Abbreviations

API – Application Programming Interface
BT – Bluetooth
BTT – Bluetooth Technology
BLE – Bluetooth Low Energy
CCIPS – Conceptual crossover Indoor Positioning System
HAIP – High Accuracy Indoors Positioning
IDE – Integrated Development Environment
ILA – InLocation Alliance
IR – Infra Red
ISM – Industrial, Scientific and Medical
MC – Mobile Centric
MCHAIP – Mobile Centric High Accuracy Indoor Positioning System
NC – Network Centric
NCHAIP – Network Centric High Accuracy Indoor Positioning System
SIG – Special Interest Group
GATT- Generic Attribute Profile
GPS – Global Positioning System
IPS – Indoor Positioning System
PAA- Phased Array Antennas
RF – Radio Frequency-based
RQ – Research Question
RR – Request Rate
RSSI – Receiver Signal Strength Indicator
SHF – Super High Frequency
TS – Training & Simulation
UDP – User Datagram Protocol
UHF – Ultra High Frequency
UNII – Unlicensed National Information Infrastructure
URL – Uniform Resource Locator
WLAN – Wireless Local Area Network

Contents

Table of equations

Table of figures

1 Introduction

In this chapter the problem area, the purpose, and the research questions this thesis aims to answer is introduced. The Background and the Purpose and research questions give a clear explanation to why this thesis is conducted.

1.1 Background

To know your whereabouts can be important and sometimes is exact position knowledge the determent of success or not. GPS (Global Positioning System) is probably the most developed, distributed and well-known positioning system there is. It can be used for almost anything and is being used in many critical applications where exact positioning is crucial. However, GPS only works when the hand-held devices have direct communication with the GPS satellites providing position data. This means that GPS are very limited in indoor environments. Positioning data must be provided by another system when precise whereabouts are needed in these environments. Despite this, there is no standard even close to GPS for indoor use. The problem is not lack of research, several technologies for indoor positioning systems (IPS) have been explored and some have even made it as commercial products to the market [1]. It is believed that the problem rather is the understanding of the needs of IPS. A common factor amongst IPS that have made it to the market is that they are implemented in small scale and serve a specific purpose related to a very specific use case scenario. Small-scale implementation rarely leads to acceptance of significant standards. This is de facto the case of IPS.

One of the technologies that have been proposed and are being used in some commercial IPS is the radio frequency-based (RF) Bluetooth technology (BTT). One of the biggest advantages of using Bluetooth (BT) is the deep penetration in society BT have. Most mobile and portable devices have BT as a standard communication implemented already from the start. This means that the hardware costs for BT are very low. The low cost, level of integration in the society that BT have, and research shows that BT is a viable candidate for large scale IPS deployments.

IPS has been carefully researched in several aspects the last couple of years. All kinds of technologies have been exploited. One of the more resent once are Bluetooth Low Energy (BLE) based IPS [2]. As with all other technologies, BLE have been researched, tested and commercialised with different approaches. This thesis investigates the difference between distributed and centralised IPS using BLE. The focus is on the triangulation approach by conducting experiments on a commercial centralised system working according to the Network Centric (NC) High Accuracy Indoor Positioning (HAIP) standard, and researching the non-standardised Mobile Centric (MC) HAIP system [3].

This master thesis was conducted at Saab Training & Simulation (Saab TS), which is a branch of the Swedish defence contractor Saab Group. Saab TS specialises in the development, manufacturing and sell equipment to be used in military simulations [4].

This master thesis was performed according to a hybrid method consisting of both experimental research design and systems development. The main focus is on the experimental research, which is used to test the proposed HAIP system. In order to be able to conduct the experimental research on the HAIP system, some system development has to be done. This lead to a conceptual crossover system, where a NCHAIP system has means of distribution implemented.

1.2 Purpose and research questions

This thesis originates in the positioning of exercise participants in military, law enforcements and other civil simulations in indoor environments. Today, large-scale implementations of IPS in exercise areas often uses old technologies, such as infra red light (IR). Such technologies make it possible to have a distributed IPS, but only with ”room level” accuracy of the objects being positioned.

The purpose of this thesis is to gain deeper knowledge of suitable replacement systems for existing IPS in large-scale implementations. This is done by investigating the future MCHAIP standard and by experimental research design combined with some system development on the existing NCHAIP standard for IPSs. The system development and the experiments are conducted to improve and verify the functionality of NCHAIP IPS. The system development leads to a conceptual crossover IPS (CCIPS) that utilizes a NCHAIP IPS to collect and estimate location data, and a smart device as a receiver of the collected and estimated data. This is done because there are several application areas where a CCIPS capable of providing positioning data with accuracy of less than one meter (sub meter accuracy), could be considered as a future replacement system for the existing IPS.

As a part of this thesis, current exercise and simulation models regarding positioning and the effects on participants related to positioning will be reviewed. Replacing a positioning system could affect the entire model that is being used in simulations today. Providing more precise positioning data makes it possible to have a more realistic simulation regarding events taking place in close proximity to the simulation participants. This means that danger and damage levels can be more elaborate, and that dangerous objects and unstable buildings can have more realistic effects upon participants. Replacing existing systems with non-IR-based IPSs will not only improve the accuracy, but will also eliminate IR light sources that are affecting the night vision equipment used by participants in simulations during dark hours.

For this thesis project a small demonstration kit (“demo kit”) for indoor positioning is being used. Quuppa, a Finish company with its roots in Nokia, produces the demo kit [5]. This system is a BLE IPS and it is used as the test equipment in this thesis project. The intention is to learn if the Quuppa IPS could be a suitable contender as replacement for existing IPSs, and how to best implement it as a distributed system. The optimal outcome is an implementation method for this conceptual crossover IPS that can support up scaling (going from a small set of antennas and one tag in one room to a larger amount of antennas and several tags distributed in several rooms and even buildings). A Full-scale implementation of this system will be extensive and have the capacity for a large amount of exercise participants.

With the Background in mind, and based on the purpose of this thesis project, the following research questions (RQs) have been established to describe what the investigation and project depicts:

RQ1: What differentiate a distributed simulation system from a centralized simulation system?
  - What differences are there in the implementation of centralized vs. distributed simulation system?
  - How to implement a distributed system to support scaling-up?
  - When is it suitable to have centralized vs distributed IPS?

RQ2: How will current exercise models be affected by improved position granularity?
  - What changes have to be made in the exercise model?
  - What accuracy can be achieved?

RQ3: Could a conceptual crossover IPS (CCIPS) be a valid contender to replace today’s established IR-based IPS?
  - How can positioning data be distributed in a NCHAIP system?
  - Can the CCIPS meet the real-time requirements of the established IR-based IPS?

RQ4: What other sensors existing in a smart device can be used to aid a BLE IPS?
  - Can the BLE IPS data be combined with other sensor data to provide more accurate and stable location data?

1.3 Delimitations

This thesis covers both theory and practical work regarding IPS using technologies that are available in smartphones today. There is “Internet Of Things” (IOF) suitable communication languages widely distributed, such as Zigbee [6], which is competing with BT and BLE in several application areas, but not available in smart devices as an adopted standard. Due to this, systems, such as Zigbee will not be a part of this thesis.

The Quuppa IPS is a network centric high accuracy indoor positioning system (NCHAIP). NCHAIP is an adopted standard for BLE IPS. The Quuppa IPS is used to conduct experiments, to test theories and as a base for smart device application integration. This thesis will not result in a "ready-to-sell" system that can be sold the customers of interest.

The application being developed will only contain basic functionality and is likely to be developed further in the future. The application will be developed for Android devices only. This decision is based on the fact that Android is an open platform. This means that there will not be any devices for IOS or any other smart device system architecture. The application is developed to show how the information collected in a centralized IPS can be distributed the equipment of the participants. The application will not be integrated into any other equipment in an existing system.

Quuppa claims that their system can be used as a mobile centric high accuracy indoor positioning system (MCHAIP), but there is no MCHAIP standard on the market yet. In this thesis, investigation of the future MCHAIP standard is being done, but no attempt to develop a MCHAIP system is made while the Bluetooth Special Interest Group (BT SIG) is working on a standard [3]. Attempts to develop an own version of a MCHAIP system in the near future could potentially be a waste of time.

1.4 Outline

What follows from here are five parts. First part, chapter two, is allocated to give the reader a better understanding of the technologies in today's smart devices that can be used for indoor positioning systems. In this chapter, related work to the different technologies and commercial systems will also be covered. Chapter three is allocated to describe the method of choice. Chapter four is allocated for the actual work being done. The course of action to answer the research questions for this thesis are explained. In chapter five, the findings are discussed and analysed. Finally, the discussion and conclusion, where the method and findings are discussed, conclusions are finalised and recommendations are made.

2 Theoretical background

In this chapter, the theory behind the project work will be highlighted and discussed. The different technologies and how they are used in IPS are explained here. Focus has been on BLE IPS, but some IPS using alternative technologies has been researched as well.

2.1 Technologies

Indoor positioning is a relatively new thing. Global positioning system (GPS) has been around since the introduction in the late 1970s' as a result of the need for accurate global guidance for military as well as civilian use. The expressed need for indoor positioning is more recent than the need for global navigation, but indoor positioning has been the topic of research for the last two decades [7]. As Technology evolves and matures, new areas of use become possible and the technology becomes the solution for several applications. It is quite known that GPS works well and provides accurate positioning data as long as the GPS device have direct contact with the dedicated satellites orbiting some 20 000 km above the face of the earth [8]. But when the GPS device is inside a building, the direct line of sight becomes disturbed and the GPS are likely to fail in delivery. This has been a problem without technical solution for positioning systems in indoor environments until quite recently. Today, several technologies can provide coverage for positioning devices even inside buildings where the GPS satellites cannot reach.

In this section, some of the technologies available today are covered. The focus of this thesis is on technologies that are available for smart devices, such as IOS- and Android-devices.

2.1.1 Wireless network (Wi-Fi)

Wi-Fi is a wireless local area network (WLAN) technology that allows electronic devices, such as computers and smartphones, to communicate and network. The communication use either the industrial, scientific and medical (ISM) radio band of 2.4 GHz ultra high frequency (UHF) or the unlicensed national information infrastructure (UNII) of 5 GHz super high frequency (SHF).

2.1.2 Bluetooth

Today, Bluetooth is a well-distributed technology for communication, connecting phone, headsets and other communication devices together. One of the areas where Bluetooth is exceptionally good is wireless transferring or streaming stereo sound between devices. This is perhaps what the technology is best known for. Developed during the ‘90s by the Swedish company Ericsson as a wireless alternative to the RS-232 data cables [9], Bluetooth soon caught the interest of other companies as well. In 1998, Ericsson and four other major companies founded the Special Interest Group (SIG), with the purpose to develop the technology further. From now on, the technology is formally named Bluetooth (BT). SIG and its members are responsible for the standardisation of any new Bluetooth standard, and in July 2010 SIG announced the adoption of core version 4.0. Now for the first time, the core version of BT supported Bluetooth Smart, also known as Bluetooth Low Energy (BLE), which is a scaled down communications protocol with low energy consumption. [10]

2.1.3 Bluetooth Low Energy

As the BT technology matures, more areas of use become clear and drives the development of the technology further with faster and more powerful radio transmitters. Despite the fact that BLE borrows a lot from its bigger brother, the technology should be seen as a completely separate technology [11, p. 3]. BLE is developed to be the most energy efficient wireless technology for the market, and aims to be used as a technical solution for different problems than BT. In difference to BT, BLE is supposed to transfer low data rates in an efficient way rather than a large quantity of data in a rapid pace. This opens up new possibilities previously limited by the battery life of transmitters and receivers. Devices can be implemented in inconvenient places and in consumer products where the lifetime expectancy no longer exceeds the lifetime of the BLE transmitters battery. The idea is to have small BLE transmitters embedded in any product where it would be beneficial to have a wireless communication link.

Radio

The radio is one of the most important parts of BLE; it is one of the major components of the technology. Whenever the radio is on, no matter for how long, energy is being consumed. Minimizing the time the radio is active, sending or receiving, is one of the cornerstones of BLE [11, p. 5].

BLE devices communicate with each other as masters and slaves. BLE slave devices are also known as advertisers. A device implemented as a slave unit advertises its presence to other units by sending three consecutive regular communications over its radio. BLE technology uses three distinct frequencies as advertising frequencies. They are sending one advertising communication per frequency. Three frequencies are a compromise between stability and efficiency. Fewer than two frequencies would mean increased risk of the system locking itself while more frequencies would increase the energy consumption doing more frequency jumping. [11, p. 8]

As with several other wireless technologies, the radio in BLE operates at 2.4 GHz ISM band. In Figure 1, below, is an illustration of how BLE and Wi-Fi are coexisting. Despite the fact, that the two technologies are in the same ISM band, not all frequencies have to be shared. The illustration shows that some of the channels used by BLE are outside or between the channels of Wi-Fi. The green spikes are BLE advertising channels, and the darker blue spikes are BLE data channels that are outside of Wi-Fi channel-frequency scopes. A complete description of the actual frequencies used by BLE is given in the Link Layer section.

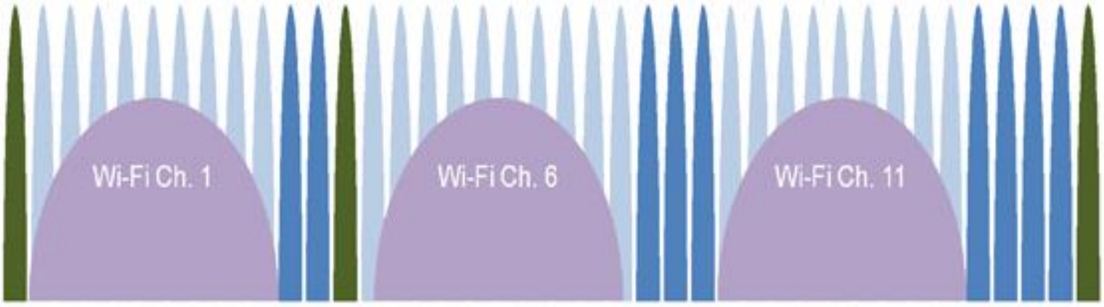


Figure 1: The 2.4 GHz ISM band is clustered with wireless transmissions from several technologies [12].

Once a BLE slave device have advertised its presence to a BLE master device, it opens its radio and listens for responses. The response will be instructions for the slave or requests for collected data, which the master units need in order to complete their tasks. BLE Master units are also known as scanners. They are scanning for these three consecutive regular communications from BLE slave units, and after receiving such a communication sequence, starts to send instructions for the slaves to handle.

The radio is, by far, the most energy consuming component on a BLE device, but it is the most important too. Since the slaves are advertising their presence every now and then, the master need to have its radio activated and ready to receive the slaves communications during a longer time than the slaves. This results in the master having significantly higher energy consumption than the slaves.

The whole idea of a radio is to transmit data, no matter what system or technology it uses. The data being sent, including the meaningful payload, are sent in short packages. This has several benefits and a few drawbacks. Efficient coding means that the same amount of data can be sent faster using less of the device's energy reserve. Short packages are also beneficial in the sense that the recipient does not have to make adjustments and calibrations on the device's internal radio clock during the time packages are being transmitted.

Another aspect to consider is that shorter packages avoid the radio being active long enough to heat up the entire chip, where the radio component is placed. Warm components on a silicon chip will eventually warm the entire chip. This can cause a slight change in the character of the silicon chip, leading to higher resistance in the conducting line. Higher resistance in turn leads to more heat [11, p. 12]. The heat generated internally in the radio component and the silicon chip can be calculated using Joule's law of heating [13, pp. 303, 304].

$$H \propto I^2 * K * R * t$$

Equation 1: Joule's law of heating, where H = heat, I = current, K = constant of calories/joule, R = resistance and t = time of transmission measured in seconds [13, p. 303].

Design

The BLE design is fundamentally asymmetric. This is to ensure that application devices with the smaller energy storage are more energy efficient by having fewer radio transmissions to do than the device with the larger energy storage. A radio generally has two purposes, transmitting and receiving. In BLE, a device can have bot types implemented, but it is also possible to implement an asymmetric network, where only one device is transmitting and the rest is receiving.

The intended tasks for a BLE device have a considerable effect on how it is designed. In the architecture, there is two stages where it is decided what typed of device it is supposed be: The Link Layer and the Attribute Protocol Layer.

In the Link Layer, it is decided if the device is supposed to be a Master, Slave, Scanner or Advertiser [11, p. 14]. The different tasks a BLE device have depends on what type of device it is. For instance, an advertiser device sends data and a scanner device mainly receives data. There are also different types of connections decided in the link layer and roles for communications are set here. A slave device is very limited in its connections and tasks. It must always be connected to a master device in order to be useful, and it cannot introduce any complex tasks. The master device is the hard working device, it is responsible for the frequency hopping, piconet timing, any encryption and several other complex tasks the system have to cope with [11, p. 14]. All of these tasks are vital for the system to work correctly. Piconet timing synchronizes the master and the slave during transmission over data channels used by BLE. In this way, collision of data packages on the same data channels is avoided. The way Bluetooth units communicate over channels is called frequency hopping; the transmitter is jumping between several channels switching between frequencies accordingly to a predefined schedule. Making the master device responsible for these tasks make the slave device free from several responsibilities, and the slave can be very simple in its construction. Apart from being very simple in the construction, the slave devices are energy efficient and production costs are low.

At Attribute Protocol Layer, the different devices are known as clients and servers [11, p. 14]. Server devices are basically the same as slaves; they can only perform tasks they are ordered to do. Just as master devices, clients are the once performing the actual work. BLE uses this asymmetric design for the security as well. Slave devices shares distribution scheduling key with their masters, and once the key has been shared the sole responsibility rests on the master device to remember this key in order to be able to connect to the slave devices.

In the Figure 2, below, two slave devices advertising their presence to a master device can be seen. Even if slave devices can't start any complex procedures, they are the initiators of the two device types. The slaves are sending three short messages on three different frequencies advertising their presence making it possible for master devices to connect to them. Once the connection has been made the slave devices performs tasks given to them by the master. It should be noted that slaves are also known as advertisers and masters as scanners.

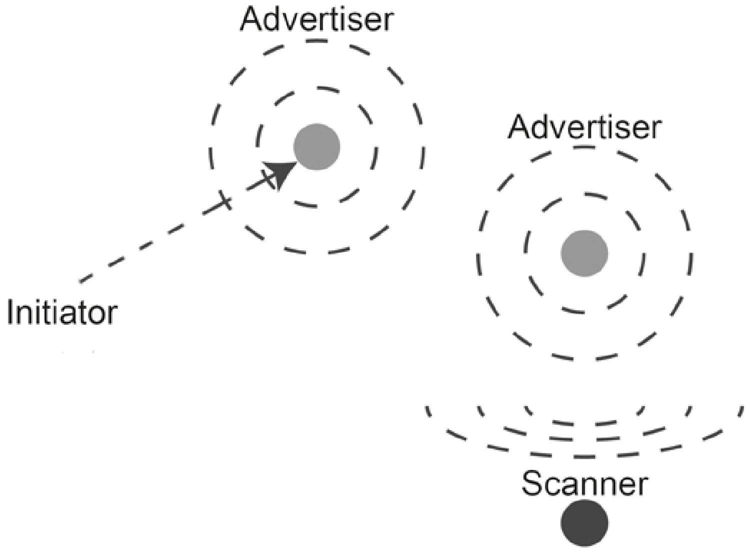


Figure 2: The scanner can see one or more BLE advertisers. Advertisers are the initiators, since they advertise their presence and await orders [12].

Architecture

Bluetooth core specification 4.0 was the first to include BLE (Bluetooth smart). BLE have its own protocols and functions, but still share some features with regular BT. Logical link control and adaptation protocol (L2CAP) is such a feature [11, p. 169]. Put simply, the architecture of BLE can be divided into three parts: Controller, Host and Application. In Figure 3, the three major parts can clearly be viewed. The Controller is the lowest section in the architecture. It includes the Link Layer, Direct Test Mode and the Physical Layer. The Controller is a physical unit, able to send and receive data packages using radio signals. Both the Host and the Application parts build upon the Controller, and it is in the Application part the user interface, whatever it is, will be.

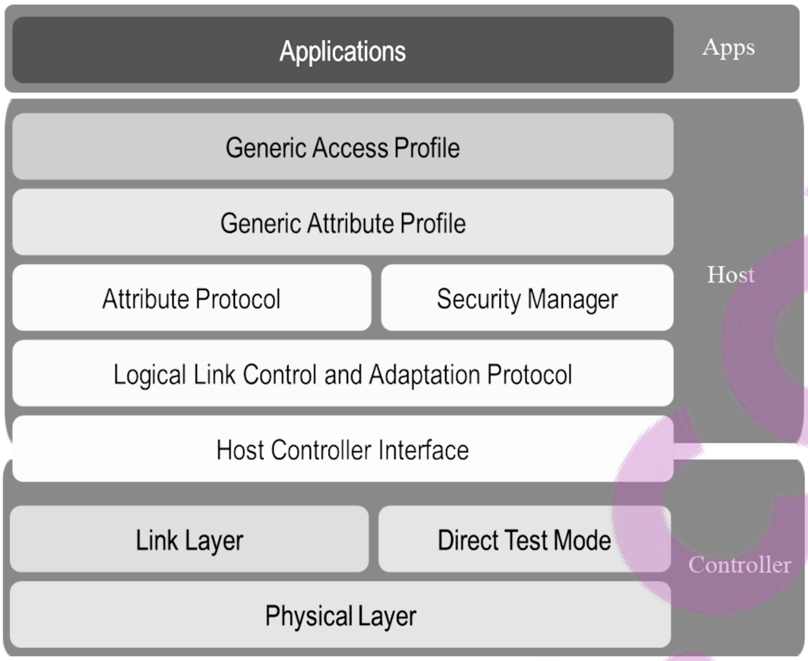


Figure 3: BLE architecture [11, p. 27].

Physical layer

In the physical layer are the radio signals transmitted and received using a 2.4 GHz radio. The data in a received signal is interpreted by the amplitude, phase and frequency of the wave [11, p. 27]. In BLE radio frequencies are switching between zero and one by using Gaussian Frequency Shift Keying (GFSK), which is modulation scheme. Shift Keying allows ones and zeros to be implemented with slightly shifting frequency up or down. BLE channels are stacked upon each other, and BLE uses something called Adaptive Frequency Hopping Spread Spectrum (AFHSS) [11, p. 27]. This allows signals to be spread over several frequencies and solves a problem with data channels on radio devices. Two data channels next to each other have very similar frequencies, and a “zero” sent on the lowest frequency of a data channel could be interpreted as a “one” on the highest frequency of the data channel below. This way, some space between frequencies is introduced.

Link Layer

The Link Layer is a complex part of the BLE architecture, which is responsible for several of the radio communications activities. Scanning for, Advertising, creating and maintaining connections between BLE devices are some of the link layers’ responsibilities. Another responsibility is to make sure that data packages are structured correctly. A package is a data being transferred over the radio according to a specific procedure. The handle packages three basic concepts are used: Packet, Channels and Procedures.

In order for the radio to be more energy efficient than regular BT, BLE uses fewer channels than BT. Instead of 79 channels BLE has 40 [11, p. 55]. Out of those 40 channels, BLE utilises three as advertising channels used by slave units to advertise their presence, and the other 37 as data channels used to transfer data. The three advertising channels are spread across the entire range of channels to avoid collisions and interference and the 37 data channels are used through an adaptive frequency-hopping engine that ensures stable connections and data transfer [11, p. 55]. The Figure 4, below, BLE channels range and the frequencies used are illustrated. The channels marked as green are advertising channels.

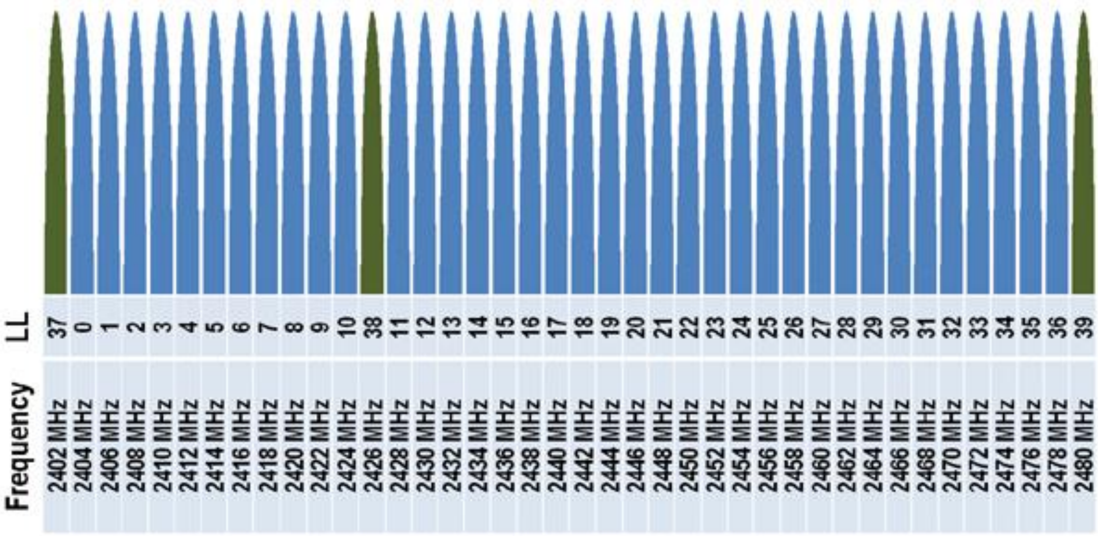


Figure 4: BLE advertising and data channels. 37, 38 and 39 are advertising channels [12].

Any BLE device can hear the broadcasts from other devices on the advertising channels, the small amount of data on these channels are public to any device within range. However, the data channels can be encrypted. The encryption, as well as the destination and the actual content of the package, must first be defined according to the BLE standard. Packages look the same if they are sent as broadcasts on the advertising channels as if they are sent as actual data on the data channels. The minimal size of a package is 80 bits, which is the number of bits required to send an empty package [11, pp. 76-84]. An empty package means that there is no payload, useful data, being sent. All packages, non-dependent on the content or purpose, are structured the same way and contains the following parts:

- A preamble of 8-bits, which is enough to let the receiver synchronize its internal bit timing and sets the radio to automatic gain control.
- A 32-bit access address, which is the receivers’ address but fixed for broadcasting packages.
- An 8-bit header

  - An 8-bit length defining the length of the package. Not all bits are used here due to a maximum of 37 octets of payload are allowed in the package.
  - Payload, the number of bits depends on the actual information being sent.
  - A 24-bit Cyclic Redundancy Check (CRC) makes sure that no bit error goes unnoticed.

In most cases, some data are going to be sent in the packages. The sizes of the packages depend on the information contained in it, but 376 bits are the largest packages allowed in the BLE standard [11, pp. 76-84]. Figure 5, below, is an illustration of a typical BLE package. In the image, all the needed parts are illustrated and marked with their size in bits.

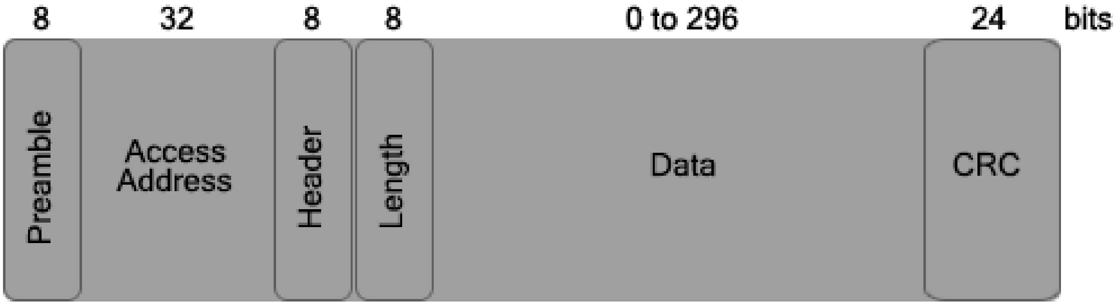


Figure 5: A typical BLE package [11, pp. 76-84].

Generic attribute profile – GATT

As mentioned before, BLE devices have two configuration options; they can be configured as masters or slaves. This configuration is made in the generic attribute profile (GATT). The GATT construction supports client and server communications between BLE devices at the application level [11, p. 231]. This is why the masters and slaves are known as clients and servers in the GATT profile. The GATT has three basic procedures: Discovering, server and client procedures. The server and client procedures are the way the different devices communicate and the discovering procedure is how the devices find and connects to each other [11, pp. 231-240].

Bluetooth low energy profiles

A common expression when talking about BLE is profiles. The profiles are basically the highest level of software in a BLE GATT server device. It is the software that makes the device perform certain tasks. The differences between different profiles are the kind of data they transmit. For instance, a thermometer profile transmits thermometer related data and a blood pressure profile transmits blood pressure data [11, pp. 294-299].

2.2 Positioning techniques

Generally, positioning using modern technology is based on radio signals being sent from a known object and location and received by a mobile device, which uses the data, transmitted in the radio signals, to navigate.

Radio frequency based (RF-based) positioning techniques can be divided into six different approaches: trilateration, time of flight (TOF), filter-based positioning, cell-based positioning, fingerprinting and triangulation [1].

The triangulation technique is the one being used in this thesis. Triangulation is a trigonometric way to determine the position of an object. It utilises the angle of arrival (AOA) or angle of departure (AOD) of radio signals to calculate the position of the radio signals source (the beacon node). There are several ways for the receiver to determine the AOA or AOD from a source of signals (beacon node). The receiver can be equipped with a directional antenna, a compass model, an antenna array or two ultrasonic receivers. Triangulation requires that the antennas be aware of the reference axis (X, Y, Z), against which the AOA from the transmitter being trigonometric calculated. [1]

The Quuppa IPS uses triangulation to determine the position of beacon nodes, and uses an antenna array to determine the AOA [5].

2.3 Standards for IPS using BLE

Since there are several different approaches and techniques to use BLE in an IPS, there are also different standards. In this section of the thesis, the different standards and approaches of using an antenna array to determine the AOA or the AOD will be discussed. There are basically two ways of looking at the data collection. The data collection is the measurements being sampled and used to calculate the position of a device. The first, centralisation, is when several antennas (Locators) are deployed in an environment, and are listening for radio signals (beacons) from a given source (tag), which marks the devices being positioned. The antennas collect signals from the tags and forward the data to a central unit that calculates the tag's position. Centralised systems could be seen as tracking systems, where individuals or devices carrying tags are tracked in a given environment.

The other approach is a distributed system. Distributed systems are basically the opposite of centralised systems. Here are beacons mounted in the same positions as the antennas in the centralised system. The beacons are transmitting signals, which the moving device hears and interprets, and calculates its own position.

Both of these approaches are described in more detail in the following sections. The different standards that exist and are under development are discussed here as well.

2.3.1 High Accuracy Indoor Positioning (HAIP)

There are several IPS that are said to be able to perform with high accuracy, but there is a few IPS that are classified as High Accuracy Indoor Positioning (HAIP) systems. HAIP is an IPS standard with accuracy of less than one meter (sub-meter accuracy) developed at Nokia Research Center [2]. In 2012, the original inventors of HAIP started Quuppa, a company that brings HAIP solutions to the market [14].

The HAIP technology utilises phased array antennas (PAA), which is several radio receivers connected in a system. The PAA is in some cases bi-directional, meaning that they are constructed of a set of radio components capable of both transmitting and receiving signals. In the HAIP standard, PAA is bi-directional. The PAA are used to determine the AOA of RF-based transmissions [3]. In the future, when the mobile-centric HAIP (MCHAIP) standard is released and available, the PAA could be used to determine the AOD of the RF transmissions.

