Indoor Localisation System Based On Low-Cost Commodity Hardware

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Abstract
Pervasive indoor positioning is a key enabler for ubiquitous computing. Although a number of indoor positioning systems exist, we identify that there still is a barrier between these and the consumer. There is a need for a cost-effective, practical solution that can be easily designed, built, tested and deployed.

We have built a low-cost indoor positioning system with off-the-shelf commodity hardware, to provide an example of an accessible ubiquitous platform for developers, academia, private individuals, big and small companies and institutions. The system is low-power, modular, performs auto-calibration, can track any WiFi-enabled device and can be used for other applications alongside indoor positioning.

Author Keywords
ubiquitous; low-cost; Raspberry Pi; location-aware

ACM Classification Keywords
C.3 [SPECIAL-PURPOSE AND APPLICATION-BASED SYSTEMS]: Real-time and embedded systems

Introduction
A practical, cost-effective indoor positioning system (IPS) is one of the key enablers of ubiquitous computing. Although a large number of such systems [3] have emerged since

	Model	Price
RPi 2	Model B	$ 35
WiFi	RATLINK3070	$ 17
WiFi	EW 7811UN	$ 10

Table 1: Details of the components of the locator nodes used for this study. Please, note that the prices are subject to change.

Raspberry Pi and WiFi are widely available, low-cost and accessible and easy-to-use. Raspberry Pi has low power consumption, enables modular designs and it is very popular with a wide community developed around it. It can provide high power computing capabilities, can be used as an IoT development board [2] and it can be used for other applications alongside tracking. Due to the modular configuration of each node, other sensors can be used alongside WiFi such as lightning, air quality, temperature, energy monitoring.

Weiser defined ubiquitous computing [8], we believe that there still exists a barrier between these and the consumer. For example, industry does not focus on developing ubiquitous solutions, and some commercial products [1] [2] [3] do not provide services for small spaces, aiming at large areas such as airports, universities, hospitals and large retail companies; their products are expensive and the tracked asset requires specific localisation hardware such as smart tags. Table 2 details costs and performance of some of the leading systems. Academia developed high accuracy algorithms and systems, but they are often not ubiquitous and require specialised knowledge [7, 5]. Fingerprinting-based indoor positioning seems to be a popular choice, but collecting fingerprints requires user interaction, is impractical and imposes a barrier on the user. There is a need for a low-cost, practical IPS that can be easily deployed. Weiser claims that in ubiquitous computing we can only learn by experimenting. Hence, we need a simple system that allows for further experimentation with location-aware applications, but also with WiFi-based indoor positioning algorithms.

We present a low-cost WiFi-based IPS that uses Raspberry Pi devices for collecting and processing data. The system is ubiquitous, it collects the data without user input and the remaining Control Processing Unit (CPU) capacity can be used for other applications, representing a valuable development platform for ubiquitous applications. It performs auto-calibration: for each node all the other nodes of the system act as anchors, allowing for wall alleviation factor to be calculated. Each node can be battery powered and has a modular configuration, allowing for swapping and adding sensors. The system can track any WiFi-enabled device and it works with Linux-based Operating Systems (OS).

[1] http://www.infsoft.co.uk
[2] https://www.navizon.com
[3] air-go.es

Design of the Indoor Localisation System

The system has two components: locator nodes that collect data from WiFi-enabled devices and a server that runs on one of the nodes. Figure 1 shows one of the locator nodes and Table 1 details the hardware components of each locator node. The two WiFi cards are used for monitoring the tracked devices and to connect to the local network.

The tests presented in this work have been performed using Raspbian OS. OpenWrt, that is an OS specifically designed to deploy on Access Points and routers [1], has also been successfully tested.

The Free Space Path Loss theory [6] and the trilateration algorithm [4] have been used to compute locations of the tracked devices. The final location estimate is assumed to be the centre of the smallest circle that can be formed using the best k solutions yielded by the trilateration algorithm.

The best k solutions are filtered based on the Euclidean distance between them and the locator node with the highest signal strength. k and the number of locator nodes were chosen to be 2 based on iterations made on multiple data sets.

Each locator node collects data (the Media Access Control address, received signal strength) on channel 11 using the Python library `scapy` and sends it to an `HTTP` server, that computes the coordinates of the active WiFi devices and displays them on a web page in real time. The data from the locator nodes is sent continuously to the server and saved in log files, but not used for coordinate computations if it has been in the system for more than one minute.

[1] monthly subscription to the cloud server - up to 50 tracked devices

[2] per device running Accuware software

[3] per year

[4] approximate price of an access point

[5] per month

[6] per month

[7] per year

[8] ah-hoc - approx. 15% of the total project cost

Table 2: Price per year and accuracy of indoor positioning systems that are currently on market and have their pricing available. Please, note that the prices are subject to change, and the accuracy of the systems depends on the density of locator nodes per m^2.

