Tampere University

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FEASIBILITY ANALYSIS OF NON-ELECTROMAGNETICAL SIGNALS COLLECTED VIA THINGSEE SENSORS FOR INDOOR POSITIONING

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ABSTRACT

ANIK DAS: FEASIBLITY ANALYSIS OF NON-ELECTROMAGNETICAL SIGNALS COLLECTED VIA THINGSEE SENSORS FOR INDOOR POSITIONING
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Internet of Things (IoT) has significant impacts on wireless networking and communication technologies of modern times. Recently it has gained also attention in the field of indoor positioning and localization, both in research and industrial markets. IoT technologies enables access to the real time information about indoor environment which are collected through sensors. The sensor data is processed and analysed to understand the complexity of the indoor environment so that it can be used for making applications based on positioning. This thesis deals with some modern applications, challenges, key technologies and architectural overviews of Internet of Things including some recent works which were carried out based on electromagnetical and non-electromagnetical approaches. Then. a feasibility analysis is made for indoor positioning using non-electromagnetical sensor data which includes temperature, humidity, pressure and luminance. These sensors are also known as environmental sensors. An IoT development device named 'Thingsee One' was used where the environmental sensors were embedded in. The device was used for capturing environmental data from different locations inside a university building in Tampere, Finland. At first, Thingsee One device was configured for capturing temperature, humidity, pressure and luminance data from an indoor environment. Measurements were taken from different locations of the building, from first and second floor. Different times and weather condition were also taken into account during data capturing. Then the captured data has been analysed for identifying those positions through histograms and power maps. The results show that, the data captured by the sensors are highly dependent on time and weather which makes them rather inconsistent over the same position in different situations and time and therefore not likely candidates for positioning estimation.

Keywords: Internet of Things, Indoor Positioning, Non-Electromagnetical Signals, Environmental Sensors, Thingsee One

The originality of this thesis has been checked using the Turnitin Originality Check service.

PREFACE

This thesis was conducted at Tampere University as a requirement of the Degree Program Master of Science in Information Technology. The whole experiment and analysis were supervised and examined by **Associate Professor Elena-Simona Lohan** and **Professor Jari Nurmi**. I would like to thank both of my supervisors for their cordial support and guideline. Next, I would like to thank the support team of Thingsee and Haltian for their quick support and help. Finally, I want to thank my parents for supporting me throughout my whole life.

Tampere, 18 October 2019

Anik Das

CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ADAS	Advanced Driver Assistant System
AOA	Angel of Arrival
AP	Access Point
AR	Augmented Reality
ASCO	American Society of Clinical Oncology
B2B	Business to Business
BIM	Building Information Model
CV2X	Cellular vehicle-to-Everything
CGM	Continuous Glucose Monitoring
DOA	Direction of Arrival
DoS	Denial of Service
ECG	Electrocardiogram
EKF	Extended Kalman Filter
GPS	Global Positioning System
IoT	Internet of Things
IP	Internet Protocol
IPS	Indoor Positioning System
ITS	Intelligent Transport System
ITU	International Telecommunication Union
LED	Light Emitting Diode
LPWA	Low-Power Wide Area
LS	Least square
LSM	Least Square Method
M2M	Machine to Machine
MEMS	Microelectromechanical Systems
MIT	Massachusetts Institute of Technology
NE	Nash Equilibrium
NFC	Near Field Communication
NOLS	Non-Line-of-Sight
OFDM	Orthogonal Frequency Division Multiplexing
PDR	Pedestrian Dead Reckoning
PSO	Particle Swarm Optimization
RLS	Recursive Least Square
RCRLS	Reduced Complexity RLS
RPM	Revolutions per Minute
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
SMS	Short Message Service
STVBF	Skew-t Variational Bayes Filter
SUP	Suspected Unapproved Parts
TDMA	Time Division Multiplexing
TOA	Time of Arrival
TOF	Time of Flight
UIPS	Ultrasonic Indoor Positioning System
USB	Universal Serial Bus
UWB	Ultra-Wide Band
V2I	Vehicle to Infrastructure
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle
VLP	Visible Light Positioning
VR	Virtual Reality
WLAN	Wireless Local Area Network

WSN	Wireless Sensor Network
%	Percentage
C	Celsius
hPa	Hectopascal
lux	Luminous Intensity

1. INTRODUCTION

Internet of Things or IoT refers to the interconnection of smart devices over the internet. According to [4], the Internet of Things enables the data collection and communication among physical objects and devices through a communication network, software and sensors. The concept of Internet of Things was first introduced by Kevin Ashton, founder of Auto-ID centre, Massachusetts Institute of Technology (MIT) in 1999 [55]. Since then, the terminology of IoT has gone through several changes and now we are experiencing one of the most advance phases of IoT technologies. In [14], the author has compered Internet of Things with an umbrella keyword as it covers almost every aspect related to web and internet and believed that it will create a whole new world by interconnecting the physical and digital world in the future. There are hardly any field exists in the world where Internet of Things has failed to place its footprints.

1.1 Motivation

Most of the technologies related IoT are still under development. Developing new IoT based applications requires strong and depth knowledge about these technologies (e.g. programming language). In most of the cases, it becomes unclear especially for a non-technical person. As a result, many manufacturers are focusing on making IoT development kits which allow to make simple applications quite easily even for a non-technical person who does not have any prior knowledge of programming languages. Recently, the market of such kind of development kits has increased drastically. Companies such as Particle, Haltian, Konekt, Arduino, Qualcomm and many more have launched IoT development kits for different purposes in recent times which make developing IoT based applications smooth and simple.

IoT technologies in indoor positioning is a hot topic in recent times. Indoor and outdoor positioning systems are totally different from each other. Satellite-based positioning system are widely used all over the world for outdoor positioning which deliberately provides location information in time with high accuracy. However, designing an indoor positioning system is much more challenging than designing an outdoor positioning system due to the complexity of indoor environment and unpredictable frequent movements. As a result, a lot of existing indoor positioning system lacks precisions and accuracy and therefore, using IoT technologies might be a game changing approach.

1.2 Recent Works

A lot of recent works has been performed in order to bring better positioning results for indoor environment that use IoT technologies and most of them are based on electromagnetic signals. A new indoor positioning platform named ThingsLocate was introduced in [58] which works with Wi-Fi based fingerprinting and Received Signal Strength Indicator (RSSI). In [56], an improved indoor positioning algorithm was proposed with the combination of clustering algorithm which increases the computational efficiency and K-nearest algorithm which increases the positioning accuracy for Wi-Fi based indoor positioning system. In [57], an area-independent tractable model was introduced for low-power wide area (LPWA) IoT. However, very few research works include non-electromagnetical approaches in this field where visible light, sound, odour and smell based positioning are notable. There are hardly any research works focused on wireless positioning that use environmental data using environmental sensors e.g. temperature, humidity, pressure, luminance.

1.3 Thesis Objectives

In this thesis, a feasibility analysis for indoor positioning is made based on sensor data captured by an IoT development device named ‘Thingsee One’. Four environmental sensors embedded in Thingsee One device, namely: temperature, humidity, pressure and luminance were used for taking the measurements. The measurements were taken from different locations of a university building located in Tampere, Finland from ground and second floor. The measurements were taken in three days in three different times in order to observe the impact of time and weather to the data. Later, an analysis is made for each sensor data for indoor positioning using histograms and power maps. Before using Thingsee One, another device was tested for this purpose named uBeacon Mesh, but the campaign was stopped due to its platform dependency and discontinuity in uBeacon Mesh support.

1.4 Author’s Contributions

Author’s contributions to the thesis are listed below.

- Literature review on the IoT applications, challenges, key technologies and architectures, current electromagnetical and non-electromagnetical positioning approaches.

- Documentation study about Thingsee and Ubudu sensors.
- Tested devices- uBeacon Mesh and Thingsee One.
- Measurement via Thingsee One sensors.
- Implementation of a Python-based program to extract and separate Thingsee sensor data e.g. temperature, humidity, luminance and pressure from one file into four different files.
- Analysis of the sensor data for indoor positioning based on histograms and power maps.

1.5 Thesis Structure

The rest of this thesis is organized as follows.

- In the second chapter, some IoT based applications and challenges were discussed.
- Chapter 3 includes some key technologies and architectures of IoT.
- In chapter 4 some positioning approaches are discussed based on electromagnetical and non-electromagnetical signals in indoor environments.
- Chapter 5 includes all the information related to the tested devices which includes uBeacon mesh and Thingsee One.
- Chapter 6 describes the measurement setup and feasibility analysis of the measurements for positioning. A comparison between the measurement data in both floors is also presented in this chapter.
- Finally, chapter 7 provides the conclusion and future aspects of using environmental sensors for indoor positioning.

2. IOT APPLICATIONS AND CHALLENGES

This chapter deals with some applications and open issues related to present and future IoT technologies.

2.1 Applications of IoT

A multitude of services and applications can be built with the help of IoT technologies and most of them are currently under development. In future, there will be more aspects to be taken into account, as the IoT market is growing rapidly. IoT applications are meant to make the human life easier and more comfortable and to provide better services and security. More intelligent devices and applications will be developed such as smarter home and offices, smart cities, smart transportation, smart energy, smart industry, smart education, smart hospitals, and so on. In this subsection, some of the applications are briefly discussed.

Applications in Telecommunication Industry: The use of mobile internet is increasing day by day because of its easy access to data and to the fact that it provides flexibility in exchanging multimedia contents. IoT will take this into the next level by merging huge amount of telecommunication technologies over internet, which will create the possibility to open new services. Smart payment (i.e. Google pay) can be a good example to illustrate this application. It uses a process called Tokenization, where a token is used instead of actual payment cards and this way, the actual card number does not get reviled to the merchant. Near Field Communication (NFC) enables a secure communication between mobile phone and payment terminal during in store payment and transmits token information into the central server. During payment via mobile app, SIM- card stores and authenticates the information. Several factors work together in order to facilitate the whole process, i.e. NFC, multi-hop networks, GSM, GPS, SIM-card technologies etc. [1].

Applications in Smart Homes: Smart home, where all the appliances and equipment will be connected in order to save energy and make more convenient way of living. It involves automated heating systems with temperature sensors, alarm clock synced with traffic apps, automated lights, air condition and ventilation with motion detectors, automated waste management, washer, dryer, oven, refrigerators etc. Altogether, they will be connected through Wi-Fi, making the possibility for remote monitoring [7]. This way we could save a lot of money on those bills.

Applications in Environmental Monitoring: IoT technologies will play one of the most promising roles in order to access real-time information about the environment. Combining with information and communication technologies, IoT technologies can conduct satisfactory services and infrastructures for residents and visitors [2]. Thus, people living in the city can get real-time information about the environment such as temperature, humidity, precipitation and also get cautious before any natural calamity in order to reduce damages across the city. In [1], the authors believe that IoT technologies such as wireless identifiable devices will play a promising role, both commercially and environmentally, running environment friendly programs all over the world.

Applications in Transportation Industry: IoT technologies can offer improved travel experience by enhancing customer services and communication systems. Providing real-time information about transit systems, luggage monitoring, automated tracking, and sorting will improve the security and will reduce congestion and energy use. By using smart containers, transportation companies can reduce their cost and act more efficiently. These containers are capable of scanning and weighing the packages all by themselves [1]. Traffic monitoring system will be improved through Intelligent Transport System (ITS). Fast changing traffic patterns can be monitor quickly through cell phones which will make the transport system more efficient and reliable. Using IoT technologies for monitoring vehicle health can help the owner to get information about vehicle parts, if they are working properly or not. This way, identifying the fault part becomes easy and efficient.

Applications in Automotive Industry: Applications created by IoT technologies can provide solutions for making smarter and intelligent vehicles like smart cars, smart trains and smart bicycle. These vehicles are well equipped with advanced sensors which have incredibly powerful processor. In recent years, EASYBIKE (smart bicycle) and VOI (smart scooter) have got attention in Finland which became very popular specially among students. In-built sensors in smart cars facilitate the driving experience by enabling parking, car maintenance and collision detection.

Many key applications of IoT technologies in automotive industry are mentioned in [62]. Advanced Driver Assistant System (ADAS) provides solutions like Blind Spot detection, Collision detection, Lane Departure Warning System, Night Vision and Parking Assistant which plays significant role reducing the amount of road accidents. Depending on the technologies used in ADAS system, they were categorised into three categories, such as Vison, RADAR and LIDAR based ADAS. Advance vehicle tracking system e.g. telematics can track real-time details about vehicles such as, Revolutions per minute

(RPM), fuel, engine status and so on which enables benefits like cost optimization, maintenance remotely and improved security.

In [3], Reilly Dunn mentioned about Cellular vehicle-to-Everything (C-V2X) and its modes of operations. Device to device communication mode includes vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-pedestrians (V2P). These applications can handle traffic management systems more efficiently through advance Intelligent Transport System (ITS). On the other hand, Device-to-Network mode possess vehicle-to-network communication where cellular networks and cloud infrastructures seamlessly work together in order to give real-time traffic updates and data streaming.

Applications in Medical and Healthcare: Technologies used in medical ground are changing rapidly. Conventional paper and pad tradition have been already been replaced by mobile and tablet technology. IoT technologies have one of the most important impacts in the changes of medical and healthcare. In accordance to [5], 40% of IoT technologies will be implemented in the health sector by the end of 2020 and will create $117 billion market, which is the highest percentage compared to other fields of technologies. In future, monitoring of medical parameters and drug delivery might be possible by using cell phones with RFID sensors [1].

Applications in Health Monitoring: Health monitoring applications such as heart-rate, Electrocardiogram (ECG) have already been deployed into wearable devices that uses sensors in order to extract data from the user's body, stores them and give notifications in time. In accordance to [1], wireless devices can be implanted into patient's body in order to receive and store real-time health reports in case of emergency situations, especially for the patients suffering from severe heart diseases, cancer, Alzheimer, stroke. Smart devices like CGM (Continuous Glucose Monitoring), Smart Insulin Pens, connected inhalers have already been developed for efficiently handling medical situations like diabetes and asthma. Remote health monitoring and diagnosis become possible which does not require the patient to stay in the hospital for their treatment.

At ASCO (American Society of Clinical Oncology) annual meeting in June 2018, a data of 357 patients was shown in a clinical trial receiving head and neck cancer treatment [63]. A symptom tracking app along with a Bluetooth sensor device, enabled with weight scale and blood pressure cuff was used on 169 patients, in order to send updates to patients' physicians on symptoms and responses to treatment every weekday. The study has shown that, these patients experienced less severe symptoms and treatments of cancer compared to the rest of the 188 patients who went to visit their physicians personally. This report clearly shows how this kind of technologies are capable of delivering medical services in much more efficient way, even for severe diseases like cancer.

IoT technologies can help patients suffering from chronic diseases like diabetes. Based on the literature [1], pattern recognition and machine learning algorithms can seamlessly work together with IoT technologies in order to develop applications which can learn about the regular routine of the patients, detect abnormal situations and react according to it. The author believes that it is also possible to merge this technology with IoT in medical technology. IoT technologies have an important impact on elderly monitoring. According to the presented theory in [6], the author has proposed a hierarchical model in order to investigate the current situations of elderly cantered monitoring. This model includes elderly monitoring support applications and services like event detection, diet monitoring, emergency support, outdoor positioning, weight monitoring, sleep monitoring, fall detection, shopping assistant, security, entertainment, path planning, abnormal behaviour detection, privacy etc.

Another notable IoT technology involved in this industry is Telemedicine monitoring, that collects data from patient’s old medical record and their lifestyle for better treatment at reduced cost [20]. RFID tags and sensors can be used for collecting data and pharma manufacturers and researchers can use them in order to develop new pharmaceutical products at minimal cost in shorter period of time without compromising the rules and regulations, thus accelerating the production speed and making them available in the market for the customers [17].

Applications in Pharmaceuticals Industry: One of the major concerns in pharmaceutical industry is safety and security which can be dealt with attaching smart labels to drugs, tracking them through the supply chain and monitoring their status with sensors [1]. Counterfeiting is a huge challenge in this area as described in [18], and it affects both the manufactures and the government invading safety and security [17]. Temperature control is another major challenge for pharmaceutical industries as most of the pharmaceutical products are needed to be maintained at some specific temperature level throughout the whole supply chain and environmental sensors can monitor the condition of the products and raise alert if the temperature does not match [17]. According to [19], 90% of the logistics cost depends on warehouse operation. Building smart warehouse, where embedded sensors and RFID tags can be used in order to track and analyze the inventory flow and capture inconsistency to ensure maximum floor space utilization and higher productivity [17]. Connecting smart labels on medicine and a smart medicine cabinet that reads the information from the labels attached with the medicine, the whole application together would be beneficial as it can remind the patients to take their medicine in specific time and monitor their compliance [1].

Applications in Personal Life: The potential applications of IoT technology are limitless and IoT can play a vital role to facilitate our daily life. A literature study in [9] indicates that by the help of IoT technologies, it is possible to establish advance connection among systems, devices and services which goes beyond machine-to-machine (M2M) communication. In recent times, we are experiencing the fact that a huge number of companies are involved in making wearable devices such as smart watch and fitness band. These devices are well equipped with different sensors which gather information about the condition of our body and track our daily activities and give response. These technologies are also involved with sports like cycling, running, swimming, tennis, football. It enables monitoring and tracking our progress, errors, power, agility and overall cardiovascular fitness level.

Applications in Smart Agriculture: World's population is increasing at a dynamic rate and food production needs to be accelerated according to it. Food and Agriculture Organization of United Nation thinks our food production must be increased 60% by 2050 where the population expectation is 9 billion [11]. IoT technologies can play supreme role by monitoring crops and the environment through sensors and analysing the condition of fertilisation and irrigation that meet the highest possible productivity.

IoT technologies can maintain the track of weather changing, productivity of the crops and cattle health. This enables applications like smart greenhouse, where temperature, humidity and other environmental parameters can be monitored and stored in a cloud-based system. There are many Agri-Tech organizations that provide such services at affordable cost. Illuminum Greenhouses is one of these organizations, which offers to build smart greenhouse by using solar powered IoT sensors [64].

Using smart devices can reduce the production cost and enhance the efficiency. According to [1], the author believes that IoT technologies will enable the scope for the single farmers to deliver their crops directly to the consumers, both in smaller region including shops and markets, and in wider area which will make the supply chain short and more direct. In [12], the author presented an IoT based application name **SmartFarmNet** for smart farming by which the users can get information like this in real-time. Applications like this can meet the requirements for modern day farming. Although, IoT technologies in agriculture is not as popular as other sectors but the adaptation of IoT technologies in agriculture is very dynamic. According to Business Insider, 75 million IoT devices will be installed in agriculture by 2020 [10].

Applications in Aviation and Aerospace Industry: In section 2.4, we have already seen that, IoT technologies enable the potentiality to gather information from every operational part of a vehicle. This can be also implemented into an aircraft. Using IoT technologies safety, security and operational reliability of the products and services of the aviation industry can be improved in a significant way. In [1], the author mentioned about the vulnerability of SUP (Suspected Unapproved Parts) in the aviation industry. SUP refers to an aircraft part which does satisfy the requirements of an approved aircraft part, violating the security standards. The authenticity of an aircraft part can be performed by inspection the accompanying documents. There are two major problems in this process. First, the documents can be forged easily and secondly, the whole process is very time consuming. According to the author, the solution of this problem is electronic pedigrees. RFID tags will be connected to those parts. Before installing them into the aircraft, authenticity of those parts can be tested by storing these pedigrees within a decentralised database along with RFID tags. According to IBM, the approach of IoT technologies in aerospace industry is evolving, because many manufacturers in the aerospace industry currently share data through fragile point-to-point integration and messaging networks. This makes the implementation of the technology not only just difficult but also expensive [65].

Applications in Advertisement Industry: The majority of media and entertainment industry depends on advertisements. The conventional mediums of media and entertainments such as newspapers, radios, televisions are slowly fading away as the world is getting more depended upon the internet. As a result, mediums like Facebook and YouTube took over the conventional mediums of entertainment. This is why internet has become one of the most profitable sources for the advertisement industries. Now it is time for IoT technologies to take this into a higher level. In order to get highest benefits from the advertisement industry, it is important to show relevant adds to targeted audience. To achieve this, advertising companies need to gather information about the customers, analyze them and then represent their marketing campaigns only to those who are interested in them. IoT sensors are capable of creating enormous amount of data for the advertising companies and the broadcasters, producing highly focused marketing campaigns for the relevant customers [66]. With the basic fundamental of gathering ad sharing information, IoT technologies can help the audience to avoid irrelevant adds and also the advertising companies by increasing their profit.

Applications in Gaming Industry: Internet gaming has become more popular with time, replacing traditional gaming with the development of IoT technologies. Before that, gamers could enjoy the game only being at home in computers or consoles, which required additional hardware and a series of cables. Now people can play the same games both in their computer or console at home and also in their cell phones and tablets anywhere they want. Recently, Google has introduced a new gaming controller name Stadia that provides a solution to play games any platform we want such as tablets, laptop, cell phones and so on [67]. This is a cloud-based gaming service that only requires the controller and a strong internet connection. Working atop of YouTube's streaming functionality, Stadia enables us to participate in a video game actively while watching live streaming of it in YouTube. Combined with IoT technologies, virtual and augmented reality (VR/AR) have facilitated the gamers providing more deeper connection and experience with the game as if they are personally in it. According to select USA, VR gaming has grown more than 16 percent since 2018. U.S developer and scientists are creating cutting-edge solution in healthcare, education, online shopping and entertainment using this technology [68].

Applications in Waste Management: IoT technologies in managing wastes can effectively improve municipal operations. Automated route optimization of garbage pickup trucks is one of the most popular IoT application in waste management. In order to collect trash, a garbage pickup truck follows a regular route, without knowing if the trash bins are empty or full. Sensors connected with garbage bins can notify the truck drivers about the situation of the bins. The sanitation department can store the information which can be useful for future smart cities by generating deeper understanding of waste management like better distribution of the bins, accurate disposal practice and reducing waste going to land.

Applications in Process Industry: A study of high cost accidents in petrochemical industries in United Kingdom [13] has shown that in most of the cases the reason of these disaster was lack of understanding and poor management skills in segregating, storing and processing chemicals. IoT technologies can provide solution in order to reduce the number of accidents in this industry by developing smart containers with wireless sensors for hazardous chemicals. According to the literature review at [1], many oil and gas industry use scalable architectures that enables the possibility to use IoT infrastructure with sensors and actuators in order to monitor critical operations of the workers and equipment, tracking containers, tracking of drill string components pipes and so on.