When a PAA receives a signal, there is an implicit delay in the signal arriving at the different sensors in the PAA [15, p. 2]. The sensors are mounted with some distance from each other, and the signal has a finite velocity. The delay at each sensor will be different from the next. Because of this, the PAA can calculate from what direction the signal is arriving, and the array can be tuned to focus in a specific direction. This is called Beamforming [15, p. 2]. Different configuration of antenna elements within the PAA gives different reception and radiation patterns [16, pp. 10-16]. Figure 6, below, is an example of this. Here four antenna elements have been placed with different spacing from each other during tests.

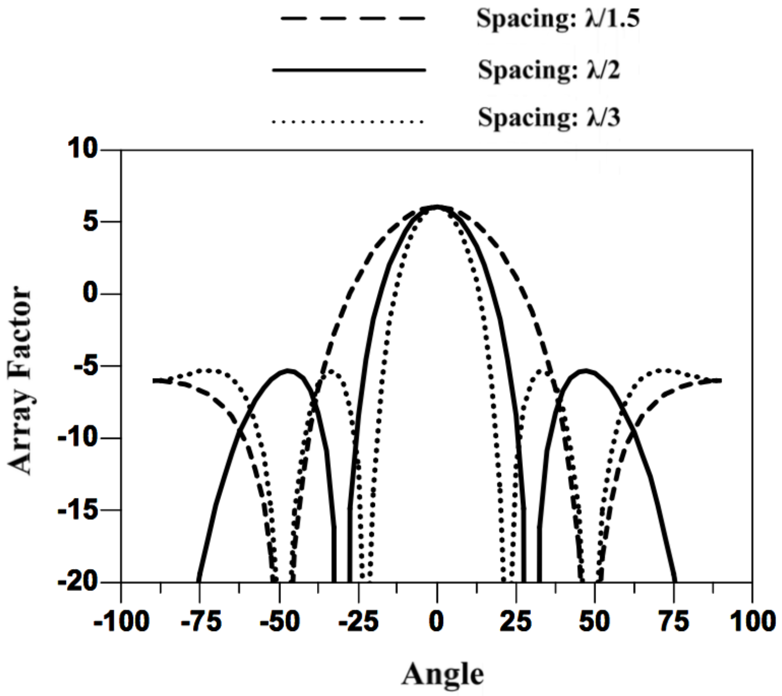


Figure 6: PAA with 4 antenna elements arranged with different spacing [16, p. 15].

In the Figure 7, below, the positioning principle of HAIP is illustrated. The PAA is located in a device referred to as "HAIP Locator". The HAIP Locator has a fixed, known position, and it is fully aware of the reference axis (X, Y, Z).

The HAIP Tag is a device that broadcasts data about itself using BLE signals. These signals are what the HAIP Locator is using to determine the location of the HAIP Tag. The Locators internal PAA makes it possible for a single HAIP Locator to, with high accuracy, estimate the location of the HAIP Tag in a two-dimensional coordinate system [2] [3].

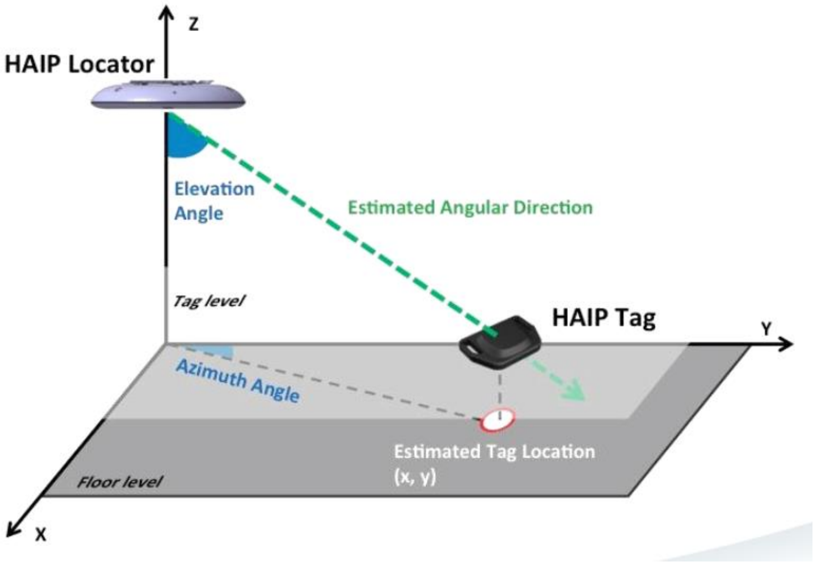


Figure 7: Positioning principle of HAIP [3].

Using two or more HAIP Locators give the possibility to calculate the HAIP Tag in a three-dimensional coordinate system. In Figure 8, below, a case where two HAIP Locators are used to determine the location of an HAIP Tag, or in this case a smartphone, in a three-dimensional coordinate system is seen.

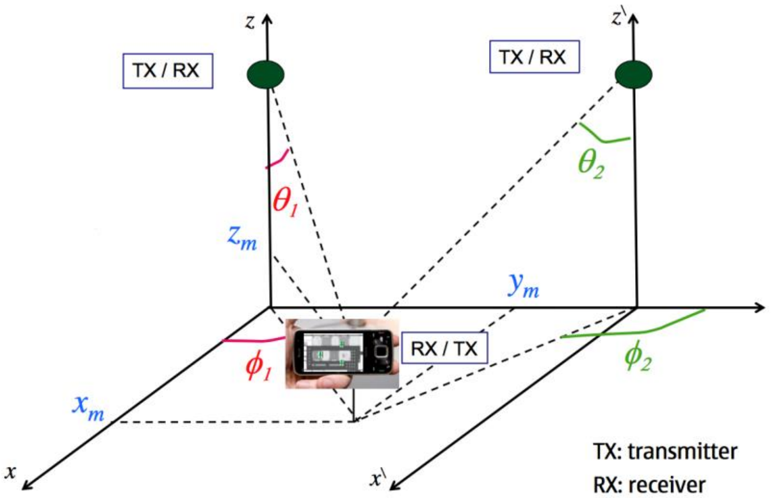


Figure 8: Positioning principle with two HAIP Locators [2].

The accuracy of the location estimates depends at large on how accurate the PAA itself is, and how much of the received radio signals are non-reflected signals. The

PAA in the HAIP Locators of the Quuppa system have a reception angle of roughly 100 degrees (°) where the signals are likely to generate high location precision, and a reception angle of roughly 130° where the precision is reduced [3].

2.3.2 Centralised

Network Centric High Accuracy Indoor Positioning (NCHAIP)

NCHAIP is an HAIP system where a tag is broadcasting (ping) its location [3]. Locators typically mounted in the ceiling retrieve the radio signals, and a central control unit, which is connected to the locators, is calculating the location of the tag. NCHAIP is a track and trace system where the position and location of devices are known by the control unit.

2.3.3 Distributed

Mobile Centric High Accuracy Indoor Positioning (MCHAIP)

MCHAIP is a pending standard for a distributed version of the NCHAIP [3]. In the MCHAIP, the locators are now transmitting data instead of listening. They transmit data about their own location for the recipient device to use as reference to calculate its own location. The MCHAIP system, in its functionality, is closer and more typically a navigation system than NCHAIP. Only the device receiving the RF-based signals knows its location. Seen from a privacy perspective, this approach is preferable since no one else has access to the location of the device. It is private.

2.4 The CCIPS

As discussed in the chapter 2.3, HAIP systems have two major disciplines, of which only the NCHAIP standard is available on the market. NCHAIP systems are designed for tracking of objects and offer little support for navigation. Creating a conceptual crossover indoors positioning system (CCIPS) could fill the void of the MCHAIP standard and missing features of the NCHAIP standard. This is discussed in detail in 4.1.1.

2.5 Embedded sensors in smartphones

Smartphones have a variety of embedded sensors that are being used by the phone for different purposes, such as controls for games and for determining the brightness of the screen. Considering the Locantis as a possible replacement system for the established IPS of today puts a smart device as a central component embedded in the exercise participant's equipment. This means that the smartphones embedded sensors could beneficially be used together with the positioning data from Locantis.

Samsung Galaxy S5 (SM-G900F), which is a popular phone on the market today and it is a device that is considered to be a valid platform for the Locantis investigation, has a variety of sensors that can be used in combination with the Locantis positioning data. It has [17]:

- Gesture sensor
- Fingerprint sensor
- Hall sensor
- Accelerometer
- Geomagnetic sensor
- Gyro sensor
- Light sensor
- Barometer
- Proximity sensor

Some of these sensors are of more interest than others for applications such as Locantis. Two of the sensors that have been considered and are of interest are the geomagnetic sensor and the accelerometer. The geomagnetic sensor is of interest since it could be used give the geomagnetic heading acting as a compass. Using the compass could give the heading of exercise participants. The heading could be estimated without the compass if the direction of movement is considered to always be face forward. However, since a human being can walk forwards, backwards and sideways, a more realistic and natural movement is desirable and an appropriate goal of the implementation.

Knowing the heading could give better indications of what directions possible dangers could be in relation to an exercise participant.

This information could be used to improve the simulation systems’ equipment and environmental fidelity and let the system give more realistic data in the exercise model regarding movement and even damage levels to participants in the simulation. Improved damage levels could impact on participants during the simulation, while realistic movement helps the reviewers of the simulation to give more accurate feedback to the participants after the simulation.

The accelerometer could be used when measuring how much exercise participants are moving and how much they are standing still. A tactical simulation, where the mission is to test stealth abilities, would have much lower acceleration forces on the accelerometer than in a full speed simulation. The acceleration data could be used as an indication of how well exercise participants are performing in different simulations. It would potentially be possible to introduce new damage levels where the simulation takes into account exercise participants acting recklessly and injuring themselves, for instance when falling. The accelerometer could also be used to confirm or discard possible errors occurring when simulations are being reviewed. Glitches and temporary signal losses might cause tracked objects, such as exercise and simulation participants, appear to “jump” and “leap” long distances faster than they actually have, or to slowly move when they are actually at rest. Such phenomena can occur when the tracking equipment temporary loses the signal or misses a position update.

Accelerometer data could be compared to data from the IPS to eliminate odd behaviour from the simulation after the simulation is finished. Reviewing and evaluation of the simulation and the participant’s behaviour is important for the purpose of the simulation, and processed reviewing material improve the visualisation of the simulation could enhance the impact of the simulation.

2.6 Precision, accuracy and granularity

In this thesis, precision, accuracy and granularity are very important factors. As stated in the Purpose and research questions, one of the purposes of this thesis is to test and verify the operational capabilities of the defined IPS. To give precision, accuracy and granularitymore meaning, an explanation is given here.

Precision is a measure of how great the variance is of a set of repeated measurements of a single position. When talking about location and positioning it can be said that precision quantifies the ability to repeat the determination of a position within a reference frame. [18]

Accuracy is a measure of how close a position is to reality, to the true value. This must be calculated mathematically. It is easier to achieve great accuracy through high precision. For location and position this is a measurement of how close the estimated and calculated position is to the absolute true physical position of the object that is being located. [18]

Figure 9, Figure 10, Figure 11 and Figure 12, below, exemplifies what high/low accuracy and precision look like.

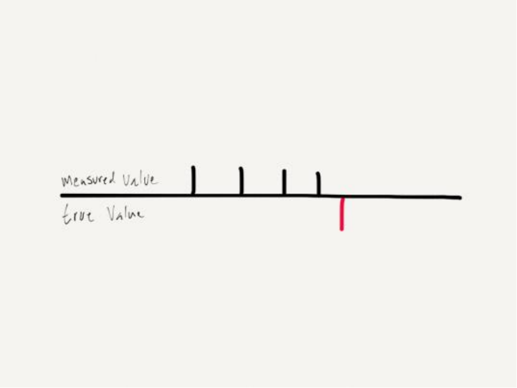


Figure 9: Low accuracy and precision.

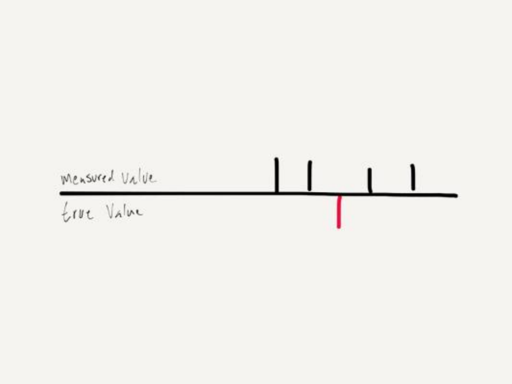


Figure 10: Accurate, but low precision.

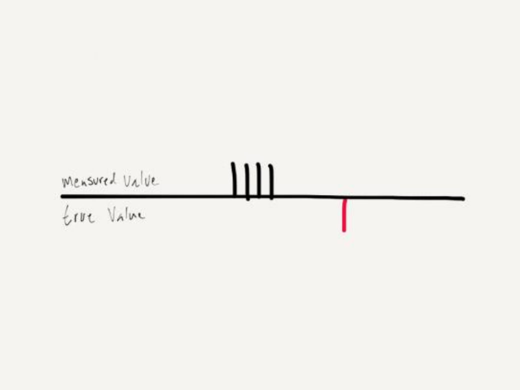


Figure 11: Precise, but low accuracy.

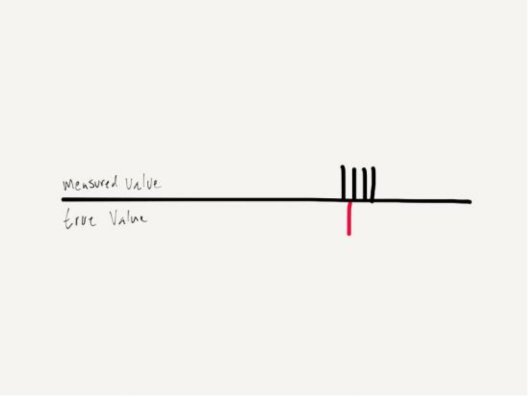


Figure 12: Both accurate and precise.

As we can see above, accuracy and precision is related to each other but not the same thing. Both rely on granularity, which is a static property of scale [19]. Take a ruler and a micrometre for instance. Both these instruments measure length using the same scale. However, the micrometre is much more precise since it has finer granularity of units. For this thesis, it can be said that measuring accuracy and precision is done to investigate the granularity of the IPS.

2.7 Simulations

This thesis is conducted to investigate how well a conceptual crossover system could work as replacement system for the established IPS used in environments where simulations are carried out. Simulations can mean different things to different individuals, especially if the individuals have different careers and backgrounds. To sort this out, an explanation to the concept simulation is given below.

In general, a simulation is an attempt to recreate characteristics of the real world in a controlled environment [20]. There are several benefits of using simulations and simulator devices during training. Simulations give the educator the possibility to control the learning environment by carefully changing aspects of the simulation to test participants' abilities to work with different scenarios. When talking about simulations, the word fidelity is frequently used. Fidelity is traditionally used as a measure of the degree of "realness" of a simulation. What high fidelity is has been lively debated, and opinions depend largely on debaters' background and what is considered to be important for simulations and simulators to them.

Rehmann A. and his colleagues proposed a typology where high fidelity is dependent on more than just the technical dimension [21]. This typology can be seen in **Figure 13** below. It suggests that technical aspects, such as how closely simulation equipment replicates the feel and appearance of a real system, environmental aspects, such as how realistically the simulation environment is, and the psychological aspect, how believable is it to the participants, are equally important for a high fidelity simulation. [20]

The maximal learning outcome from a simulation is reached when participants can act as they do in real life, and when realistic equipment and environment aspects let the participants relate to the scenario on a psychological level. That combination motivates them to see the simulation as vital experience and an opportunity to learn or perfect skills that later could be applicable in real life scenarios.

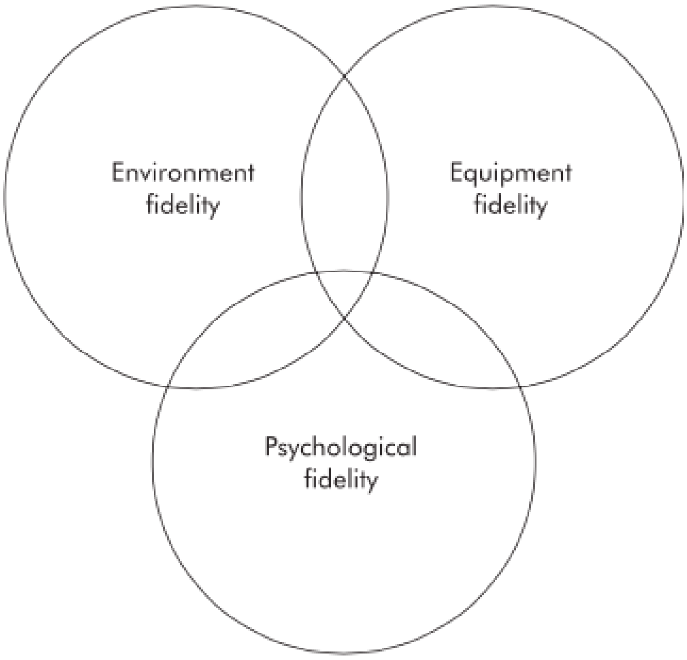


Figure 13: A typology for fidelity. Based on Rehmann et al, 1995 and modified by Beaubien & Baker. [20]

2.8 Exercise model

Improving the granularity of exercise participant's position when monitoring, in both real-time and post-exercise, could potentially affect the exercise model. The exercise model depends on the fidelity of the simulation, including both technical (equipment) and environmental aspects as discussed in chapter 2.7. The exercise model is to what degree a simulation is carried out, either if it is practicing of individual tasks or if it is a full-flagged simulation. If the granularity of the participant's position could be improved, monitoring of events taking place in close proximity to the exercise participants could also be improved. This could include monitoring of hidden objects, simulated unstable buildings and other dangers in the simulation. In combat simulations, where groups of exercise participants are exchanging simulated fire, damage levels from simulated grenades and mortar fire on exercise participants might have to be modified to better suite the higher granularity of the IPS. This could ultimately improve the simulations fidelity.

3 Method

This thesis investigates the current state of HAIP system standards. What future HAIP standards may offer, and how suitable they are as replacements for existing IPS that relies on old technology. This is done by carefully examining current systems available with the HAIP standard today, and by conducting experiments on a defined HAIP system. As previously mentioned, a hybrid method of experimental design and system development is used in this thesis. These two methods are selected based on the formulation of the research questions. Experimental research design is selected since this thesis seeks to answer questions about a specific IPS suitability as a replacement system. The other method is system development. It is selected in order to support the development of the CCIPS that is being used in the experiments. Data collected from the experiments using the developed prototype CCIPS are used to determine the accuracy, reliability and for what application purposes the BLE IPS is suitable.

3.1 Experimental research designs

Experimental research is a scientific method in which testing of hypothesis is done using reasoning processes to go from general principles towards individual instances [22, pp. 125-126]. Experiments are undertaken to trace cause and effect relations between variables defined specifically for the experiments.

In experimental research, it is typical to use some terminology that normally is not used to describe every day scenarios. [22, pp. 126-127]inspires the terminology used in the experiments for this thesis, and here stated and explained:

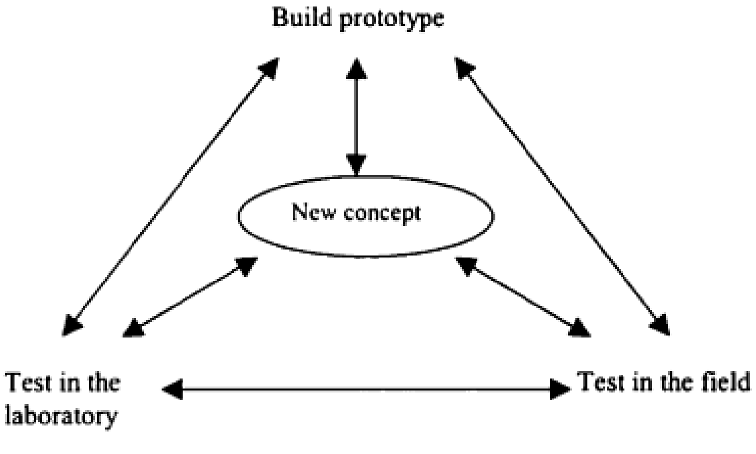
> *Hypothesis* - proposition or statement about predictions in relations between variables. Hypothesis exists in hierarchies going from general to operational hypothesis.
>
> *Independent variable:* factors that are under investigation. This variable is manipulated in order to see what changes are caused on other variables.
>
> *Dependent variable:* elements and/or factors that are being measured in order to determine the effects of the changes on the independent variables.
>
> *Extraneous variables:* unknown factors, which are not a part of the scope of the study but which, can be assumed to have some observable effects on the dependent variables.

3.2 System development

System development as a research model can be considered to be an engineering type of research that falls under the applied science category. It is based on the general assumption and philosophical belief that development, without exception, is associated with exploration, advanced application and realization of theory. [22, p. 148]

The system development approach as a research model may be classified as "research and development" when theory and scientific knowledge are used to produce artefacts, such as devices, systems or methods including the actual design and development of prototype process. [22, p. 148]

System development commonly exists as a "state" in a generalised research process model for information system research. The actual system development as a research procedure can be used to address an existing problem, from which a hypothesis has emerged, to produce artefacts in forms of systems and system prototypes. System development is firmly oriented around the testing of theories, and as Figure 14 indicates, has less focus on the theory building aspect than other research methods. It can be used to prove theories and can be thought of as proof-of-concept or proof-by-demonstration. [22, pp. 148-151]



(available from http://www.cmi.arizona.edu/)

Figure 14: The CMI Arizona research model, as can be found on the University of Arizona web page [22, p. 151].

4 Implementation

This chapter is allocated to explain how the chose research methods were implemented, what was developed, and how the experimental procedures were planned and conducted.

4.1 Application development

The application developed for this research was an Android application. The application was developed using Android Studio [23], which is an integrated development environment (IDE) for development on the Android platform. Android Studio is a relatively new IDE. It is based on JetBrains IntelliJ IDE, and the first stable version of Android Studio was released in December 2014 [24].

4.1.1 Locantis

The CCIPS that is designed for this thesis has been named Locantis. It is a crossover system between a centralized and a distributed IPS, in which the centralized system has means of distributing its location data. In this case, a NCHAIP system is being used as the platform for collecting location data of the objects being tracked. By distributing the collected location data to a mobile device, providing navigation is a possibility.

The Locantis system is the first NCHAIP system that has means of distribution of location data to a mobile device using Wi-Fi connections. This possibility has not been provided before. Figure 15 is a concept picture of the Locantis system, and shows how different communication types are used. Locantis also provides the possibility to experiment with different combinations of data from the embedded sensors in the android smartphone combined with the location data provided by the NCHAIP system. The embedded sensors that are available in a smart device, and how they can be used together with the location data from the Quuppa system, are covered in a later section: 4.1.2.

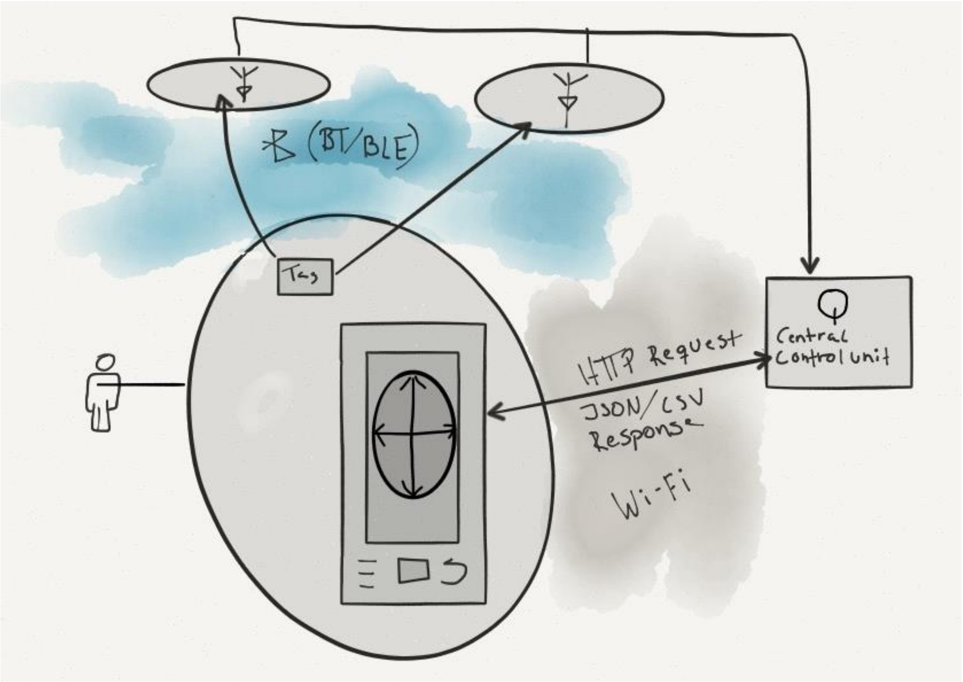


Figure 15: A concept picture of the Locantis CCIPS. Blue colour indicates BLE communication and grey colour indicates Wi-Fi communication. The needed infrastructure, central control unit and locators, can be seen as well.

As explained above and shown in Figure 15, Locantis is based on a centralised IPS to collect position data and a smart device that acts recipient in a semi-distributed system. Adding more technology and changing the purpose of the system to the one of Locantis creates a new timeline of events. When Locantis is active and running four major events, tag ping, position estimated, request and retrieve position data, are taking place. An example of this can be seen in Figure 16, where the duration of little more than one second is illustrated. The red square marks the events that would be taking place within the duration of one second. Here, the tag is configured to ping its location with 5 Hz and Locantis app is requesting positioning data at 2Hz.

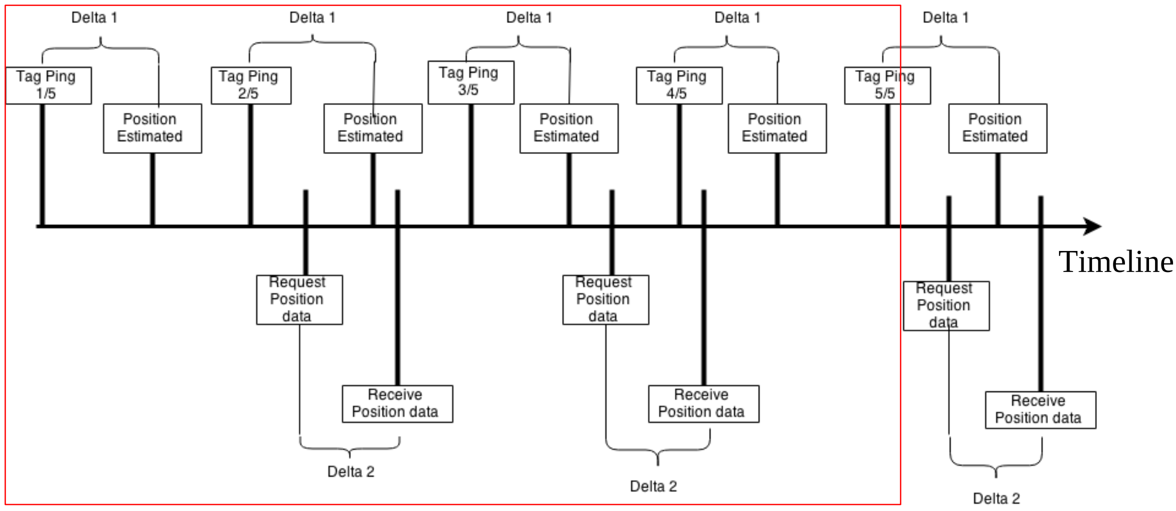


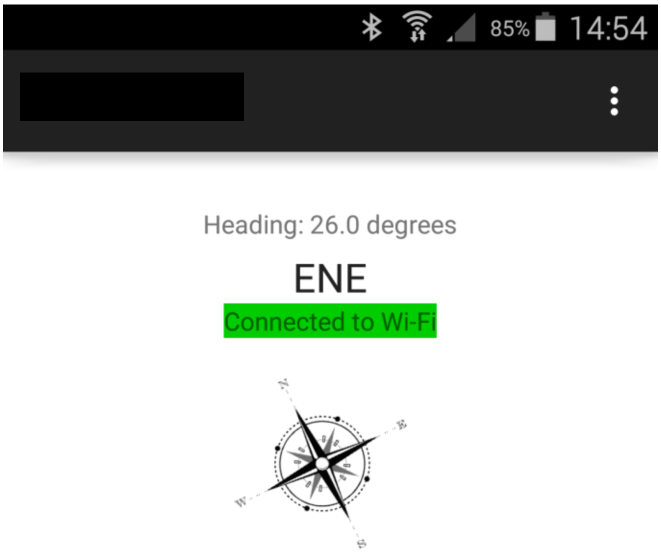
Figure 16: Locantis timeline of events.

The experimental investigation determines the performance of Locantis by examining how the system is reacting to controlled changes made within the system. In chapter 3.1, the terminology for the experimental investigation is stated and explained. Delta 1 & 2, as can be seen in Figure 16, are under investigation and described in more detail in 4.2.3 and 4.2.3, where the experiments are stated and explained.

4.1.2 Embedded sensors

In chapter 2.5 a number of sensors are listed and two are stated as interesting for this thesis and implementation into Locantis. In this thesis the smartphone running Locantis application is not embedded in any other equipment and is a standalone device. To prove the concept of data combination of the embedded sensor data combined with positioning data, all data is displayed on the smartphones display. In the future, this data would be used as discussed in chapter 2.5.

The geomagnetic sensors application-programming interface (API) is used as a compass to display the heading of exercise participants. The heading and compass data are displayed as shown Figure 17 below. Here it is seen that the current heading is 26° to east-northeast.



[redacted]

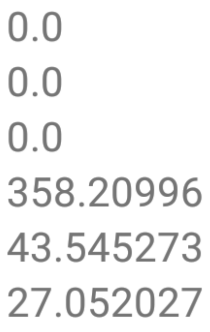
Heading: 26.0 degrees

ENE

Connected to Wi-Fi

Figure 17: Compass and heading representation in Locantis app.

The accelerometer data is collected using the accelerometer API. The accelerometer gives values for acceleration forces on the device in relation to X, Y and Z reference planes. The values are represented as numerical values. In **Figure 18**, below, the acceleration data representation can be seen. These values are from a device that has undergone heavy shaking and then positioned flat on the back on top of a table. The first three rows are the current acceleration forces on the device and the later three rows are maximum-recorded acceleration forces on the device. It should be noted that 0.0 means that there is no change in force on the device. In reality, objects at rest are under the force of 1.0 G in reference to the Z plane.



```
0.0
0.0
0.0
358.20996
43.545273
27.052027
```

Figure 18: Acceleration values representation in Locantis app.

4.1.3 Communication

In order for the smartphone with the developed application to be able to receive the centrally collected positioning data the application must have some means of communication. Having a smartphone as a platform for simulation equipment has some benefits regarding the communication. Smartphones today have several means of radio communication, such as GSM, 3G, 4G, BT and Wi-Fi, that could be used for this purpose. In this project, Wi-Fi is considered to be the most sufficient and suitable mean of communication for distribution of the positioning data. Wi-Fi requires access points the smartphone can connect to. In this project, the experimental procedure is taking place in a room small enough for only one access point to be required in order to be able to conduct the investigation. Measuring the receiver signal strength indicator (RSSI) value of the single Wi-Fi access point in this investigation ensures that this is the case.

Locantis app receives positioning data by sending HTTP requests to a uniform resource locator (URL) that is unique for the tag that is being tracked. This way of distribution provides posibility to request positioning data from a single tag. There are other ways that the positioning data could be distributed. For instance, user datagram protocol (UDP). This way the NCHAIP system broadcasts the positioning data on a designate internet protocol address (IP address) and the receiving device are listening for broadcasts on that specific IP address. HTTP requests are selected as the way for Locantis app to receive positioning data since the implementation is fairly straight forward and HTTP requests can provide high enough update frequency.