Product	Locator node (per unit)	Accuracy	Services	Installation	Smart tag (per unit)	Licence	Support
Accuware	$ 30 - 40	2 - 4 m	$195 [1]	$ 60000	$ 59	$ 99 [2]	$ 75000 [3]
Indoors	$ 30 - 40 [4]	2 - 5 m	$ 499 - 999 [5]	ad-hoc		N/A	$ 95 - 990 [6]
infsoft	$ 170	2 - 5 m	N/A	$ 1000 [8]	Not required	5500	ad-hoc
Air-Go	$ 230	up to 2 m	$ 163 [7]		$ 51	N/A	ad-hoc

Figure 1: Locator node

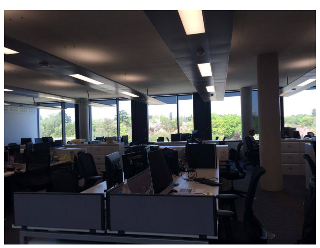

Figure 2: Image of a section of the office area illustrating the testing environment

Besides tracked devices, the locator nodes are also monitoring each other. Knowing the real location and the signal strength variation at each locator node allows for the wall alleviation factor to be calculated. This enables the system to adapt at changes in the environment.

Preliminary Testing

Methods

The tests have been conducted in a busy office area of 30x13 m^2. The office, shown in Figure 2, contains computers, tall metal drawers, thick pillars, four Access Points, printers, microwaves, Bluetooth enabled devices and other furniture and equipment typical in an office environment. Figure 3 shows a 2D top view representation of the testing area and the positions of test points.

The measurements have been taken using a Fluke 414D laser distance meter that has an accuracy of $\pm$ 2 mm and the tracked object was a Kazam Thunder 45L smart phone.

The tracked device was held stationary at each of the test points. The results represent the average of all the coordinate estimates obtained at each of the test points.

The error has been calculated as the Euclidian distance between the coordinates yielded by the positioning system and the physical location of the tracked device.

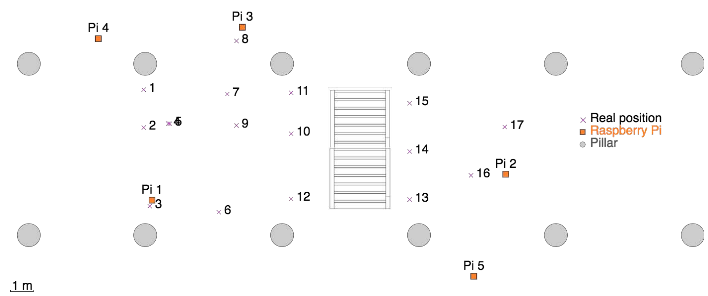

Figure 3: The testing area layout showing the position of the locator nodes (Pi) and the locations where data is collected. The test points are numbered in an ascending order from left to right hand side along the width of the test environment.

Results

Tests were taken using five locator nodes and the results are illustrated in Figure 4. It is noticed that the accuracy decreases from the left to the right hand side of the testing area. The results are influenced by the positioning of the locator nodes relative to the measurement points and to each other, and by interference and Line-of-sight (LOS) obstructions.

To prove this theory, we re-calculated the tracked device coordinates in the test section where the nodes are evenly

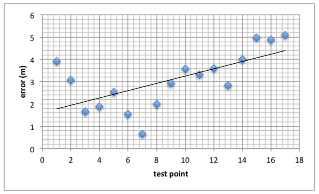

Figure 4: Figures illustrating the error variation at 17 measurement points. The accuracy of the system is 3.09 m with standard deviation of 1.24 m

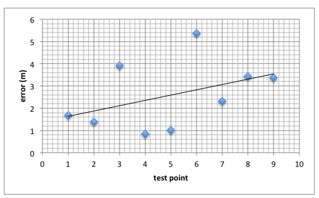

Figure 5: The error variation at the first nine measurement points when three locator nodes have been considered: Pis 1, 3, 4. A median accuracy of 2.59 m with a standard deviation of 1.44 m are obtained.

spread and less LOS obstructions and interference are present. We chose to use three locator nodes only (one, three and four) to re-calculate the coordinates at the first nine test points. The results, illustrated in Figure 5, support our theory. Furthermore, comparing these results with the ones that were obtained previously at the same points, it is noticed that a better accuracy is obtained when more locator nodes are used. It demonstrates the impact of the number of locator nodes on the accuracy of the system.

Conclusions and Further Work

This work presents a low-cost IPS system that can be used as a development platform for location-aware applications. Preliminary tests demonstrated 2 - 3 m average accuracies.

To further validate the system and analyse its accuracy, as well as the impact of interference and LOS obstructions on its performance, we designed more experiments.

The Raspberry Pi 2 model will be replaced by Raspberry Pi 3 model, that has a built-in WiFi card. The server will be located on a separate Raspberry Pi that will run as an Access Point, to which the locator nodes will connect and the data will be transmitted without Internet connection.

More devices will be tracked simultaneously, evenly spread through the test environment so that information independent of the WiFi signal variation over time can be collected. The capacity of the system to track devices in motion will also be assessed. The experiment will be reproduced within an open area with less interference and LOS obstructions to determine their effect on the accuracy of the system.

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