Applications in Supply Chain Management: Supply chain management combined with IoT technologies has created a revolutionary change in recent times, making it easier to understand the location of the items, quantity in the storage and expected delivery time to a specific location by using GPS and other technologies [70]. According to [15], items and shelves can be connected through RFID that will enable tracking of the present item in shelves where the retailer can optimize many applications in order to get real time information about the stock. According to [16], 3.9% loss in sells happen throughout the world for empty shelves. IoT technologies can help to deal with the situation of over-production or underproduction by enabling free access to the information of retailer's sales and stock, so that the manufacturers can produce and ship sufficient amount of products [1].

2.2 Challenges in IoT

From sub-section 2.1, it is clear that there is enormous amount of applications of IoT technologies, most of them are still under development and in the future, more technologies will be introduced. As the number of applications is huge, installing them would be much more challenging. In this sub-section, the major challenges and the open issues of present and future IoT technologies are briefly discussed.

As discussed earlier, the basic functionality of IoT technology is to collect information, storing them and provide service after analyzing them. As these IoT sensors and actuators need to collect enormous amount of data, it might be challenging to manage them. Strong networking architecture is needed in order to improve service efficiency and designing such complex infrastructure for sensor networking would be challenging [1].

The number of connected devices in the internet is increasing day by day. According to CISCO this number has already surpassed the total number of humans in 2008 or 2009 [9]. The connected devices must be less expensive. According to [72], low cost positioning IoT solutions have been failed to carry out so far. However, the precision and accuracy must be high for short-range IoT. Inexpensive connected devices will have performance and latency issues which will lead to higher power consumption.

In [72], the authors believe that very narrow band which is not yet been used, might be used in the future which will raise the expenses of the passive components. Also, it is very challenging to provide positioning solutions for low complexity bandwidth reduced devices with precision, accuracy and extreme coverage [73].

Another major challenge of implementing IoT technologies into positioning is lack of device availability. According to [74], UWB-based positioning systems shows accuracy of 10-20 cm where most of the connected devices lack to have UWB chip.

There will be more connected device in future as IoT progresses. Each of them needs unique identification which requires an efficient and unified identity management system [22]. Designing such system might be very complicated and challenging. With the increasing number of connected devices in the internet, the consumption of the network energy is also increasing rapidly, and green technologies need to be introduced in IoT in order to maintain energy efficiency as much as possible [22]. According to [9], M2M communication can be broken down into four major layers which includes sensors, communication, computation and service. The major challenges faced in each layer are described in [9] as:

- Maintaining cost of an immense number of sensors, complexity in sensor deployment and the battery life.
- The number of connected devices in the internet today has already outnumbered the number of users.
- Gathering accurate data in real-time requires very powerful and intelligent devices.
- Developing unified standards for everyone in order to build a successful M2M ecosystem.

Security and privacy are the foremost considerations for any application and IoT technologies are no different. Before building any IoT based application we must provide strong security services in order to ensure there is no violation of data manipulation or hacking from unauthorised users or devices which is also very challenging. In chapter 4.1, we have seen that IoT architecture consists with several layers and each layer has different security issues. So, it is important to study security issues on every layer in order to make strong IoT infrastructure. In [21], the authors have represented security issues faced in each layer of an IoT infrastructure, which includes:

- **Application Layer:** Malicious attack e.g. worm attack in the operating system, tempering into node-based applications e.g. temperature sensors, incapability of receiving security patches, hacking in smart-grid/smart-meter.
- **Perception Layer:** Mostly node/sensor level attacks from outside entities, Eavesdropping, sniffing attack, noise in data due to large are wireless transmission.
- **Network Layer:** Denial-of-service (DoS) attack in order to disrupting a process by overflowing information, Gateway attack like routing attack that disrupts connection between sensors and internet, Unauthorized access to the crucial devices, storage and cloud attack, manipulating the system by injecting false data.
- **Physical Layer**: Physical damage to the sensors, nodes and actuators, environmental attacks due to natural calamity, power loss issue, hardware failure.

3. IOT ARCHITECTURE AND KEY TECHNOLOGIES

Before developing an IoT based application, the first thing to know is the architecture and key technologies involved in IoT. This chapter deals with some architectural model and key technologies involved in IoT. Several IoT architectural models have been discussed in the first sub-section. In the second sub-section, key technologies involved in IoT are presented. Later, a diagram combining IoT architectures and technologies is illustrated.

3.1 Architecture of IoT

Regarding IoT architecture, there are no single or unified model. Different architectures have been proposed by different organizations and researchers. In this thesis, three types of architectural models are discussed, which includes:

- Protocol-based architecture
- Cloud-based architecture
- Fog architecture

According to International Telecommunication Union (ITU), an IoT based architecture should have five layers [23] which can be seen in Figure 1.

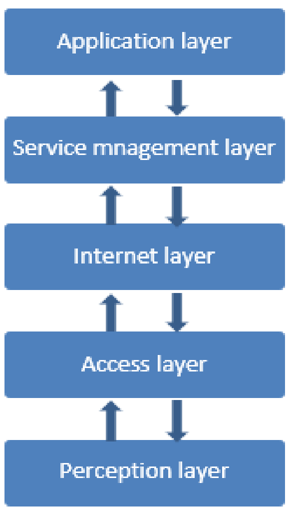


Figure 1. *ITU recommended architecture of IoT*

- Perception layer is the physical layer which consists with various sensors e.g. temperature, humidity or RFID which allows the device to sense physical parameters or other objects [21], [23], [24].
- Access layer collects the information from the perception layer and transmits the information using communication networks such like cellular networks, Wi-Fi or satellite networks [23].
- Internet layer creates a reliable and efficient platform, connecting large-scale application and global Internet. [23]
- Service time management layer gathers a numerous amount of real-time information from the Internet layer, manages and controls them in the cluster server network in order to provide a user-friendly application interface. [23]
- Application layer integrates underlay system function in order to deliver practical applications for industries [23]. Basically, application layer identifies the sectors where the deployment of IoT technologies is possible [21], [24] such as transportation, environment, medical and healthcare, agriculture and so on.

According to [23], although the ITU based model which is illustrated above covers factors like internet connectivity and senor's interpretability, it lacks software applications and implementation. Therefore, a new three-layered model has been proposed in [23], which can be seen in Figure 2.

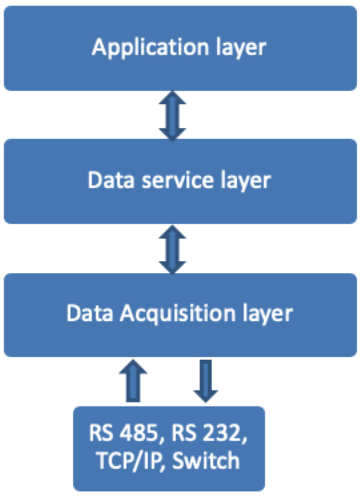


Figure 2. *3-layer architecture of IoT proposed in [23]*

- Data acquisition layer has the same functionality of perception and access layer of the ITU model combinedly, connected with sensors and devices e.g. RS485/RS232 with some extra features like data analysis, device management, SOCKET communication and device configuration (such as, IP address/port configuration in the interface) [23].
- The main function of the data service layer is equivalent to the ITU model's service management layer including collecting data from the acquisition layer by SOCKET communication, unique identification of the devices, storing the data and transferring them to the application layer [23].
- The purpose of the application layer is equivalent to rest of the layers of ITU model which are Internet and Application layer, providing deployment of an application and a system for clients in order to access easily.

In [24], a three and five-layer architecture has been illustrated, where the three-layered architecture is the most basic, consisting Perception layer, Network layer and Application layer, and the five layered architecture model additionally includes Transport, Processing and Business layer. The purposes of Perception and Application layer has been discussed early, which are also same in here. Now let's discuss the rest of the four layers which can be seen in Figure 3.

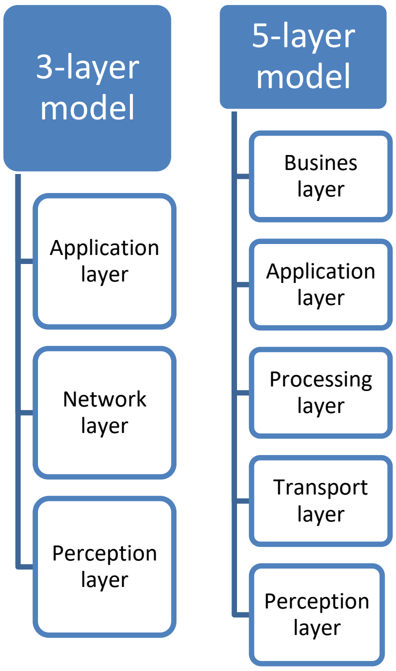


Figure 3. *3-layer and 5-layer architecture of IoT*

- The main function of network layer is interconnecting network components, smart things and server by network communication software and transfer and process data which is collected by the sensors [21], [24].
- The purpose of transport layer is to transfer the data from perception layer to processing layer using communication network (such as NFC, Bluetooth, cellular networks, RFID) and vice-versa [24].
- Processing layer or middleware layer stores a numerous amount of sensor data from the transport layer, process and analyze them by employing technology modules like cloud and database [24].
- Business layer provides total management to the entire system including security and privacy [24].

In [24], two kinds of system architectures have been discussed which are cloud and fog computing and it is different from the protocol-based architecture which has been illustrated above. Based on the literature review of [24], short insight about cloud and fog-based architecture is given below.

Cloud based architecture has been given top priority because of its outstanding potentiality of scalability and flexibility, providing services like core infrastructure, platform, software and storage [24].

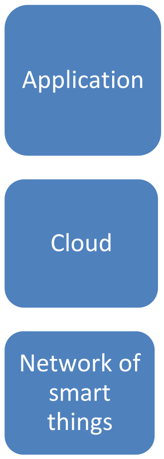


Figure 4. *Cloud based architecture of IoT*

As shown in Figure 4, clouds operate in the centre of the architecture, application layer and network layer operate above and below of the cloud respectively [24].

In [24], a layered approach has been illustrated for fog architecture that includes transport layer, security layer, storage layer, pre-processing layer, monitoring layer and physical layer, which can be seen in Figure 5. Monitoring and pre-processing layer work on the edge of the network before the data is sent to the cloud [24].

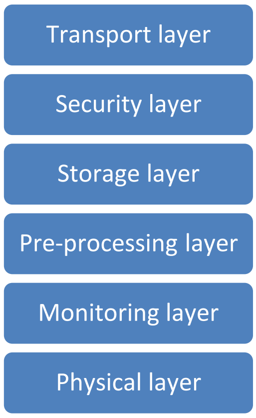


Figure 5. *Fog architecture of IoT*

- The main function of monitoring layer is to monitor the resources of power, services and their responses [24].
- The purpose of pre-processing layer is to filter, process and analyze the sensor data [24].
- Storage layer stores the sensor data and performs data replication and distribution [24].
- Security layer provides security and privacy by encrypting or decrypting sensor data [24].

3.2 Key Technologies Involved in IoT

According to [25], ITU has reported about four key technologies for IoT development which includes RFID, sensor, smart and nano-technology. It can be seen in Figure 6.

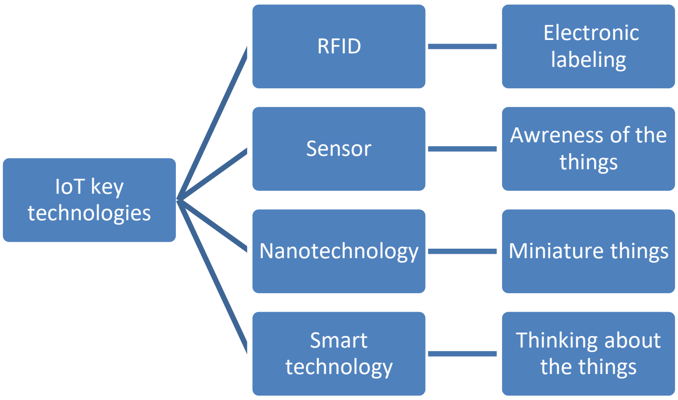


Figure 6. *ITU recommended technologies of IoT*

These technologies are not sufficient enough to support the whole infrastructure of IoT. There are some other technologies has been mentioned in [25] which includes awareness technology, network communication technology, data fusion and intelligence technology and cloud computing. Based on [25], a short insight of these technology is given in Figure 7.

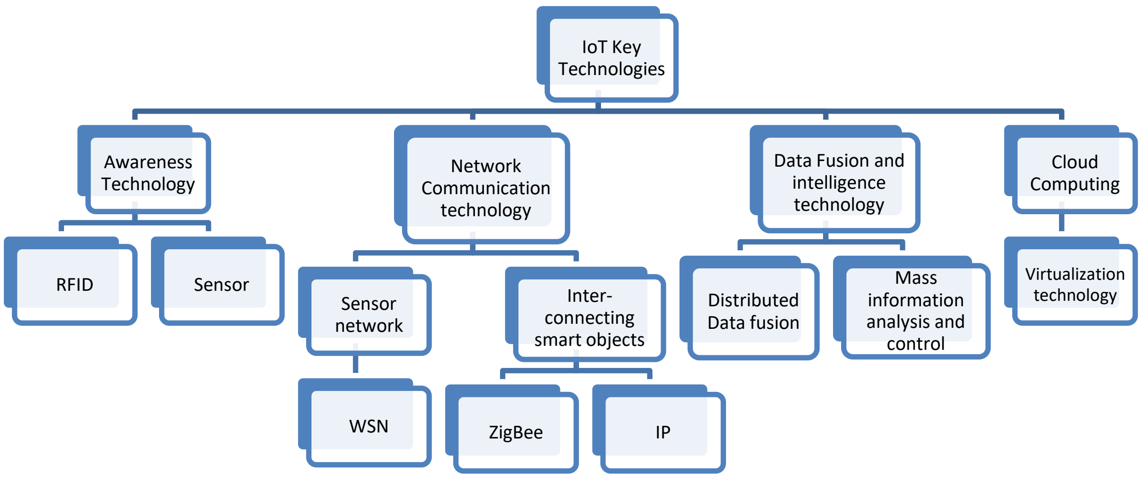


Figure 7. *Key technologies of IoT*

Awareness technology mainly works with collecting information based on RFID and sensors.

- Sensors are used to gather information from the environment and provide the information in real-time.
- RFID technologies are used for unique identification on collected information, which is a contactless short-range communication technology along with Bluetooth [25].

The main function of network and communication technology is to transmit information from one place to another. According to [25], the total function can be divided into two scopes: sensor network and interconnection between smart objects.

- Sensor network can be wired or wireless. As IoT devices work with sensor data and mostly deployed in the field, therefore Wireless Sensor Network (WSN) is the most common technology for communication.

- There are two major technologies for interconnecting smart objects and terminal, such as ZigBee technology (node based) and IP technology.

The main focus of Data Fusion and Intelligent Technology is to process enormous amount of sensor data timely and in a highly efficient way, so that there is no data redundancy and bandwidth loss [25].

As discussed earlier, IoT technology needs to work with numerous amounts of data and therefore, we need a technology which is powerful enough to store and process this huge amount of data. According to [25], cloud computing will become the cornerstone of IoT development because of it allows the network service provider to handle massive amount of data in time and helps them to provide the same services as the super computer such as virtualization technology.

According to the discussion in this chapter, IoT architecture and key technologies can be summed up into Figure 8.

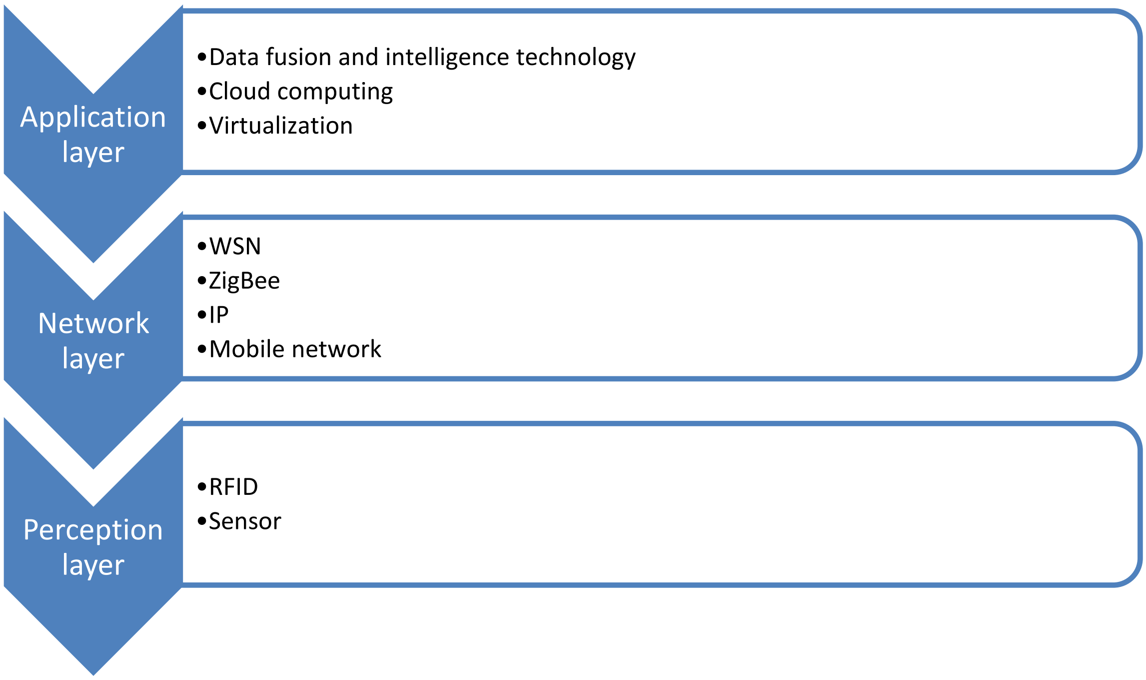


Figure 8. *IoT architecture and key technologies*

4. INDOOR POSITIONING APPROCHES ON IOT DEVICES

Global positioning system (GPS) is a satellite-based positioning system which is widely used all over the world due to its accuracy of providing information about location of a device or human. Satellite signals are unable to penetrate in an indoor environment, as a result, GPS system cannot be used in indoor positioning [41]. Therefore, different technologies are needed in order to enable indoor positioning. In this chapter, we are going to discuss some technologies based on the literature studies, which are commonly used in indoor positioning nowadays.

4.1 Positioning via Electromagnetical Signals

Different researchers propose different techniques and algorithm to investigate positioning problems. In this section, we are going to discuss some of the classical positioning approaches with electromagnetical signals such as Time-of-Arrival (TOA), Angle-of-Arrival (AOA), Received Signal Strength (RSS) and fingerprint.

Time of arrival (TOA) refers to the required time of a signal, travelling from one transmitter to one receiver. On the other hand, angle of arrival (AOA) refers to the method of determining the propagation direction of a radio frequency. TOA and AOA based positioning is one of the most popular positioning techniques in wireless sensor networks because of their high precision ranging systems [35].

Several methods and algorithm are used in order to investigate positioning problems and among them, distributed algorithms are more noteworthy because it requires less computations [32]. Least square (LS), Recursive least square (RLS), Reduced Complexity RLS (RCRLS), Best response (BR) etc are the most common approaches in this field. In [32], the author has represented a distributed TOA based positioning technique with a game approach and it turns out to reach the Nash Equilibrium (NE) point in a limited number of steps by using the best response (BR) algorithm. According to the author, the presented technique in [32] has outperformed all the previous mentioned approaches as it gives an optimal or suboptimal solution by reaching the NE point and also in accuracy, number of calculations and convergence rate.

Non-line-of-sight (NOLS) scenario is one of the major problems in indoor positioning which degrades the accuracy compared to Line-of-sight (LOS) situations [33]. Using Extended Kalman Filter (EKF) in NOLS situation cannot be a good solution as it gives location estimation errors in a huge amount [34]. In [33], the author has proposed TOA based positioning technique with pedestrian dead reckoning (PDR) using a skew-t variational Bayes filter (STVBF) and applied in a NOLS and LOS mixed condition which solves the problem of the EKF filter, both in accuracy and computational complexity.

There are also some works done by the researchers, which use hybrid models having TOA, AOA and DOA (Direction of arrival) estimations in order to get positional information more accurately with simpler calculations. In [35], the authors proposed a joint positioning technique with IP-OFDM (Orthogonal Frequency Division Multiplexing) and MUSIC algorithm, that uses both TOA and AOA schemes. In [38], a hybrid TOA and AOA scheme was proposed for ultra-wide band indoor LOS condition. In [39] and [40], TOA and DOA hybrid scheme was introduced where matrix pencil algorithm and MUSIC algorithm was used respectively. However, in [49] the author believes that TOA approaches in positioning is inadequate because of the presence of severe multipaths in the indoor environment and it requires time synchronization.

Received Signal Strength (RSS) is commonly used technology in wireless communication system which is used to estimate distance between two nodes [42]. In accordance to [43], the author believes that most of RSS based positioning approaches are assumed to have the knowledge about the location of the base stations, where the position of an object can be determined by measuring the distance or presuming the angles to base stations.

Quantized RSS techniques can lower the amount of energy consumption and bring significant benefits, although in most of the cases, RSS is used without quantization [44]. However, RSS based positioning is very challenging due to scattering, reflection and attenuation of electromagnetic signals [43]. This might be the cause of resulting more energy consumptions and reduced positioning accuracy. Energy efficient algorithm can be used in order to save energy, but it is possible that improving energy efficiency by using energy efficient algorithm could lead to reduce positioning accuracy [46].

Fingerprint matching technology is the most common indoor positioning technique of recent times [47]. In a Wi-Fi based fingerprint positioning technology, the Wi-Fi signal strength is used for measurements and it does not require the identification of the exact location of the access points (AP) [48]. It is possible to deploy fingerprint positioning technology in any indoor environment having Wi-Fi networks without the hassle of putting additional hardware making it cost efficient [48]. However, deploying this technology is very complicated as it requires many complex algorithms and the signal strength of APs might be influenced by the environmental factors [48]. Therefore, it might be necessary to combine fingerprint technology with other technologies such as with TOA, AOA or RSS. The RSS based positioning system proposed at [45] used compressive sensing in Wireless Local Area Network (WLAN) which demonstrates that the two-stage localization method can increase positioning accuracy and reduce complexity over conventional fingerprinting methods.