4.2 Experimental research

In this chapter the experimental investigation is discussed. The experiments are explained and the different components used are stated.

4.2.1 Experimental set up

The experiments designed for this thesis are conducted in what will be an office landscape, but for now is empty. The testing and experiment area is some 130 m^2 with concrete walls and roof pillars. The IPS used in the experiments is a NCHAIP system from Quuppa. The system consists of five HAIP locators, a power over Ethernet (POE) switch that connects the HAIP locators and a HAIP controller in a wired network, and 15 HAIP tags included in the demo kit. Figure 19 shows how the different components of HAIP system are connected to each other.

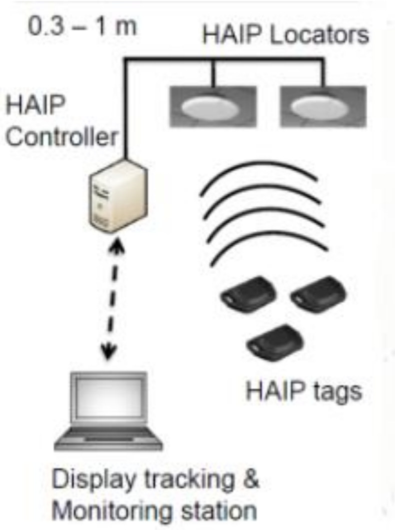


Figure 19: Network centric HAIP system that is being used during the experiments.

HAIP Locators

HAIP locators are the name of the arrayed antenna elements that are used individually to estimate the location of the tracked objects. Each locators of this NCHAIP system contain nine radio antenna components in an arrayed antenna. The locators are mounted in the ceiling at a tilt elevation angle of 0°.

HAIP Tag setup, configuration and frequency

The frequency on an HAIP tag determines how often the IPS will know the location of the tag, and also decides how much information the IPS has to work with. The NCHAIP system used in these experiments have the possibility to configure the tags to use BLE or regular BT. In these experiments the emphasis is on tags communicating using BLE and the tags are only configured to BLE advertisement on BLE channel 37. The frequency of the tag configured to BLE is in the span of 2Hz to 9Hz. The tags are mounted on a 100x100x600 mm piece of wood. This arrangement is easy to move and gives some elevation from the steel reinforced concrete floor that is believed to cause some distortion.

HAIP controller

HAIP controller is the machine, computer or server, which is running the IPS necessary software's and it is used to start and stop the IPS. In the demo kit that is being used for this study, the HAIP controller is a Mac mini computer with a Linux-based operating system. Since the Mac mini is a computer and not an unmitigated server, it is connected to keyboard, mouse and screen, which enable real-time monitoring of the tags.

Display Tracking & Monitoring station

Display tracking and monitoring station indicates that real-time monitoring of the tags can be made on external monitoring station that are connected to the HAIP controller.

Figure 20 shows the deployment of the NCHAIP system in the empty office landscaped used during the experiments. In **Figure 20**, the circular objects represents the HAIP locators and the square objects represents known physical locations that are used as reference points when the true physical location of the locators is triangulated. These reference points are not used for anything else. The red lines indicate the X- and Y-axis of the coordinate system in which the NCHAIP system operates. All measurements and coordinates are in reference to the origin (0.0) of the coordinate system, which is in the cross section of the red lines.

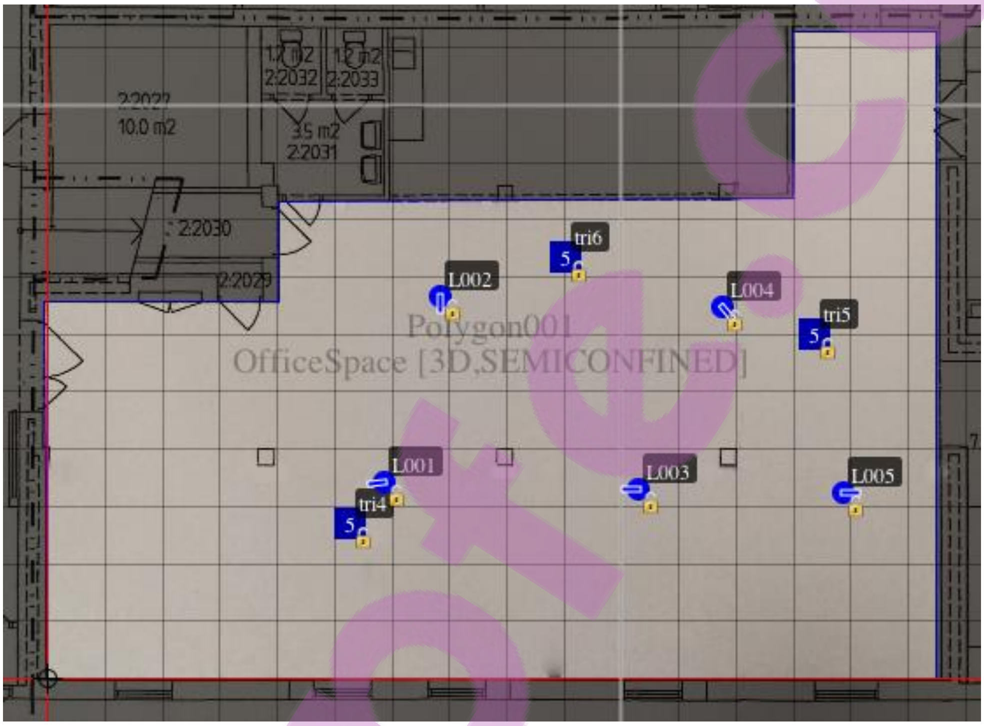


Figure 20: Experimental setup of the NCHAIP.

4.2.2 Experimental design

General Hypothesis

The CCIPS is a good replacement system for the established IR-based IPSs that are being used in simulation environments today. The CCIPS can perform within sub-meter accuracy and that latency of the information delivery (distribution) is within the real-time requirements set up for it to be a viable contender as replacement system for the established IPS.

Dependant variable

Precision and accuracy of the location are the dependent variables of these experiments. As explained before, it is important to have both good accuracy and precision in order to be able to rely on the derived location data.

Independent variable

In the experiments conducted, the independent variables that are being manipulated are:

- Ping frequency (Ping Frq) of the tag.
- Request rate (RR) of information on the Locantis app.
- Tag movement, either stationary or moving.
- Tag configuration

The tags can be configured as either single tags or combinations of tags. This means that two or more tags are used to estimate an object's location. The returned location estimates are the combined data of the tags in the combination. This feature is being used in Experiment 3: Estimation accuracy and precision.

Data collection

To be able to determine the suitability of the crossover concept as a suitable replacement system for today's existing IPSs, some data need to be collected and analysed. This is done by conducting experiments and collecting generated data during the time of the experiments. Data from Experiment 1: Delta time 1 and Experiment 3: Estimation accuracy and precision is collected in log files on the NCHAIP controller. Data from Experiment 2: Delta time 2 is collected from log files generated by the Locantis app. Data from Experiment 2: Delta time 2 is logged by the Locantis app and saved locally on the android phone in order to save time and to avoid having to establish additional connections.

4.2.3 Experiment 1: Delta time 1

The first experiment is to determine how long it takes the NCHAIP system to estimate and calculate the location of the tracked object. This is done to investigate if the location process is fast enough for the system to be viable from a real time perspective. Delta time 1 is calculated by the time difference between the "tags ping" and the instance the NCHAIP has located the origin of that tag.

This experiment is conducted in different configurations, where the tags have different frequencies, and are either stationary or moving. The frequencies selected for this experiment is 2Hz, 5Hz and 9Hz. They are selected to represent slow, medium and high frequency settings in the 2-9Hz-frequency span that is supported BLE frequencies in this NCHAIP system. Figure 21 below shows the different tag configurations for this experiment. All configurations are for single tags if nothing else is stated. "Two-tag combo" indicates that the tag configuration is for a combination of two tags.

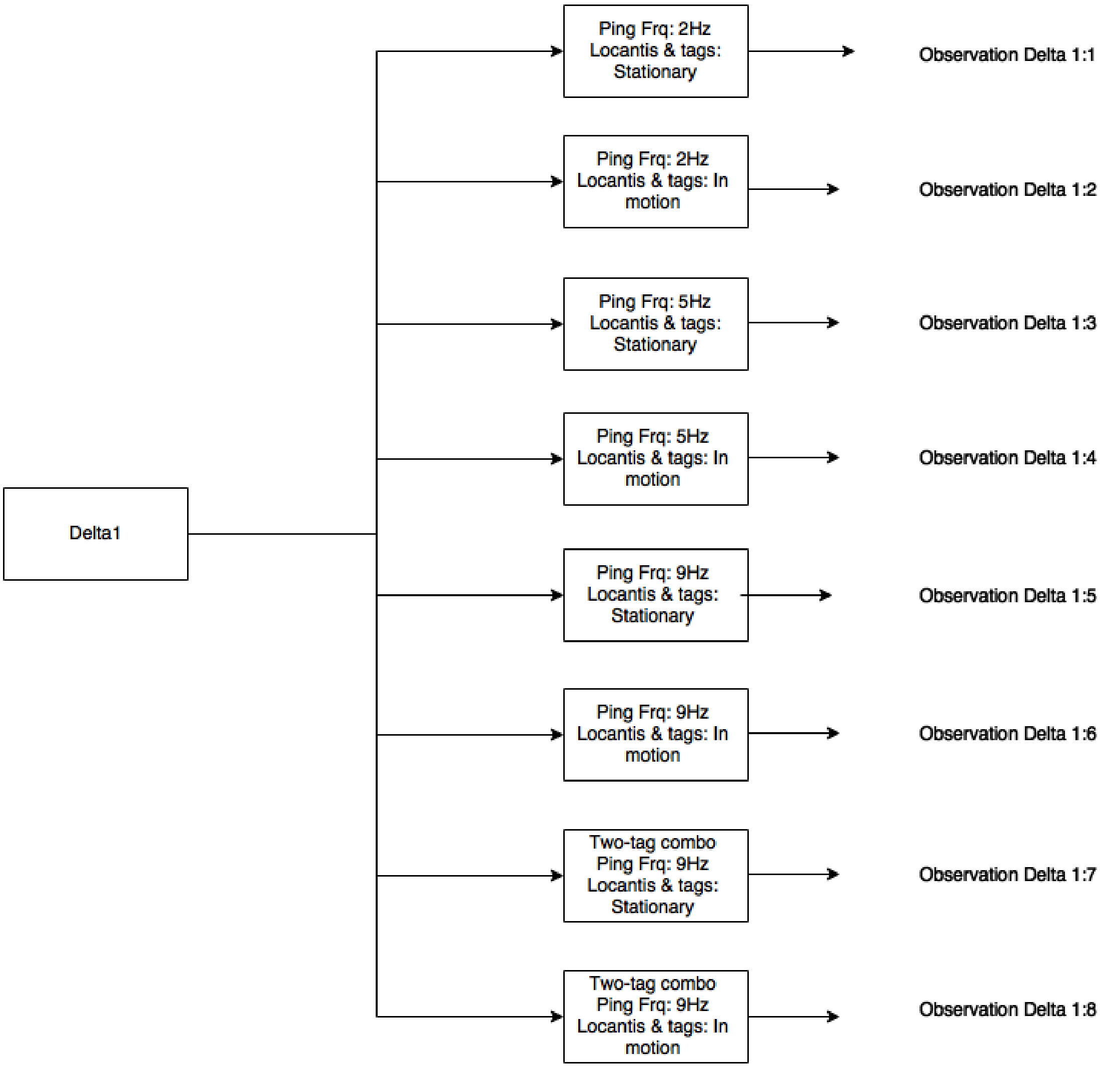


Figure 21: Experimental groups for Delta time 1 experiment.

The objective is to find out if the different configurations have impact on Delta time 1, which is the time it takes the NCHAIP system to estimate where the tag is. Figure 22, below, shows where in the CCIPS the tag is located. In this experiment the focus is on the tag and the android device running Locantis app is stationary during the experiment. Observations of moving tags are compared to observations of stationary tags in order to test the operational hypothesis.

Operational Hypothesis: Moving and stationary tags have the same Delta time 1, tag configurations with different "ping frequencies" have no impact on Delta time1.

Independent variables: Tag configurations, ping frequencies and if the tags are stationary or moving.

Dependent variables: Delta time 1.

Extraneous variables: Non- equal and non- constant BLE coverage; both are difficult to verify or dismiss.

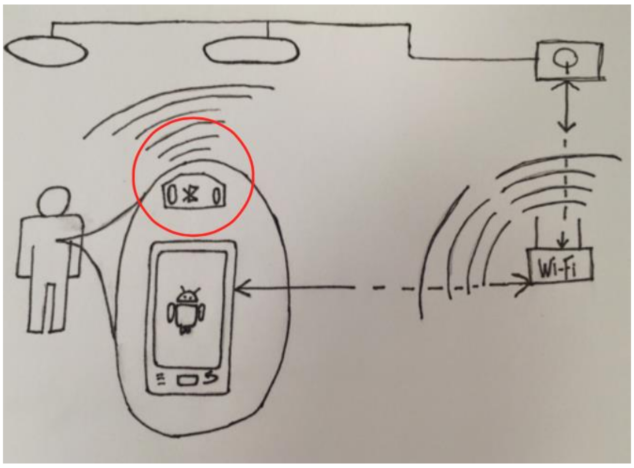
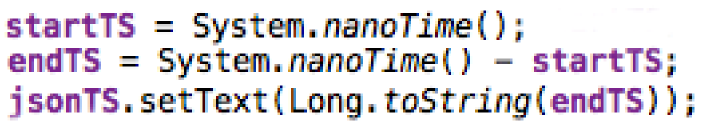


Figure 22: The tag frequency and configuration as independent variables.

4.2.4 Experiment 2: Delta time 2

The Locantis app is supposed to be running on an android device carried by the simulation participant who is also carrying the tag. This provides the possibility to distribute the participant's own location back to him or her. The second experiment is to investigate the time it takes to distribute the location information to the Locantis app from the NCHAIP system. Delta time 2 is the time it takes Locantis app to request and to receive the location information from the NCHAIP system. Figure 23 is an illustration of the code snippets that are used to start and stop the timer function on Locantis app.



```
startTS = System.nanoTime();
endTS = System.nanoTime() - startTS;
jsonTS.setText(Long.toString(endTS));
```

Figure 23: System nano time function that is used to start and stop the timer for Delta time 2.

This experiment is conducted in different modes, where Locantis app has different request rates (RR) and is either stationary, with stationary tags, or moving together with the tags. The objective is to find out if Delta time 2 increases when the request rate increases. Figure 24, below, shows where the Locantis app is in the CCIPS.

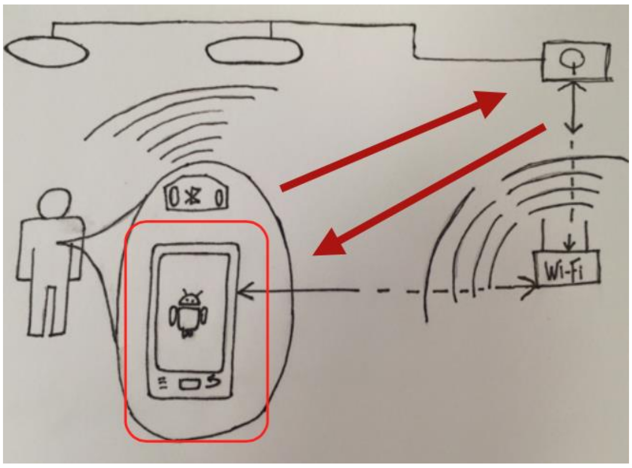


Figure 24: The Locantis app requesting and receiving location data from the NCHAIP system using Wi-Fi connections.

To cover all the previously mentioned modes in this experiment, some experimental groups are formulated. Figure 25 shows the experimental groups that are used in this experiment. The experimental groups have request rate (RR) of 1Hz, 2Hz, or 4Hz. Observations are made when Locantis app and the tags are both stationary and moving. This is to simulate when an exercise participant is stationary and in motion.

At this point, the tag configuration is not important. Since this experiment focuses on the request-response time rather than the actual content of the response, the tag frequency has very little or no impact at al on the experiment.

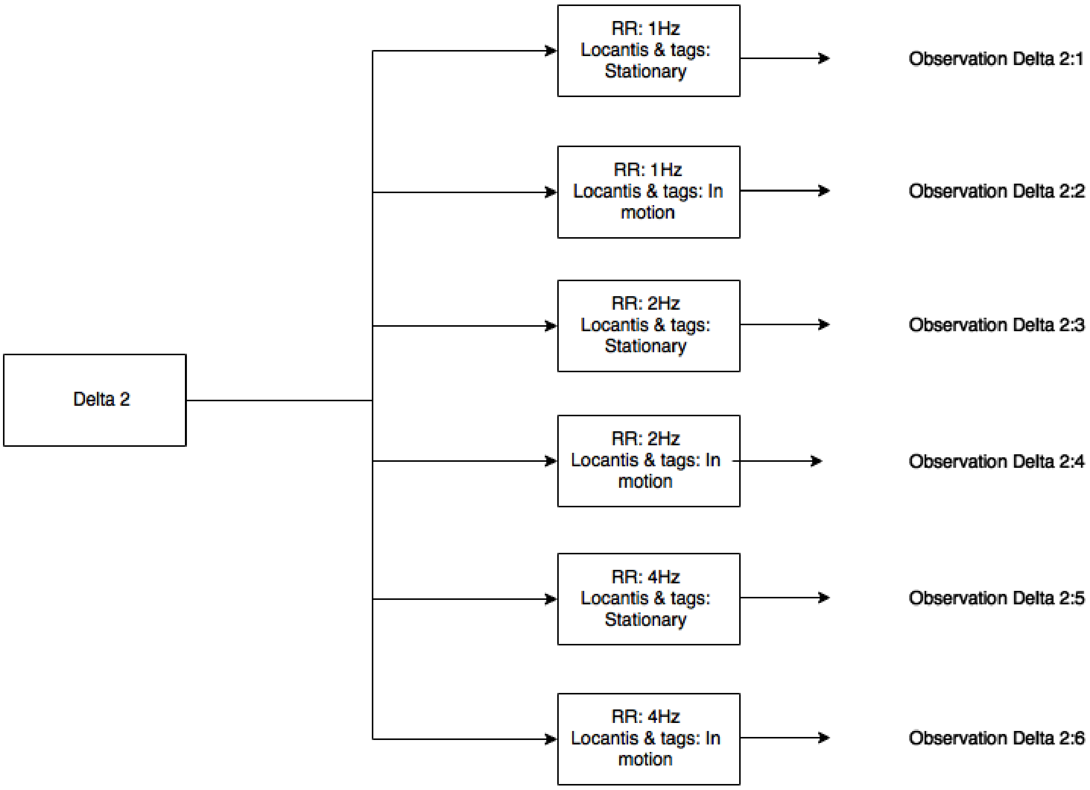


Figure 25: Experimental groups for Delta time 2 experiment. "Stationary and "Moving" refers to both the Locantis app and the tags.

Operational Hypothesis: Increased request rate dose not impact the information's delivery time (Delta time 2).

Independent variables: Request rate set on the Locantis app.

Dependent variables: Delta time 2.

Extraneous variables: Non- equal and non- constant Wi-Fi coverage, difficult to verify or dismiss.

4.2.5 Experiment 3: Estimation accuracy and precision

The NCHAIP system used to locate and estimate the location of tags being tracked has sub-meter accuracy. This means that the estimation of the tag location is less than a meter away from the real physical tag. Granularity is one of the most important aspects of this investigation, and here the accuracy and precision are being tested. As previously stated, the tags can be configured in several different ways, and one of the possible configurations supports combinations of tags. This means that two or more tags are used to represent a common object. The location data generated from this configuration is seen as a single "tagged object" and it is the combination of all the tags. Both a single tag and the two-tag combination are used in this experiment. As discussed above, the tags are positioned to be clear of any distortion from steel reinforcements in the floor and in the case of the two-tag combo configuration; the tags are positioned centre-to-centre 550 millimetres apart. Two tags are combined as on in this experiment to simulate the effects of two tags positioned on the shoulders of a simulation participant and to investigate if the two-tag combination centre point has the same or even greater accuracy and precision than a single tag.

The tag estimates done in this experiment are compared to 14 randomly selected reference points. The reference points are selected at random in the area where the NCHAIP is most likely to have good coverage. The coverage estimation is determined using Quuppa site planner and deployment tools option for rendering coverage estimate. The reference points are marked up on the floor with tape and are measured against the origin (0.0) in the coordinate system where the NCHAIP system is working using laser tape measure. This gives the reference points coordinates with a margin of error of less than 5 mm, which is considered to have insignificant impact on the observations. **Figure 26**, below, shows these 14 reference points in the area where the experiments are conducted and **Figure 27** shows the rendered coverage estimates.

During the experiment, the tag rig is positioned with its centre point on the reference point and the tag rig aligning the Y-axis. The correctness of the aligning along the Y-axis is not critical since it is the centre point compared to the reference point that is interesting. However, to have some consistency during the measures, the rig is aligned against the tape and markings on the floor.

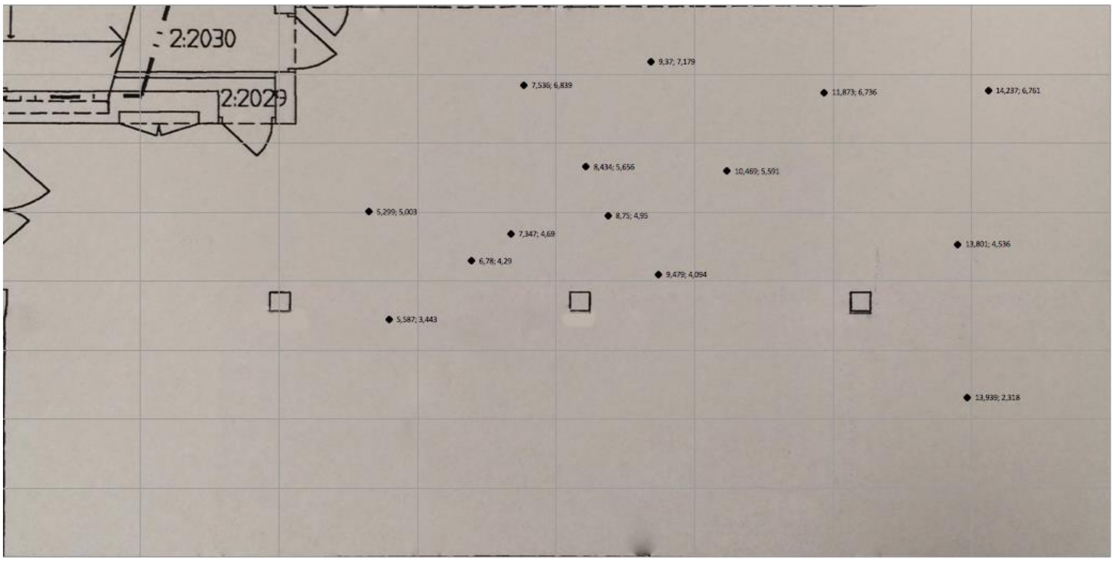


Figure 26: Fixed, known reference points used for the granularity experiment.

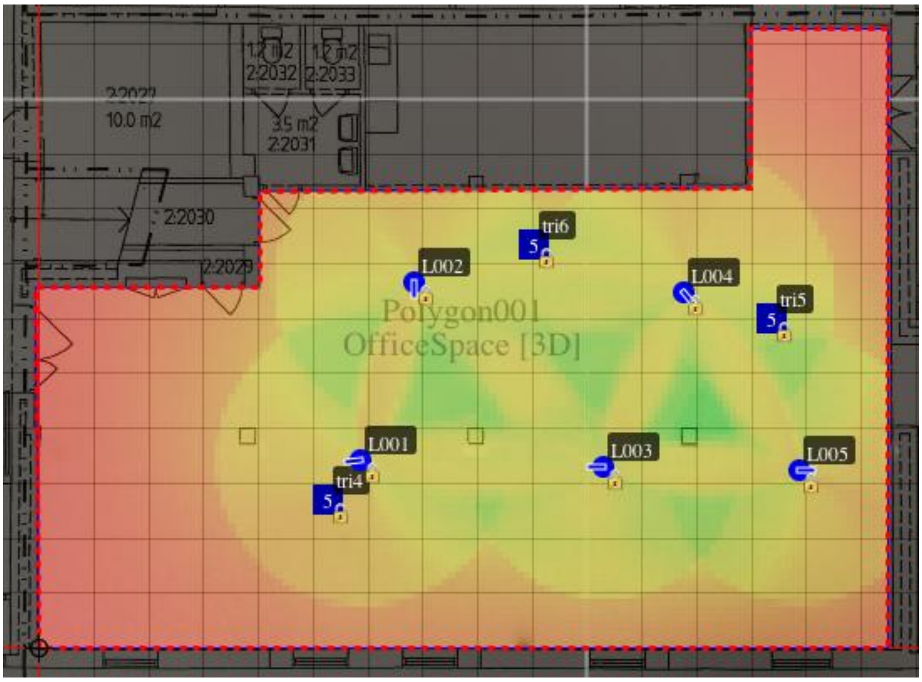


Figure 27: Rendered coverage estimate using Quuppa site planner and deployment tool.

Operational Hypothesis 1: The granularity (accuracy) of the NCHAIP system is within 300 mm of the physical reference points.

Operational Hypothesis 2: The combo-Tag configuration has greater accuracy and precision than the single tag configuration.

Independent variables: Tag configurations, both single tag and combo tag configurations.

Dependent variables: Accuracy and granularity of the tag location.

Extraneous variables: Non- equal and non- constant BLE coverage and distortions in the environment, such as from steel reinforced concrete. This is difficult to dismiss despite countermeasures.

4.3 Reliability of measures

Reliability refers to consistency and repeatability of measurable results from methods or instruments [22, p. 128].

Delta 1

Delta 1 is the time it takes the NCHAIP system to estimate the location of the tag. Comparing Linux epoch timestamps created when the tag is pinging its location and when the location is estimated does this calculation. Delta 1 does not include the time it takes the signal to reach the receivers. BLE signals are radio waves and travels close to the speed of light (approx. 300,000,000 meters/second). Since the longest tag-to-locator distance in these experiments are approx. 10 meters, the time it takes the signal to reach the locators is negligible.

Delta 1 is calculated after the experiments are conducted by importing logged data from the experiments into Microsoft Office Excel, and by subtracting the numerical value of the earlier Linux epoch timestamp from the numerical value of the later one. What is left from the subtraction is a delta time measured in milliseconds. Using Microsoft Excel to do the calculations is considered to be reliable; the tool is not going to do calculation errors.

Delta 2

Delta 2 is calculated by setting a timer at the moment the request for location information is sent and by stopping the timer the moment the requested information has reached the Locantis app. The timer is an embedded function in the java language named "SystemNanoTime()" that returns the Linux epoch timestamp in nanoseconds when the call for the function is made. This makes it available and easy to use in android studio development tool. Delta 2 is the difference between the start and stop timestamps. Figure 23 shows how easily the system nano-time function can be used to time operations.

Using this function to calculate Delta 2 is considered to be reliable. It is an embedded function in the java language that cannot be bypassed in any way other that removing the function calls from the source code. Delta 2 is logged in the log file generated by the Locantis app, and for the data analysis to be convenient, this too is imported into Microsoft Excel. The calculation of Delta 2 is considered to be reliable.

Estimation accuracy and precision

Estimation of accuracy and precision is a comparative operation, where positioning data from tags are collected and compared to reference points. To be able to determine the accuracy and precision, the logged data has to be imported into Microsoft Excel in order to be able to present the data as human readable. Here the logged positioning data is compared to manually entered reference points of the physical spots where the measurements have been done. Even thou the tools are reliable, determine what is considered to be high accuracy and precision is very subjective, it has to be done by a human. Someone has to decide if the measured data is accurate or not.

4.4 Validity

Validity is important for both physical instruments and experiments. Validity for instruments refers to the instruments capacity and the instrument's ability to measure what is intended to measure. For experiments, this translates to the accuracy of observations [22, p. 128]. There are several different kinds of validity that needs to be considered.

Internal validity

Internal validity is the degree of confidence that observed results is related to the changes made on independent variables rather than unrelated or unknown factors [22, p. 128].

The internal validity for the experiments conducted is considered to be high. The data collected during the test indicates that the independent variables have an impact on the dependent variables. Thou some extraneous variables have some influence on the tests; the independent variables impact have significant and clear impact on the dependent variable.

External validity

External validity refers to the generalizability of research findings, and the extent to which the findings can be generalized [22, p. 128].

Generally, experiments conducted in closed and laboratory environments tend to have low external validity. It is difficult to generalise the findings enough for them to be valid for anything else than the study that generated them. But this study is conducted in an environment that very well could be a real deployment based on an actual business case. The external validity is considered to be high as the research findings from this study easily could be generalised and translated for other purposes.

5 Findings and analysis

This chapter is allocated for the findings done in this study. The findings are both from investigational research and from the experiments conducted on the CCIPS, including the NCHAIPS and the Locantis app.

5.1 Difference between centralized and distributed simulation systems

The most obvious difference between the different systems is the way they work. A centralized system is based on infrastructure in buildings that are tracking objects. In the case of this study, the infrastructure of the NCHAIP system consists of HAIP locators that are listening and locating the origin of BLE beacons. The infrastructures control unit, the HAIP controller, estimates the origin of each beacon. The tracked objects do not necessarily have to be aware that they are being tracked since the communication is strictly one way, from tag to locator.

A distributed system basically works the other way, from locator to tag. In a distributed system, the infrastructure does not necessarily have any information about the objects in its operational are. There are no distributed systems in the HAIP standard on the market yet, but there are under construction. The issue of the distributed HAIP, also known as MCHAIP, is neither the infrastructure nor the software, NCHAIP systems are going to be able to share the infrastructure with MCHAIP systems, however not operate simultaneously. The obstacle lies within today's smart devices, they do not have BT/BLE chip sets that support this features. They are not able to receive multiple BLE signals in order to calculate their own location

It is proven that both NCHAIP and MCHAIP can use the same infrastructure by replacing the smart device with a laptop and a custom-built receiver unit. The receiver unit is a substitute to the BT/BLE chipsets that will be embedded in future smart devices. This way, the MCHAIP system has been developed to the point that only the smart devices BT/BLE chipsets need to be developed to support this standard. This is likely to takes several years since the adoption of new standards normally is a time-consuming procedure.

5.2 Impact on current exercise models

There is a difference in the usage of the system; either training exercises or simulations are conducted. Training exercises means that participants are training and learning a specific task. This can be compared to football players practicing free kicks during football practice. At this point, correctness of environmental and other aspects are not of absolute importance.

During simulations, where participants are supposed to practice in an environment that closely replicates the real thing, correctness of environmental and equipment aspects are of great importance in order to achieve high fidelity simulations. Chapter 2.7 talks more about simulation aspects. It is during simulations that the exercise model could have to be modified. A greater granularity of the participants and other objects position comes with the potential for monitoring even more aspects. But it is the possibility to have great position granularity without the IR-light sources that are especially interesting in this case. Removing IR-light sources improves simulations during dark hours significantly.

5.3 Delta time1

Delta 1 is the time it takes the NCHAIP system to hear the "ping" from the tag being tracked, to the moment the NCHAIP system has estimated the location of the tag. The findings show that the average Delta1 time is quite similar between active (moving) and stationary tags for all five configurations. However, some bigger differences in the response time might due to that a tag might have fallen asleep during the stationary tag test.

