undertaken in the topic of indoor positioning, especially with Bluetooth and BLE. Therefore there is a lot of information about Bluetooth and Trilateration and filtering techniques. I will be undertaking a research in the use of Bluetooth for positioning in a smaller area. Where I believe the error in sensing would be much smaller. Basic sensing of Bluetooth signalling augmented with odometer data and filtering techniques would give me positioning information to a quite a good accuracy level.

There are several ways for me to evaluate the research I have done and the accuracy of the techniques I have used. As you can see from the progress plan I aim to gather information about distance measurements through Bluetooth and compare it to real world, physical distance and calculate the error for it. Another experiment I would do after that it to work out the error for trilateration and dead reckoning and create an app, which uses a filtration method like the Monte Carlo localization filter to gain a confidence level of where the device is. I would do this by having a large sheet of paper, which would be divided into a grid and calculating where the device is. All of this data combined should give me an accurate picture of the sensing abilities of a device. This should in turn help me build an app where I can take these error information into account and create a robust app which should be quite accurate. I am aiming to get as close as possible to the sub-centimetre range that HuddleLamp was able to achieve with their implementation.

Another evaluation experiment I would like to try is a way to benchmark the loading time. How quickly panning and gesture could be passed back to the app. It is something I would also evaluate by comparing it to the HuddleLamp setup I have in the office. Comparison between the implementation for load times might not be the ideal scenario since the loading of information in HuddleLamp is subject to the computer in which the Visual Studio project is running. Different computers can give different result for this experiment.

Finally I would also have an evaluation where I would give some users an opportunity to use the app and see how they do. Then I would try and do get a questionnaire filled to get their feedback. I would try and get a wider variety of views including from graphic designers, students, lecturers etc.

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