4.2 Positioning via Non-electromagnetical Signals

Visible Light Communication (VLC) is one of the most spectacular phenomena in indoor positioning field. The range of visible light that is used in VLC is in between 400-800 THz which is emitted and modulated by Light Emitting Diodes (LED) [74]. Many electronics and light companies have achieved initial success in this approach. Philips has developed an indoor positioning system for larger shops with LED embedded in VLC which is used sending a unique code to user's cell phone indicating accurate location on the store map [50]. The system uses cloud to store the information which can be used to analyze to improve the service of the system [50]. Figure 9 illustrates the process of the positioning system.

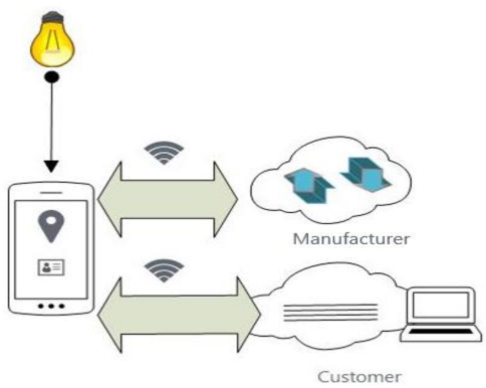


Figure 9. *VLC based positioning by Philips*

In [51], the author has mentioned that there are four major components in indoor positioning system (IPS) such as, modulation technique, multiple access scheme, channel measurements and positioning algorithm. The combination of these four components might be an important factor for implementing VLP based IPS solutions, along with the amount of anchor luminaries. Therefore, a solution has been proposed at [51] which does not depend on the combination of the major components of IPS and also can work robustly during the absence of sufficient anchor luminaries. The solution proposed in [51] uses a two-phase algorithmic framework and the complexity of the algorithm is moderate compared to other positioning techniques.

Recent studies show that, visible light positioning (VLP) has gained a lot of attention in indoor positioning system (IPS). In [52], an IPS solution was proposed based on the fusion of multiple classifiers which shows 93.03% improvements over the RSS ratio methods and 93.15% improvement over RSS matching methods. Another simple but effective VLC based positioning implementation proposed in [53] that uses a dual function machine learning algorithm which gives 52.55% improvement over the accuracy in 78.26% less time.

According to [74], ultrasound-based positioning refers to TOF measurements where ultrasound signals and sound velocity is used to calculate the distance between a transmitter and a receiver. In [54], the authors introduced a new envelop detection method for ultrasonic indoor positioning system (UIPS). Here they proposed the idea of using several wireless ultrasonic beacons that have fixed predefined location and can collect transmission information from a targeted node. Every wireless sensor network has two way of communication system; one uses Wi-Fi to transmit data to server. Another uses Radio wave to establish synchronization between different nodes. The measurement between beacon and target node is calculated by the time-of-flight (TOF) for ultrasonic signals and ultimately the position can be calculated by this distance and known coordinate of the beacons. To achieve this goal a new way of envelop detection filter is introduced in this paper which estimates sampled values by using least squares method (LSM). This envelop method gives precision that reaches 0.61mm and its variance can reach up to 0.23mm. For a moving robot the maximum location error is 10.2mm for line-of-sight signal. As it is quite expensive for installing visible light-based system and as it involves ultra-wide-band (UWB) which requires large infrastructure to operate, UIPS is becoming more attractive to researchers these days.

A similar method was also proposed in [59]. Both papers mentioned that in cricket system proposed in [60] nodes act as receiver while beacons act as ultrasonic transmitter. In that system ultrasonic pulse was used in radio frequency for synchronization. Mobile

location is calculated at the central node that was sent by receiver through RF link. However modern techniques like two-part beacon i.e. (RF for determining location and Wi-Fi for communication) is used in both papers.

Another work has been done in [61] on seamless transition of handover for indoor and outdoor positioning system. In this paper they proposed a system that will switch to GPS to IPS based on the nodes position using sound wave. They generated a variety of reverberation patterns and tried to distinguish indoor pattern from outdoor. Firstly, a mobile node generates chirp signal and then it processes the reverberation pattern and analyses. Finally, it classifies whether the node is in indoor or outdoor based on these patterns. Authors claim experiments show better result than current models. In their experiment it took 3.81 second in average to detect the location (indoor or outdoor).

According to [75], odour/smell-based positioning is constructed in three phases which includes plume finding, plume following and source declaration. An overview of these three phases is presented in Table 1 based on the literature review of [75].

Table 1. *Overview of the phases of Odour/smell based positioning*

Phase name	Phase description
Plume finding	Investigating the environment in search of plume area using robots.
Plume following	Reaching odour source by plum tracking when a plume area is found.
Source declaration	Odour source declaration.

Several researches have been carried out related to odour/smell-based smart positioning. In [76], a prototype of an olfaction mechanism system, namely Cogno-detective is introduced for human odour where machines are trained to recognize different patterns of smell/odour from same or different human. Another work has been done in [77] to identify contaminated area in an indoor environment. In this paper, an olfaction system is proposed by using an advance particle swarm optimization (PSO) algorithm with multi-robots. Compared to conventional PSO and Wind Utilization II method, the proposed result showed the same efficiency and higher success rate.

Using barometer sensor of smartphones is one of the most energy efficient approaches for indoor localization. In [80], a location data collecting system, named SEloc is proposed that uses low power barometer sensors of smartphones. It uses the combination of a deep learning and clustering-based extraction algorithm that provides 85% positioning accuracy along with 22% energy efficiency. Another method is proposed in [81] for floor positioning, where pressure data was used from different mobile devices to identify the activity of a user in different floors. This experiment showed average accuracy of 85% for three types of mobile devices and 94.2% accuracy on a Huawei mate 10 Pro device compared to Magnetic, Neural Network and Fingerprint-based positioning systems. Some of other related studies use barometric formulas for the calculation of the altitude of smartphones and compare the altitude with floor height, where in most of the cases the actual height of the floor is assumed, resulting significant errors in calculation. In order to solve the problem, a method is presented in [82], where knowing the actual height is not required. This method also deals with the sensitivity to the change of the environmental factors such as humidity, temperature or pressure at different locations that validates the effectiveness of this approach.

According to [83], Inertial Sensors refer to a group of sensors consists with accelerometer, gyroscope and magnetometer, that allows portability and absolute orientation. Some research works related to inertial sensor-based indoor positioning show significant result in terms of accuracy and robustness. In [84], a Wi-Fi-based PDR system is proposed for pedestrian navigation in an indoor environment, that relies on inertial sensors and integrates with intelligent fusion algorithm to remove the weakness of conventional PDR and Wi-Fi based positioning systems. However, Wi-Fi and RSSI based positioning systems lack accuracy due to the presence of multipath and signal absorption by walls. Also, these approaches require installation of a WSN with tons of transmitter which increases overall cost and complexity to the system. In order to deal with these problems, an indoor positioning system is proposed in [85] by using visual and inertial sensors of a cellphone that only required the sensor suit and a Building Information Model (BIM). Another approach using inertial sensor is proposed in [86] that introduces the concept of 'virtual camera' to derive a 3D moving object. This experiment showed effectiveness and robustness both in static and dynamic environments.

A summary of existing studies in the literature in the field of positioning via non-electromagnetical signals is summarized in Table 2.

Table 2. *Examples of non-electromagnetical signals used for indoor positioning*

Types of non-electromagnetical signal used for indoor positioning	**References**
VLC	[50], [51], [53], [74]
VLP	[51], [52]
Ultra-Sound	[54], [59], [60], [61]
Odour/Smell	[75], [76], [77]
Barometer Data	[80], [81], [82]
Inertial Sensors	[83], [84], [85], [86]

5. ANALYSED DEVICES

In this chapter, an elaborated discussion is presented about the devices which were analysed and used for this thesis, namely: uBeacon Mesh and Thingsee One. The discussion includes what sensors they rely upon and what they measure, how the measurements are stored (cloud or non-cloud), and how to extract data and the current market situation.

5.1 uBeacon Mesh

uBeacon mesh is a next generation beacon which is introduced by Ubudu company. The main objective was to design a mesh network using these beacons for indoor positioning. According to [71], 'Mesh' refers to a network created by beacons. uBeacon mesh includes three pieces of beacons with a charger and a USB connector. One of these beacons were supposed to work as a gateway to a server or external network for establishing communications. Figure 10 illustrates the working process of uBeacon mesh.

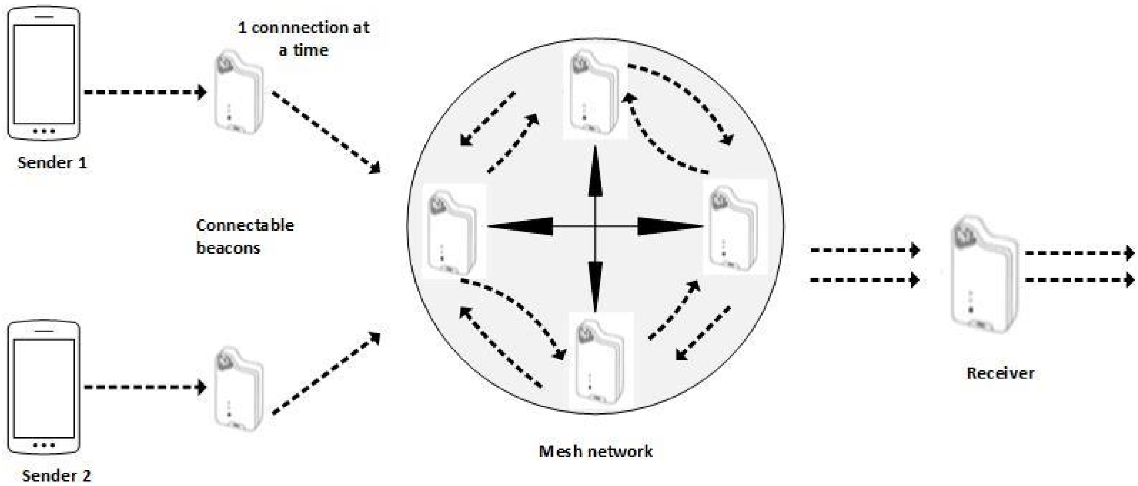


Figure 10. *uBeacon Mesh Network*

In accordance to [71], Ubudu provides a manager console for handling business rules and technical configurations. However, configuring the beacons required an Apple device (iPhone or iPad) with latest operating system (i.e. iOS). Due to this platform dependency (not available during thesis work) and limited support of Ubudu regarding their sensors, the campaign with uBeacons was stopped.

5.2 Thingsee One

Thingsee One is a developer device for IoT introduced by Haltian, a Finnish company [26]. With ultra-low power hardware design and adaptive power consumption property, Thingsee One is a gamechanger in the IoT industry [27]. Thingsee One enables the opportunity to develop simple IoT based applications even for those who does not have any prior knowledge about programming languages [27]. The functionality of Thingsee One device is very simple and easy to understand. It can be divided into two segments such as: Sensors and Thingsee Creator. An illustrative description of these two segments are presented in the following sub-sections.

5.2.1 Thingsee One Sensors

Thingsee one has a wide range of Microelectromechanical systems (MEMS) such as 3D accelerometer, magnetometer, gyroscope, temperature, humidity, pressure and ambient light [27]. Inside Thingsee one, there is a micro sim card slot, Bluetooth Low Energy and WLAN. The device also has a micro SD memory card slot to enable storage for sensor data into the device along with the cloud. There is a USB 2.0 port in the device for charging and extracting data from the device. Figure 11 shows an overview of Thingsee One device and its sensors.

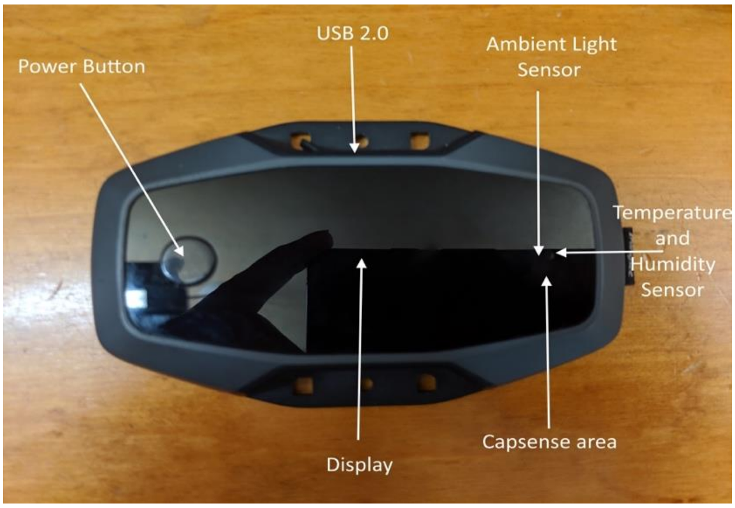


Figure 11. *Thingsee One device*

Each of these sensors has unique properties and based on their properties they can be classified into several groups such as location, orientation, environment, acceleration and so on. According to [28], Thigsee uses SenseID for unique identification of different groups and sensors. SenseID is a 32-bit hexadecimal string having a structure like

0xAABBCCDD where AA is reserved for future use, BB represents the group, CC identifies the property and DD gives the index number within a device. A classification of different groups and sensors is given below in Figure 12.

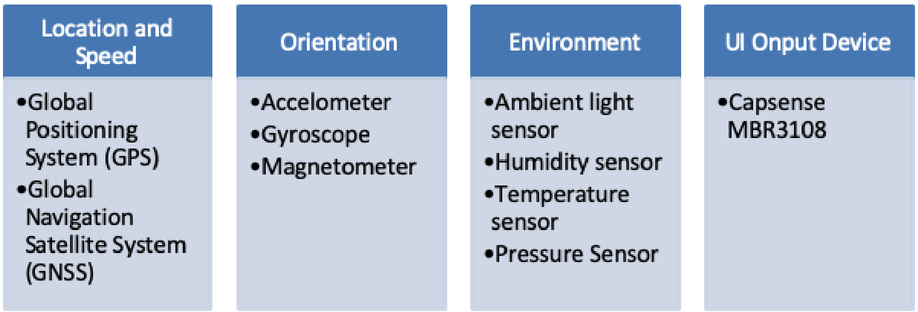


Figure 12. *Thingsee One sensors*

This thesis has been done using temperature, pressure, humidity and ambient light sensors. So, let's focus only on these environmental sensors.

- **Temperature Sensor**: This sensor senses the temperature in degree Celsius. The property ID of temperature sensor is 0x01 and the data type is float [28].
- **Humidity Sensor**: This sensor senses the relative humidity as percentage (%) from the air. The property ID is 0x02 and the data type is float [28].
- **Ambient Light Sensor**: This sensor senses the luminance or light intensity from the environment. The unit is lux and the data type is float. The property ID of ambient light sensor is 0x03 [28].
- **Pressure Sensor**: This sensor senses the air pressure in hectopascal (hPa). The data type is float and the property ID is 0x04 [28].

The group ID of the environment sensor is 0x06 [28]. Based on the studies of the documentation at [28], a total overview of the environmental sensors of Thingsee One device is shown in Table 3.

Table 3. *Thingsee One environmental sensors overview*

Environmental Sensors	SenseID	Unit
Temperature	0x00060100	Degree Celsius (C)
Humidity	0x00060200	Percentage (%)
Ambient light	0x00060300	Lux
Pressure	0x00060400	Hectopascal (hPa)

5.2.2 Thingsee Creator

Thingsee Creator is a tool for creating IoT based application with Thingsee one device. An account will be needed in order to getting connected to Thingsee cloud which can be done by visiting app.thingsee.com. After creating an account and a successful login, a screen should pop up like Figure 13.

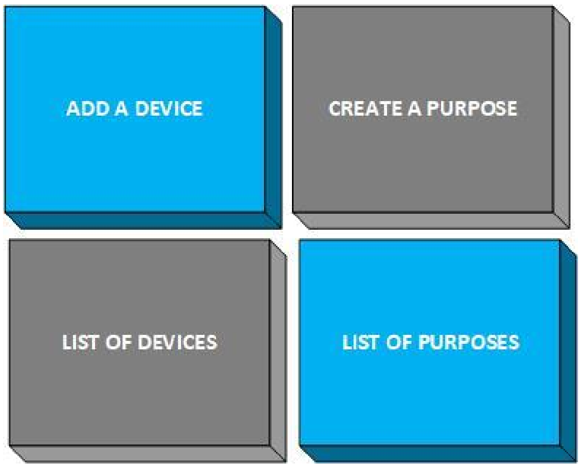


Figure 13. *Thingsee Creator homepage*

5.2.3 Add Device

According to the documentation [29], when a device is connected to a computer, an external disk named “Thingsee” should show up. The device should be turned on while connected to the computer. There should be a file named “DEVICE.JSN” inside the external disk which can be seen in Figure 14.

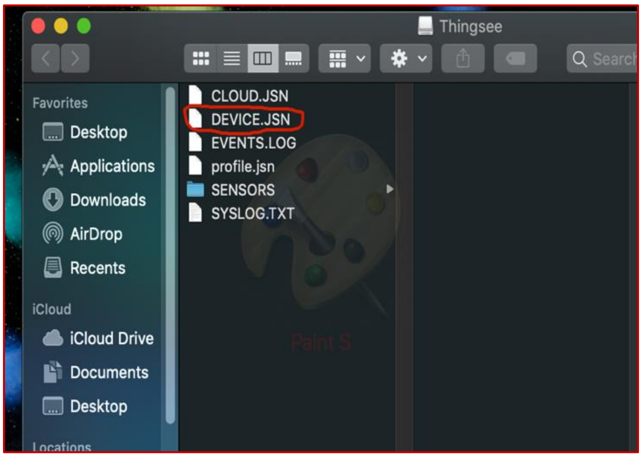


Figure 14. *DEVICE.JSN file*

This file needs to be uploaded for further steps. By selecting CHOOSE FILE, the DEVICE.JSN file can be uploaded. Thingsee creator will then ask about the preference to establish a connection between the device and the Internet which is shown in Figure 15.

Figure 15. *Connecting Thingsee One to the Internet*

Figure 15 shows that there are two options available for connecting the device with the Internet, 'Cellular Data' and 'Wi-Fi'. If the option 'No Internet Connectivity' is chosen, it will not be possible to see the captured data into the cloud and sending the purpose to the device will be possible only through USB file transfer. When this step is completed, a page should show up like Figure 16.

Figure 16. *Final step for Add Device*

Now the file CLOUD.JSN is available to download. This file is needed to be copied into the external disk Thingsee to complete the process. The device can be seen into the dashboard which is shown in Figure 17.

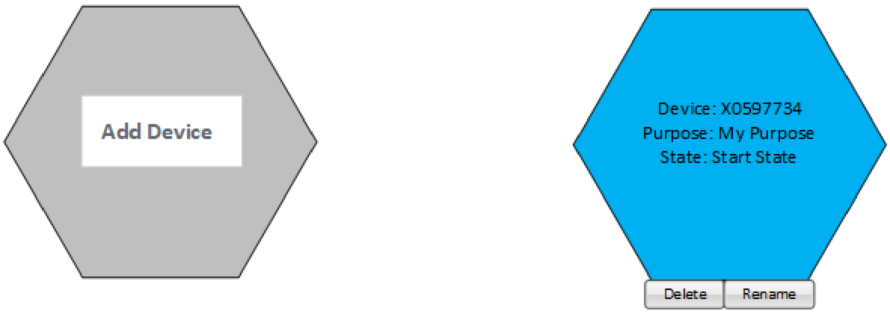


Figure 17. *Dashboard of Thingsee Creator*

If multiple Thingsee devices are needed to be added, then it is better to RENAME the device with a unique identifier so that they can be separated easily. The added devices can be found in List of Devices which can be seen in Figure 13.

5.2.4 Create Purpose

A purpose is a task that we want to perform by a Thingsee device [31]. A purpose can be added by clicking Create Purpose as shown in the Figure 13 and a page should show up like Figure 18.

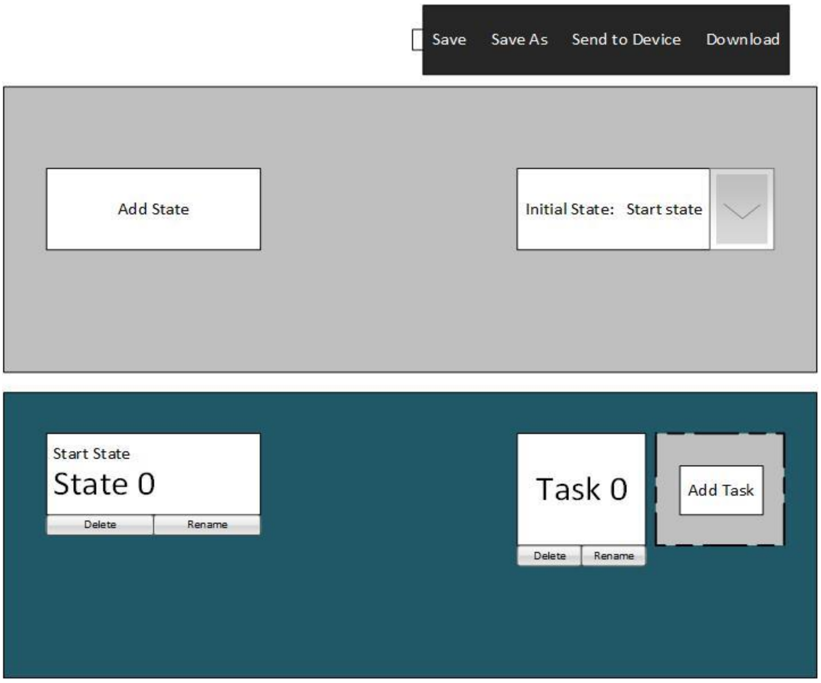


Figure 18. *Creating a purpose*

Now, there are two steps for adding a purpose: 1. Add a state and 2. Add a task. By default, the start state is added as seen in Figure 18. Multiple states can be added at a single time. Here, it is important to mention that, a device can have only one purpose at a time, but it is possible to give multiple states and tasks to a purpose. Clicking to ADD TASK or Task 0 will take to the next page. The page includes all the sensor groups in the left menu bar such as acceleration, time, location, speed, environment, energy, orientation and luminance. As this paper deals with feasibility analysis for positioning based on environmental sensors only, ENVIRONMENT option was selected from the menu-bar. A page showed up with information of all environmental sensor. By default, all of the sensor will trigger for any value as it gets from the environment, but it is possible to set a threshold value, maximum and minimum for the sensors to trigger by selecting each option. Selecting “Log values to device” will enable storing all the captured values into the device storage. There is an option named “Poll environment values every”, which represents the delay between two triggers. Finally, the purpose is needed to save and send it to the device. There are two ways to send the purpose into the device which includes-

- **USB file transfer**: The purpose can be downloaded and sent to the device through a USB file transfer. The file will be downloaded as “profile.jsn” which can be seen in Figure 19. The purpose will not work if the file name is changed.