Table 1: Summary of findings from Delta1 experiment.

	2Hz	5Hz	9Hz	9Hz two-tag combo
Stationary				
Time	5 min (300sec)			
Samples generated	994	2445	2840	2509
Average response time (ms)	975	549	352	475
Standard deviation (ms)	400	87	50	1508
Active				
Time	5 min (300sec)			
Samples generated	872	2287	2442	2926
Average response time (ms)	950	548	350	355
Standard deviation (ms)	189	95	53	35

The findings are presented in pairs. **Figure 28** below illustrates which observations are paired. Each pair consist of two observations; one observation of a specific tag configuration when the tags are at rest and one observation of a the same tag configuration when the tags are in motion.

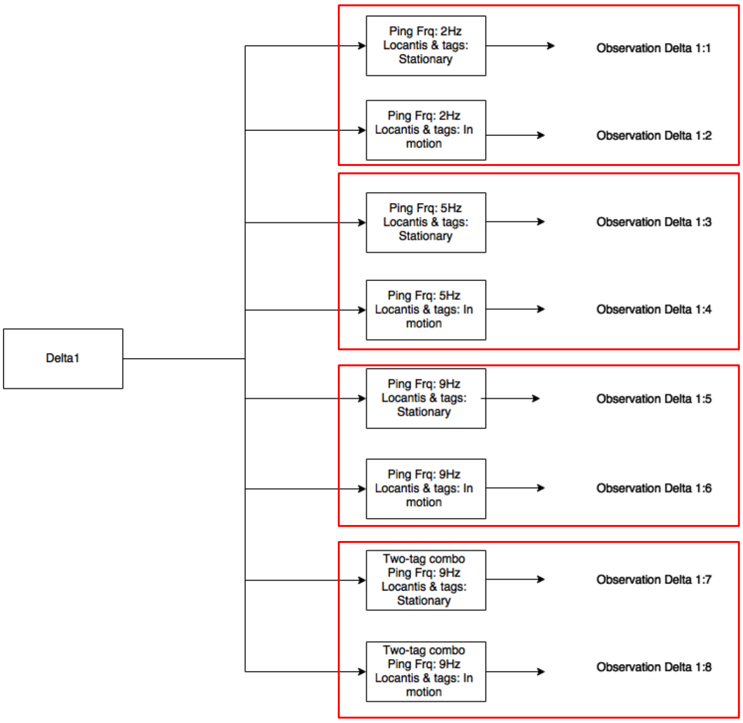


Figure 28: Pairing observations for comparison.

5.3.1 Observations on 2Hz tag configuration.

In this section comparisons between active (moving) and stationary tags with the same tag configuration and frequency can be made by taking a look at the diagrams below. **Figure 29** and **Figure 30** illustrates observations made on 2Hz single tag configurations.

Delta1:1

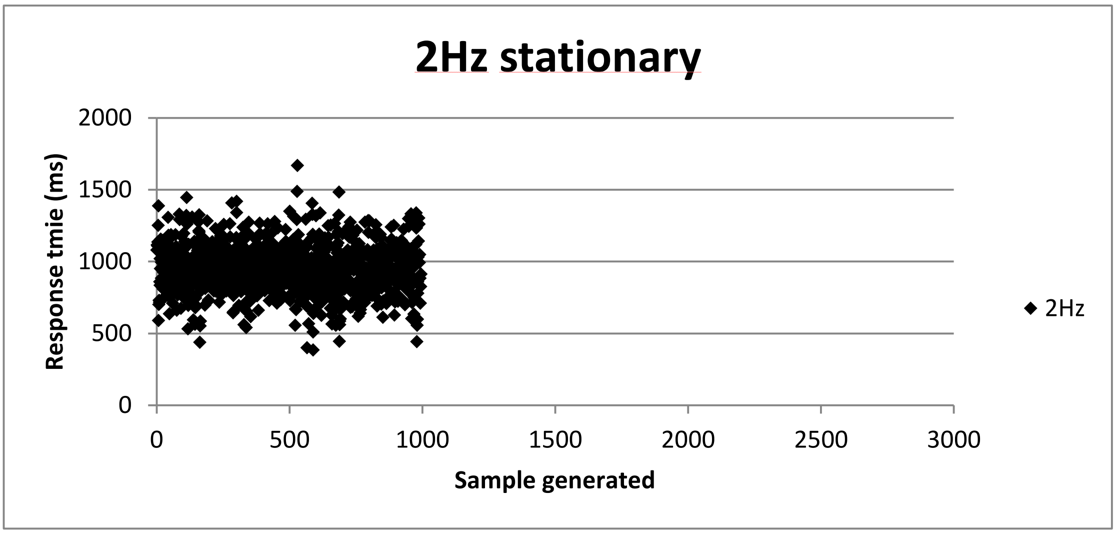


Figure 29: Delta1:1, average response time 975ms

Delta1:2

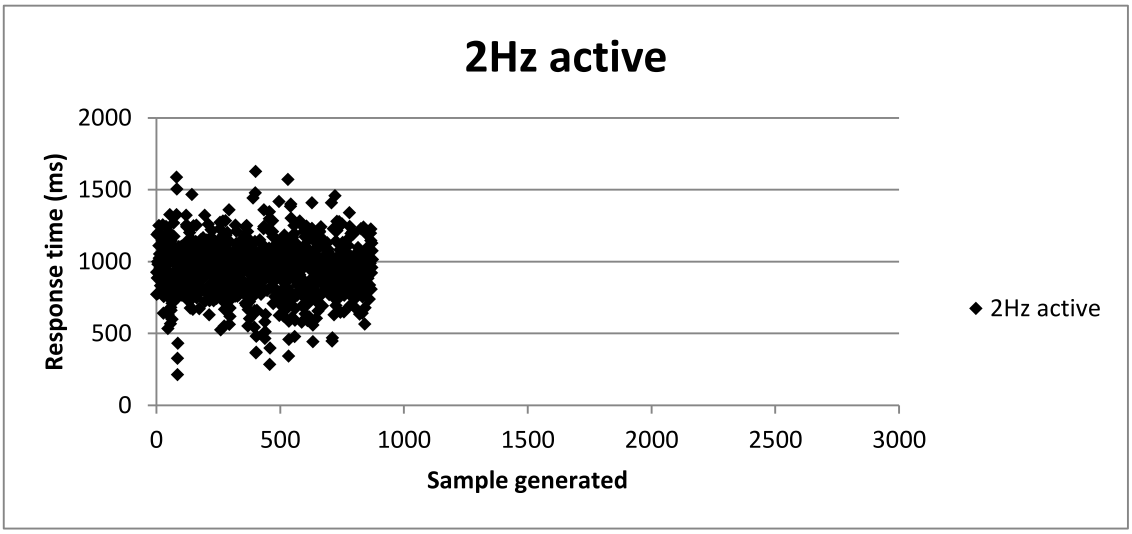


Figure 30: Delta1:2, average response time 950ms.

5.3.2 Observations on 5Hz tag configuration

In this section comparisons between active (moving) and stationary tags with the same tag configuration and frequency can be made by taking a look at the diagrams below. Figure 31 and Figure 32 illustrates observations made on 5Hz single tag configurations.

Delta1:3

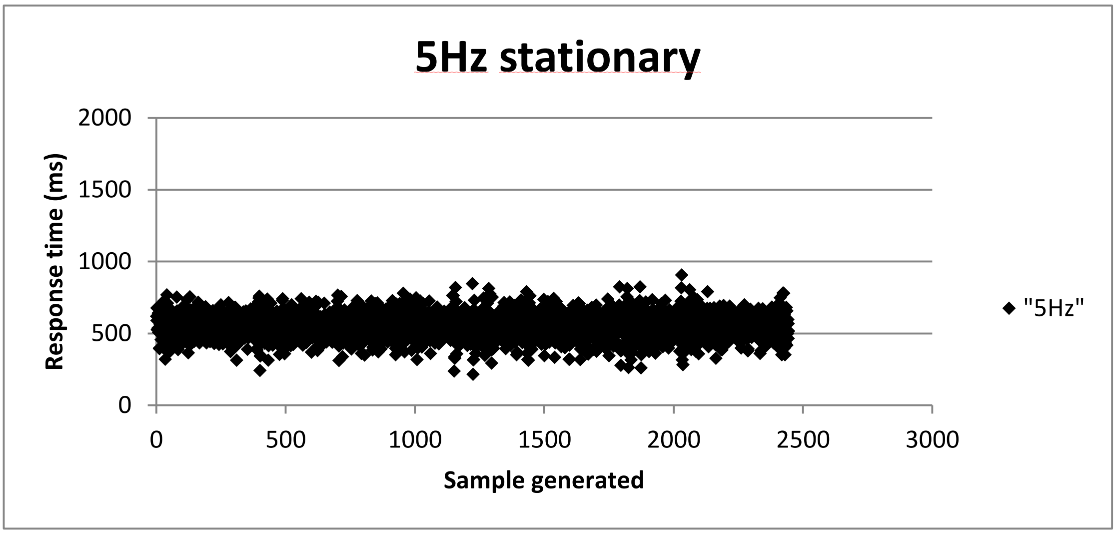


Figure 31: Delta1:3, average response time 549ms.

Delta1:4

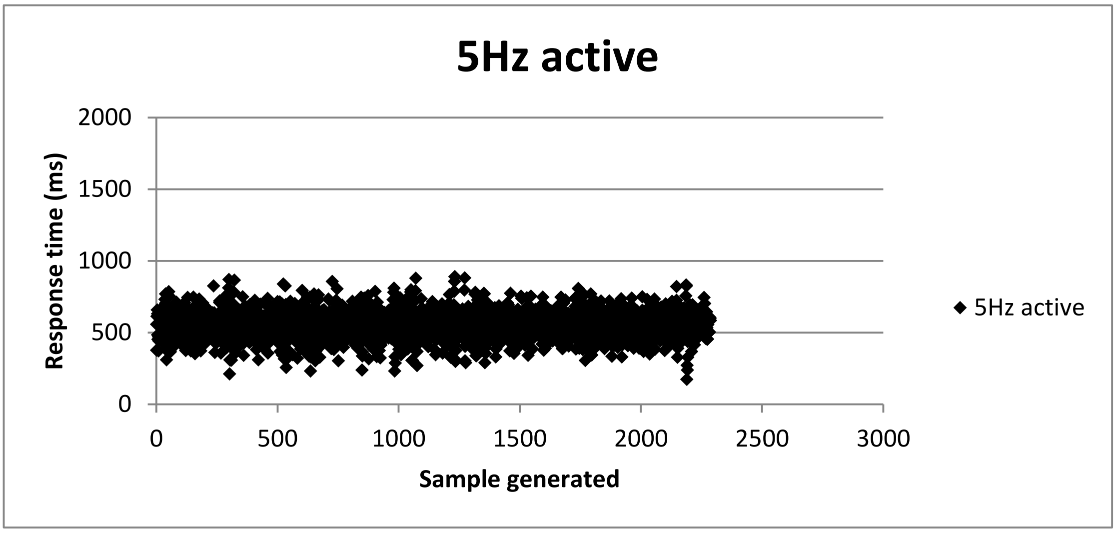


Figure 32: Delta1:4, average response time 548ms.

5.3.3 Observations on 9Hz tag configuration

In this section comparisons between active (moving) and stationary tags with the same tag configuration and frequency can be made by taking a look at the diagrams below. **Figure 33** and **Figure 34** illustrates observations made on 9Hz single tag configurations.

Delta1:5

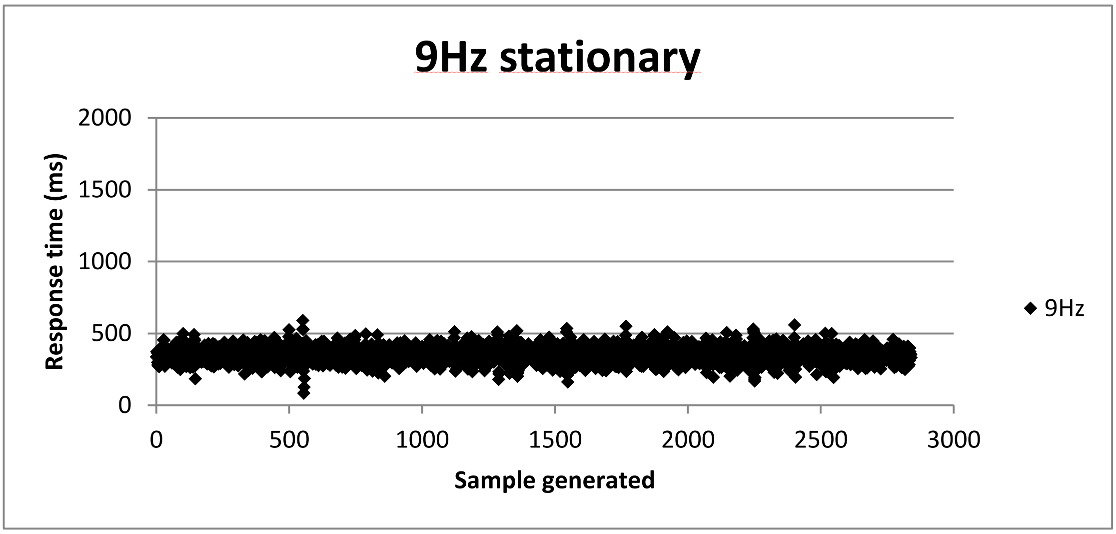


Figure 33: Delta1:5, average response time 352ms.

Delta1:6

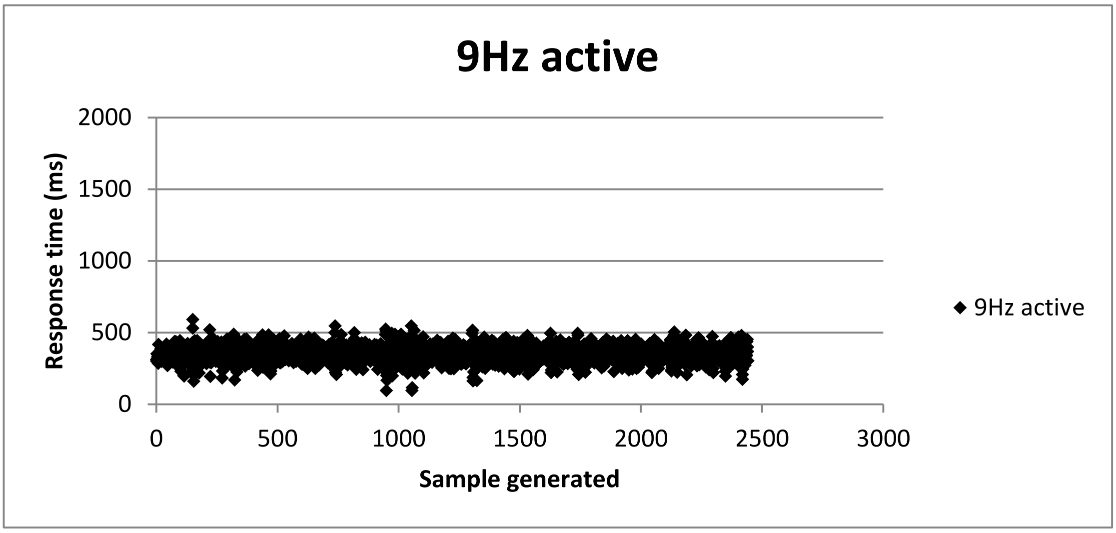


Figure 34: Delta1:6, average response time 350ms.

5.3.4 Observations on 9Hz two-tag combo configuration

In this section comparisons between active (moving) and stationary tags with the same tag configuration and frequency can be made by taking a look at the diagrams below. **Figure 35** and **Figure 36** illustrates observations made on 9Hz two-tag combo configurations.

Delta1:7

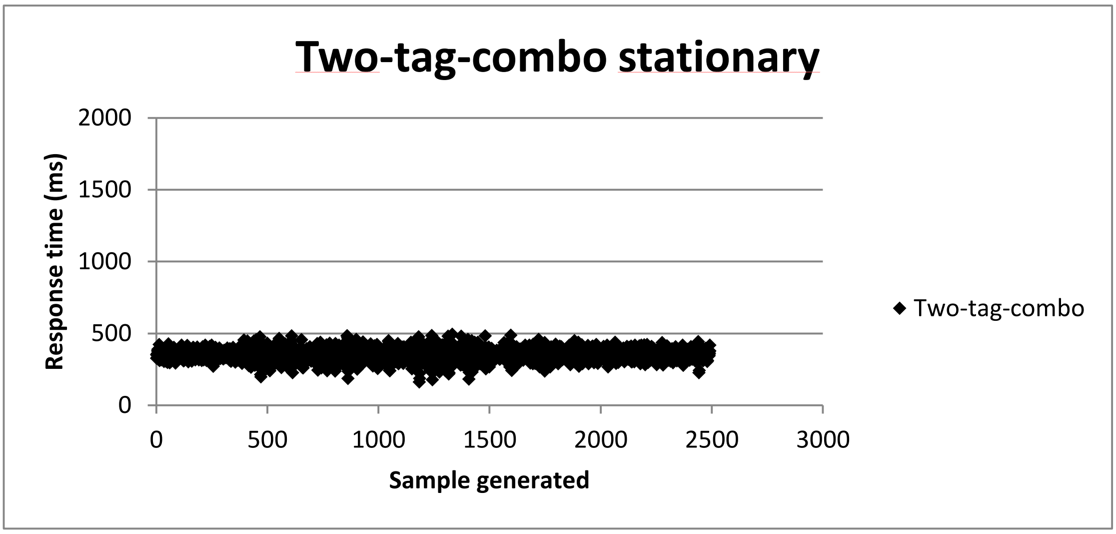


Figure 35: Delta1:7, average response time 475ms.

Delta1:8

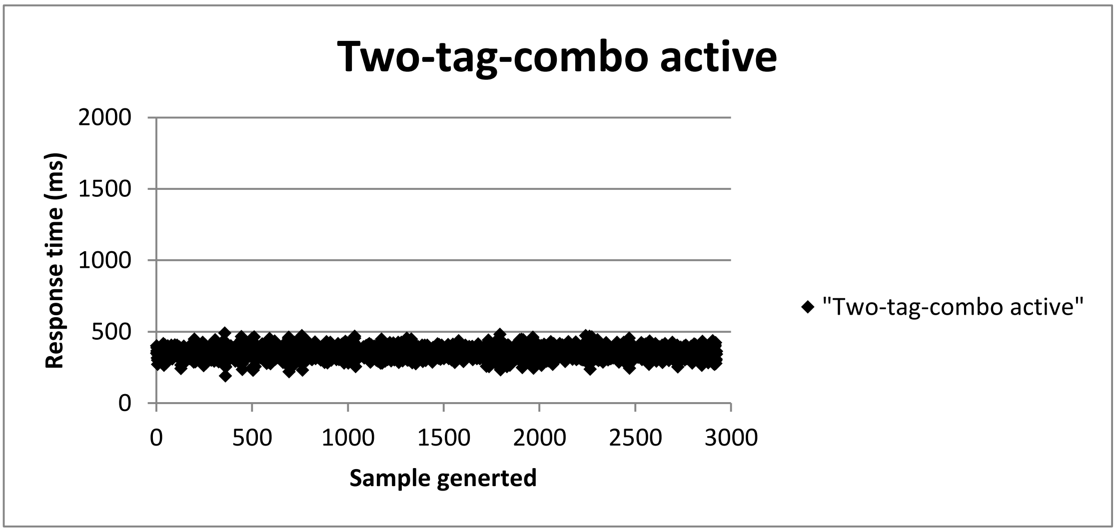


Figure 36: Delta1:8, average response time 355ms.

> *"Operational Hypothesis: Moving and stationary tags have the same Delta time 1, tag configurations with different "ping frequencies" have no impact on Delta time1"*

Table 1 indicates that the operational hypothesis for this experiment is false. Moving and stationary tags have different Delta time 1. There is also differences in Delta time 1 for the different tag configurations and frequencies. This is especially clear for the active (moving) tags. Here the lowest frequency have the highest average response time and the highest frequency has the lowest average response time. The same is true for the standard deviation.

5.4 Delta time 2

Delta time 2 is the time it takes to distribute the location information from the NCHAIP system to the Locantis app. The Locantis app requests information using HTTP, and the response contains the requested information. This experiment has been conducted in three stages, where the Locantis app has different request rates. In all tests, Locantis requests all available location data from five tags. The findings show that the average Delta2 time is quite similar in all three tests.

Table 2: Summary of findings from Delta2 experiment.

	1Hz	2Hz	4Hz
Locantis app and tags in motion			
Generated sample	319	616	1210
Average response time (ms)	112	117	98
Standard deviation (ms)	54	75	40
Locantis app and tags stationary			
Generated sample	304	609	1145
Average response time (ms)	107	110	96
Standard deviation (ms)	35	36	27

The observations show that the average response time (Delta time 2) is slightly lower when both the tags and the Locantis application are stationary than when they both are moving. The data set generated from the different configurations are similar to each other, but the stationary configuration seems to generate fewer instances that are being logged. **Figure 39**, **Figure 41**, **Figure 43**, **Figure 38**, **Figure 40** and **Figure 42** are plotted observations from the experiment. Each configuration (experimental group) from **Figure 25** has its own diagram below. The findings are presented in pairs. **Figure 37** below illustrates which observations are paired.

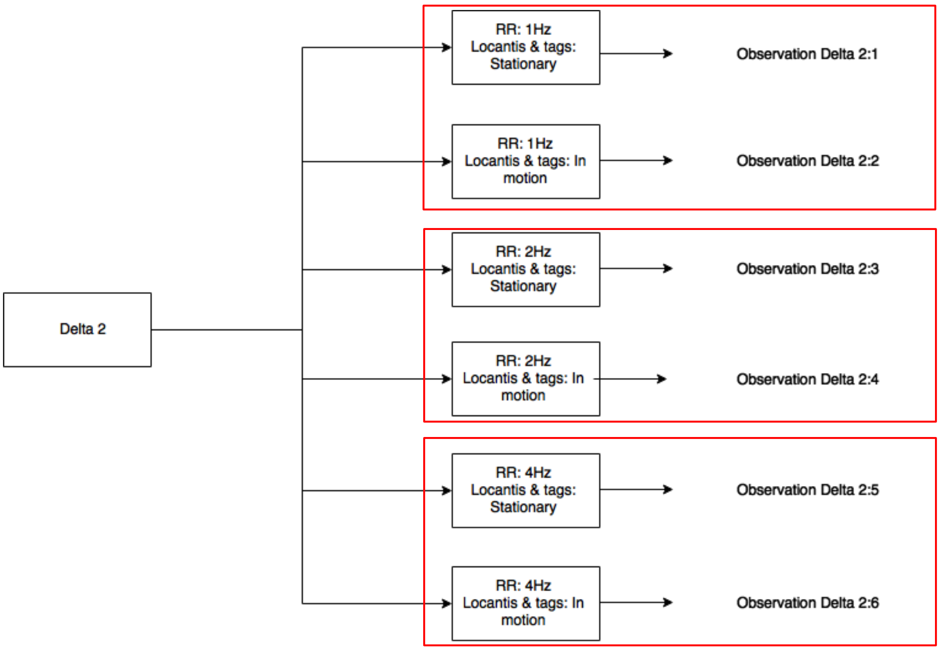


Figure 37: Pairing observations for comparison.

5.4.1 Observations on Locantis with 1Hz request rate

In this section, observations on Locantis paired in two to make it easier to compare performance of stationary settings and active settings (Locantis and tags in motion). Figure 38 is the observation on Locantis with 1Hz RR when it and the tags are stationary. Figure 39 is the observation when the same setup is active.

Delta2:1

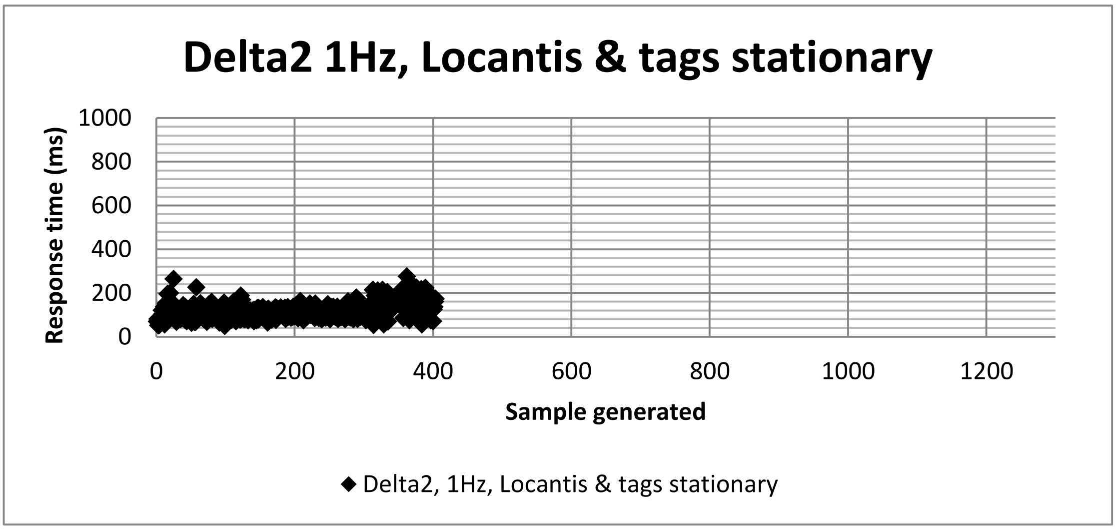


Figure 38: Locantis app with 1Hz request rate and 107 ms average response time.

Delta2:2

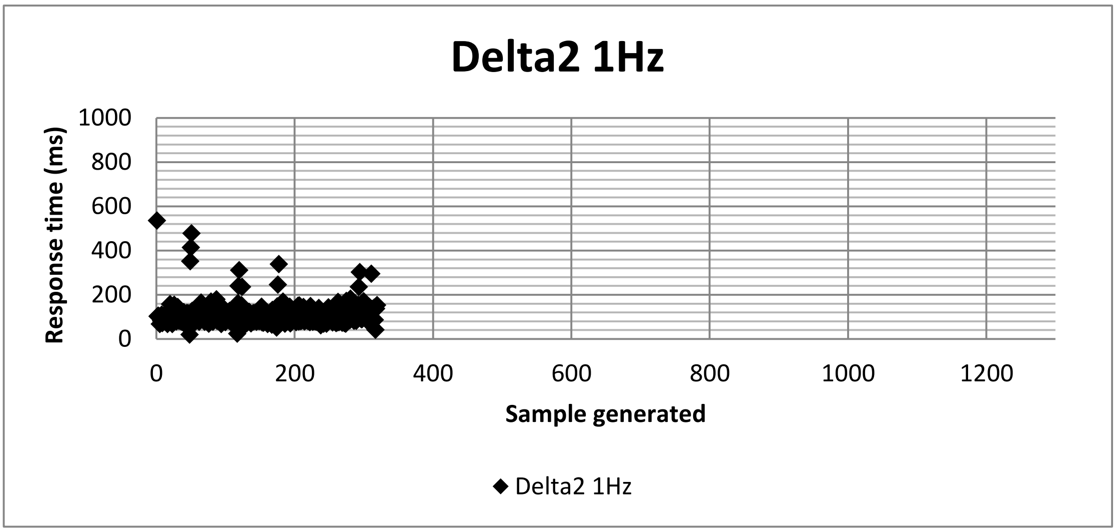


Figure 39: Locantis app with 1Hz request rate and110 ms average response time.

5.4.2 Observations on Locantis with 2Hz request rate

In this section, observations on Locantis paired in two to make it easier to compare performance of stationary settings and active settings (Locantis and tags in motion). Figure 40 is the observation on Locantis with 2Hz RR when it and the tags are stationary. Figure 41is the observation when the same setup is active.

Delta2:3

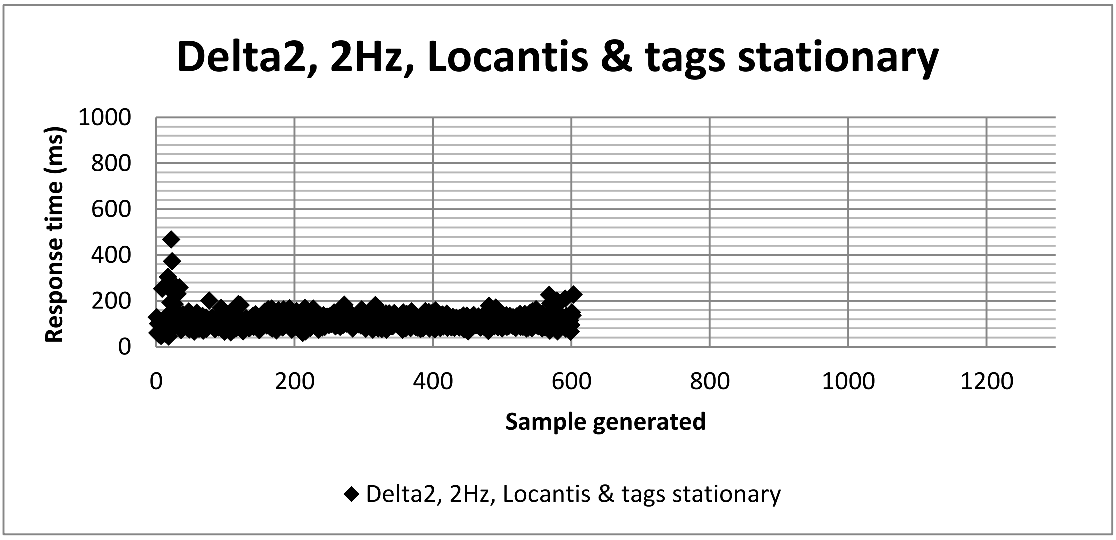


Figure 40: Locantis app with 2Hz request rate and 110 ms average response time.

Delta2:4

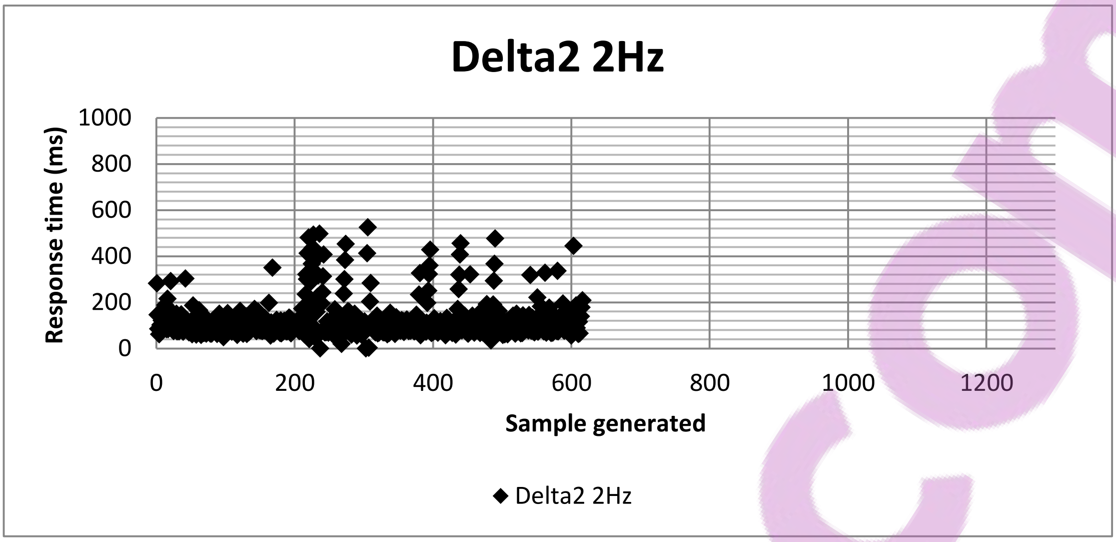


Figure 41: Locantins app with 2Hz request rate and 120 ms average response time.