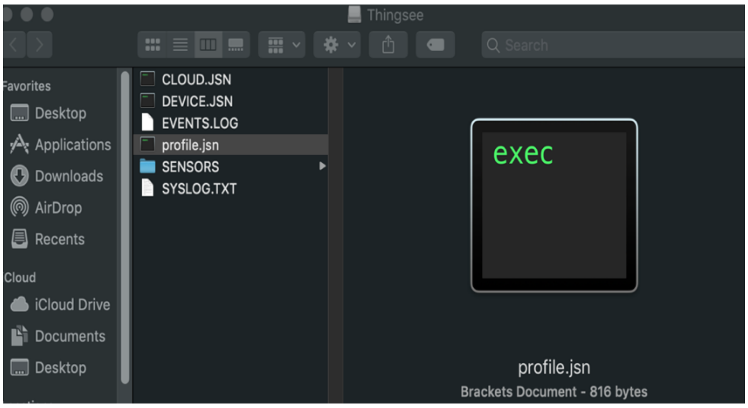


Figure 19. *profile.jsn*

- **Send to device:** The option ‘Send to device’ can be seen in Figure 18. ‘Send to device’ will directly send the purpose to the device when it is connected to the internet. The device is needed to be restarted and a backend update will be required after the restart. The CapSense area showed in Figure 11 can be used to navigate through the backend update and complete the process.

5.2.5 Extracting Sensor Data

Data captured by the sensors are sent as an event to the device and also to the cloud if the internet connection is enabled [28]. There are three ways to extract data from Thingsee One device which includes USB file transfer, custom cloud URL or Thingsee Creator cloud and sending notification to mobile through short messaging system (SMS). Data is stored in the device in a file named CAUSES.LOG, which can be seen in Figure 20 and it can be extracted through USB file transfer.

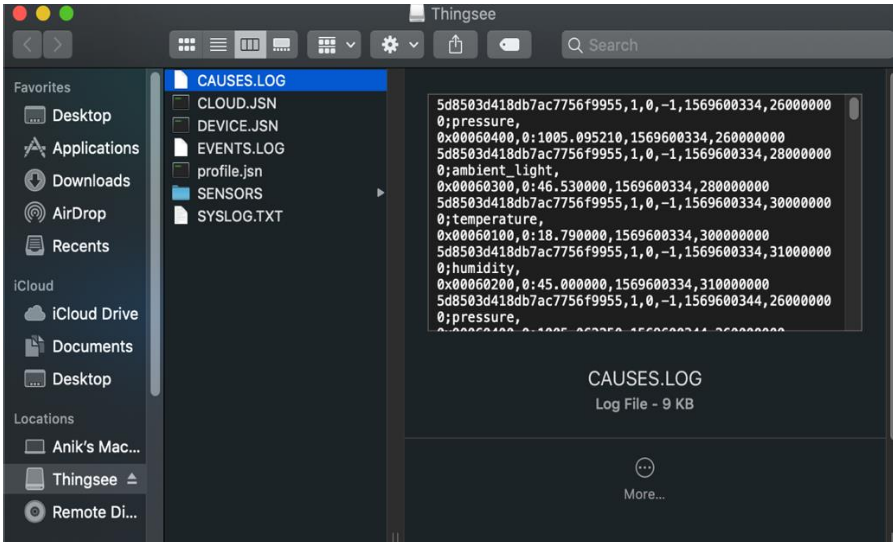


Figure 20. *Extracting CASUES.LOG file*

Also, real-time data can be seen in Thingsee Creator cloud. Extracting data from the cloud could be difficult and therefore, using custom cloud is recommended if USB file transfer is not suitable.

According to Haltian, Thigsee One is world's first developer device which was introduced for IoT development [26]. Haltian launched Thingsee One in 2015 and till now this device is being used in more than 500 projects [26]. The device is both shock and water resistance which give the device potentiality to operate at outdoor projects [27]. The customer support is also very helpful and responsive. However, the company has stopped the production of Thingsee One device. There is a possibility that the company might close the service permanently as well. According to Haltian, the employees who was behind the service and the production have been changed, resulting the company lost some knowledge of the system. Also, the maintenance cost is quite expensive for a free service like this. Furthermore, the company has shifted their concern towards business to business (B2B).

6. MEASUREMENT SETUP AND RESULTS

This chapter includes all the information about how the measurements were taken, what results they show and analysis about using the measurement data for positioning. The measurements were taken from different locations of a university building located in Tampere, Finland. Thingsee one device was configured as described in the previous chapter. The measurements were taken in three days in three different times so that it is possible to observe the impact of time and weather to the data. Table 4 includes the information of time and weather condition when each of the measurements were taken.

Table 4. *Information about the measurements*

Day	Measurements	Weather Condition	Time
Day-1	Measurement 1	Normal	12:50
Day-2	Measurement 2	Rain	14:55
Day-3	Measurement 3	Normal, mostly cloudy	17:30

The device was hold in the hand while taking measurements from different locations. Figure 21 demonstrates how the measurements were taken.

Figure 21. *Taking measurements with Thingsee One*

The measurements were taken from 32 different positions from ground floor and second floor of the university building shown in Figure 22. Four environmental parameters were captured from those locations which includes luminance, humidity, pressure and temperature.

a b

Figure 22. *Locations of the measurements a) Floor 1, b) Floor 2*

The captured data (CAUSES.LOG file) was extracted via USB file transfer. The file included all sensor data together, that means luminance, humidity, temperature and pressure data were stored into one file and it was very time consuming to store them in separate files. Therefore, a simple program (written in Python) was used in order to sperate these data from one file and store them into individual files. The purpose of the program was:

- Take a file name (CAUSES.LOG file in this case) as an input.
- Identify each of the sensor data from the file by their corresponding SenseID.
- Creating four new text files with the name of the sensors e.g. temperature.txt, pressure.txt, luminance.txt, humidity.txt
- Store sensor data into those files accordingly.

The program can be found in the Appendix A section. After storing all the sensor data into four different files, an analysis was made for each sensor data for indoor positioning. If the data is found to repeat itself in the same position during all three measurements, then it is possible to use it for indoor positioning. An imaginary (X, Y) coordinate was plotted into each of the floor maps including all 32 positions from where the measurements were taken. Floor 1 and floor 2 maps can be found in Figure 23 and Figure 24 respectively.

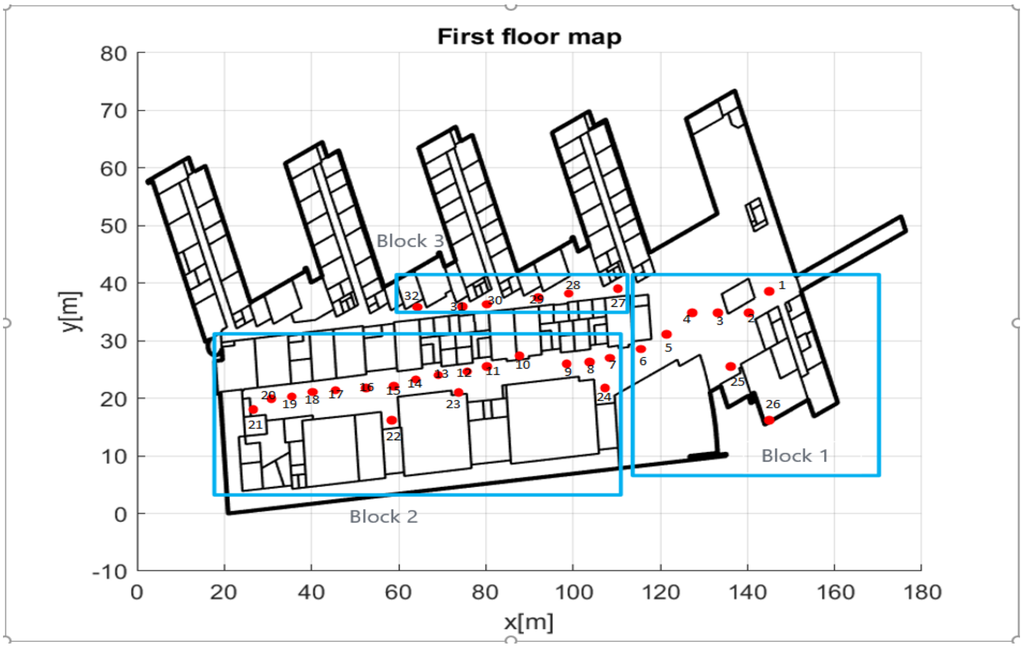


Figure 23. *Floor 1 map*

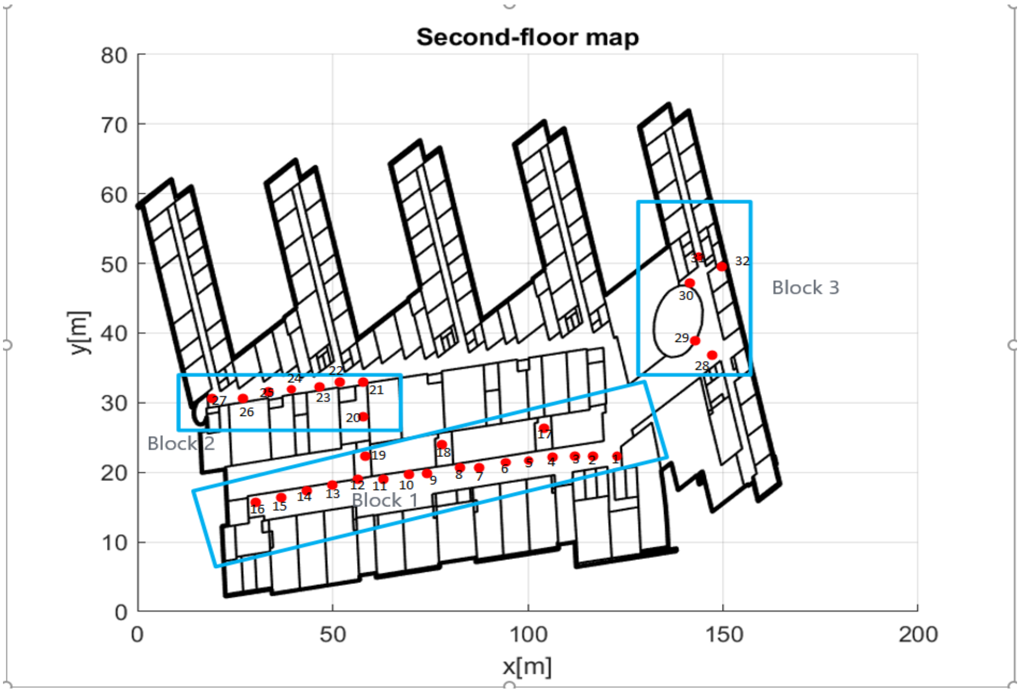


Figure 24. *Floor 2 map*

In the maps, the red dots indicate the position from where the data was captured. 1,2,3….32 represents the positions and the sequence of the measurements. From the maps, (X, Y) coordinates of those 32 positions ca be obtained. Each floor was divided into three different blocks, e.g. Block 1, Block 2 and Block 3, to make it easier to identify the location of the captured data. The blocks can be found in the floor maps in Figure 23 and Figure 24.

For analysis purpose, histograms and power maps were used. Histograms were used to calculate and analyze the number of occurrences of the data. In the histograms, X axis represents the sensor data and Y axis represents the number of occurrences of the data during all three measurements. If the data occurs three times during three different measurement into the same (X, Y) coordinate then it is possible to use the data for identifying that location. Power maps were used to identify pattern or correlation among the measurements in some specific location. In the power maps, X and Y axis represents X and Y coordinates of both floors. The corresponding value of these (X, Y) coordinates are plotted into the power maps. Both, histograms and power maps were generated using Matlab and the code can be found in the Appendix B and Appendix C section respectively. For histogram, the default bin number were set to 10 and for power maps the grid interval was set to 1.

Histograms were generated for each parameter, using the data for three days altogether. On the other hand, for each parameter power maps were done separately for each day. In the following sub-sections, we are going to make an analysis based on the histograms and power maps per floor basis and see if it is feasible enough to use these data for indoor positioning.

6.1 Measured Parameters and Units

An overview of the measured parameters is given blow.

- **Luminance:** Luminance is the photometric intensity of any surface or source in a given direction per unit of projected area of the surface or source viewed from that direction [36]. Ambient light sensor in Thingsee One device measures the luminance from the environment and the unit is lux.
- **Relative Humidity**: Relative humidity is the amount of water vapor in the air relative to its content at saturation [37]. Humidity sensor embedded in Thingsee One device measures relative humidity from the environment in percentage (%).
- **Pressure**: Pressure is an applied force in a surface of per unit area where the force is distributed [78]. Pressure sensor in Thingsee One device measures the pressure from the environment in hectopascal (hPa).
- **Temperature**: Temperature is a measurement of the state of an object or environment, i.e. hotness or coldness [79]. Temperature sensor in Thingsee One device measures the temperature of the environment in Celsius (C).

6.2 Floor 1 Measurements

This sub-section demonstrates the analysis of luminance, humidity, temperature and pressure data captured from floor 1.

6.2.1 Luminance

At first let's observe the histogram of Luminance obtained from floor 1 for three consecutive days from Figure 25.

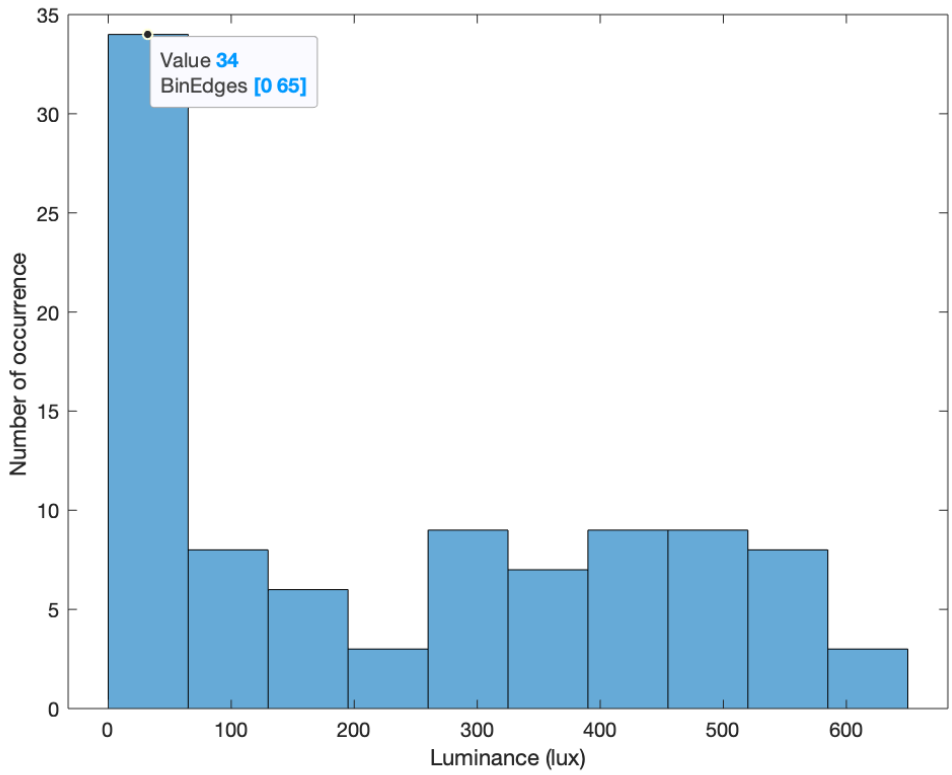


Figure 25. *Histogram of Floor 1 Luminance*

From Figure 25, it can be seen that the highest number of occurrences is 34 in the first bin and the luminance range in this bin was 0-65 lux. In this range we got 35.64 lux four times but in different coordinates. The corresponding (X, Y) coordinates of this value was (140, 37), (75, 25), (80, 37) and (140, 37).

Similarly, 22.7, 24.75 and 25.74 lux were obtained repeatedly three times, but the values occurred in different coordinates. Similar result was obtained after observing rest of the bins. There is no value which has been repeated in the same coordinate during the three measurements. As a result, luminance data obtained from floor 1 cannot be used for positioning purpose. Now let's observe the power maps of Luminance obtained from floor 1 in Figure 26, 27 and 28.

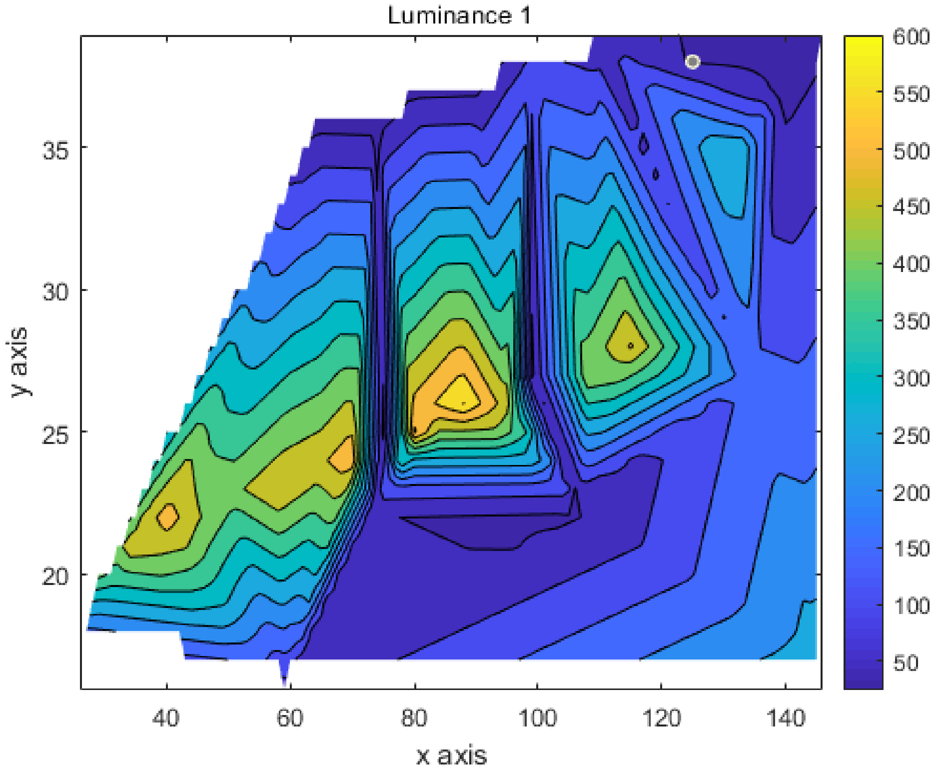


Figure 26. *Power map of Floor 1 Luminance 1*

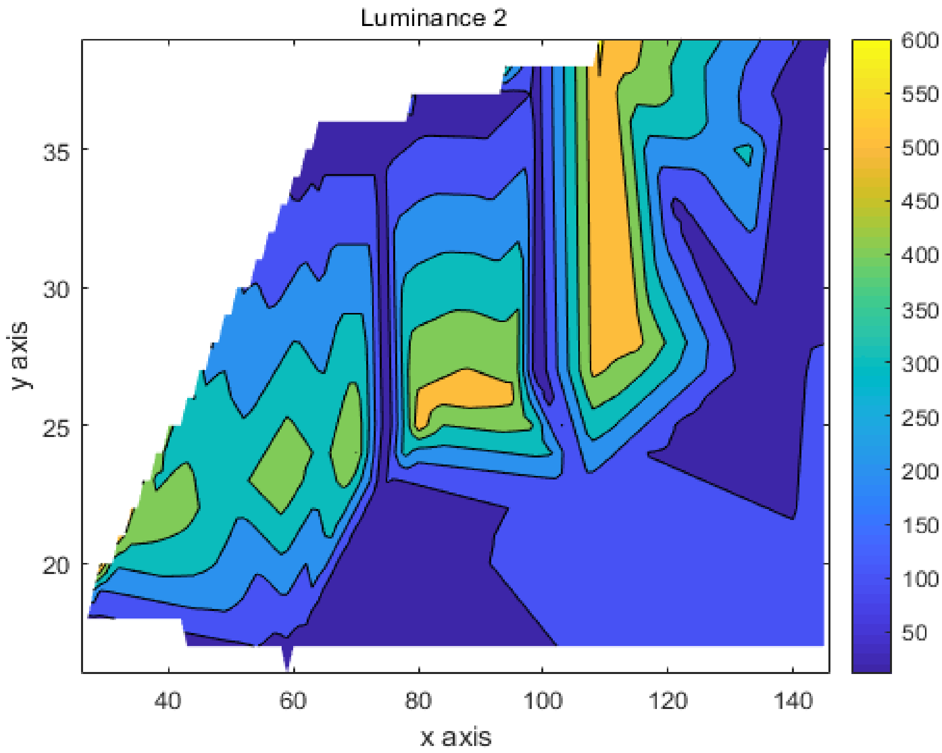


Figure 27. *Power map of Floor 1 Luminance 2*

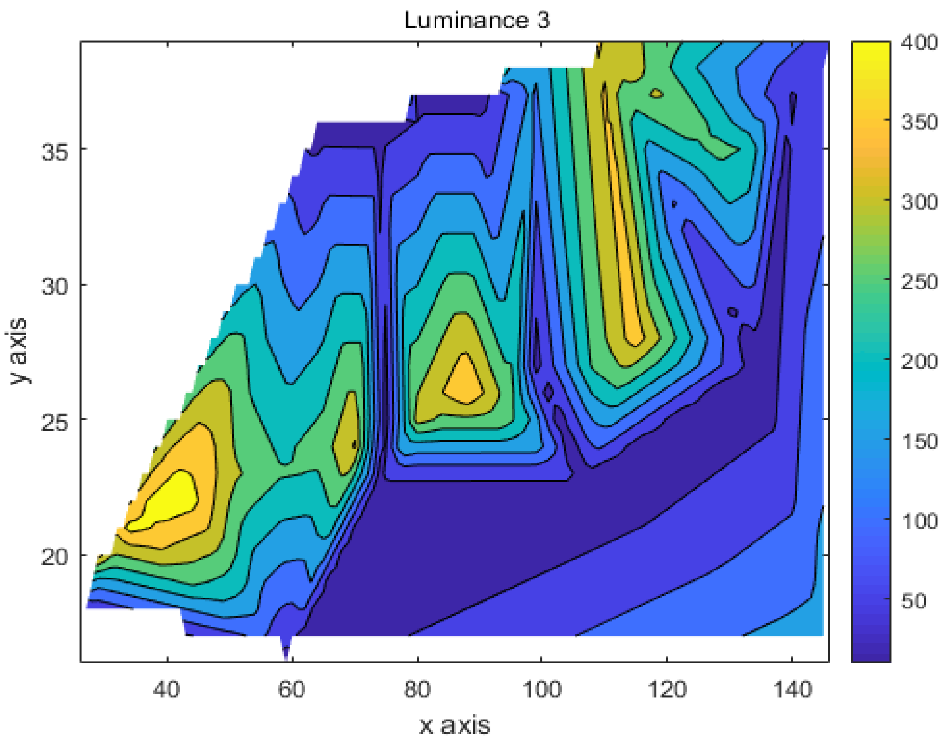
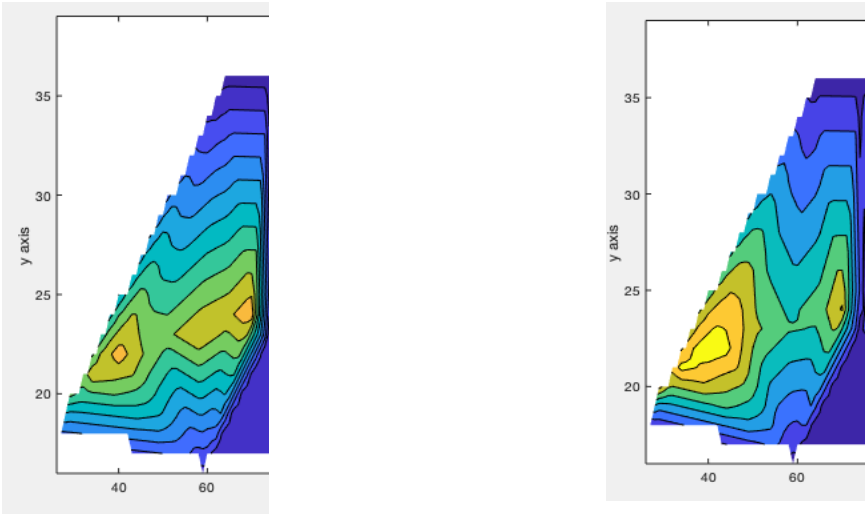


Figure 28. *Power map of Floor 1-Luminance 3*

In Figure 26, 27 and 28, Luminance 1, Luminance 2 and Luminance 3 refer to luminance data of Measurement 1, Measurement 2 and Measurement 3 respectively. It can be said that figure of Luminance 1 and Luminance 3 (Figure 26 and 28) look almost similar although the maximum value of luminance is different, 600 lux and 400 lux respectively. The weather condition of measurement 1 and 3 was almost similar, so time might be an important factor for this huge difference. As measurement 3 was taken during the afternoon and measurement 1 was taken during midday, the presence of light in the building was different.

Luminance 2 looks totally different from rest of the two measurements and the weather might be the reason in this case as it was raining during the time when the measurements were taken. Maximum luminance was same in measurements 1 and 2 as both of the measurements were taken during midday. Basically, these data are either time dependent or weather dependent and it is not feasible enough to use these data for positioning.

Two similar patterns are noticeable at Luminance 1 and Luminance 3. One at the amplitude, surrounded by (X, Y) coordinates (76,23), (105,23), (79,37) and (94,37) which can be seen in the following zoomed Figure 29.



a b

Figure 29. *Similarity between a) Luminance 1 and b) Luminance 2 at (76,23), (105,23), (79,37) and (94,37) region.*

The other one is at the area consisted with coordinates (X, Y) (28,18), (61,17), (64,36) and (74,36) which can be seen in Figure 30.

a. Luminance 1 b. Luminance 2

Figure 30. *Similarity between Luminance 1 and Luminance 2 at (28,18), (61,17), (64,36) and (74,36) region*

These two areas represent block 2 and 3 in the map of floor 1, which can be seen in Figure 23. No other similar values were obtained from those blocks, so it is not possible to identify that particular location by using this data. Also, there is a clear correlation among these values which is why almost identical power maps were generated in these two measurements (Luminance 1 and Luminance 3), but it is not possible to use the data for positioning because a different pattern was obtained from Luminance 2.

6.2.2 Humidity

Figure 31 includes the histogram of humidity obtained from floor 1 for three consecutive days.

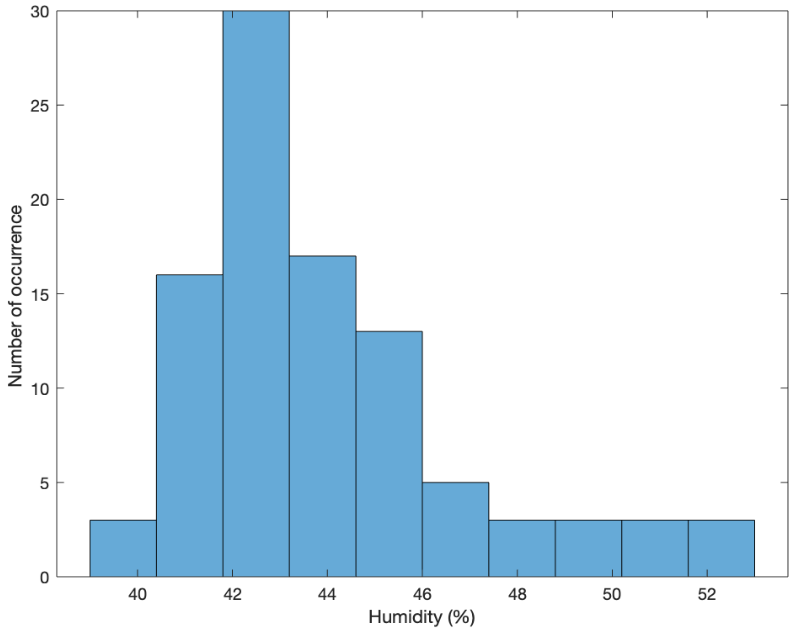


Figure 31. *Histogram of Floor 1 Humidity*

Figure 31 shows that the highest number of occurrences is 30 in the third bin and the humidity range in this bin was between 41.8% and 43.2%. There are two values in this range which have occurred four times and the values are 43.7 and 44.4. In this range we obtained 41.8% humidity four times in different coordinates during measurement 2 and measurement 3. The corresponding (X, Y) coordinates of this values are (99,27), (75,25), (135,27) and (74,36). We obtained some more values from the same range which occurred three times which includes 42.3, 42.4, 42.6, 42.7 and 42.9. All of these values were captured from different coordinates during three measurements while 42.3 and 42.6 got obtained only during measurement 3. There is no suitable information for positioning in the second and fourth bin. In bin 4, 43.3 occurred five times and in bin 2, 41.1 and 41.4 occurred three times, all in different coordinates, which is why it is not feasible enough to use this data for positioning. Now let's observe the power maps of humidity obtained from floor1 in Figure 32, 33 and 34 in order to find correlation among them.

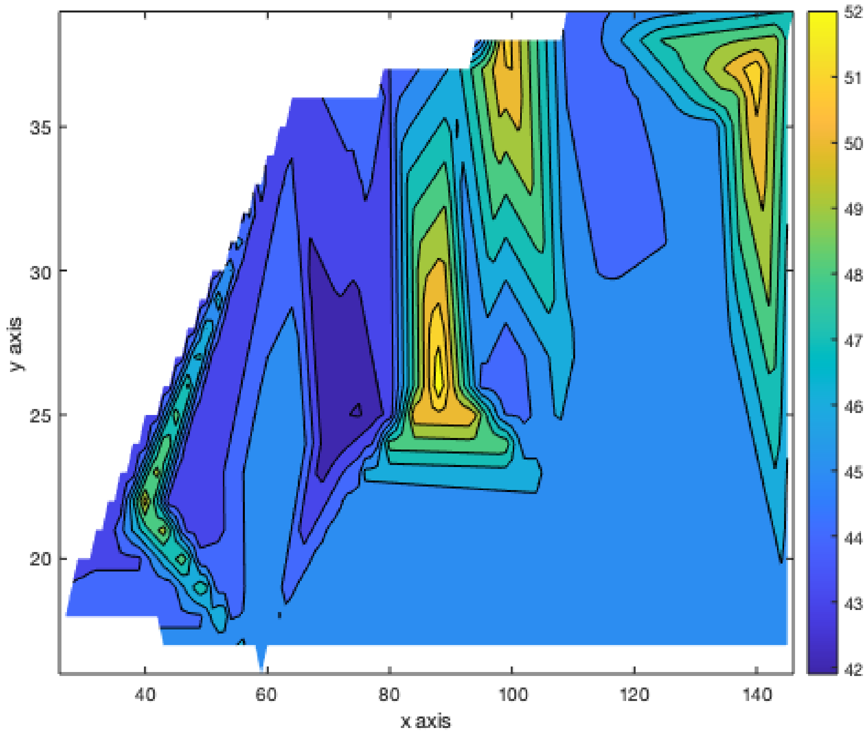


Figure 32. *Power map of Floor 1 Humidity 1*

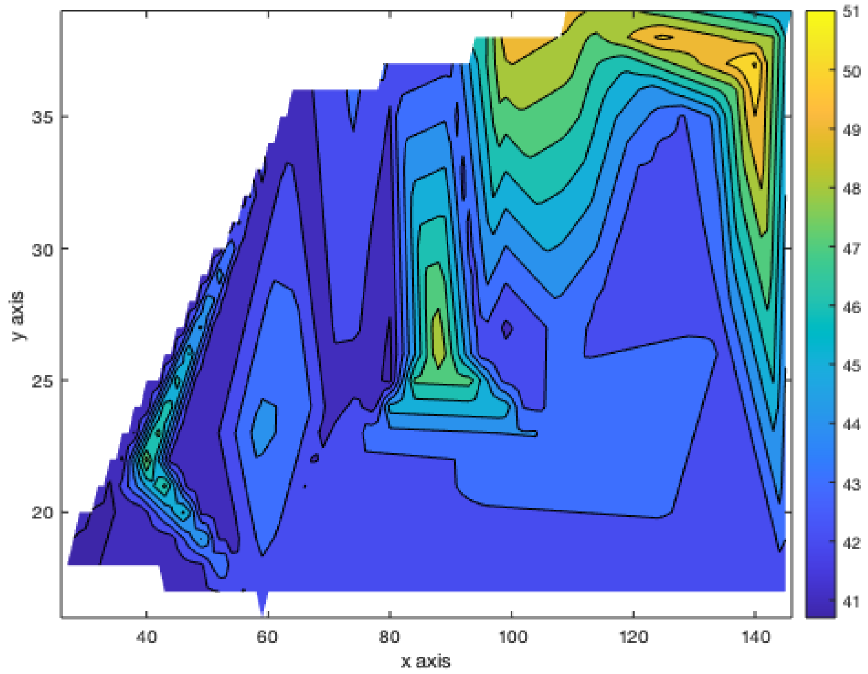


Figure 33. *Power map of Floor 1 Humidity 2*

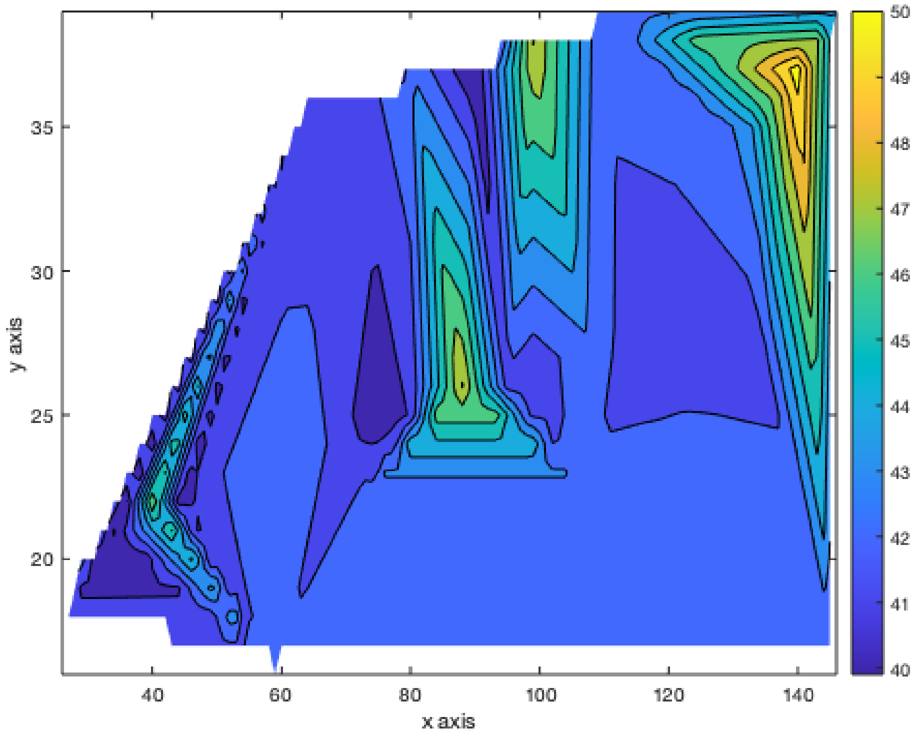


Figure 34. *Power map of Floor 1 Humidity 3*

Humidity 1, Humidity 2 and Humidity 3 in Figure 32, 33 and 34 refer to humidity data of Measurement 1, Measurement 2 and Measurement 3 respectively. There is a partial similarity in one area in the Figure 32, 33 and 34 which is consisted with (X, Y) coordinates (38,22), (52,18), (43,22) and (54,30) which can be seen in the zoomed Figure 35.

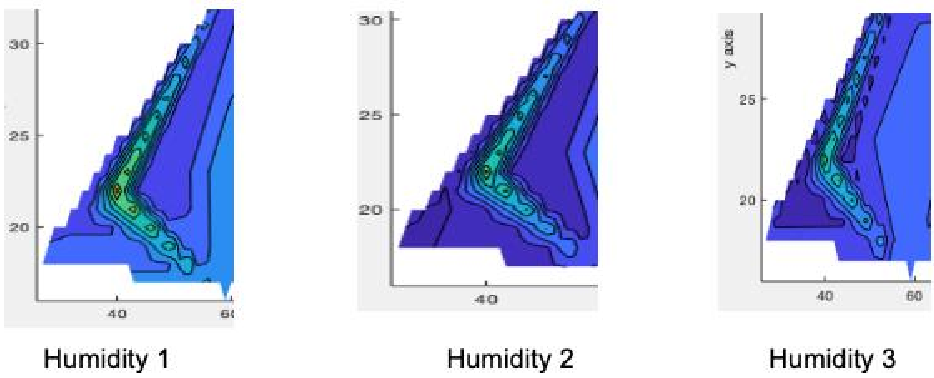


Figure 35. *Similarity in Humidity 1, Humidity 2 and Humidity 3*

It seems that it might be possible to use these data for positioning to identify a particular area as they show some similarity although the measurements were taken at different time and different weather. These coordinates indicate a small portion in block 2 and block 3 which we can see in floor 1 map. Therefore, it might be possible to identify the block using these data as we can see almost similar pattern in this particular area for all three measurements. There is another similarity between Humidity 1 and Humidity 3 at the area surrounded with (X, Y) coordinates (118, 38), (144, 20) and (145, 39). From the map in Figure 23, it can be observed that these coordinates indicate different locations in different blocks which means the data is unsuitable for positioning.

6.2.3 Pressure

Figure 36 includes the histogram of pressure obtained from floor 1 for three consecutive days.

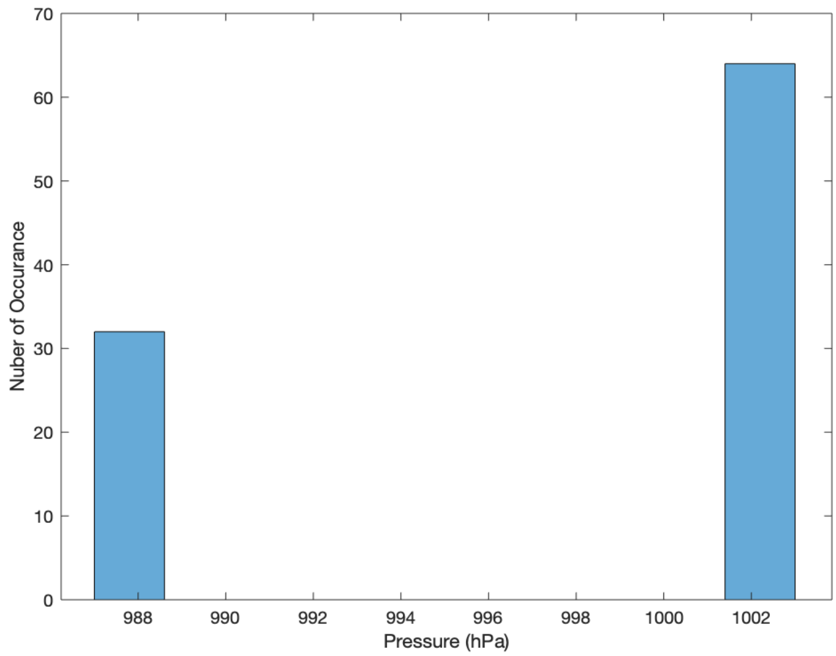


Figure 36. *Histogram of Floor 1 Pressure*

Figure 36 looks totally different than other histograms of luminance and humidity which can be seen in Figure 25 and 31 respectively. Here, the histogram includes only two bins instead of ten for all three measurements. The reason for this abnormality in the histogram is the values are very close to each other. The small bin represents the data of measurement 1 and the taller bin represents the data of measurement 2 and 3 together. Now let’s increase the bin number to 50 and observe the changes in the histogram.

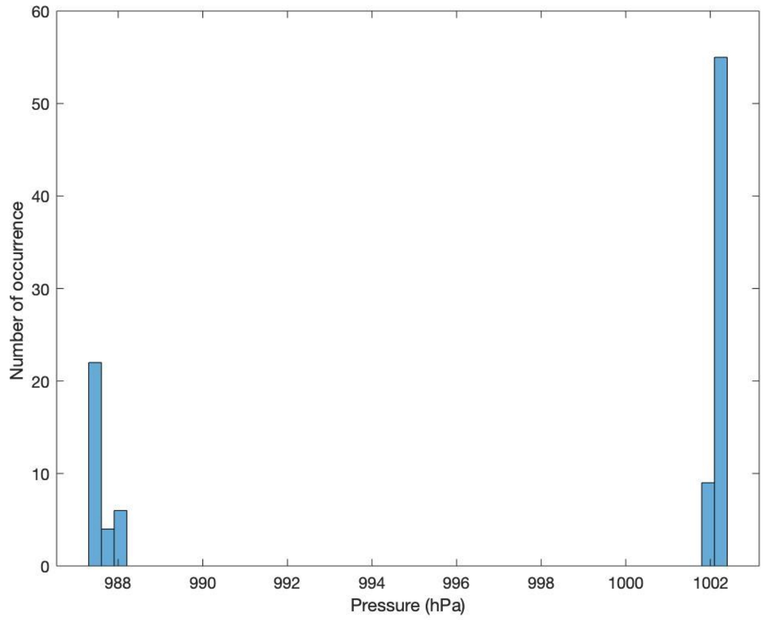


Figure 37. *Histogram of Floor 1 Pressure (bin number 50)*

Figure 37 includes the histogram of pressure obtained from floor 1 for three consecutive days with 50 number of bins. Now, this histogram includes 5 bins where the first 3 bins represent the data of measurement 1 and the last two bins represent the data of Measurement 2 and Measurement 3 together. Let's observe the power maps of floor 1 pressure from Figure 38, 39 and 40.