5.4.3 Observations on Locantis with 4Hz request rate

In this section, observations on Locantis paired in two to make it easier to compare performance of stationary settings and active settings (Locantis and tags in motion). **Figure 42** is the observation on Locantis with 4Hz RR when it and the tags are stationary. **Figure 43** is the observation when the same setup is active.

Delta2:5

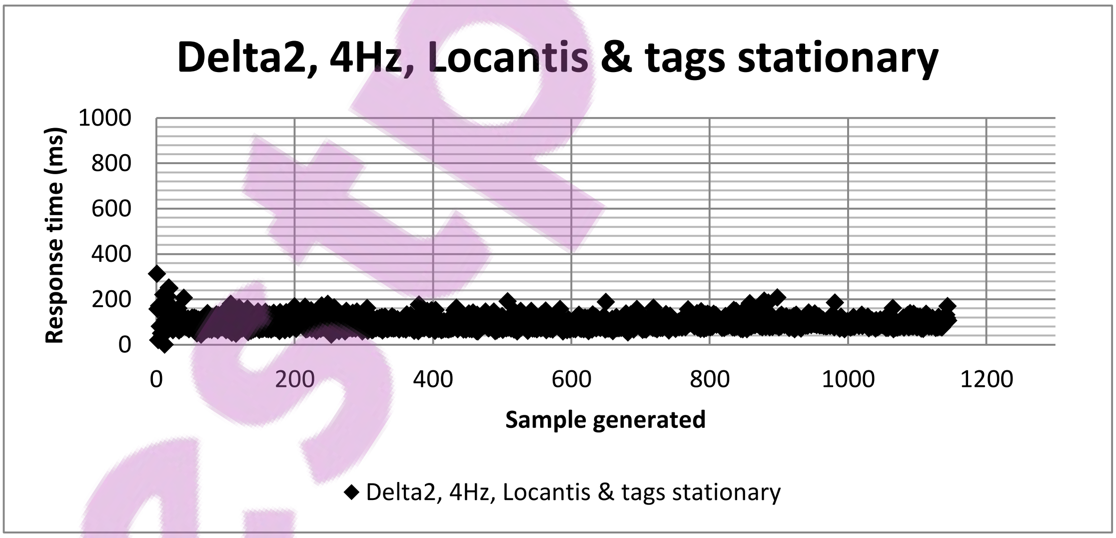


Figure 42: Locantis app with 4Hz request rate and 96 ms average response time.

Delta2:6

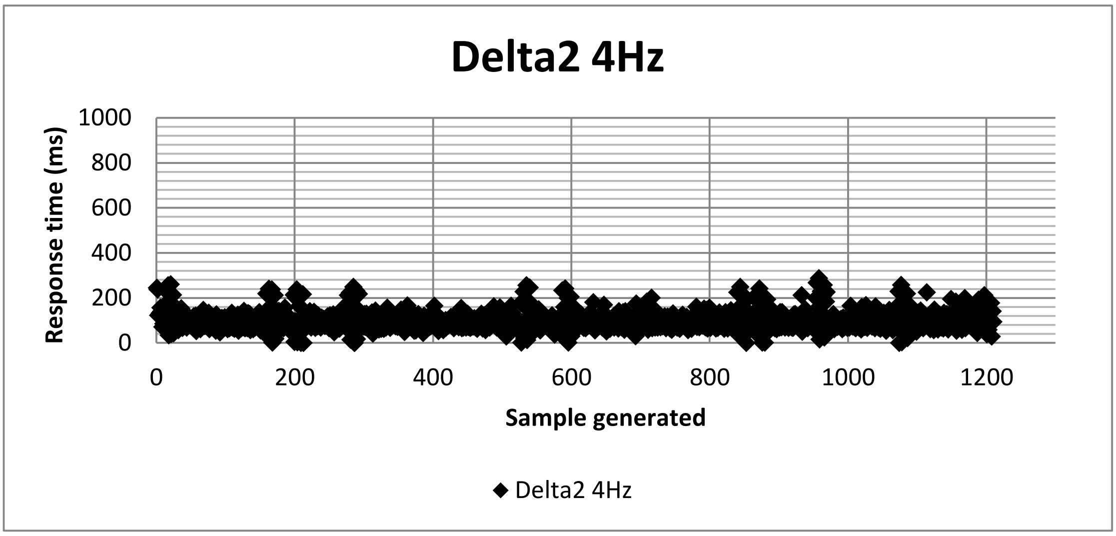


Figure 43: Locantis app with 4Hz request rate and 100 ms average response time.

The response times that exceed the average response time in each graph are caused by extraneous variables, in this case, most likely random lag in the Wi-Fi connection.

The response times that are below the average in the diagrams are likely to be late packages that are received after a new package is requested. This temporarily tricks the system to believe the receiving of the location data are faster than what actually is true. When the Locantis app is requesting location data at 4Hz, it seems to be more of these late arriving data packages that tricks the system than when both 1Hz and 2Hz is used. The growth seems to be linear, meaning there is roughly twice as many late “arrivals” for 2Hz as it is for 1Hz, and twice as many late “arrivals” for 4Hz as it is for 2Hz.

> *“Operational Hypothesis: Increased request rate dose not impact the information’s delivery time (Delta time 2)”*

Table 2 indicates that the operational hypothesis for this experiment is false. Increased RR have impact on Delta time 2. The data shows that a RR of 4Hz has lower average response time and standard deviation than the other RRs have.

5.5 Estimation accuracy and precision

Accuracy and precision experiment is to investigate the granularity of the NCHAIP system that the CCIPS, Locantis, will inherit, and to investigate if there is any difference in the performance of tags configured with different frequencies. Performance of two-tag configurations is compered to single tag configurations to investigate if two-tag configurations perform better than single tag configurations as well.

Figure 44 is an overview of how the results from the estimation accuracy and precision experiment is presented. Subsections 5.5.1, 5.5.2, 5.5.3 and 5.5.4 show results from the different tag configurations compared to the reference points used in this experiment. The results of all tag configuration at all reference points are collected and presented in subsection 5.5.5. However, these results do not provide a clear presentation of the accuracy and precision of the estimated positions in relation to the reference points. Detailed presentations of these findings can be found in Appendices as 14 diagrams, Appendix 1 to Appendix 14. In **Figure 44**, these 14 appendices are marked with a red square.

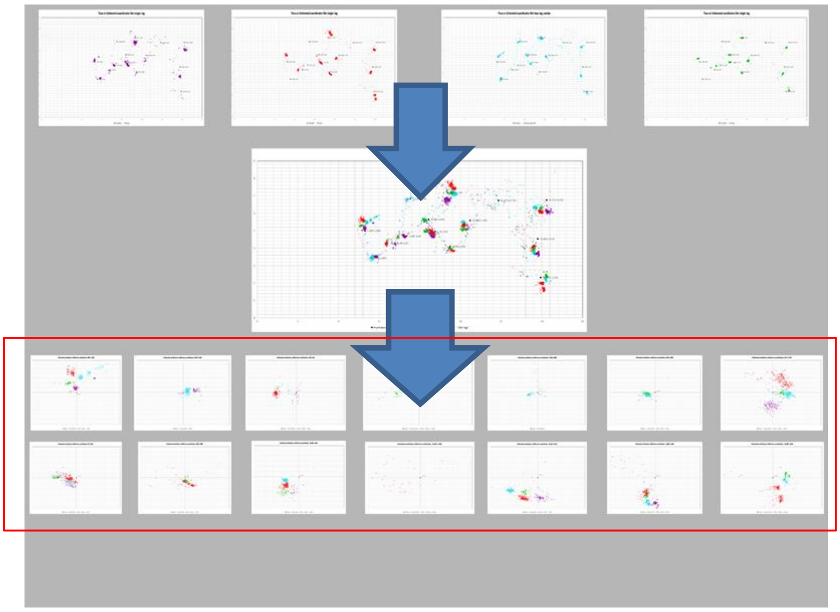


Figure 44: An overview of the accuracy and precision analysis.

5.5.1 2Hz single tag configuration

The 2Hz tag configuration is the configuration with the lowest ping frequency of all the configurations. This tag configuration is generating the lowest amount of data. **Figure 45** is a plotted diagram from the observations made on this tag configuration in this experiment.

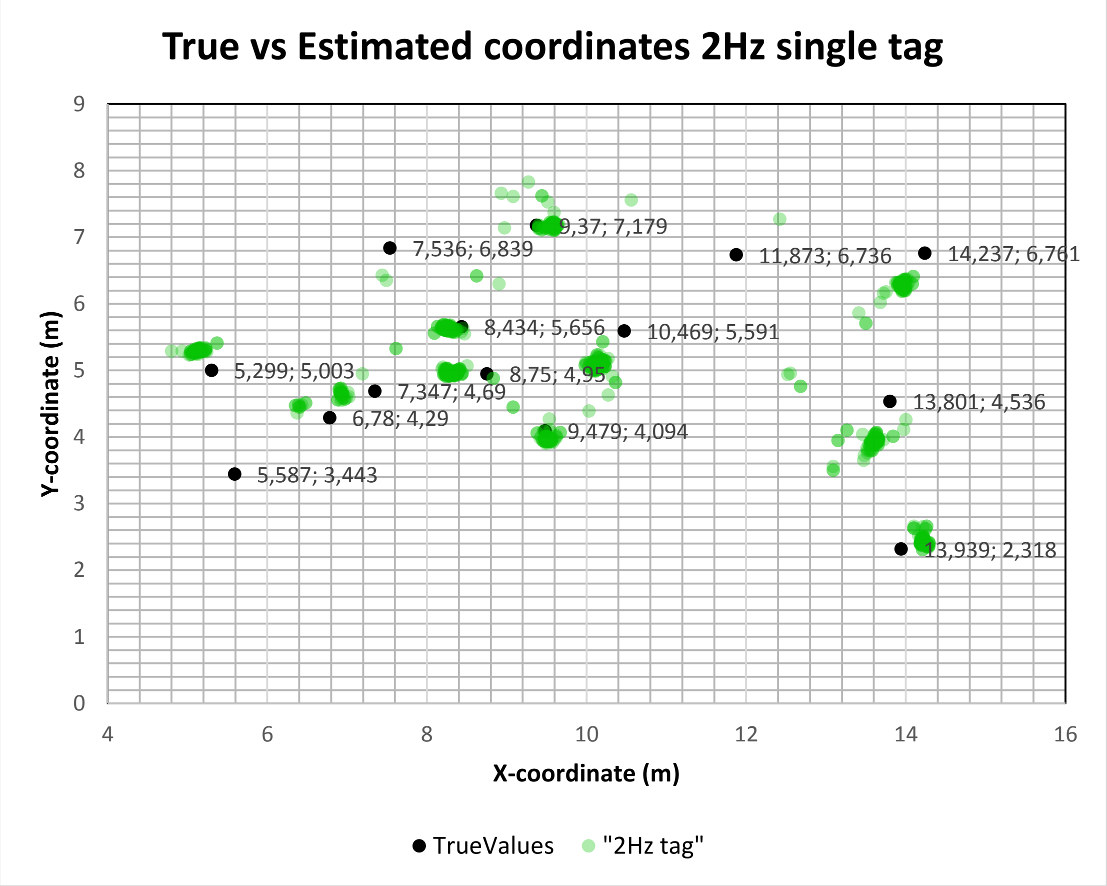


Figure 45: The results of 2Hz single tag configuration compared to the reference points.

5.5.2 5Hz single tag configuration

Figure 46 is a plotted diagram of the observations made on this tag configuration in this experiment. 5Hz is the second slowest ping frequency that is being tested in this experiment.

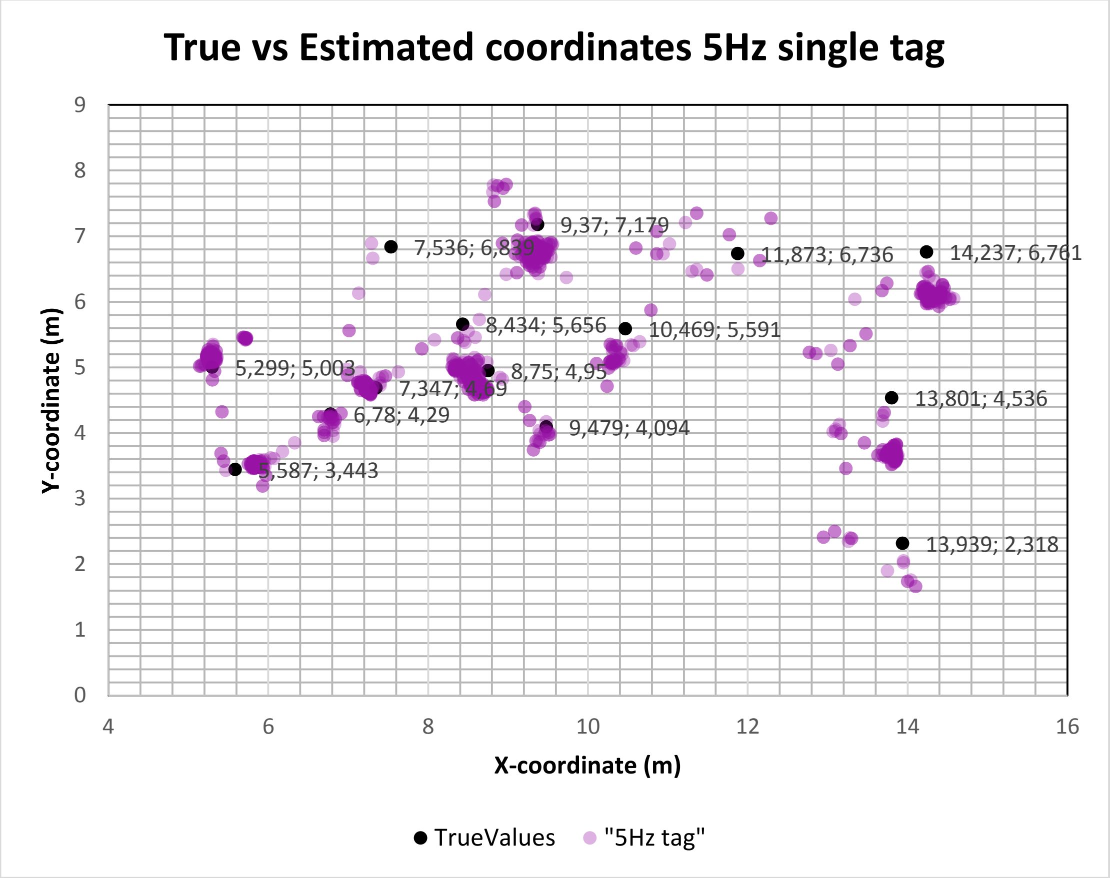


Figure 46: The results of 5Hz single tag configuration compared to the reference points.

5.5.3 9Hz single tag configuration

The 9Hz tag configuration is the configuration with the highest ping frequency. Figure 47 is a plotted diagram of the observations made on this tag configuration in this experiment.

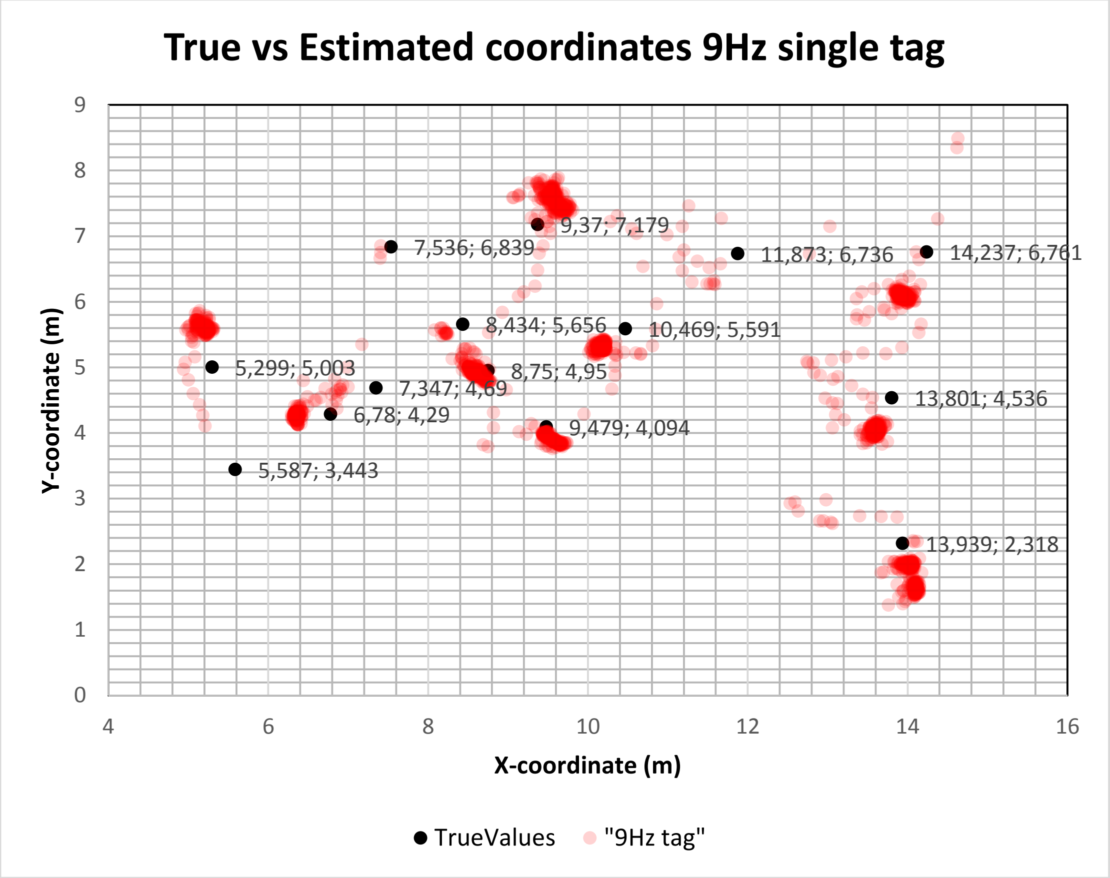


Figure 47: The results of 9Hz single tag configuration compared to the reference points.

5.5.4 9Hz two-tag configuration

The 9Hz two-tag configuration is the configuration where two tags are combined as one. This configuration is used in this experiment to represent tags mounted on an exercise participants shoulder compared against a single tag mounted on the helmet of an exercise participant. Figure 48 is a plotted diagram of the observations made on this configuration in this experiment.

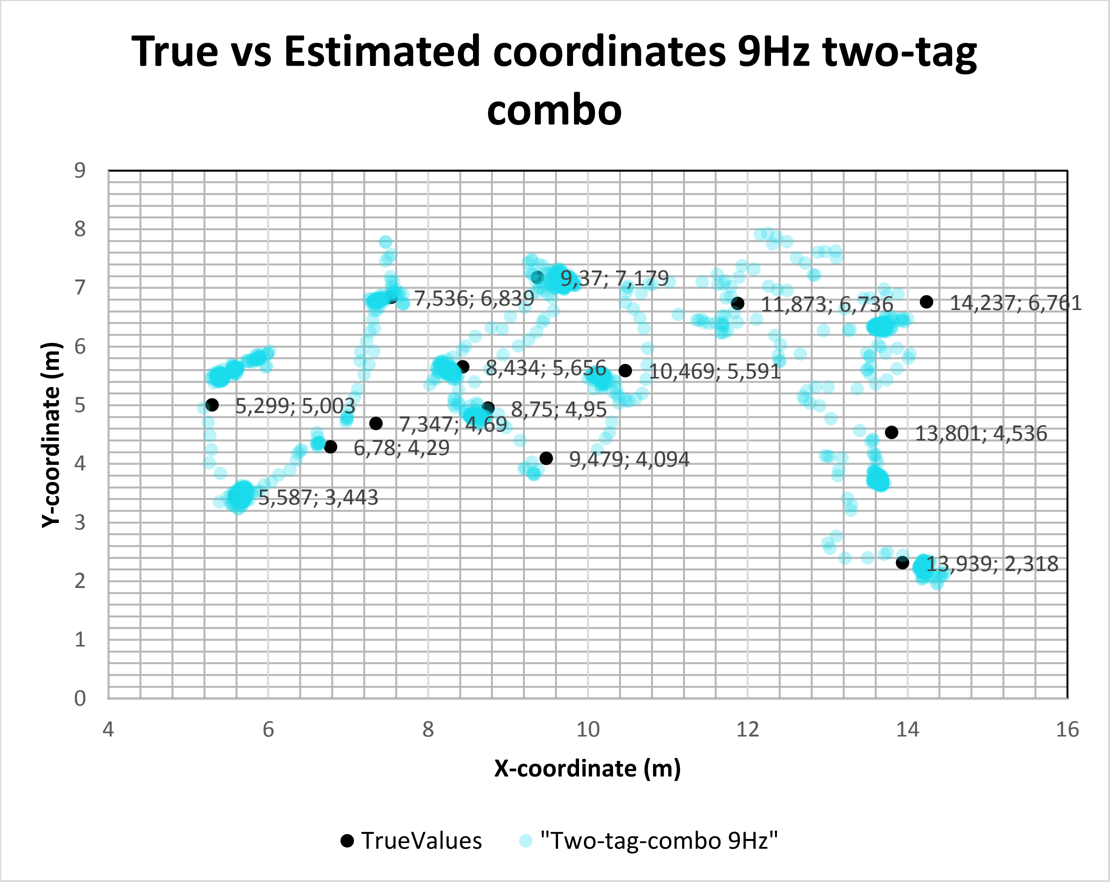


Figure 48: The results of 9Hz two-tag configuration compared to the reference points.

5.5.5 2Hz, 5Hz, 9Hz and 9Hz-combo configurations

All tags with the different tag configurations have been given the same amount of time at each reference point. Despite that, it is clear that not all measurements at the different reference points have given the same amount of data. Three of the reference points are located directly beneath three of the HAIP locators. The collected estimates from these three reference points are significantly fewer to the number than estimates collected at all the other reference points. This is probably related to the HAIP locator's operational range. The manufacturer claims that the optimal operational range of the locators is 3-50 meters. The locators are functioning in shorter distances as well, however, conducted tests indicates that shorter distances than three meters tend to lead to estimation errors and missing data. In Figure 49, all estimates are collected into a single diagram to give an overview of all the estimates from all tag configurations and frequencies. In this diagram, it is clear that some reference points have fewer estimates to be compared to.

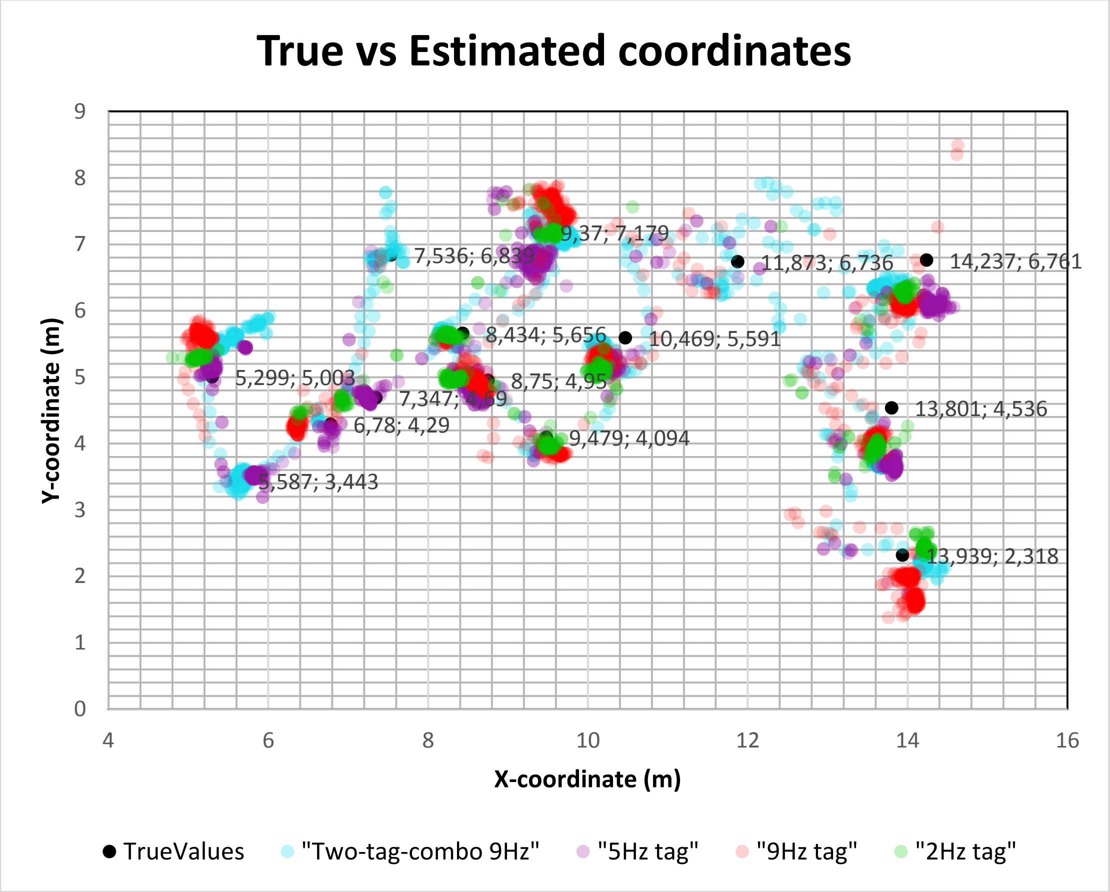


Figure 49: Location estimate in relation to true reference points.

5.5.6 Estimated error

Figure 50 is the estimated error between the reference points and the estimations. This is a representation of how far from "the truth" the different estimations are. The manufacturer claims that the NCHAIP system has sub-meter accuracy down to 0.3 meters. Looking at the diagram, it is clear that the estimated error never exceeds the meter line. As with the findings of accuracy and precision, this cannot be clearly represented in a single diagram. Table 3 summarizes the average estimated error and standard deviation of the different tag configurations in relation to the reference points. Detailed diagrams of the estimated errors at each reference point are also represented in Appendix 15 to Appendix 28.

Estimated error from each tag configuration at each reference point can be found in Appendices as 14 diagrams, Appendix 15 to Appendix 28.

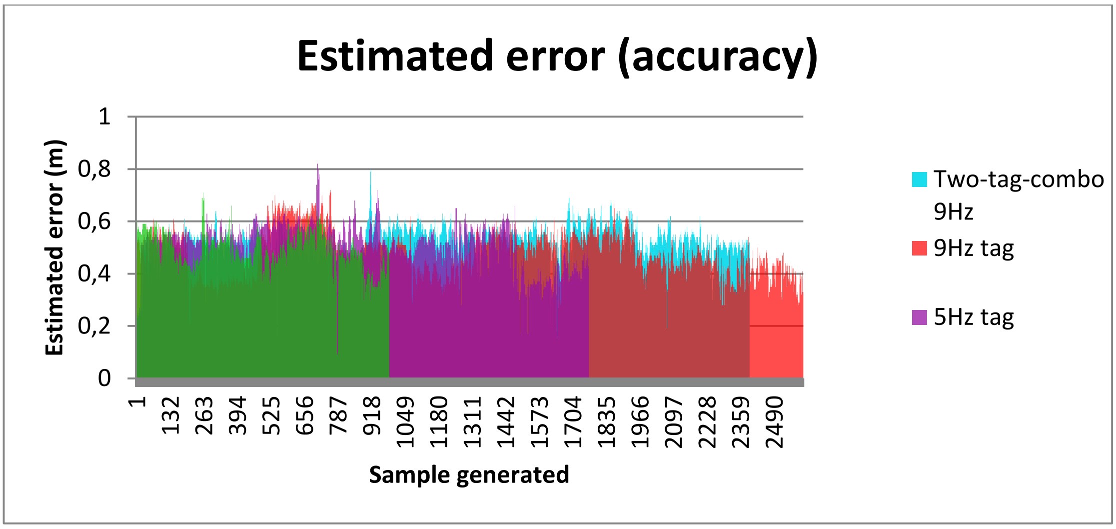


Figure 50: Estimated error for location estimate.

Table 3: Average estimated error and standard deviation at each reference point.

	2Hz single tag		5Hz single tag		9Hz single tag		9Hz two-tag combo	
Reference point	Average estimated error (m)	Standard deviation (m)	Average estimated error (m)	Standard deviation (m)	Average estimated error (m)	Standard deviation (m)	Average estimated error (m)	Standard deviation (m)
1	0,56	0,049	0,51	0,08	0,52	0,042	0,43	0,092
2	-	-	0,54	0,033	-	-	0,53	0,036
3	0,54	0,049	0,50	0,055	0,36	0,027	0,58	0,022
4	0,55	0,021	0,58	0,023	0,46	0,011	0,58	0,036
5	-	-	-	-	-	-	0,47	0,082
6	0,44	0,027	0,58	0,027	0,53	0,033	0,48	0,024
7	0,53	0,043	0,55	0,059	0,62	0,042	0,57	0,040
8	0,47	0,032	0,49	0,033	0,49	0,022	0,53	0,024
9	0,45	0,040	0,49	0,026	0,41	0,047	0,47	0,058
10	0,52	0,038	0,50	0,037	0,52	0,031	0,54	0,027
11	0,50	0,042	0,53	0,075	0,36	0,014	0,44	0,133
12	0,55	0,042	0,53	0,063	0,53	0,052	0,58	0,045
13	0,45	0,085	0,38	0,057	0,44	0,044	0,52	0,038
14	0,38	0,0401	0,44	0,26	0,40	0,53	0,49	0,039

> *"Operational Hypothesis 1: The granularity (accuracy) of the NCHAIP system is within 300 mm of the physical reference points.*
>
> *Operational Hypothesis 2: The combo-Tag configuration has greater accuracy and precision than the single tag configuration."*

Table 3 shows quite clear that non of the estimated errors are lower than 300 mm (0,3 m), meaning that the accuracy of the estimated tag location is not within 300 mm of the reference points. This falsifies the operational hypothesis 1. Table 3 indicates that the two-tag combo configuration do not have any distinct advantage over the other tag configurations in terms of accuracy. However, the two-tag combo configuration is the only tag configuration that has estimations at all reference points. Despite this, operational hypothesis 2 is also falsified.

6 Discussion and conclusions

In this chapter I, as the author of this thesis discusses and draw conclusions based on the work presented in this study. The chapter ends with my conclusion and recommendations of future work.

6.1 Discussion of method

The method used in this thesis project was chosen to focus on an experimental investigation that included software development and experimental research. The choice fell on a hybrid method based on both system development, to satisfy the software development, and experimental research to satisfy the experimental investigation. Here I discuss both theoretical and practical aspects of the chosen research method.

6.1.1 Theoretical

As previously stated, I chose a hybrid method consisting of system development and experimental research designs. Even if the hybrid method I was working by is very much hands-on working, I still needed to have some theoretical knowledge in order to be able to conduct the practicalities of my study. The theoretical part of this thesis has been conducted based on literature review of articles, reports and other materials relevant to my topic. The theory is based on ideas that have been discussed with people that are involved in Saabs current exercise and simulation system, but also based on frequent discussions with the manufacturers of the NCAHIP system.

When the theory was getting clear and I had covered what was necessary in order to continue with the practical parts of the study, I moved on to test my theory and to investigate how changes to independent variables affect the accuracy and precision of the location data in an IPS.

6.1.2 Practical

The practical part of this thesis has been conducted based on the previously described hybrid method. This method consists of system development, which is of relevance for the construction of the Locantis app, and experimental research designs used to test the NCAHIP system and Locantis. I have chosen this hybrid method based on my belief that it is most suitable for my investigational study.