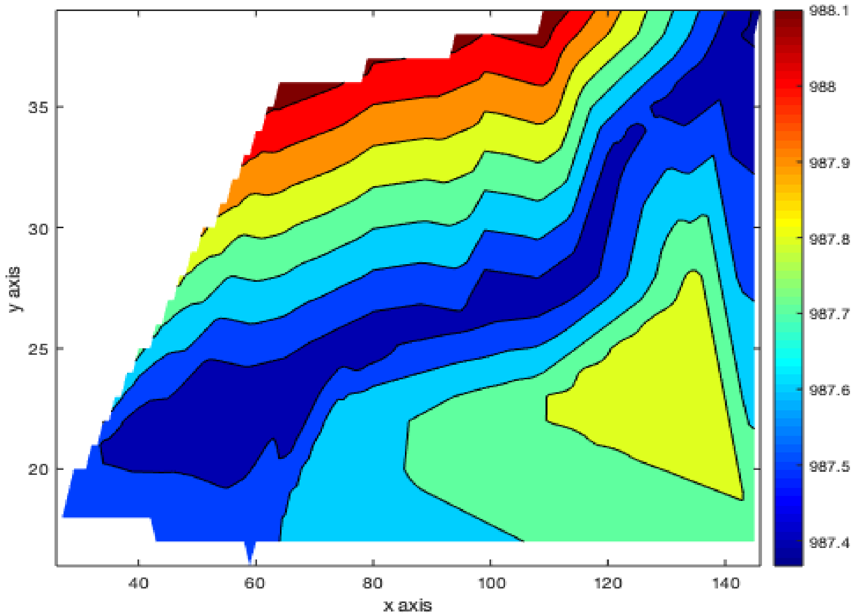


Figure 38. *Power map of Floor 1 Pressure 1*

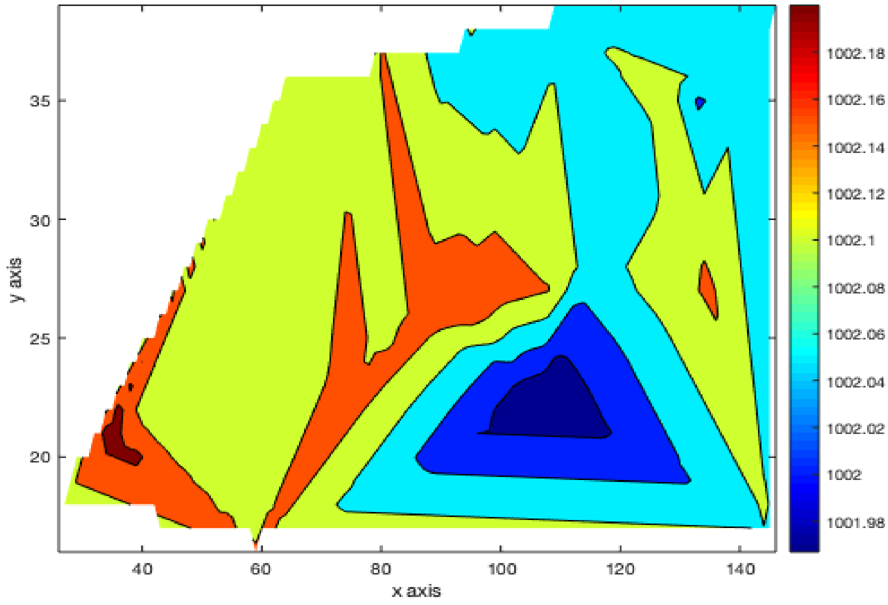


Figure 39. *Power map of Floor 1 Pressure 2*

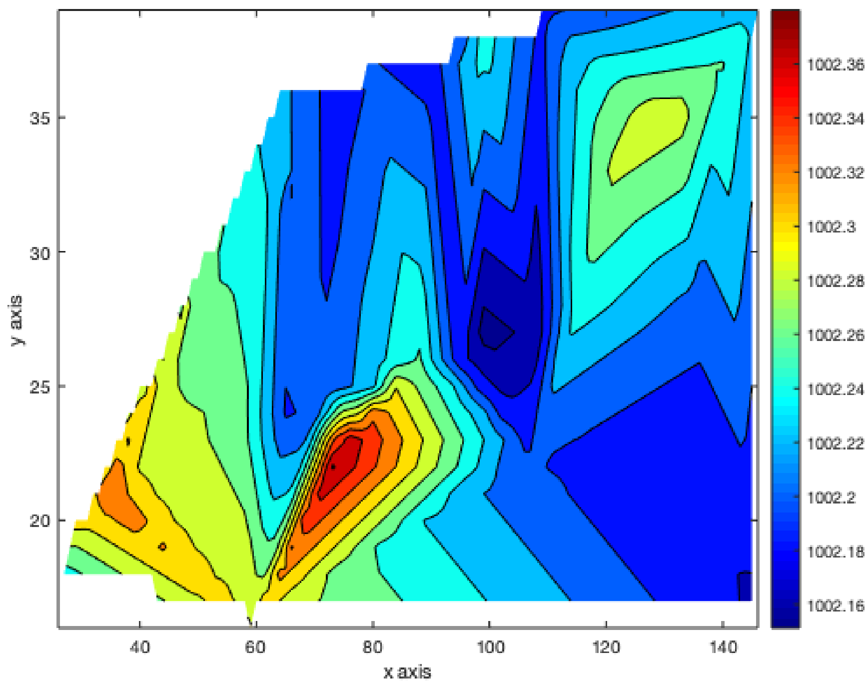


Figure 40. *Power map of Floor 1 Pressure 3*

Pressure 1, Pressure 2 and Pressure 3 in Figure 38, 39 and 40 refer to the pressure data of Measurement 1, Measurement 2 and Measurement 3 respectively. It is quite clear that there is no pattern in these figures. For Pressure 1, we got the maximum value 988.1 hPa which is very close to the minimum value 987.4 hPa. From Pressure 2 and Pressure 3, we can observe the same situation. Although there is no similarity among Figure 38, 39 and 40, it might be possible to use the data for floor detection which will be clear after comparing this data with floor 2 pressure measurements.

6.2.4 Temperature

Figure 41 includes the histogram of temperature obtained from floor 1 for measurements for three days.

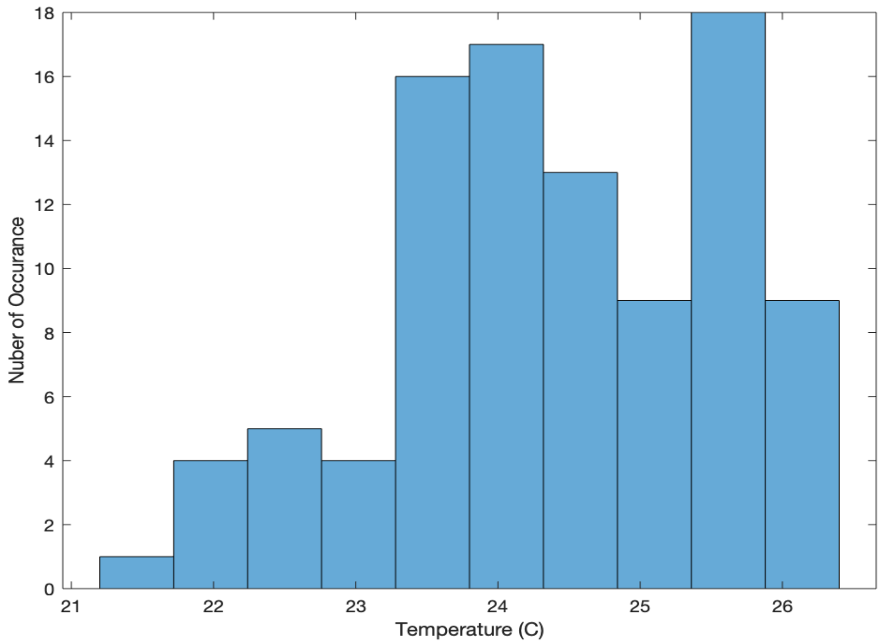


Figure 41. *Histogram of Floor 1 Temperature*

Figure 41 shows that the highest number of occurrences is 18 in bin number 9 and the temperature range in this bin was 25.36-25.80. In this range we got 25.55, 25.82 and 25.86 repeated two times but in different positions. The same situation can be observed from bin 5 and 6 which include the next highest number of occurrences. Values in rest of the bins were not well informative for positioning as well which means this data is not suitable enough.

Now let’s observe the power maps of temperature in Figure 42, 43 and 44 in order to find patterns among them.

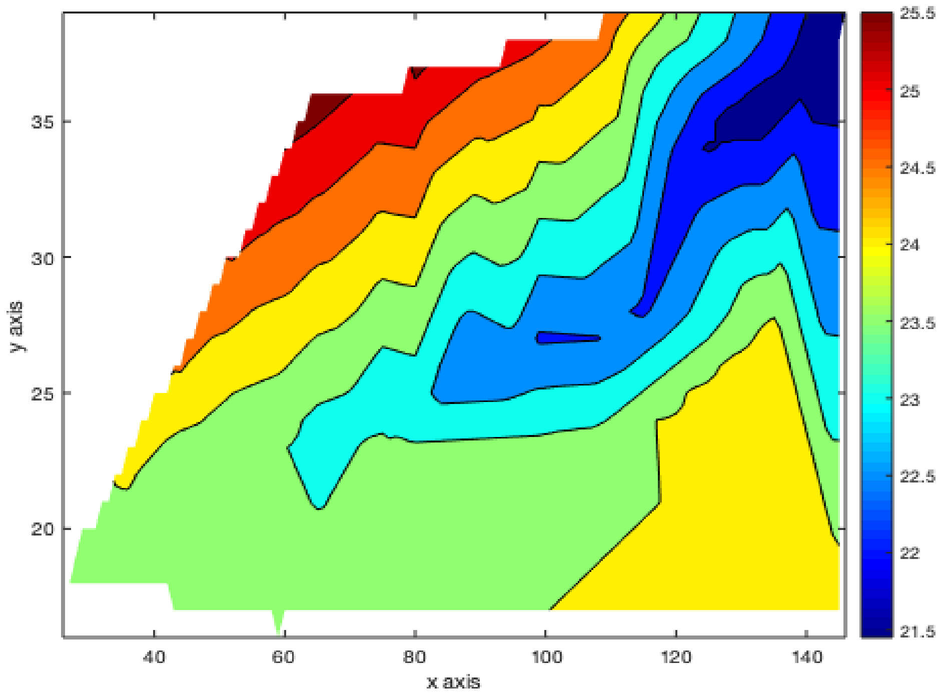


Figure 42. *Power map of Floor 1 Temperature 1*

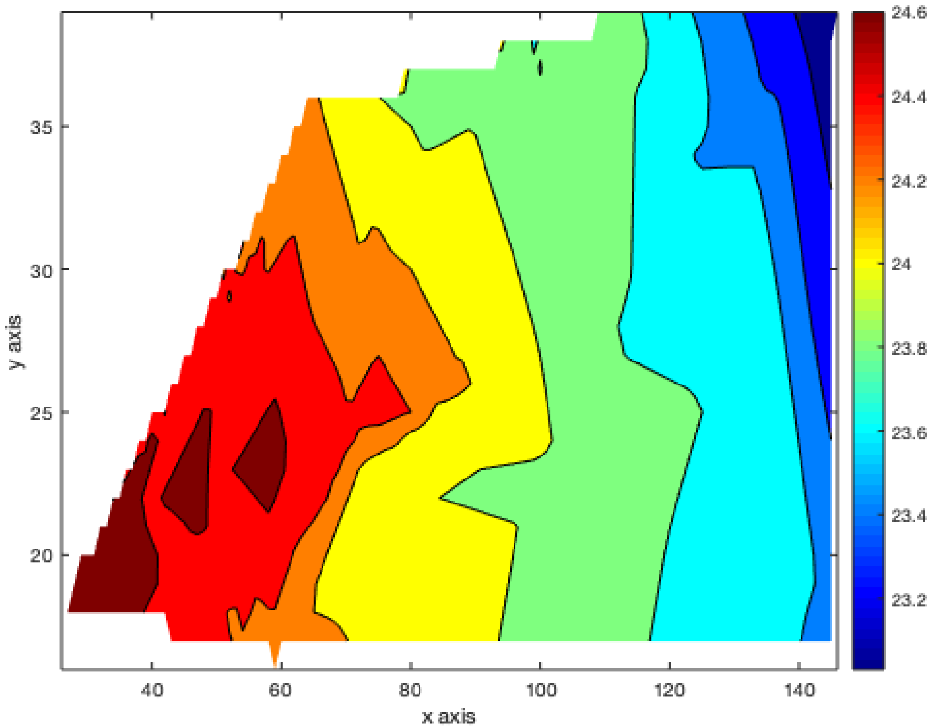


Figure 43. *Power map of Floor 1 Temperature 2*

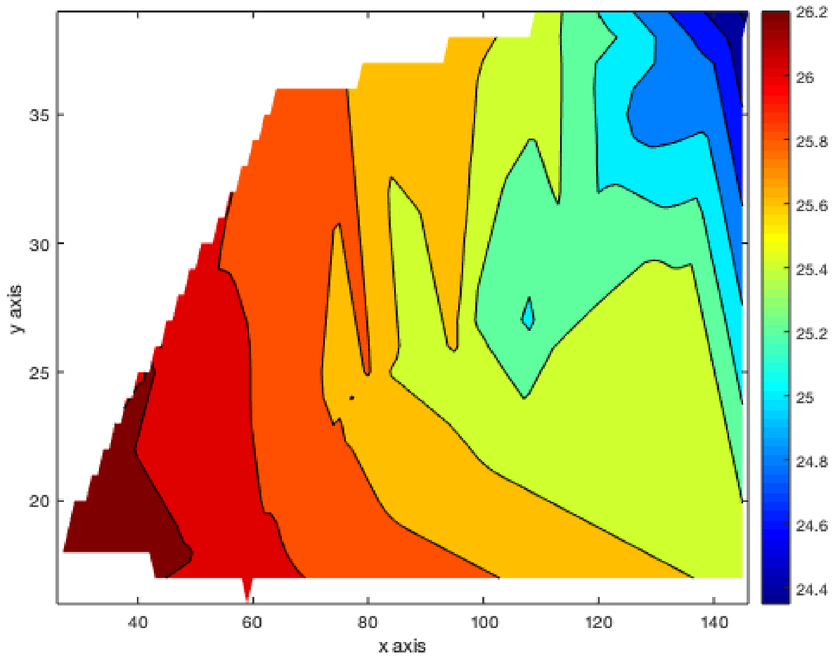


Figure 44. *Power map of Floor 1 Temperature 3*

Temperature 1, Temperature 2 and Temperature 3 in Figure 42, 43 and 44 refer to the temperature data of Measurement 1, Measurement 2 and Measurement 3 respectively. These figures show that all temperature power maps are nonidentical to each other. Although a partial similarity can be seen in Temperature 2 and Temperature 3 figure and it is in the area consisted with (X, Y) coordinates (28, 18), (39, 18) and (40, 24) which can be seen in the zoomed Figure 45.

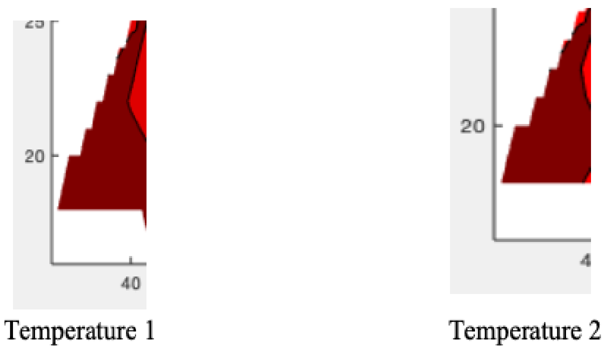


Figure 45. *Similarity between Temperature 1 and Temperature 2*

These coordinates indicate a small portion in block 2 which can be seen in floor 1 map at Figure 23. This information is not enough to identify the block as it was different during measurement 1. However, a similarity was seen in the Humidity data floor 1 approximately in the same area which can be seen in Figure 35. For humidity data, the similarity was seen in a small portion of block 2 and block 3, which can be found in floor 1 map at

Figure 23. Apparently, it is not possible to use temperature data for positioning, but a combination of temperature and humidity might be an option because altogether they show similarities in the same block or area.

6.3 Floor 2 Measurements

This sub-section demonstrates the analysis of luminance, humidity, temperature and pressure data captured from floor 2.

6.3.1 Luminance

First let's observe the histogram of Luminance obtained from floor 2 for three consecutive days in Figure 46.

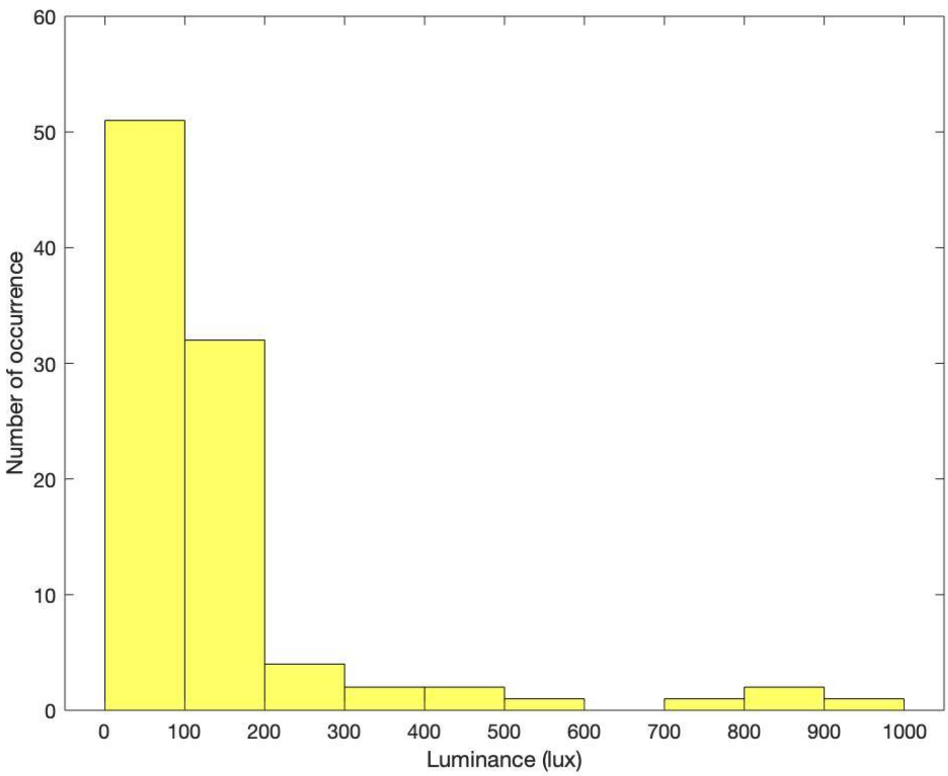


Figure 46. *Histogram of Floor 2 Luminance*

In Figure 46, it can be observed that the highest number of occurrences is 51 in the first bin and the luminance range in this bin was 0-100 lux. In this range we got 0.99 lux repeatedly three times at the same (X, Y) coordinate (150,50) during all three measurements. The value 0.99 did not occur in any other location apart from this coordinate. So, clearly it is possible to identify this coordinate with the luminance data. The position of this coordinate is identified by sequence number 32 in Figure 24, floor 2 map.

37.62 lux occurred four times in the same range which is the highest but in different coordinates. Rest of the values in this range which occurred more than once are 5.94, 18.81, 22.77, 44.55, 46.53, 64.35, 74.25 and 78.2. All these values were captured in different coordinates except 5.94 lux and it was captured during measurement 1 and measurement 2 from the same position with (X, Y) coordinate (145, 36) which can be seen in Figure 24, floor 2 map, indicated by sequence number 28. Although a different value was obtained from this coordinate during measurement 3. As measurement 1 and 2 were taken during midday and measurement 3 was taken during afternoon, the possible reason of this change would be the time. Also, data observation from rest of the bins does not show any similarity in the corresponding coordinates. Apparently, from this part of analysis, it is possible to identify only one location with coordinates (X, Y) (150, 50) using luminance data (0.99 lux). Now let's observe the power maps of luminance in Figure 47,48 and 49 to find further suitable information for positioning.

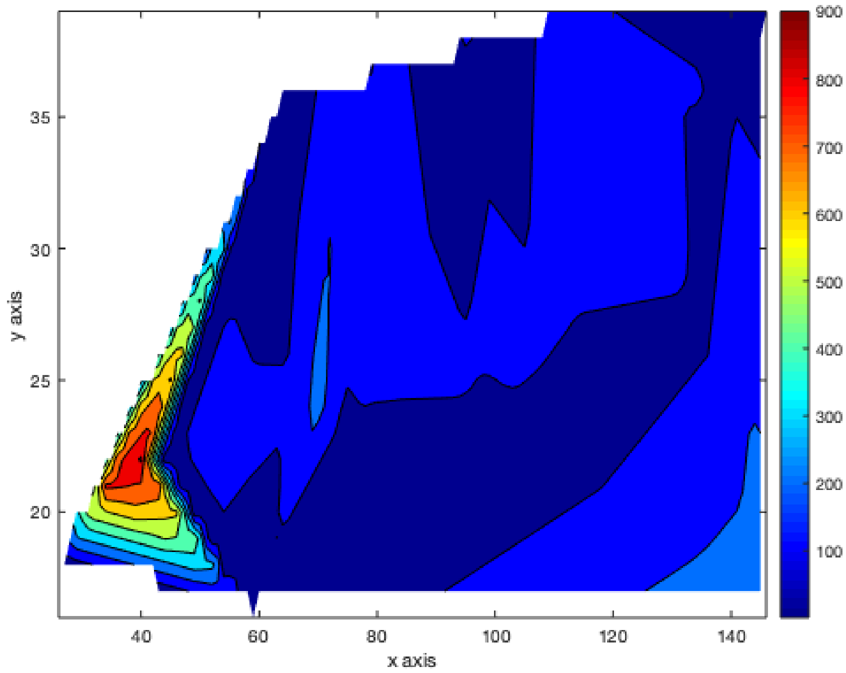


Figure 47. *Power map of Floor 2 Luminance 1*

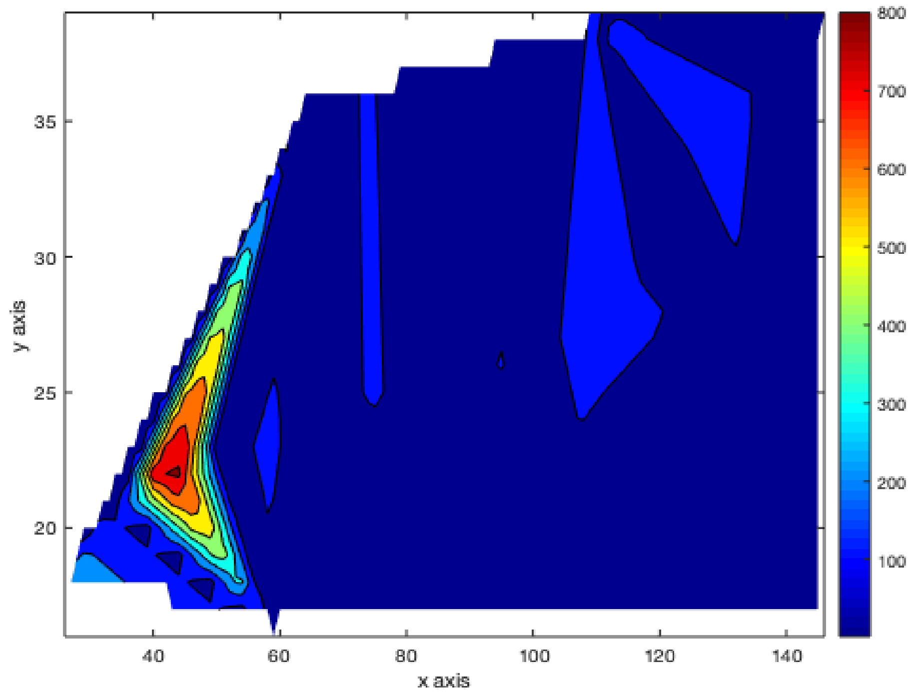


Figure 48. *Power map of Floor 2 Luminance 2*

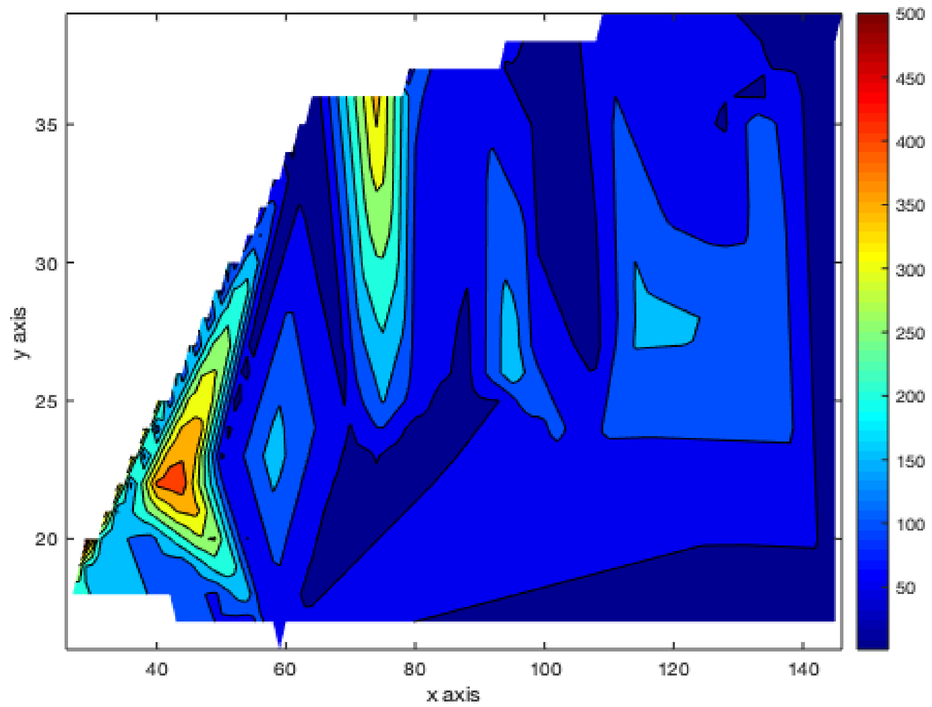


Figure 49. *Power map of Floor 2 Luminance 3*

In Figure 47, 48 and 49, Luminance 1, Luminance 2 and Luminance 3 refer to luminance data of Measurement 1, Measurement 2 and Measurement 3 respectively. These figures show no major similarity to each other. Although in all three figures, a small area around (X, Y) coordinate (42, 22) shows the maximum luminance. The area can be seen in the zoomed Figure 50.

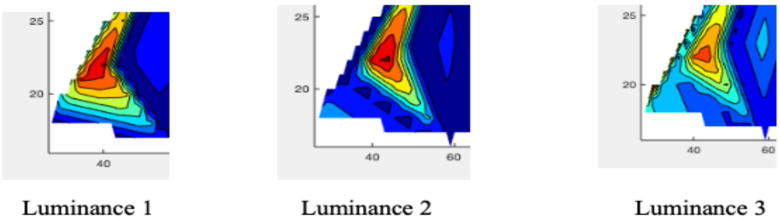


Figure 50. *Similarity in Luminance 1, Luminance 2 and Luminance 3*

The area around the coordinates indicates a small portion in block 2 in Figure 24, floor 2 map. As all three measurements show similar pattern in the same area, therefore, it might be possible to identify this area by using this data. There is no other notable similarity among the three measurements and therefore, it is not feasible enough to use rest of these data for positioning.

6.3.2 Humidity

Figure 51 includes the histogram of humidity obtained from floor 2 for three consecutive days.

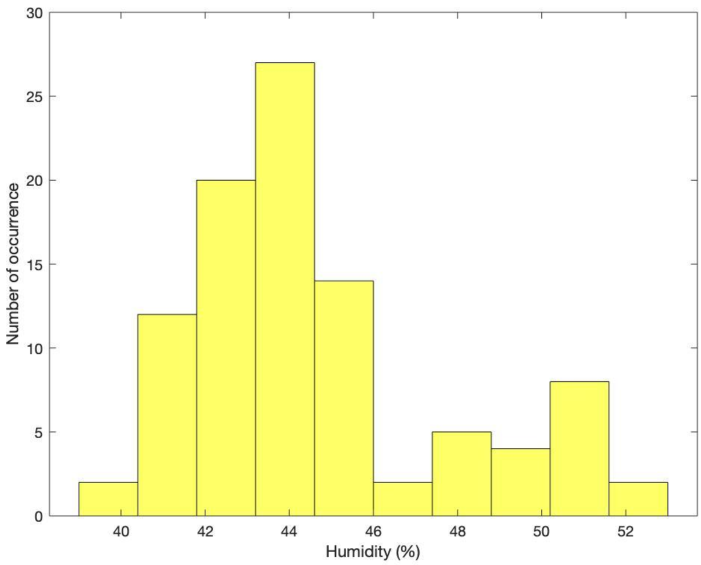


Figure 51. *Histogram of Floor 2 Humidity*

Figure 51 shows that the highest number of occurrences is 27 in bin number 4 and the humidity range in this bin was between 43.2% and 44.6%. There are two values in this range which have occurred four times and the values are 43.7 and 44.4. Although these values were obtained from different location. In bin 3, the range was from 41.8% to 43.2%. In this range, 43.1% occurred 7 times during all three measurements but no similarity in the corresponding coordinates was not observed.

There is another value which has occurred three times, but they are also captured from different coordinates during measurement 1 and 2. The value is 51.4% and the corresponding (X, Y) coordinates are (50, 18) and (45, 32) in measurement 1 and (140, 39) in measurement 2. Until now, no suitable information is found for positioning. Let's observe the power maps of humidity in floor 2 from Figure 52, 53 and 54.

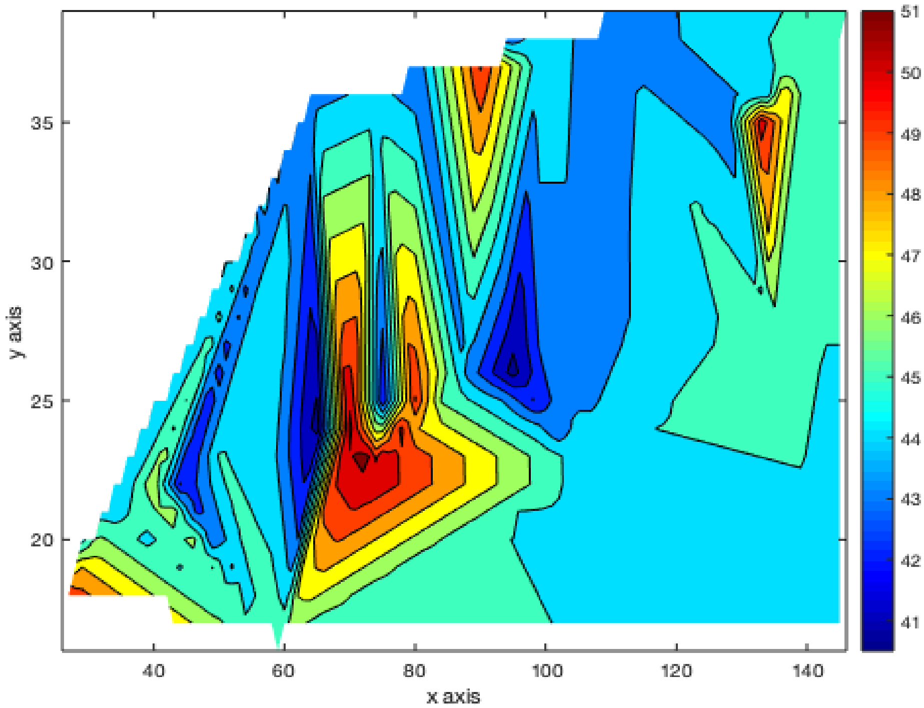


Figure 52. *Power map of Floor 2 Humidity 1*

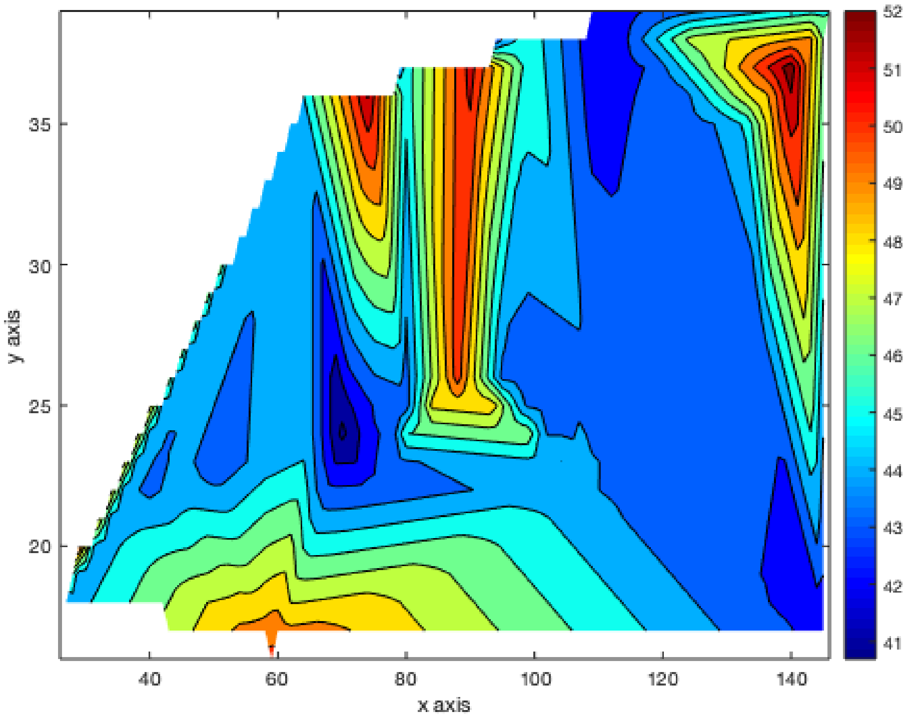


Figure 53. *Power map of Floor 2 Humidity 2*

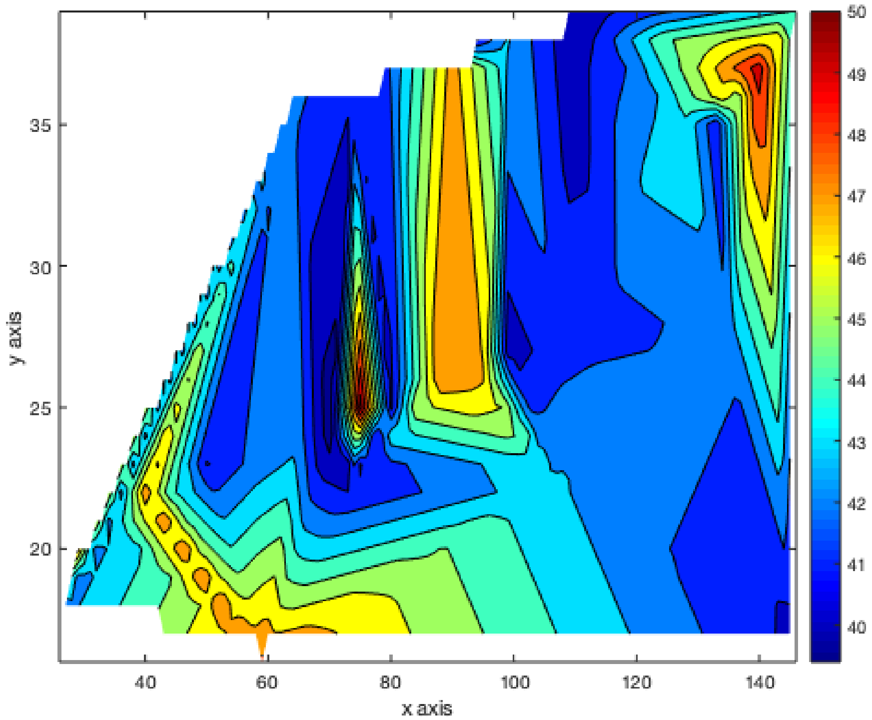


Figure 54. *Power map of Floor 2 Humidity 3*

Humidity 1, Humidity 2 and Humidity 3 in Figure 52, 53 and 54 refer to humidity data of Measurement 1, Measurement 2 and Measurement 3 respectively. These figures clearly show that there is no noticeable similar pattern among them. Therefore, it can be concluded that humidity data is not suitable enough for positioning purpose.

6.3.3 Pressure

Figure 55 includes the histogram of pressure obtained from floor 2 for three consecutive days.

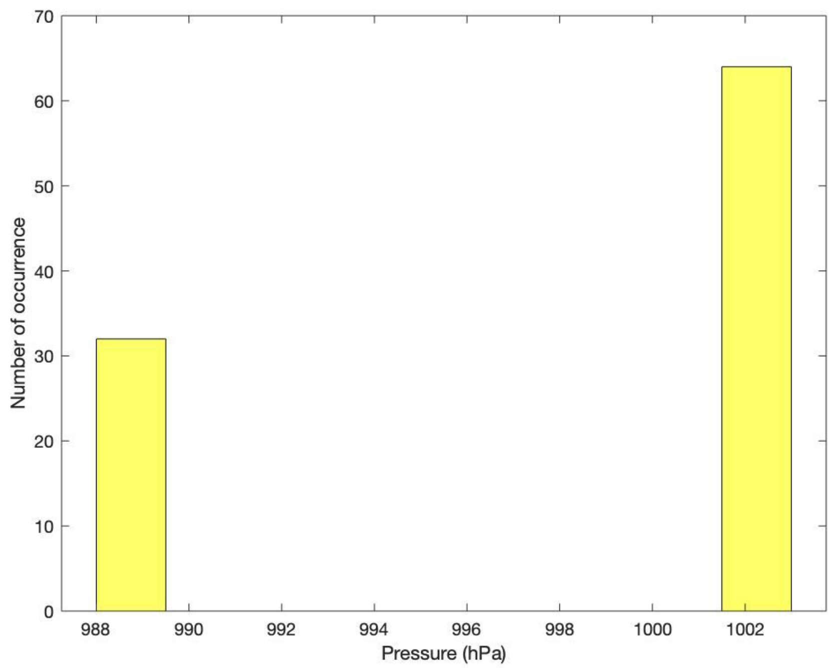


Figure 55. *Histogram of Floor 2 Pressure*

The histogram in Figure 55 shows that there are only two bins instead of ten for all three measurements, which is quite similar to the pressure histogram of floor 1 that can be seen in Figure 36. In Figure 55, the smaller bin represents the data of measurement 1 and another one represents the data of measurement 2 and 3 altogether, which is also similar with Figure 36, histogram of floor 1 pressure. Now let’s increase the number of bins to 50 for floor 2 pressure histogram in Figure 56 and observe the changes.

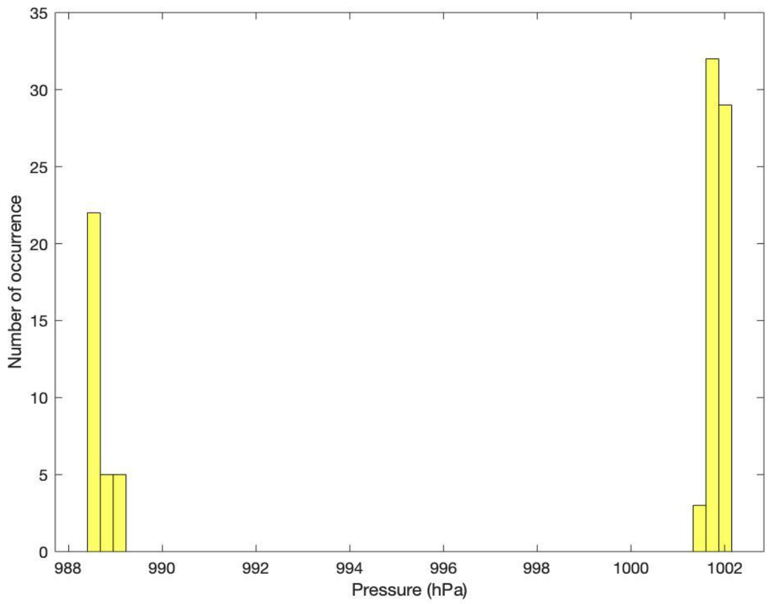


Figure 56. *Histogram of Floor 2 Pressure (bin number 50)*

Figure 56 includes the histogram of pressure obtained from floor 2 for three consecutive days with 50 number of bins. Now, the histogram includes 6 bins where the first 3 bins represent the data of Measurement 1 and the last 3 bins represent the data of Measurement 2 and Measurement 3 together. Now let's see the power maps of pressure data obtained from floor 2 in Figure 57, 58 and 59.

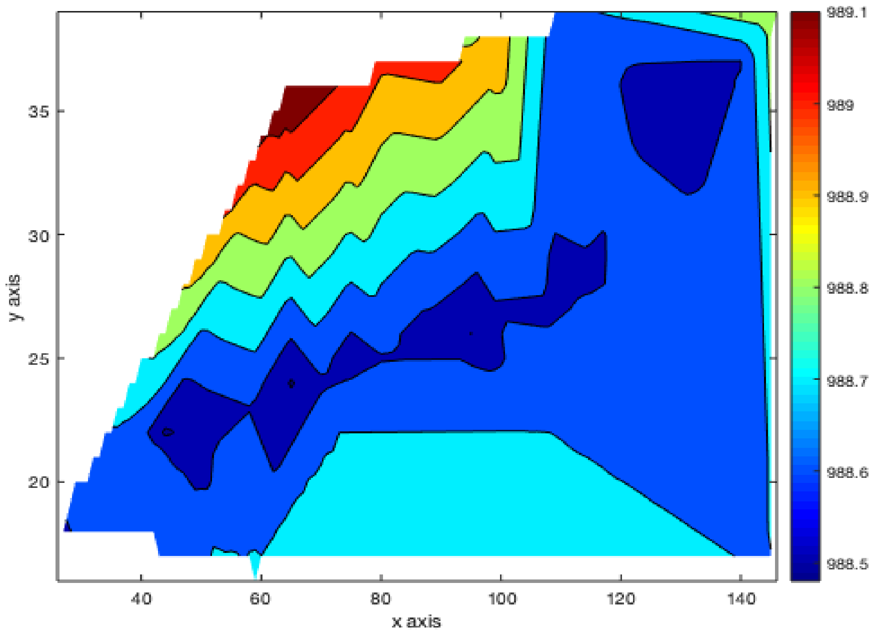


Figure 57. *Power map of Floor 2 Pressure 1*

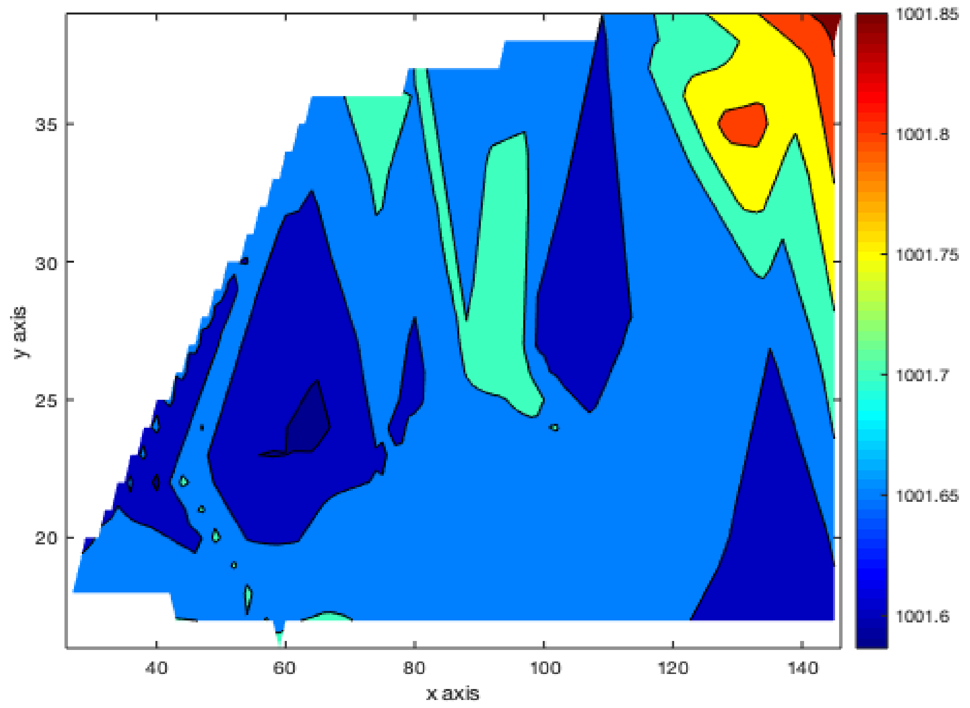


Figure 58. *Power map of Floor 2 Pressure 2*

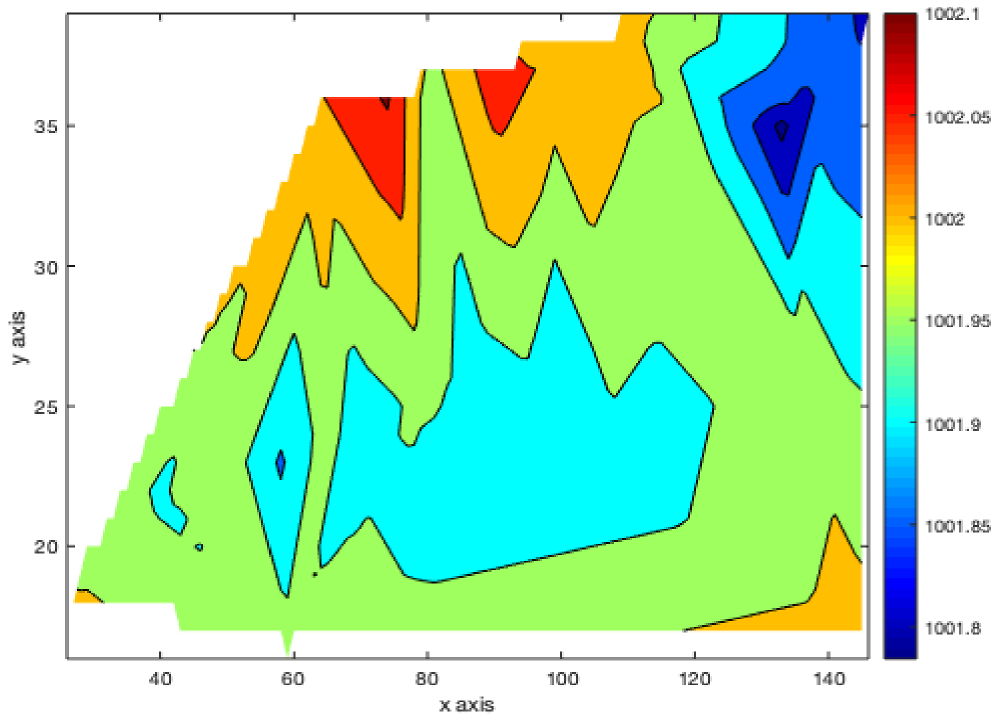


Figure 59. *Power map of Floor 2 Pressure 3*

Pressure 1, Pressure 2 and Pressure 3 in Figure 57, 58 and 59 refer to the pressure data of Measurement 1, Measurement 2 and Measurement 3 respectively. The observation shows that there is no clear pattern for the pressure data in the above three figures.