System development

In order to be able to conduct the experimental research as I set out to do, I needed to develop an android application that could interact with the IPS. The result of the development is the Locantis application, the heart of the CCIPS. It could be argued that the development was not done accordingly to what traditionally is considered as system development research method. The development was rather ad hock and the Locantis app has received new features several times. This has meant that experiments and several tests had to be remade to be sure that the latest features have no effect on the performance of the Locantis app's earlier features. The Locantis app is a mobile data collector. It collects data from some of the android phones internal sensors, such as magnetic compass and accelerometer, and external data in forms of raw and semi-treated data from the NCHAIP.

In my mind, developing the application myself was going to ensure the internal validity since that I knew how the system was working in more detail than if I was to let someone else develop it.

Experimental research

The experimental research is the part of this study that has generated observations and results. Everything has lead up to this.

For the findings to have any value, the validity of them must be high. I believe that I have achieved a high level of internal validity for the experiments, as the observations are a direct result of the independent variables being applied to the dependent variables. However, external validity cannot be guaranteed since the situation did not allow my experimental procedures to be performed by external control groups. Despite that, I believe that the observations done in the experiments can be generalised to fit other situations. The findings done in this thesis could be said to be true for projects using similar equipment set up as I did. However, large-scale implementations may have a more complex infrastructure, uncertainties, and inconsistency of equipment density that may have effects too unpredictable for my findings to be true for these cases as well.

I believe that I have achieved as high level of validity for the experiments as possible for a single researcher performing every test on my own. It could be argued that there are threats to the validity. Since I conducted the experiments myself by using equipment that I partially developed myself, it could be questioned if I was biased or not. In order to minimize threats like these, no data selection has been made. This means that all data generated in the tests is a part of the observations and can be viewed in the graphs. This has one smaller drawback; it can be difficult to understand the results at a first glance. Another aspect to consider before questioning my intentions is that I have been using a third-party NCHAIP system; neither Saab nor I have anything to win from false positive data.

6.2 Discussion of findings

In this thesis, I have conducted an experimental investigation of a conceptual crossover system for high accuracy indoor positioning system, where I have investigated the differences between different standards and proposed a concept for one of these standards. I have also investigated how greater granularity of positioning data would affect existing exercise and simulation models.

6.2.1 RQ1

What differentiate a distributed simulation system from a centralized simulation system?

- *What differences are there in the implementation of centralized vs. distributed simulation system?*
- *How to implement a distributed system to support scaling-up?*
- *When is it suitable to have centralized vs distributed IPS?*

Close discussions and meeting with the HAIP systems developer and manufacturer in combination with demonstrations has led to deeper understanding of the system and its potentials.

It can be said that even if NCHAIP and the future MCHAIP standard is working in different ways, the implementation of systems of the two standards are quite similar. They both rely on hardware and infrastructure deployed in buildings where the IPS is working; the NCHAIP standard uses the infrastructure to track objects, and the MCHAIP standard uses the infrastructure to support navigation.

It is important to know if the IPS to be selected has to support tracking of objects or navigation since both purposes not necessarily can be offered in the same system. If a storeowner wants to know where customers are walking in his store, a NCHAIP system is preferable. It supports tracking and if the tags are mounted in the shopping carts, the customers does not have to do anything else than the shopping. NCHAIP systems are great tools for collecting data to be analysed. Analysing how customers are moving inside a store is a great way for a storeowner to learn what and how the store's layout can be improved, but this is not the biggest market for the NCHAIP systems. Sports are. A NCHAIP system offers an easy and cheap way to analyse how sports teams act and perform during practice and games. Individual players as well as a whole teams performances can be evaluated by analysing data collected in a NCHAIP system.

If the application is a museum or large indoor mall where customers need to navigate, a MCHAIP system might be more suitable. Despite the fact that there are no MCHAIP systems on the market today, they might be of interest in some future applications since they operate in a way that more naturally supports navigation. In a MCHAIP implementation, it is likely that the goal is to provide indoor navigation in a large public indoors area. Here, tracking is of less interest since there is no clear benefactor from tracking individuals in a public area as there is in a privately owned store. In these cases, MCHAIP systems that provides information rather than collect information is possibly more suitable.

It is also important to consider if both navigation and tracking are needed. For the MCHAIP standard to support tracking, the hand held mobile device that is the receiving part of the system must willingly give away its location information. This is something that the owner of the receiving device must consider and agree to. Allowing third parties to collect data about personal movement for tracking and monitoring is something that end users might not be supportive of.

For a NCHAIP system to be supporting navigation, a further development, such as the CCIPS, is needed. Sending collected position data from tags to a mobile smart device is the only way for a NCHAIP system to support navigation. HTTP was selected as the way of requesting and receiving positioning data on Locantis app. UDP is another possibility to distribute the positioning data. UDP supports much higher update frequency than HTTP, and it is likely that UDP supports a higher number of tracked tags and distribution to a higher number of mobile smart devices in need of this data. The manufacturers of the NCHAIP system recommends that either data logging, which means that tag's position data is stored on a server to be reviewed later, or UDP broadcasts for cases where high update frequency is required. This is the case of sports analysing using a NCHAIP system. In the case of Locantis, HTTP is selected due to the fact that implementation of HTTP is easier than UDP on the android device which serves as the receiving mobile smart device and that data logging does not support real-time updates on the mobile smart devie. Implementation of UDP in android is not new or particular difficult in any way, however, strange problems and behaviour was encountered when UDP was used on Locantis app.

6.2.2 RQ2

How will current exercise models be affected by improved position granularity?

- *What changes have to be made in the exercise model?*
- *What accuracy can be achieved?*

Overall, it is clear that the exercise models can be improved with a greater granularity of the positioning data of the exercise participants, but of less importance than I first expected it to be. What is considered to be the most important change and improvement for the exercise and simulation models are the removing of IR-light from the exercise area. I strongly believed that exercise models where going to change drastically when the positioning was improved, but this is not the case.

The exercise mode does not have to change at all for exercises and training sessions. Here the participants are learning new skills, such as how to use new equipment, or perfecting their skills. This can be compared to a huntsman going to the shooting range for shooting at targets or a football player practising free kicks. In these cases, the participants are aware that they are here to learn or perfect skills and the realness of the environment is not of importance.

For simulations, the exercise model can benefit from greater granularity. Greater granularity in the exercise participants would impact the post simulation analysing part the most. Here, observations on individual participants movement would be improved and made easier. Improving the simulation in real-time does not have as much to do with higher granularity as it has to do with the technology. Replacing the existing IPS that is being used in exercise and simulation areas for this purpose today with a system, such as the CCIPS, would mean that IR-light sources would be removed. When night vision equipment is being used, the IR-light sources are working as a spotlight. Every time someone walks by one of these IR-light sources, they are fully visible for anyone with night vision goggles. Eliminating these flaws from the system would improve the fidelity of the simulation.

6.2.3 RQ3

Could a conceptual crossover IPS (CCIPS) be a valid contender to replace today's established IR-based IPS?

- *How can positioning data be distributed in a NCHAIP system?*
- *Can the CCIPS meet the real-time requirements of the established IR-based IPS?*

For the response time of the position estimation on the NCHAIP system, Delta1, the test groups of active tags (tags in motion) have all proven to have lower response time than the five other subgroups of stationary tags. Despite the fact that all test groups of tags constantly "ping" their location, stationary tags easier "fall asleep" and are more difficult for the NCHAIP system to locate.

Strange behaviour was encountered when the tags were positioned at floor level. It is believed that steel reinforcements in the floor could be the cause of at least some strange behaviour. This is the main reason that the tags are positioned above floor level during the experiments in this study. Strange behaviour is also encountered when tags are directly beneath the Locators, where the distance from tag to locator is less than three meters. This can be seen in Appendix 11, where there are significantly fewer estimations than at other reference points. It is believed that three meters is the shortest tag to locator distance, where the NCHAIP system can estimate with high accuracy.

For the response time of the Locantis app, Delta time 2, the two major test groups stationary and moving tags have very different behaviour, but similar results. The average response time is lower for the stationary test groups, the data sample is more focused, and the floating average is smoother than the data sample for the moving test groups. The number of anomalies is much higher in the results from the moving test groups and the number of anomalies seems to grow linear. Observation Delta2:2 seems to have roughly twice as many anomalies as observation Delta2:1 and Delta2:3 seems to have roughly twice as many anomalies as Delta2:2.

In the case of the conceptual crossover system as a contender for replacing the existing IPS used by Saab, Locantis has proven that the replacing system does not have to be fully distributed or centralised and that Locantis can offer possibilities' that none of the other systems can provide without modifications.

6.2.4 RQ4

> *What other sensors existing in a smart device can be used to aid a BLE IPS?*
>
> - *Can the BLE IPS data be combined with other sensor data to provide more accurate and stable location data?*

Locantis proves that other sensor data, such as compass data from embedded sensors in the smartphone, can be combined with the raw location data of the BLE tagged objects that are to be tracked in order to improve the simulation system and model. The Locantis app also opens the possibility to completely remove the BLE tags from the NCHAIP system and instead use Locantis internal hardware as a BLE tag.

6.3 Conclusions

During this study, I have concluded that a CCIPS is achievable by developing and android application that utilises a NCHAIP system to collect positioning data and distribute this data to the android application. A CCIPS, such as this, can provide high accuracy positioning data of multiple tracked objects to multiple android devices several times per second. The CCIPS fillse the void of the MCHAIP standard and is a good compromise between a centralized and a distributed system. It supports object tracking as well as navigation by distributing the position data back to the object.

An android application, such as the Locantis app, provides the possibility to incorporate sensor data from a wide range of embedded sensor in the android device that would not be possible without the Locantis app. Combining sensor data from embedded sensors with the positioning data could be beneficial from several aspects. For instance, reviewing of simulations could be improved by incorporate the data from the embedded compass.

The CCIPS is a valid contender to replace the existing IR-based IPS that currently is being used at training and simulation sites. It provides great accuracy and more data than a non-modified NCHAIP system and it does not utilise IR-light sources. The data distribution from the NCHAIP system to the Locantis app is fast enough to be used instead of the IR absed system.

6.4 Future work

Future research in the area of indoor positioning should be conducted in order to determine the applicability of findings in this study to real business cases. Indoor positioning is in an interesting stage at the moment. The awareness of indoor positioning grows almost every day. This creates business opportunities for the industry as well as driving the development further. As this study has shown, the current NCHAIP standard can very well be used in modified cases, such as the CCIPS Locantis, and implementing this in equipment used by simulation participants to test Locantis closer to the business cases it was designed for seems to be a logical next step.

The inventors of the NCHAIP standard are pushing for the future MCHAIP standard to be adopted. Currently, the embedded hardware in smartphones is the bottleneck and it may take several years before the standard is adopted. However, discussions with the inventors of the standards should be kept active. When the standard is ready for the market, comparison of the two standards should be conducted to clarify differences in operations and capabilities. In my mind, this is very important and interesting since the pre-standard proprietary implementation of the MCHAIP standard works, whit out a smart device, using the same infrastructure as the NCHAIP standard system. This means that very few changes have to be made in order to support the MCHAIP standard. Simply add a smart device with the right software, configure the infrastructure to work different from the NCHAIP way and the MCHAIP system may be used.

Locantis is a major part of this experimental investigation, but several aspects need to be considered. The CCIPS has been named Locantis to make it easier to talk about it, but any terminology for the system is not firmly defined. Delta times are a measurable timeslot between two events taking place, start and stop for instance. In this investigation, Delta 1 and Delta 2 are names for two timeslots that are being measured. Those names serve their purpose for this investigation, but these timeslots should be properly named to avoid confusion in the future. The terminology for a system is important, it is the foundation on which all discussions are based. This is why a clearly defined terminology for the Locantis system is needed.

Locantis has proven to work well under the circumstances of this investigation. However, further investigation of the scalability should be conducted to determine the performance of the system in a larger implementation. The infrastructure, both the HAIP locators and the Wi-Fi access points, play an important part in the Locantis system and determining their scalability is a natural but important future investigation. In relation to the scalability and the Wi-Fi access points, investigations of UDP as the main way of distributing the position data to determine if UDP or HTTP is the most suitable in large-scale implementations should be conducted.

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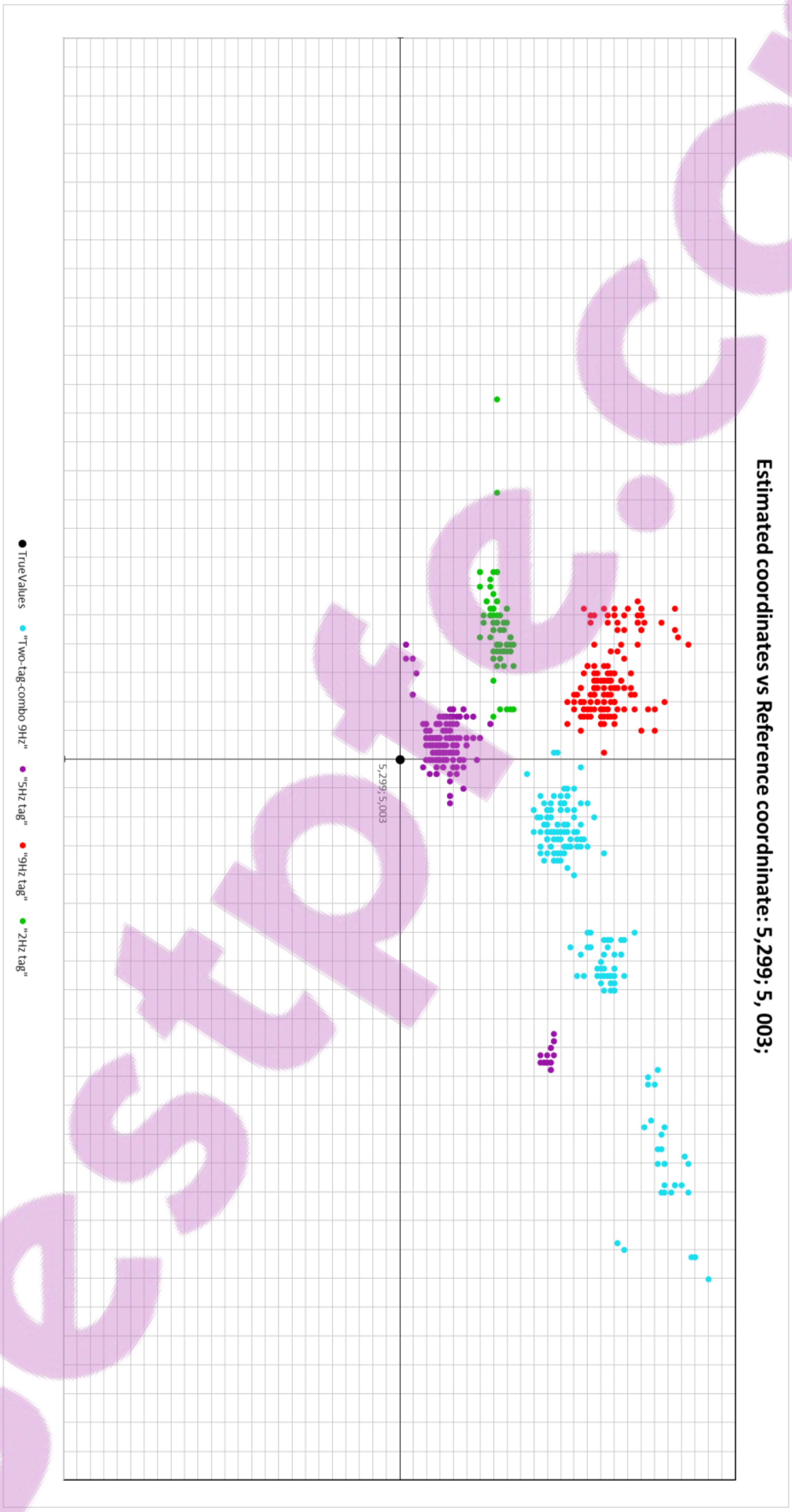
Search terms

Appendices

Appendix 1



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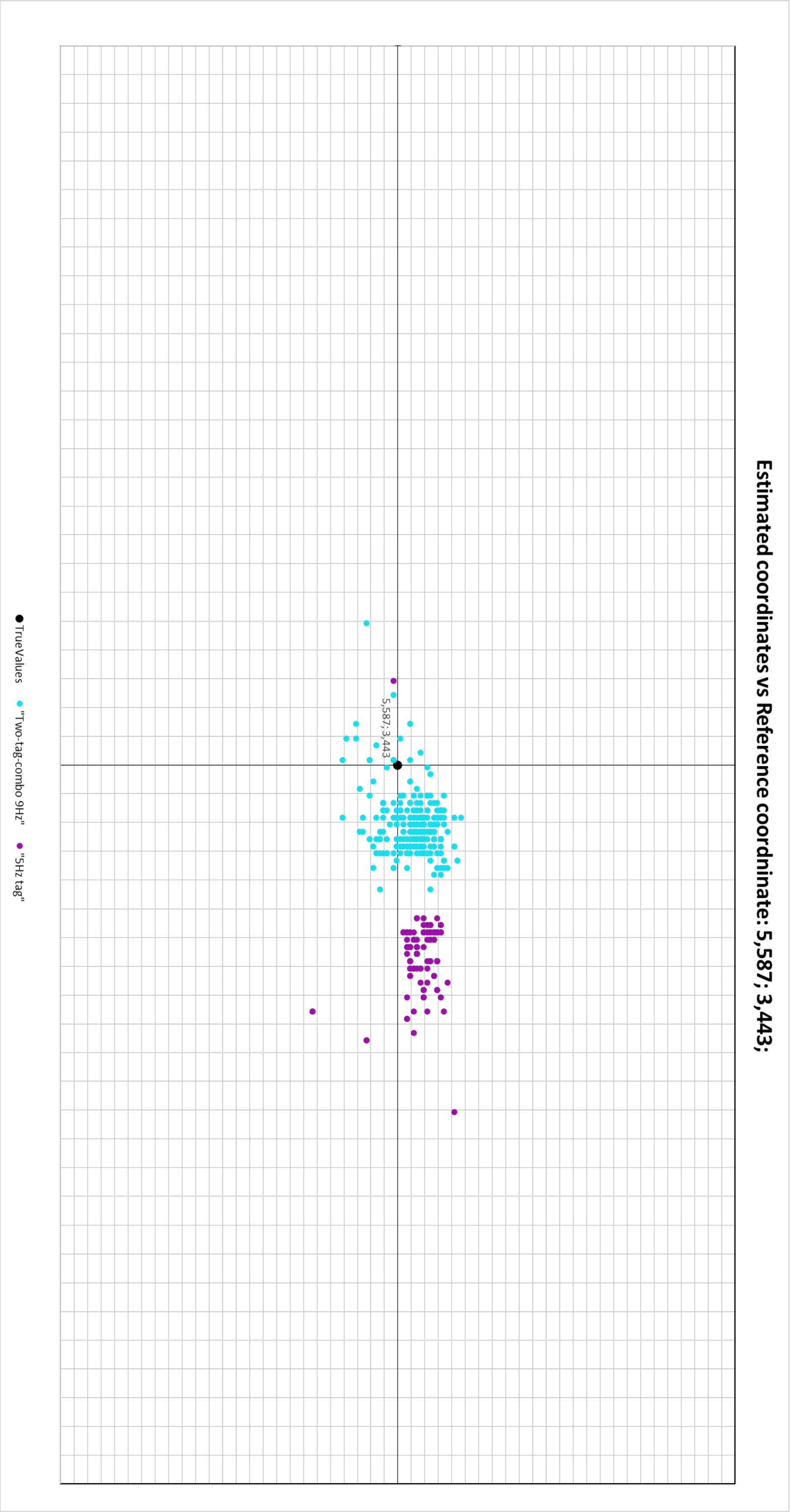

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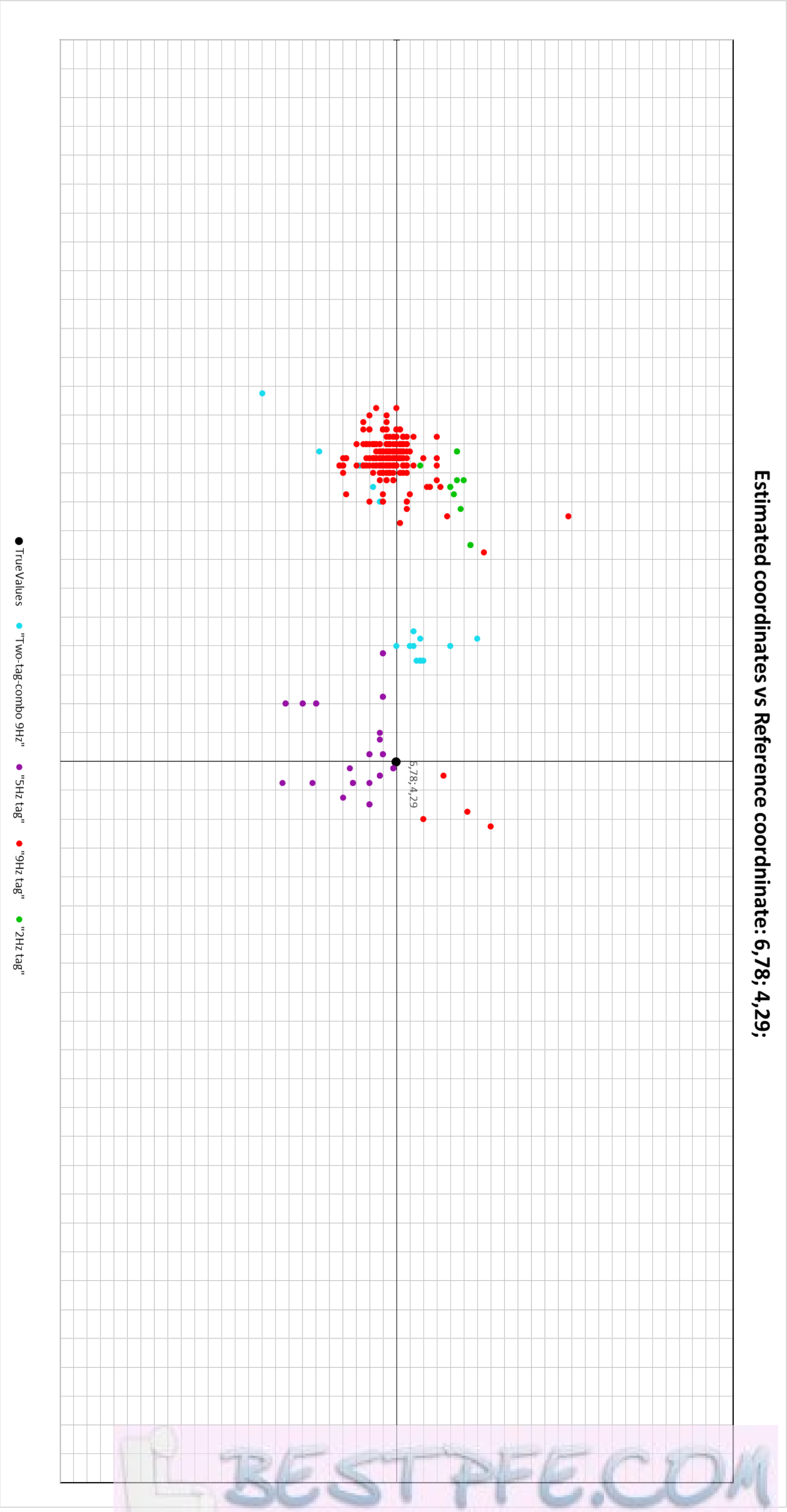
Appendix 3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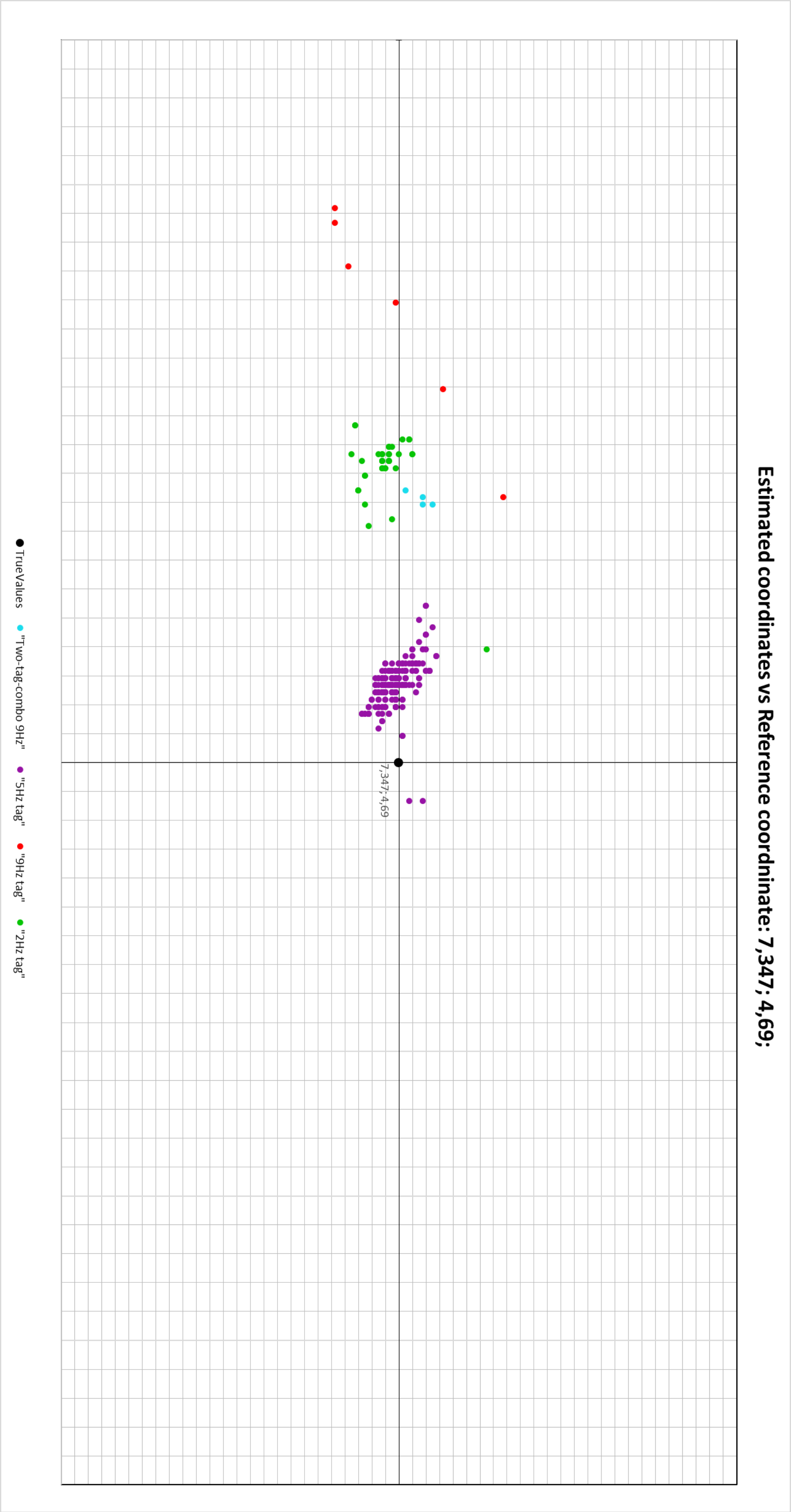
Appendix 4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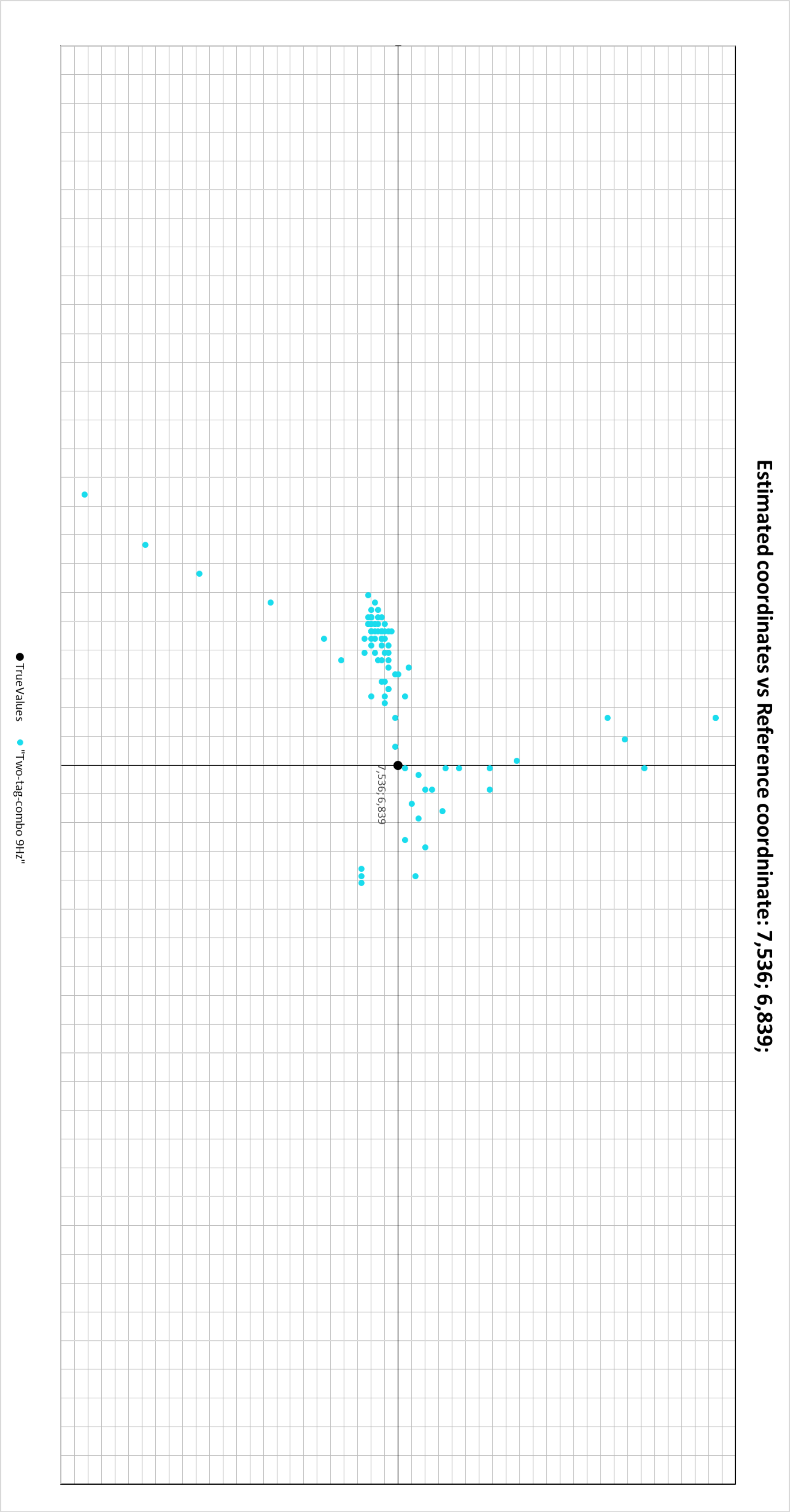
Appendix 5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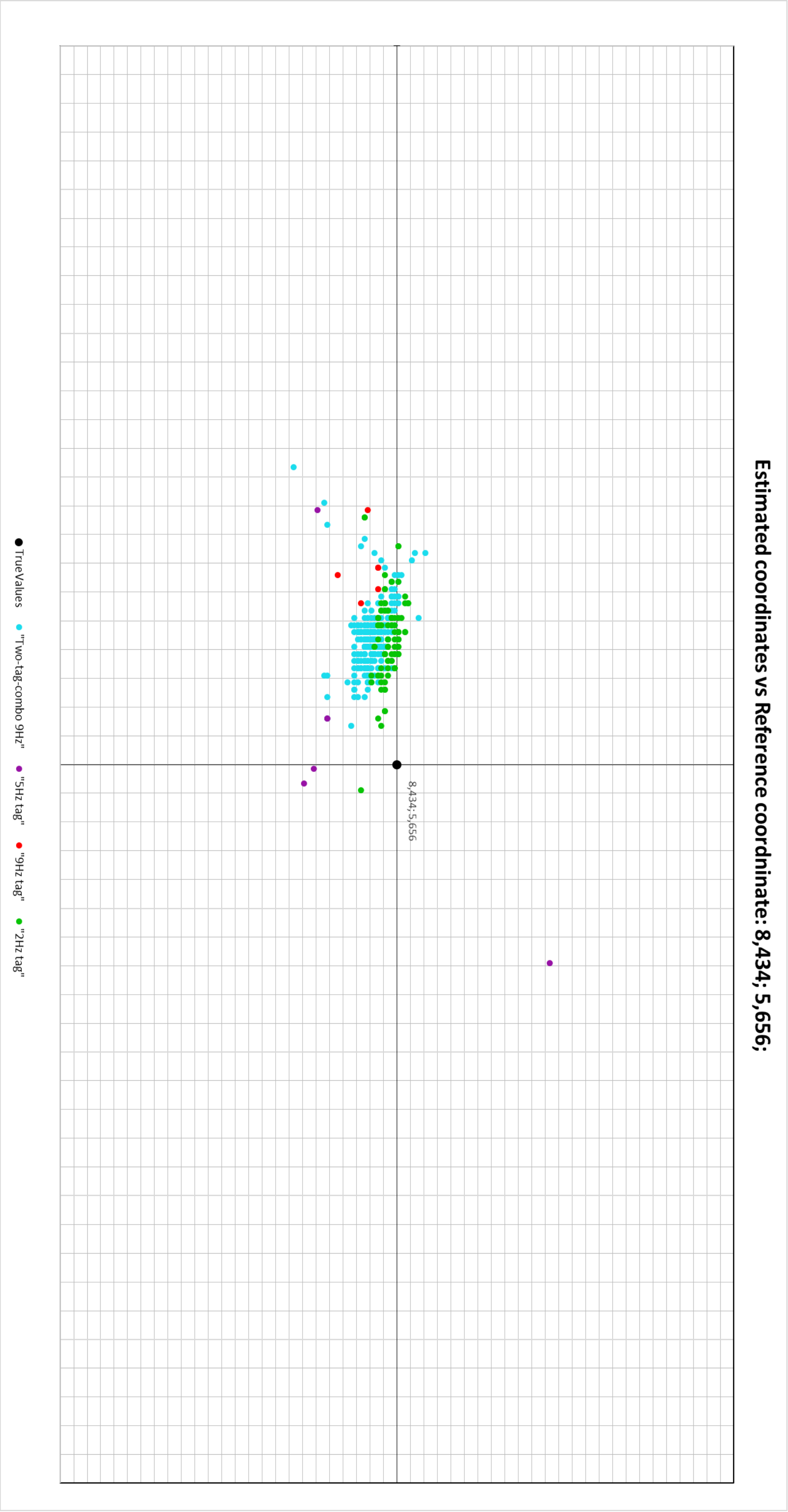
Appendix 6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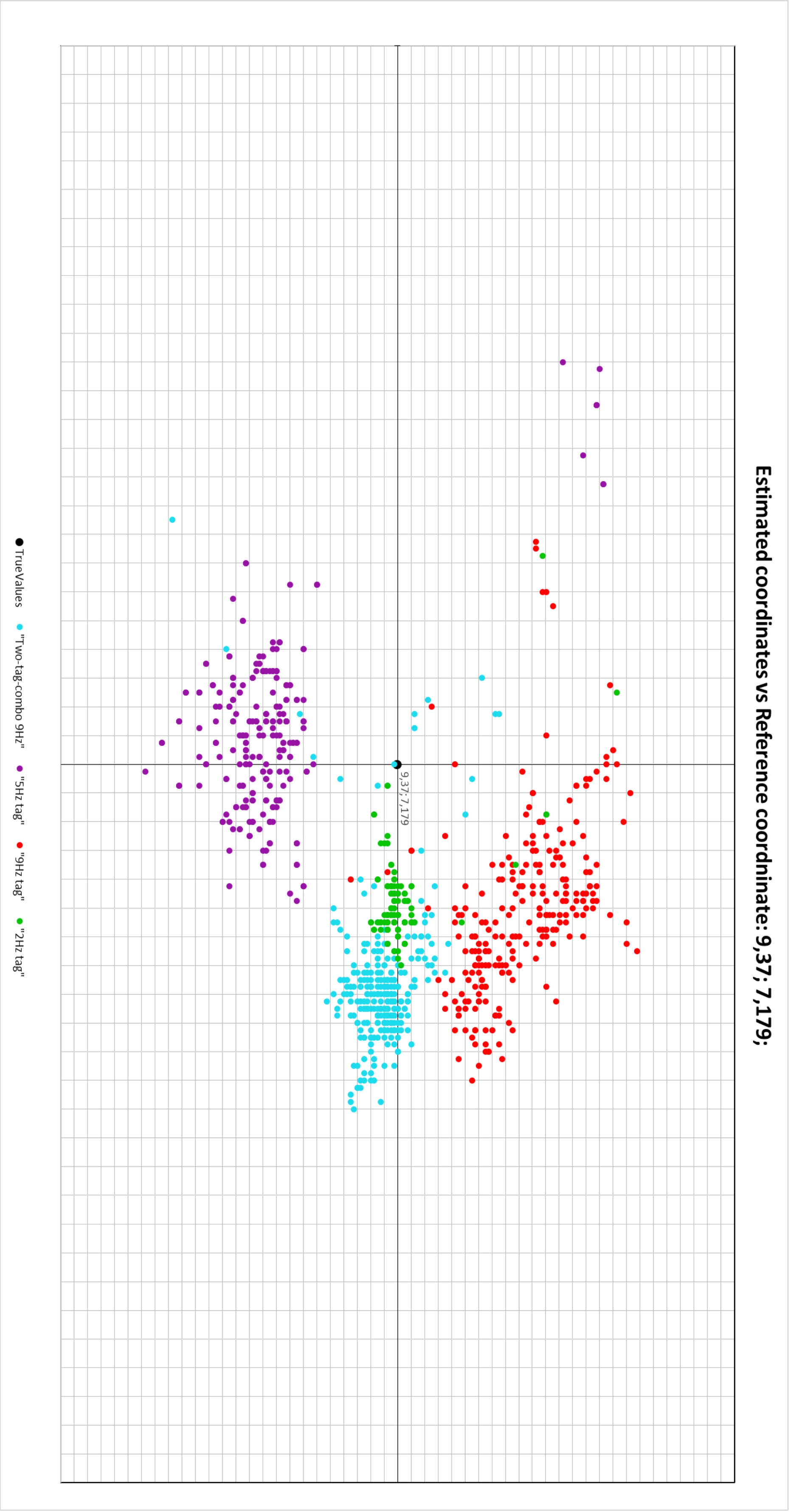
● "2Hz tag"

Appendix 7



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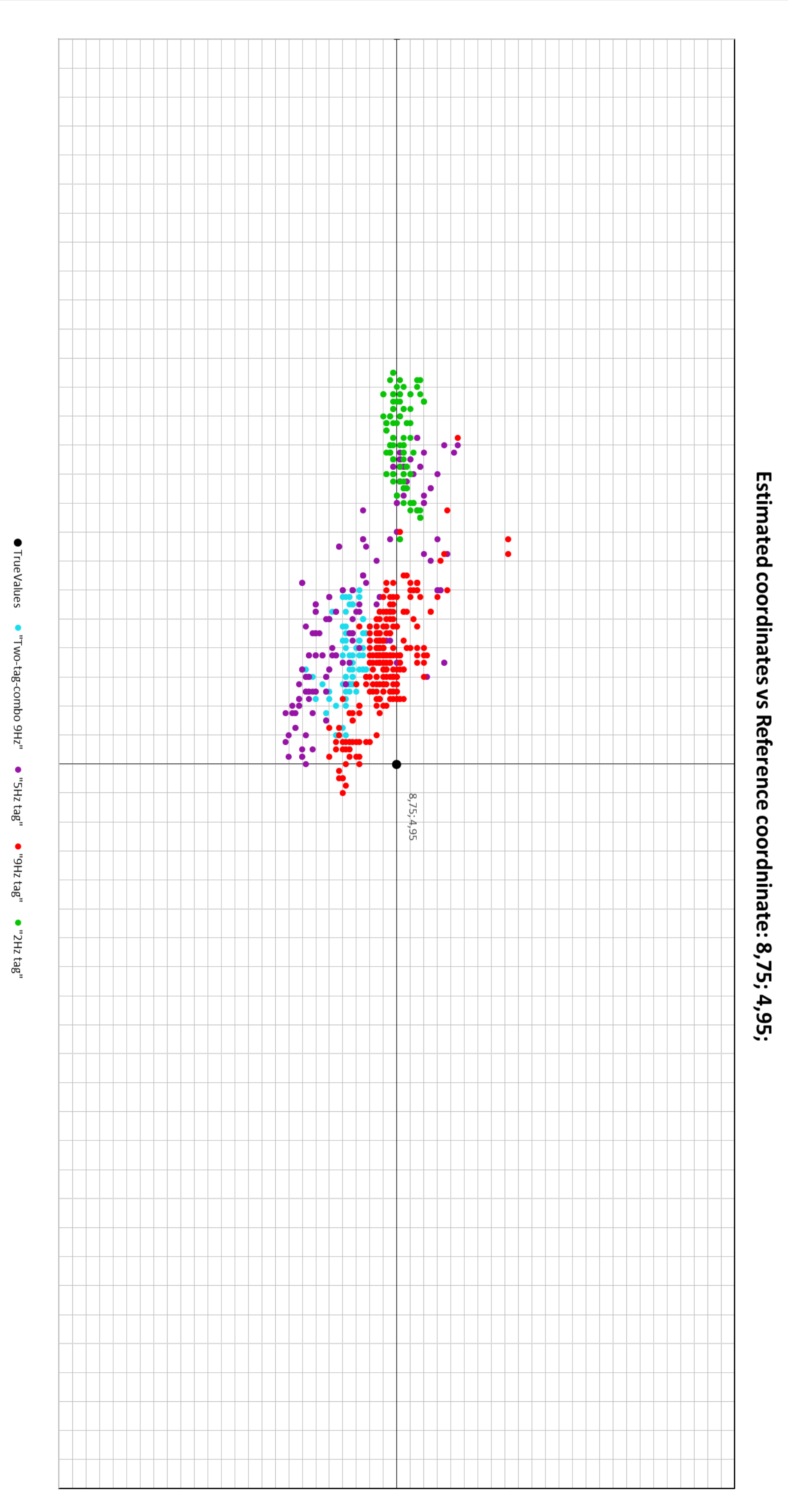
Appendix 8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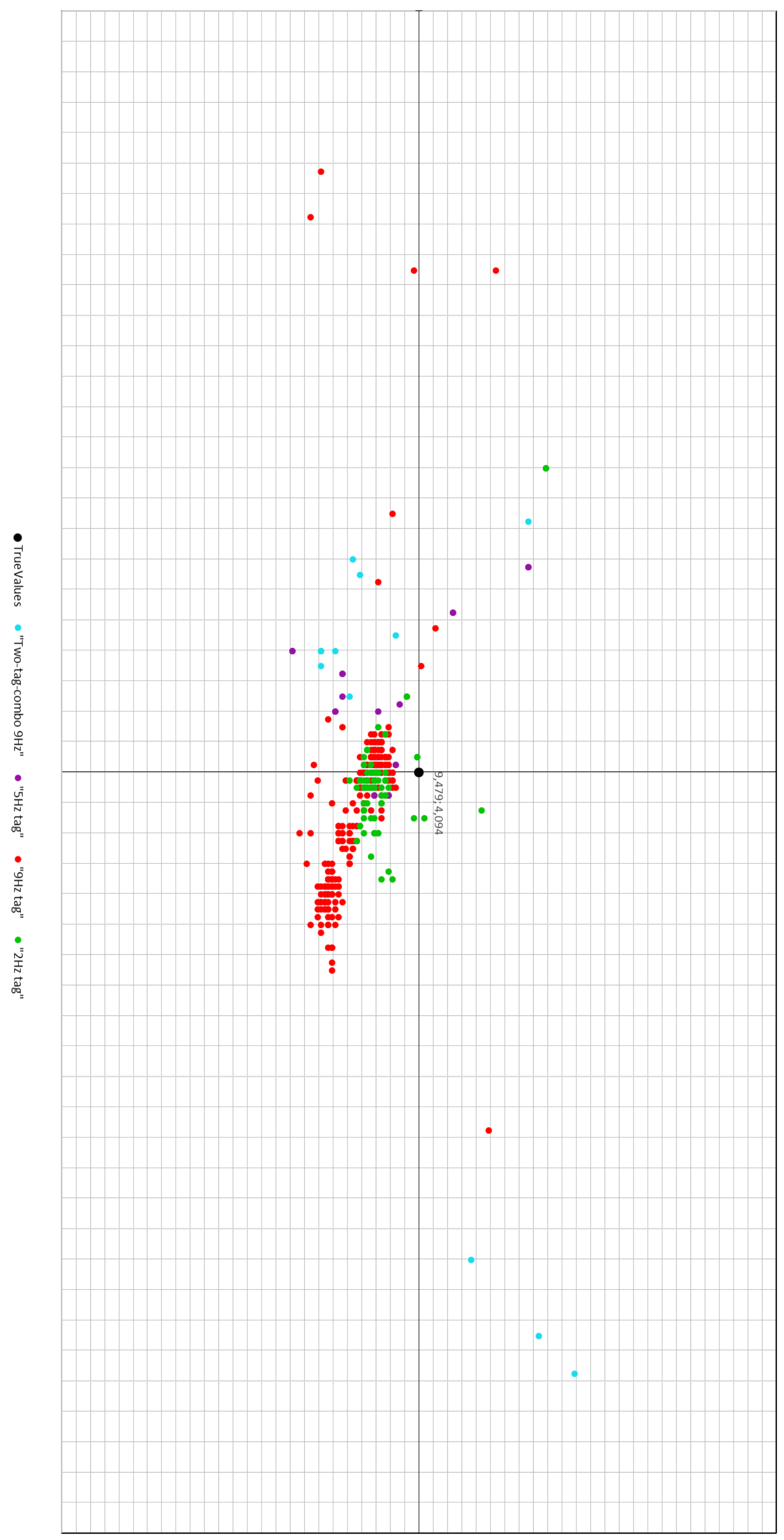
Appendix 9



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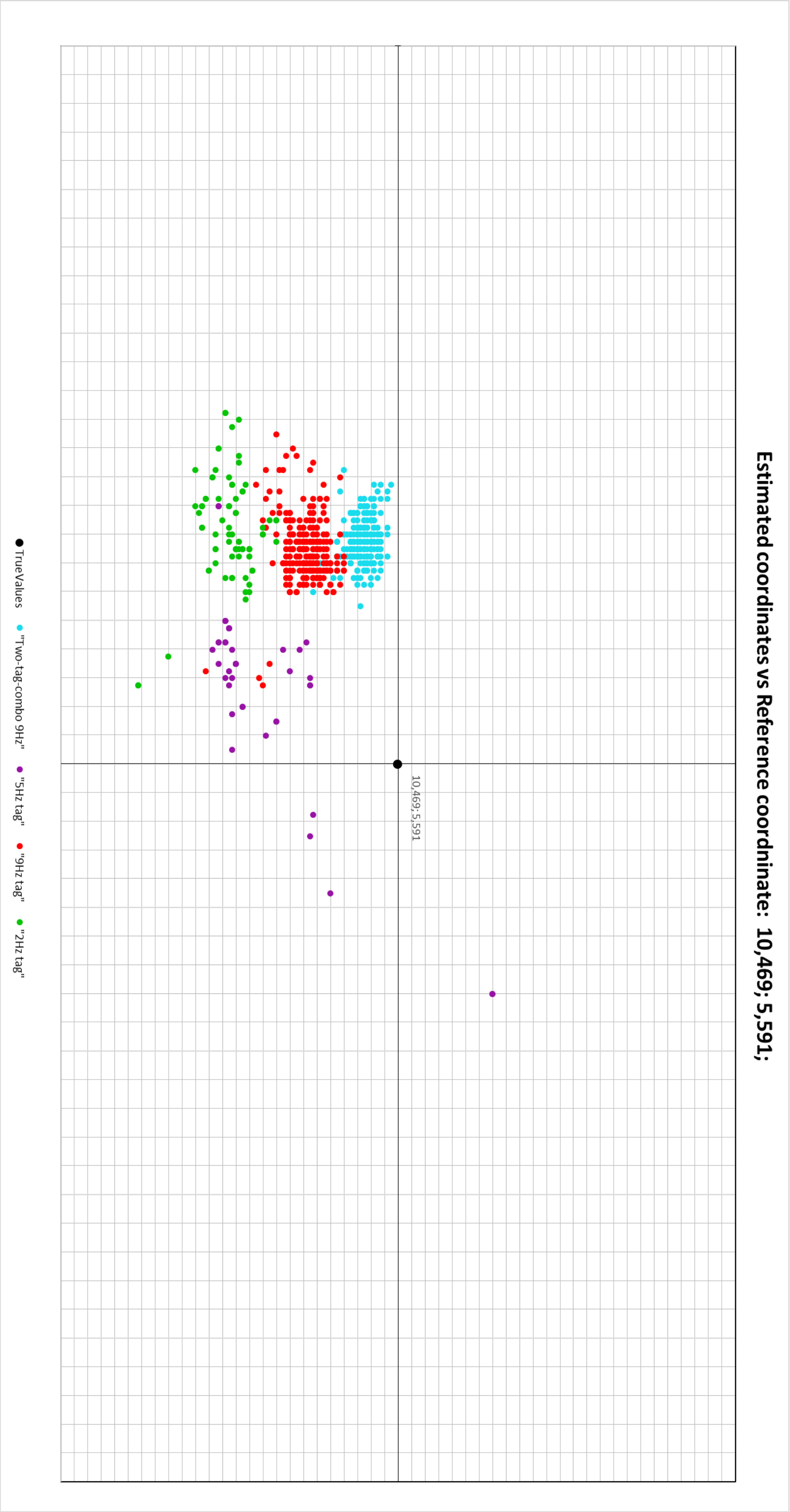
Appendix 10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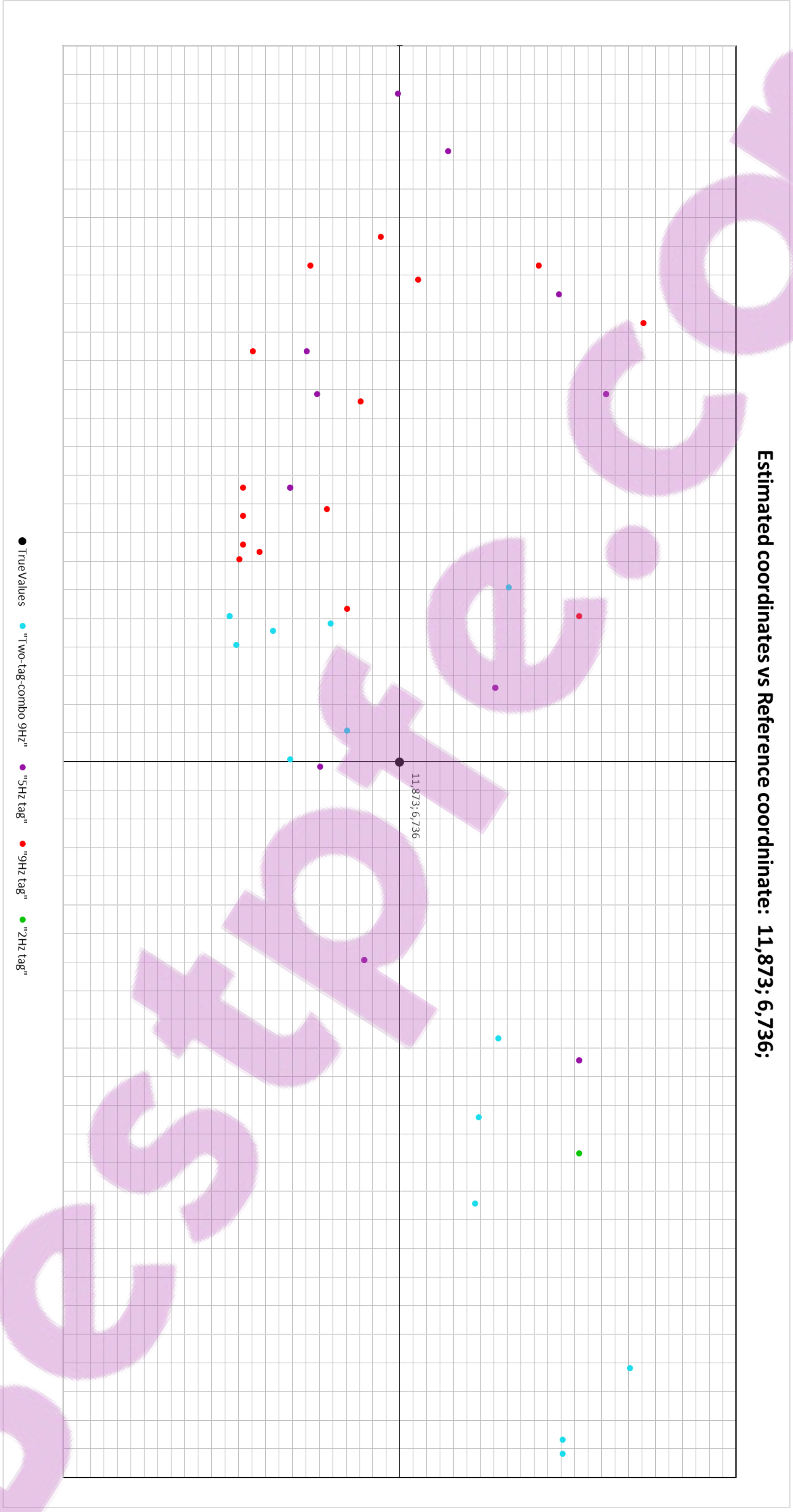
Appendix 11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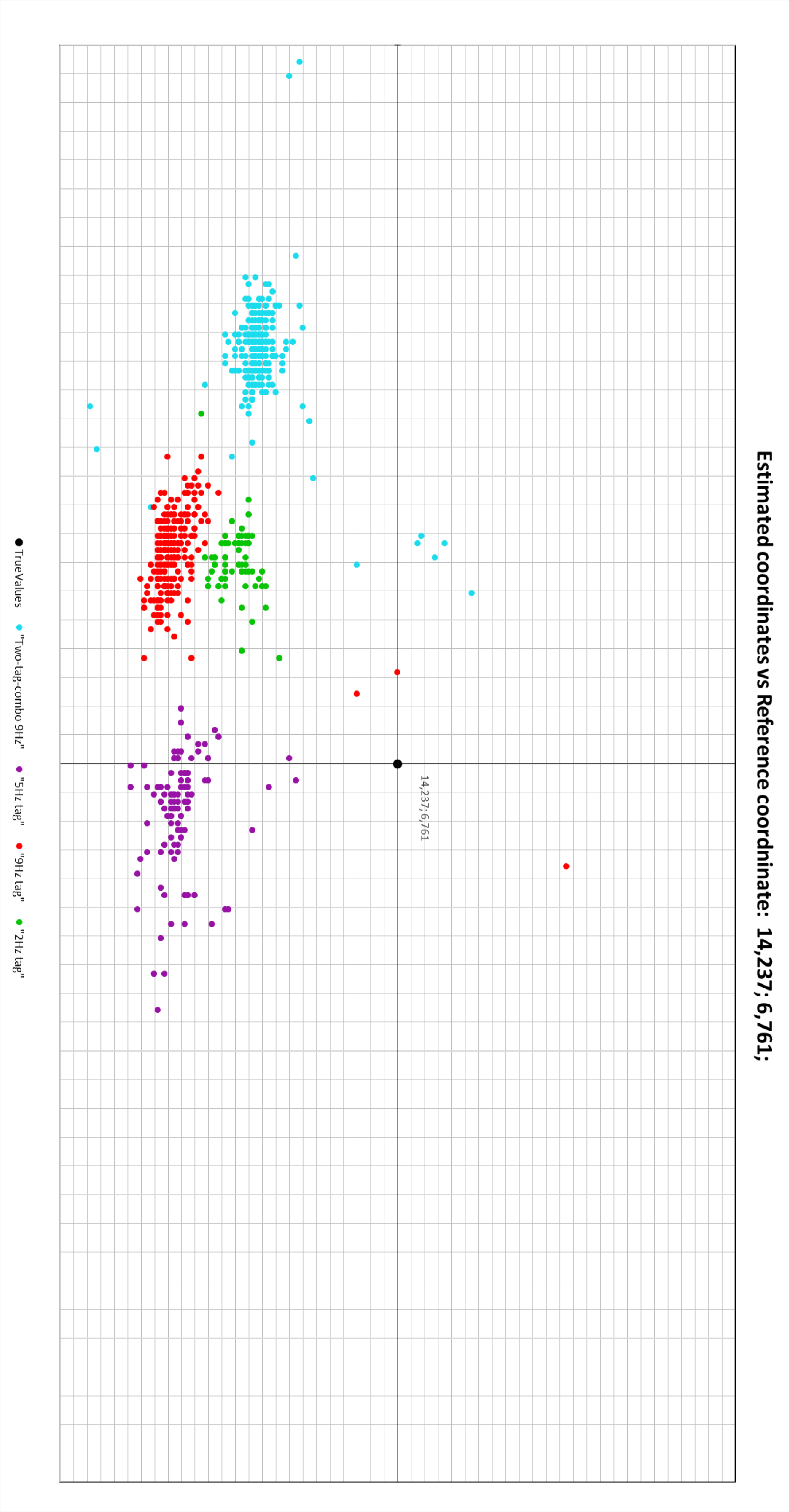
Appendix 12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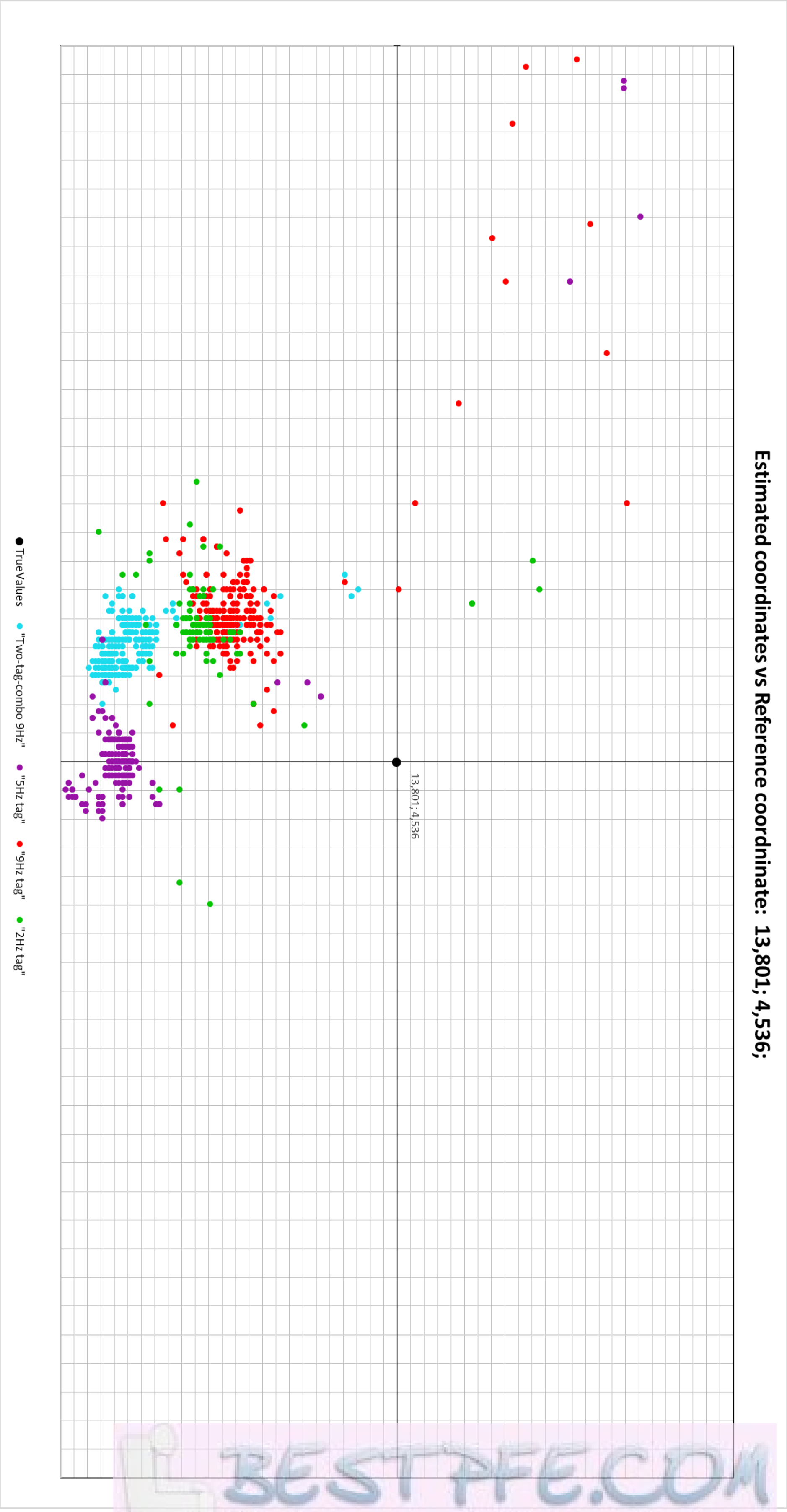
Appendix 13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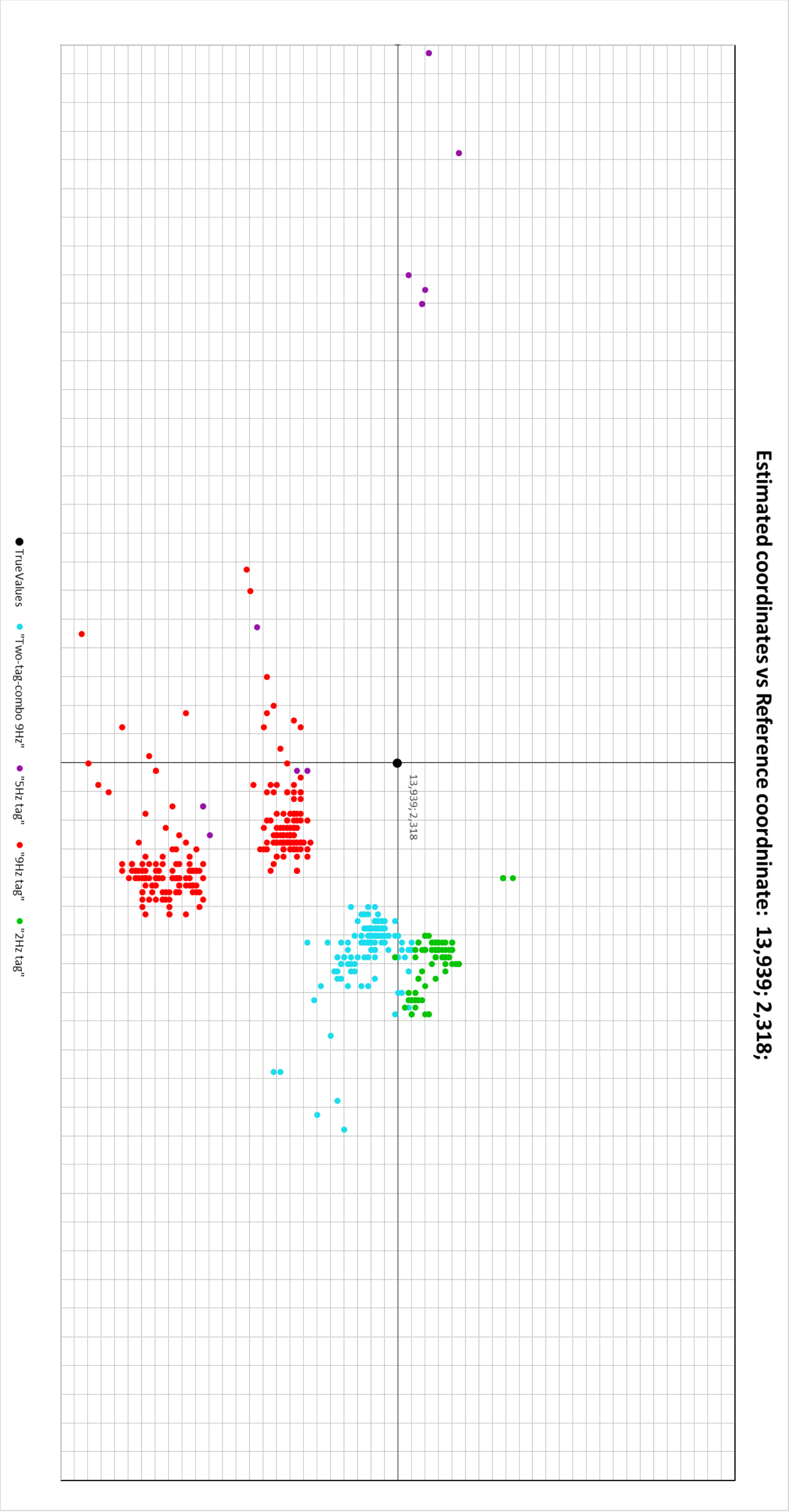
Appendix 14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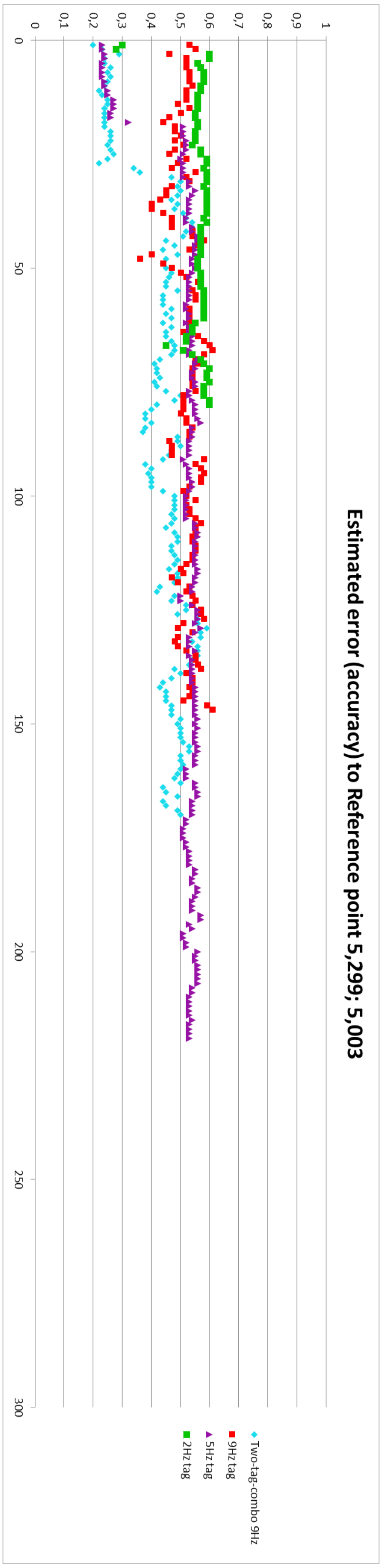
Appendix 15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0,3
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0,5
0,6
0,7
0,8
0,9
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0
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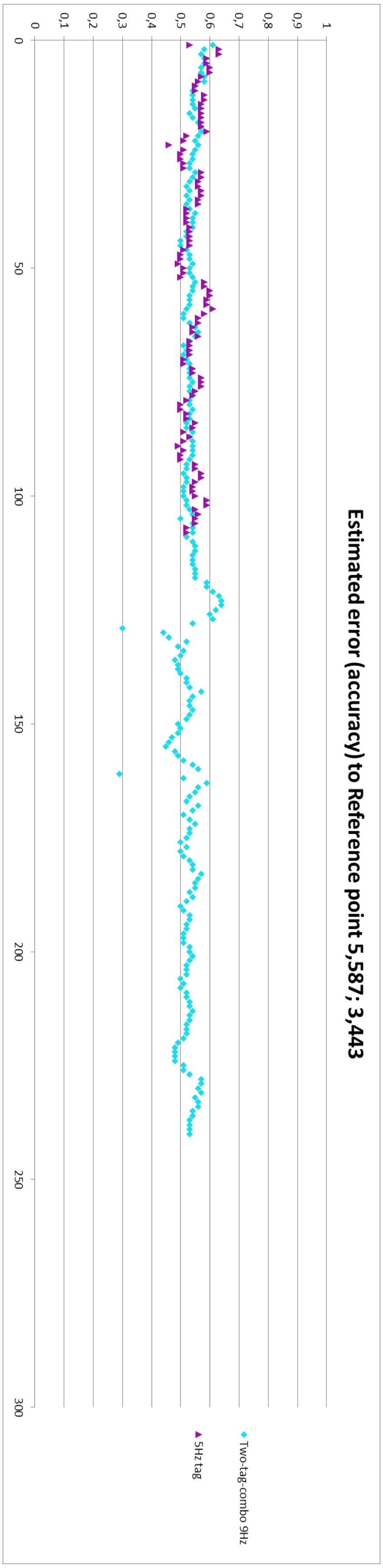
100
150
200
250
300
Two-tag-combo 9Hz
9Hz tag
5Hz tag
2Hz tag

Appendix 16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0,2
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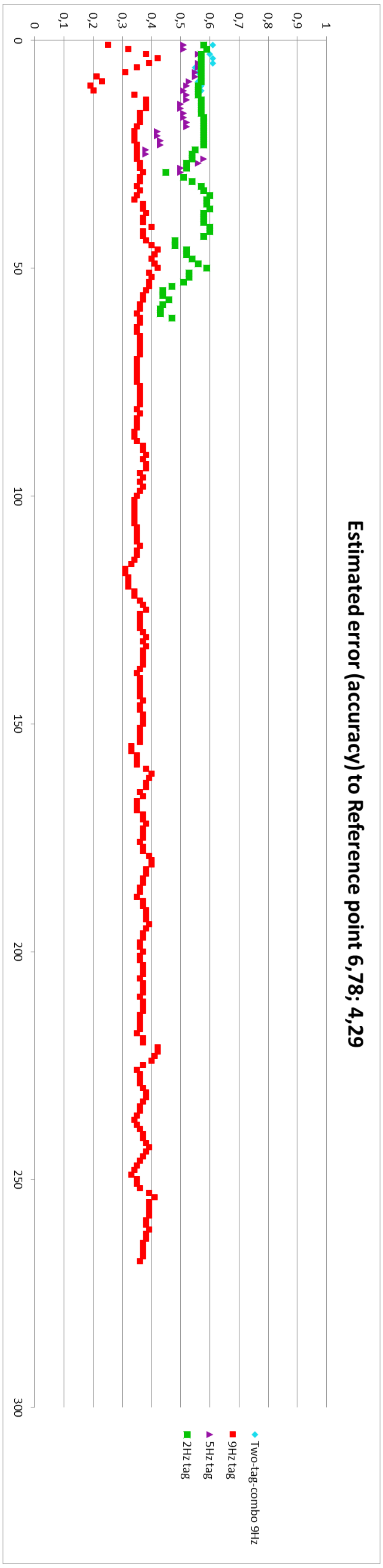
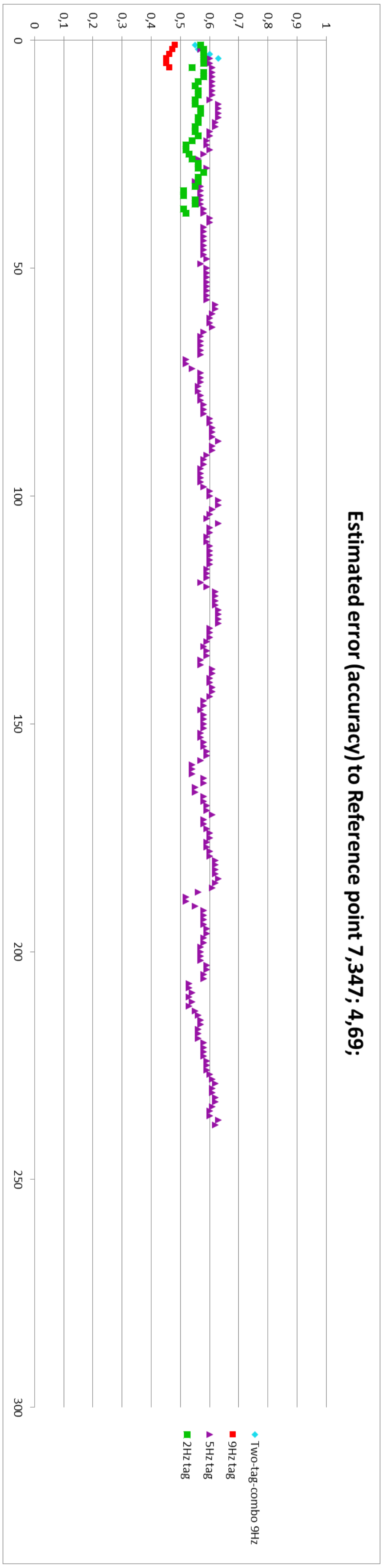
0,4
0,5
0,6
0,7
0,8
0,9
1
0
50
100
150
200
250
300
◆ Two-tag-combo 9Hz
▲ 5Hz tag

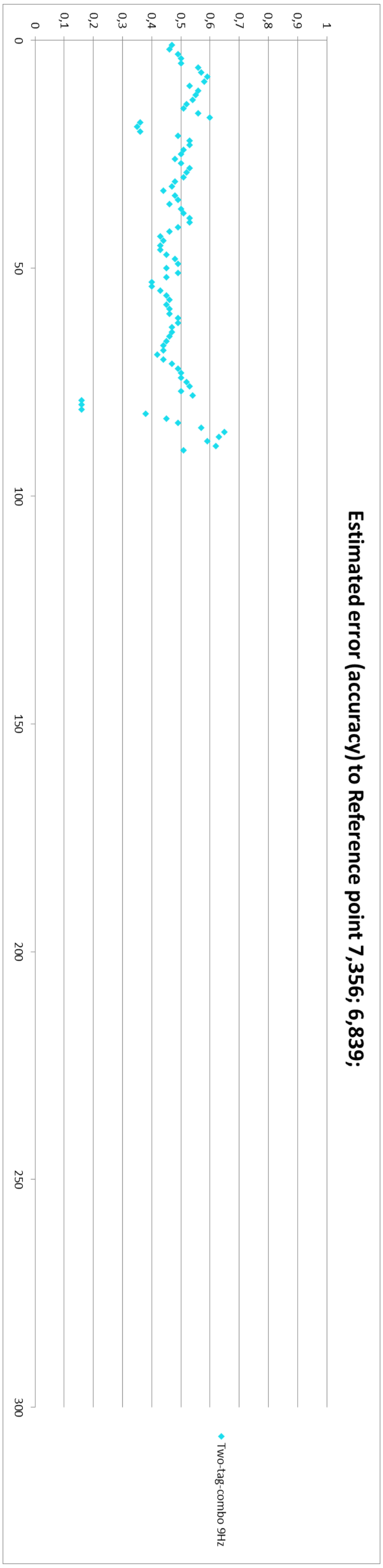
Appendix 17


Estimated error (accuracy) to Reference point 6,78; 4,29
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
0
50
100
150
200
250
300
Two-tag-combo 9Hz
9Hz tag
5Hz tag
2Hz tag

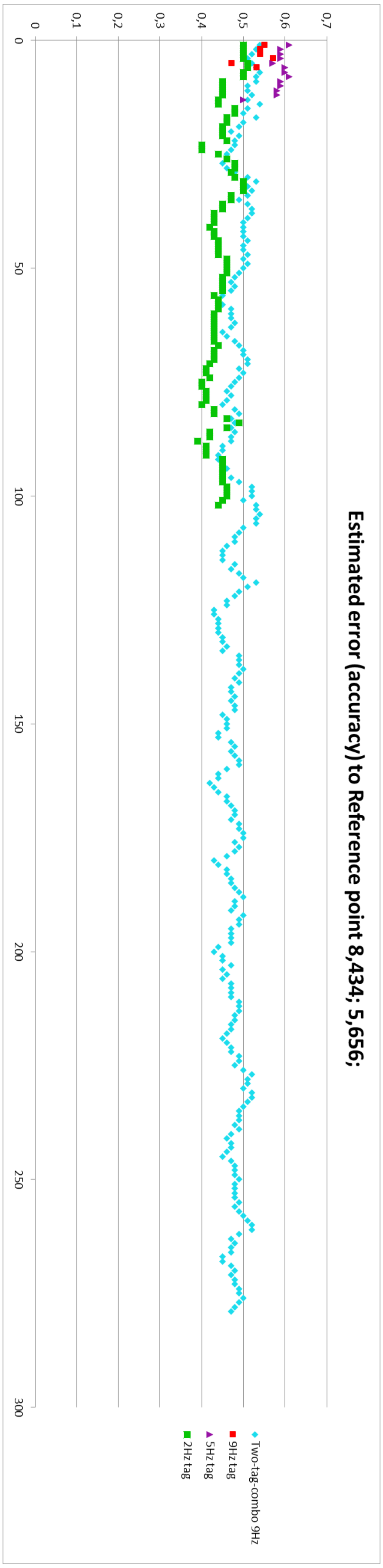
Appendix 18


Estimated error (accuracy) to Reference point 7,347; 4,69;
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
50
100
150
200
250
300
Two-tag-combo 9Hz
9Hz tag
5Hz tag
2Hz tag

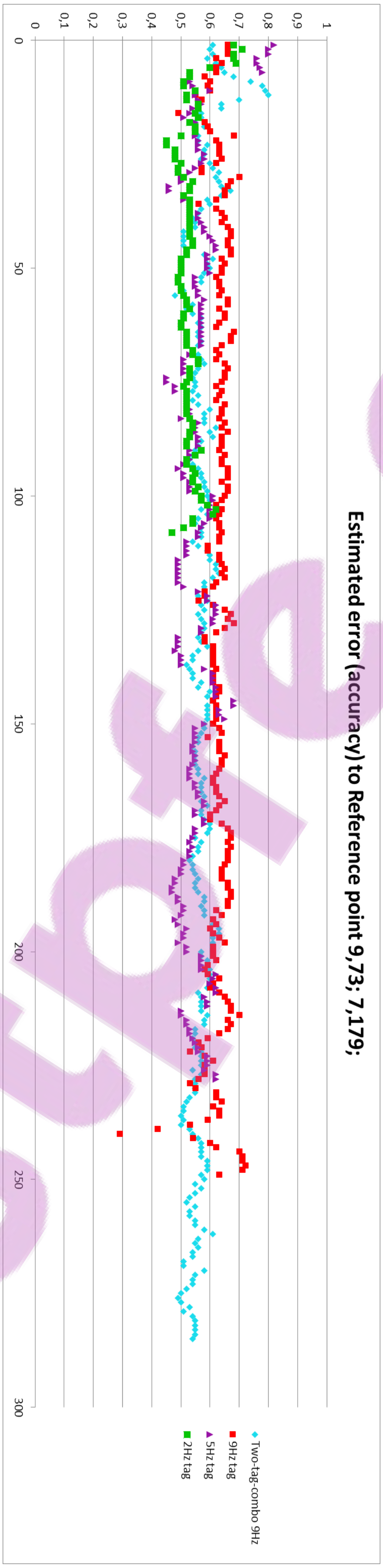
Appendix 19


Estimated error (accuracy) to Reference point 7,356; 6,839;
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
0
50
100
150
200
250
300
Two-tag-combo 9Hz

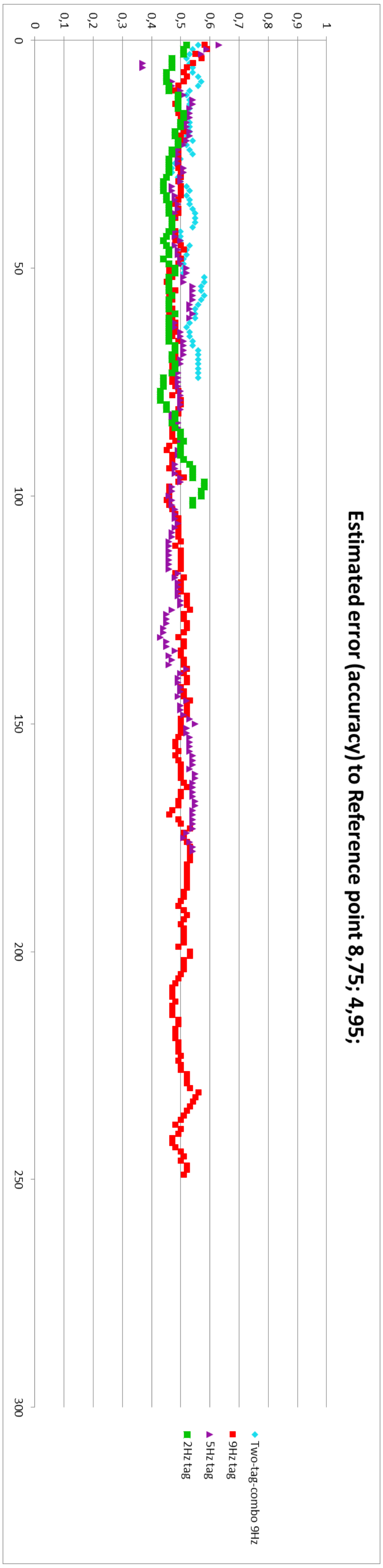
Appendix 20


Estimated error (accuracy) to Reference point 8,434; 5,656;
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0
50
100
150
200
250
300
Two-tag-combo 9Hz
9Hz tag
5Hz tag
2Hz tag

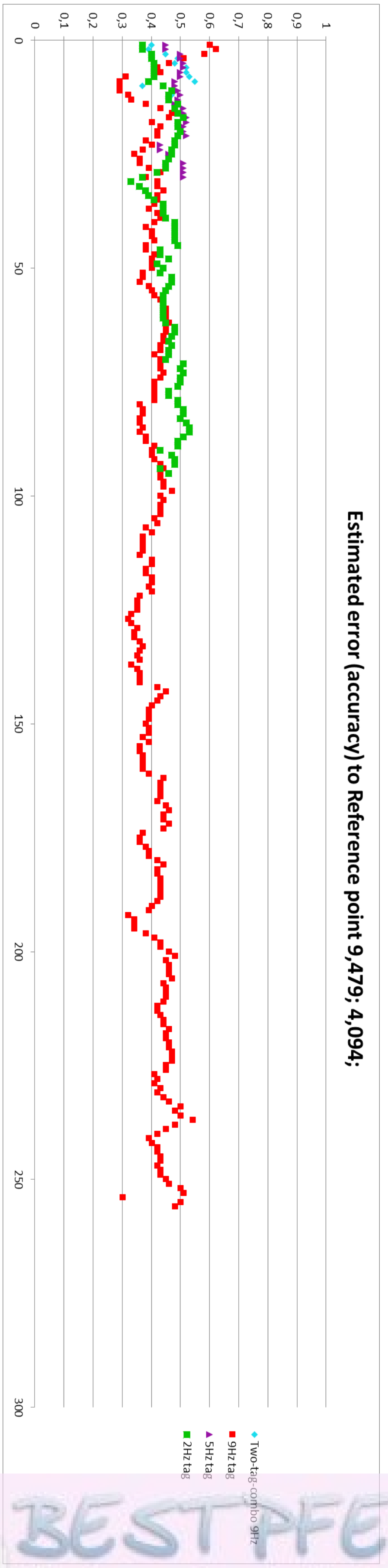
Appendix 21


Estimated error (accuracy) to Reference point 9,73; 7,179;
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
0
50
100
150
200
250
300
◆ Two-tag-combo 9Hz
■ 9Hz tag
▲ 5Hz tag
■ 2Hz tag

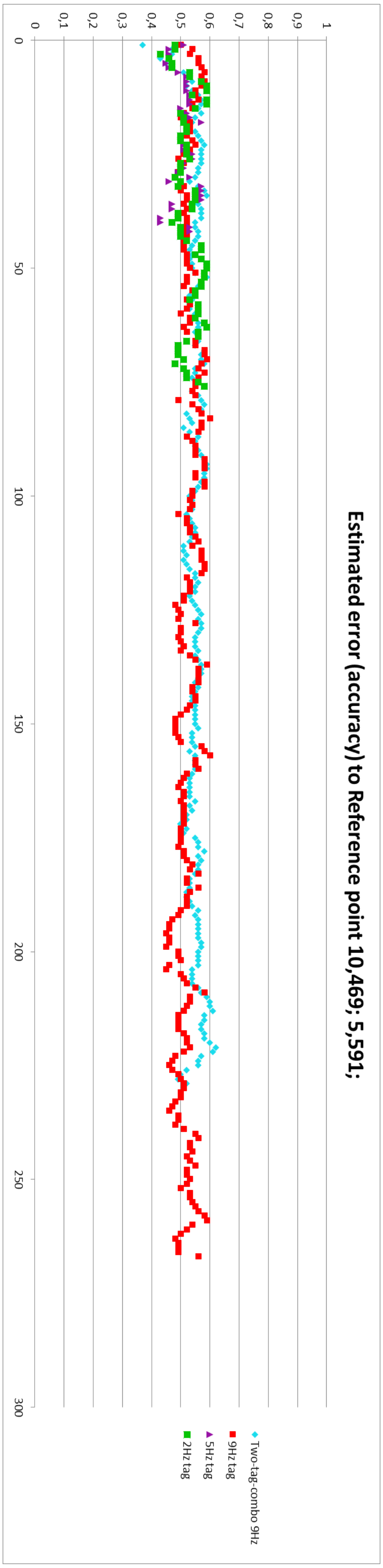
Appendix 22


Estimated error (accuracy) to Reference point 8,75; 4,95;
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
0
50
100
150
200
250
300
Two-tag-combo 9Hz
9Hz tag
5Hz tag
2Hz tag

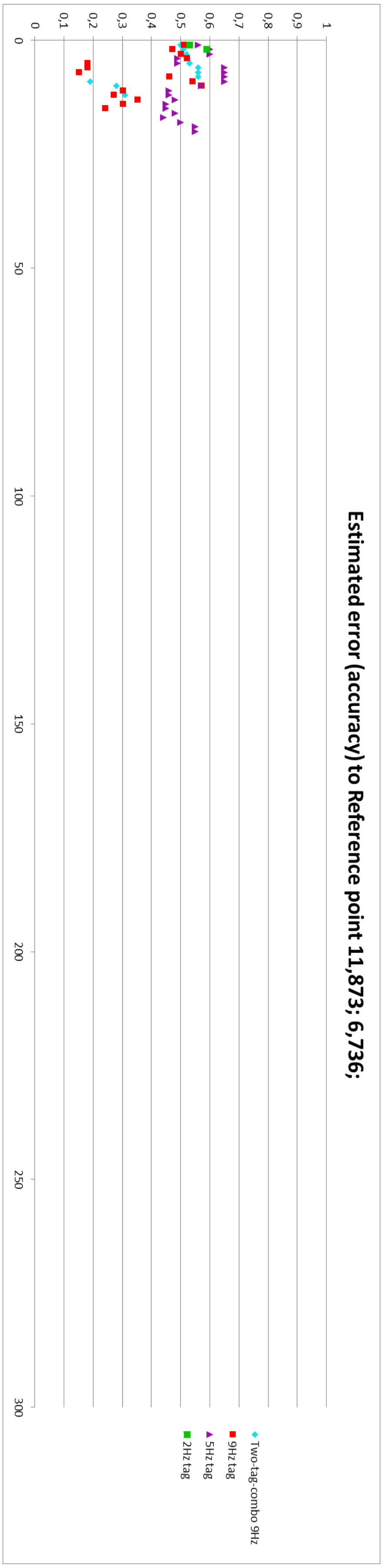
Appendix 23


Estimated error (accuracy) to Reference point 9,479; 4,094;
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
0
50
100
150
200
250
300
◆ Two-tag-combo 9Hz
■ 9Hz tag
▲ 5Hz tag
■ 2Hz tag

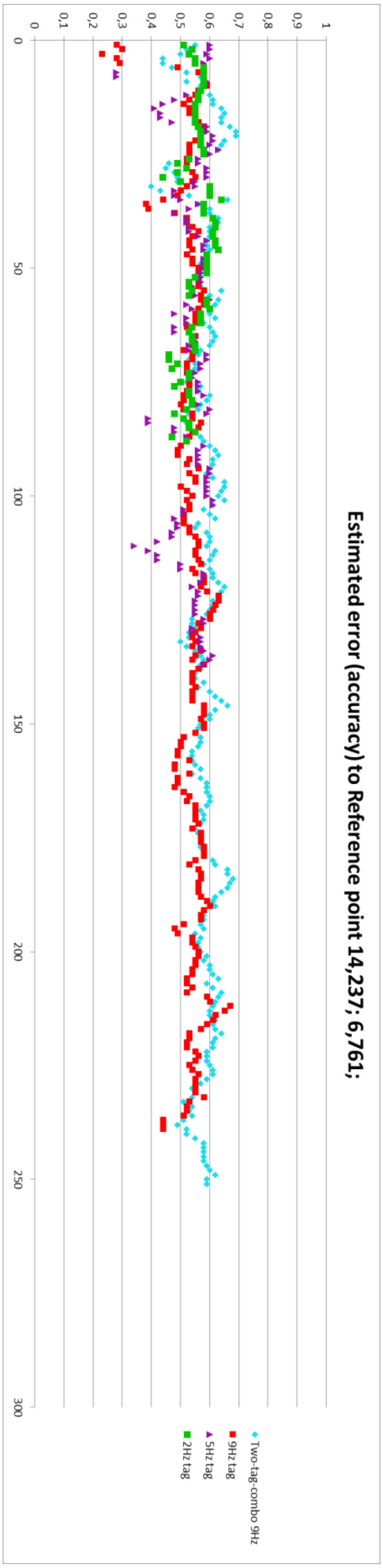
Appendix 24


Estimated error (accuracy) to Reference point 10,469; 5,591;
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
0
50
100
150
200
250
300
◆ Two-tag-combo 9Hz
■ 9Hz tag
▲ 5Hz tag
■ 2Hz tag

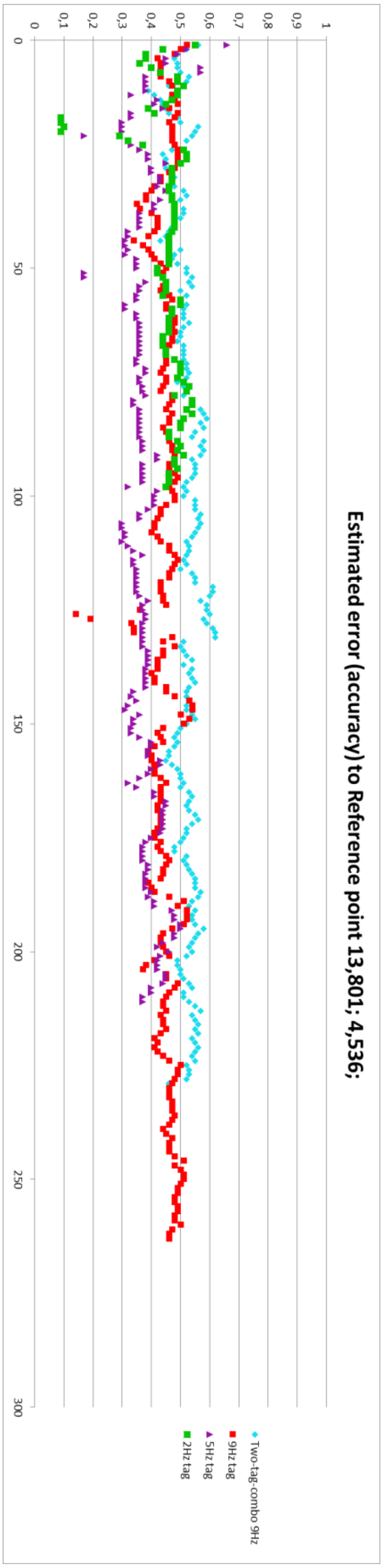
Appendix 25


Estimated error (accuracy) to Reference point 11,873; 6,736;
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
50
100
150
200
250
300
Two-tag-combo 9Hz
9Hz tag
5Hz tag
2Hz tag

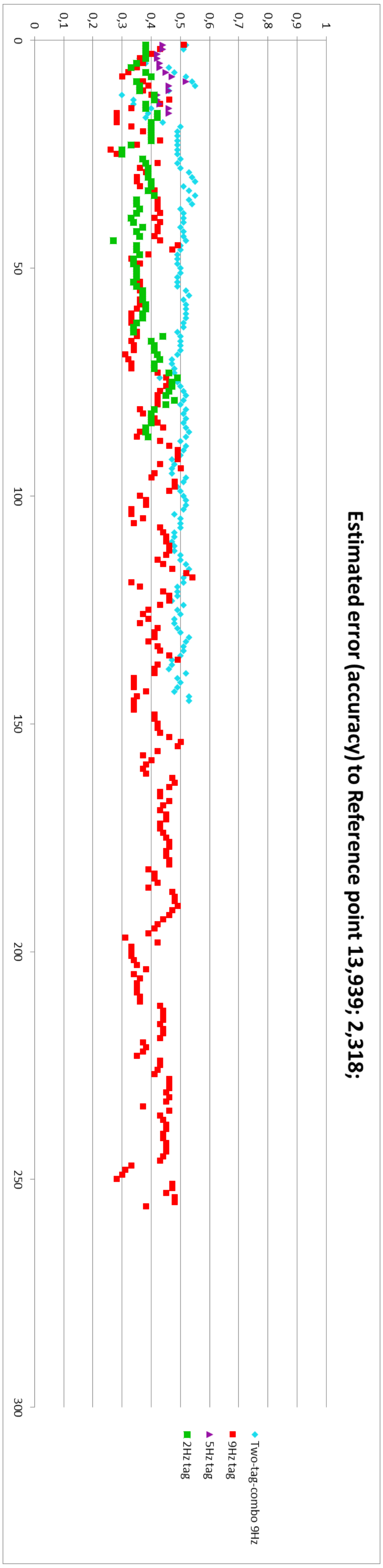
Appendix 26


Estimated error (accuracy) to Reference point 14,237; 6,761;
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
0
50
100
150
200
250
300
Two-tag-combo 9Hz
9Hz tag
5Hz tag
2Hz tag

Appendix 27


Estimated error (accuracy) to Reference point 13,801; 4,536;
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
50
100
150
200
250
300
Two-tag-combo 9Hz
9Hz tag
5Hz tag
2Hz tag

Appendix 28


Estimated error (accuracy) to Reference point 13,939; 2,318;
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
0
50
100
150
200
250
300
Two-tag-combo 9Hz
9Hz tag
5Hz tag
2Hz tag