6.3.4 Temperature

Figure 60 includes the histogram of temperature obtained from floor 2 for measurements of three days.

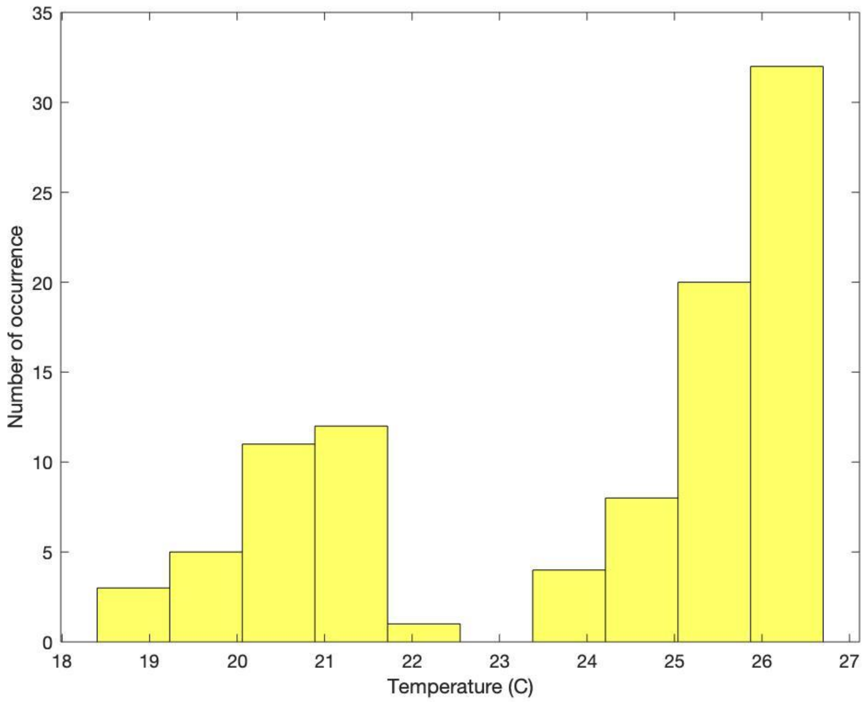


Figure 60. *Histogram of Floor 2 Temperature*

From Figure 60, it can be observed that the highest number of occurrences is 32 in bin number 10 and the temperature range in this bin is from 25.87 to 26.7 degree Celsius. Obtained values in this range are 25.88, 26.13, 26.15, 26.27, 26.27, 26.36, 26.43 and 26.47. Each value repeated two times but all of them were in different coordinates. Similar situation was also observed in the data of rest of the bins. So, using this data for positioning will not be feasible. Let's observe the power maps of temperature in floor 2 in Figure 61, 62 and 63.

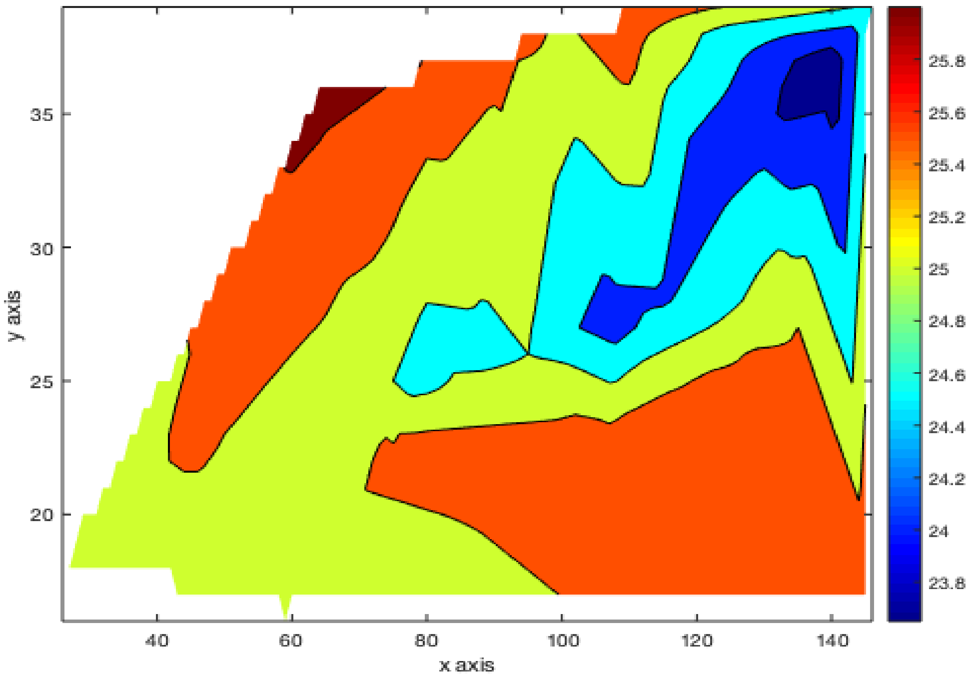


Figure 61. *Power map of Floor 2 Temperature 1*

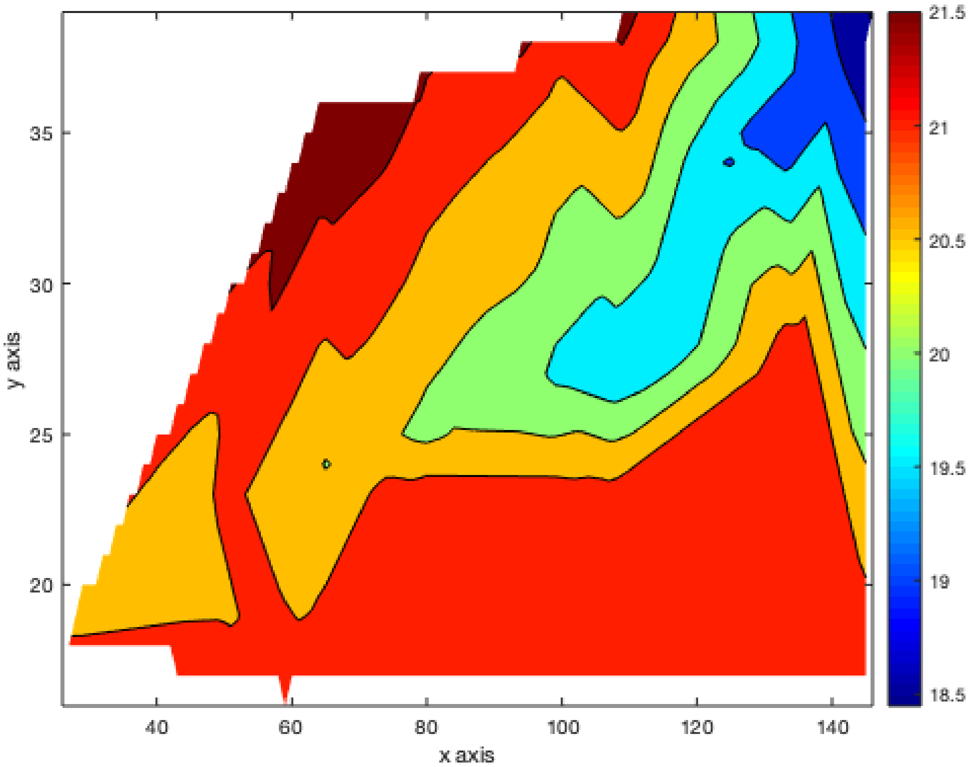


Figure 62. *Power map of Floor 2 Temperature 2*

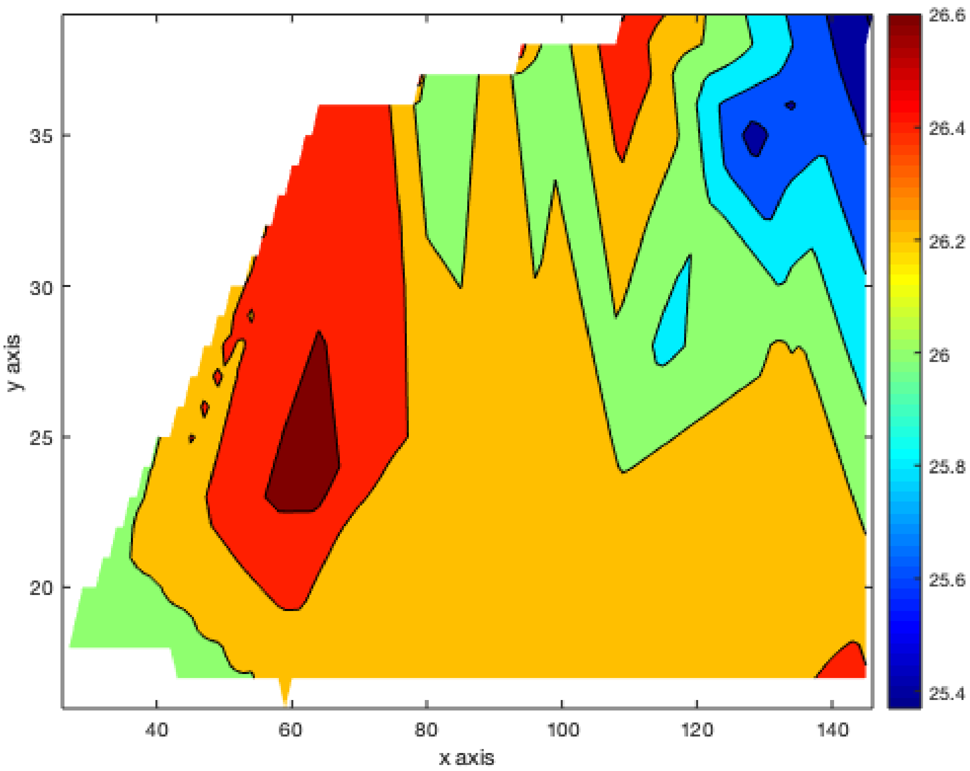


Figure 63. *Power map of Floor 2 Temperature 3*

Temperature 1, Temperature 2 and Temperature 3 in Figure 61, 62 and 63 refer to the temperature data of Measurement 1, Measurement 2 and Measurement 3 respectively. From these figures, it is clear that, all temperature power maps obtained from floor 2 are non-identical to each other apart from a partial similarity that can be seen in Temperature 1 and Temperature 2 figures. The area is consisted with (X, Y) coordinates (59, 33), (64, 36) and (73, 36). These coordinates indicate a small portion in block 2 which can be seen in the figure of second floor map. Although this information is not enough to identify the block as a different pattern was obtained in Measurement 3 in the same area. There is no other major similarity that can be noticed in these figures. Therefore, it is not suitable enough to use this temperature data for positioning.

6.4 Floor 1 Measurements vs Floor 2 Measurements

This sub-section demonstrates the comparison between floor 1 and floor 2 measurements for each of the four parameters and shows which parameters are suitable for floor detection.

6.4.1 Luminance

The histograms obtained for luminance from floor 1 and floor 2 can be compared to see if it is possible to use this parameter for floor detection. Figure 64 shows the luminance histograms obtained from both floors. The blue bars represent the data obtained from floor 1 and the yellow bars represent the data obtained from floor 2.

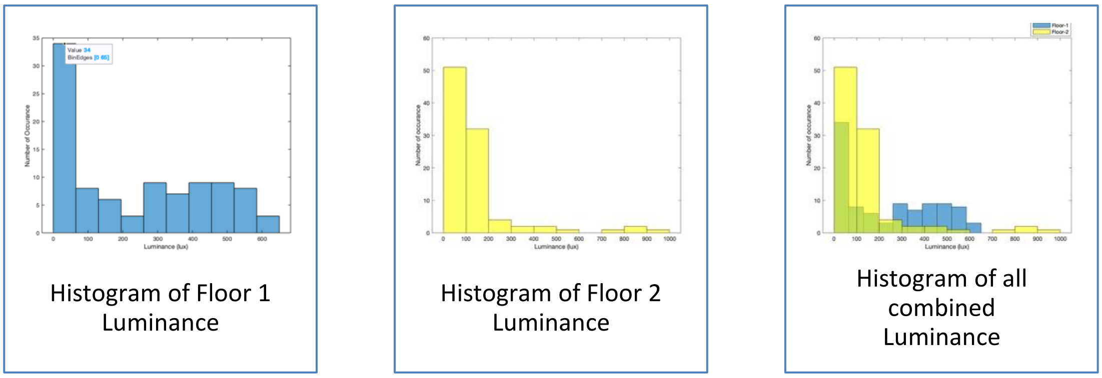


Figure 64. *Comparison between Floor 1 and Floor 2 Luminance Histograms*

Figure 64 shows that some portion of the Luminance data might be suitable to differentiate between floor 1 and floor 2. In the combined histogram, yellow bars show values exceeding the blue bars. Luminance value was obtained up to 650 lux for floor 1. For floor 2, luminance value was obtained up to 1000 lux. The data between the range of 650-1000 lux shows only yellow bars. That means the data between this range was obtained only in floor 2. This data might be useful for floor 2 detection. The overall power map obtained for luminance from floor 1 and floor 2 can be compared in Figure 65.

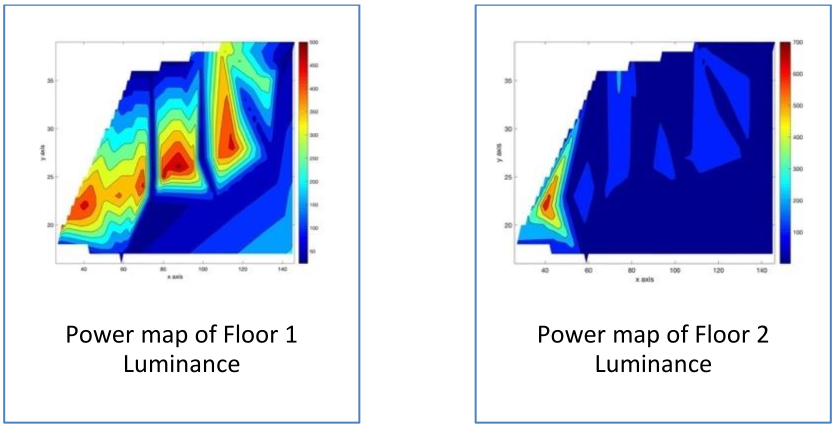


Figure 65. *Comparison between Floor 1 and Floor 2 Luminance Power maps*

Figure 65 shows that overall power map of luminance obtained from floor 2 is mostly constant compared to the overall power map of luminance obtained from floor 1. This information might be suitable for differentiating between floor 1 and floor 2.

6.4.2 Humidity

The histograms obtained for humidity from floor 1 and floor 2 can be compared to see if it is possible to use this parameter for floor detection. Figure 66 shows all the humidity histograms obtained from both floors. The blue bars represent the data obtained from floor 1 and the yellow bars represent the data obtained from floor 2.

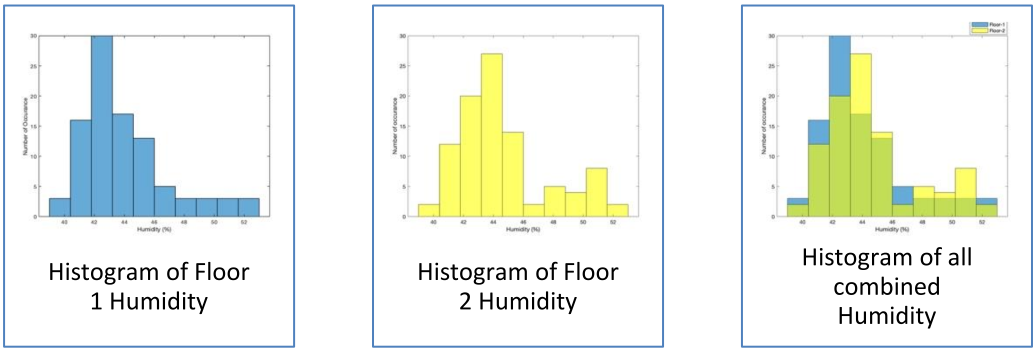


Figure 66. *Comparison between Floor 1 and Floor 2 Humidity Histograms*

Figure 66 clearly shows that the humidity data is not suitable enough for differentiating between floor 1 and floor 2. In the combined histogram, yellow and blue bars are overlapped to each other which means almost identical values were obtained from both floors. The overall power map obtained for humidity from floor 1 and floor 2 can be compared in Figure 67.

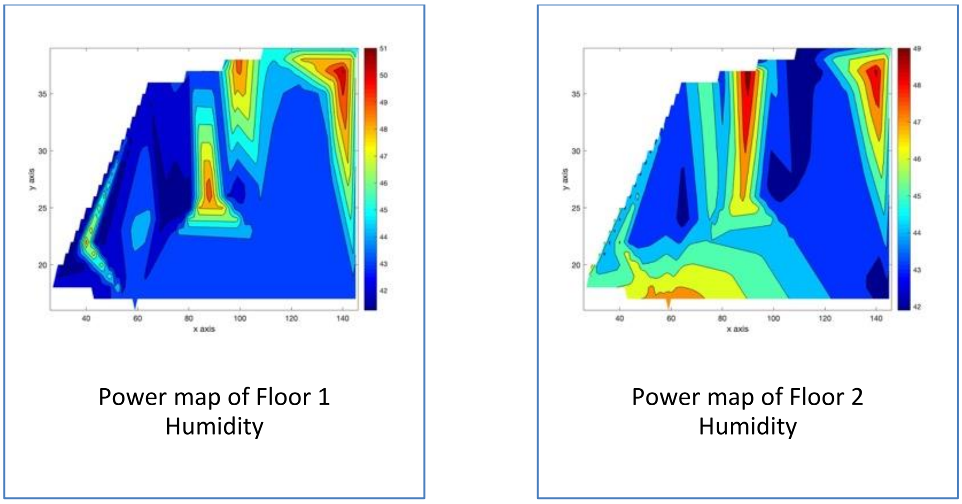


Figure 67. *Comparison between Floor 1 and Floor 2 Humidity Power maps*

Figure 67 shows some similarities between overall humidity power maps obtained from floor 1 and floor 2. One similarity can be seen in the zoomed Figure 68.

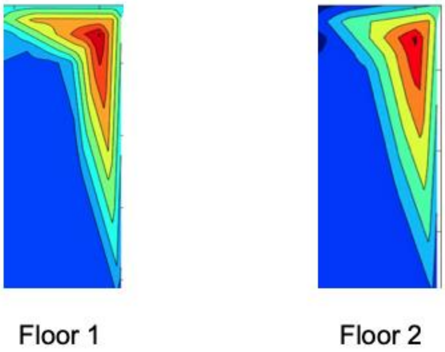


Figure 68. *Similarity between Floor 1 and Floor 2 Humidity Power maps*

Also, there are no major differences between floor 1 and floor 2 humidity power maps. Therefore, the experimental humidity data is not suitable enough to differentiate between floor 1 and floor 2.

6.4.3 Pressure

The histograms obtained for pressure from floor 1 and floor 2 can be compared to see if it is possible to use this parameter for floor detection. Using 50 bins for pressure histograms showed comparatively better results for floor 1 and floor 2 in sub-section 6.2.3 and sub-section 6.3.3 respectively. Figure 69 shows all the pressure histograms obtained from both floors. The blue bars represent the data obtained from floor 1 and the yellow bars represent the data obtained from floor 2.

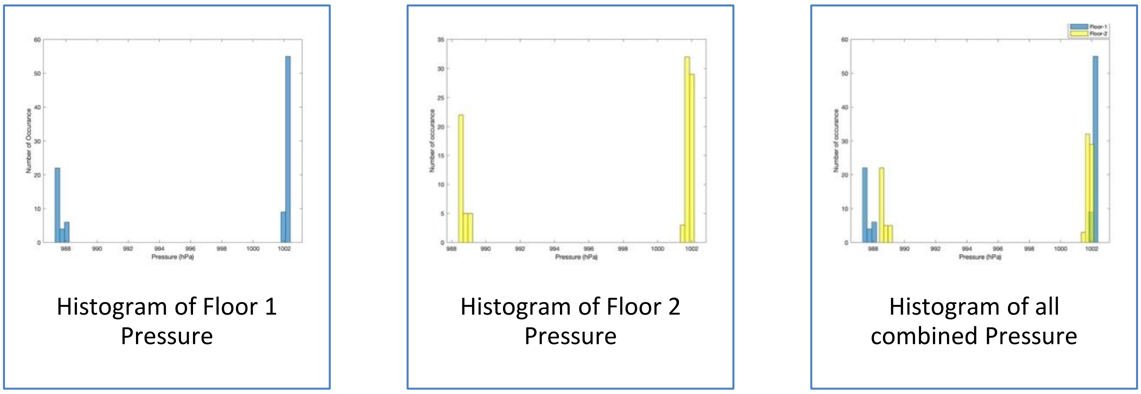


Figure 69. *Comparison between Floor 1 and Floor 2 Pressure Histograms*

Figure 69 clearly shows that some portion of the pressure data is suitable for differentiating between both floors. In the combined histogram, some yellow bars show higher values than the blue bars which can be seen in the zoomed Figure 70.

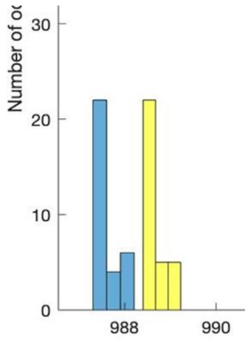
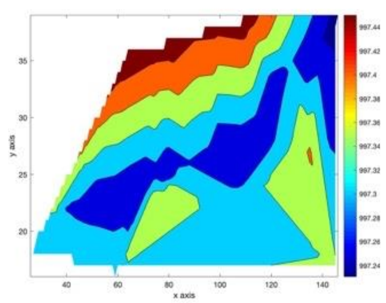
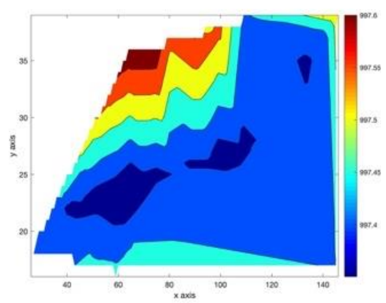


Figure 70. *Difference between Floor 1 and Floor 2 Pressure data*

Also, some overlapping of yellow and blue bars are observed in Figure 69 which cannot be used for floor detection, as these values were obtained from both floors. The overall power map obtained for pressure from floor 1 and floor 2 can be compared in Figure 71.



Power map of Floor 1 Pressure



Power map of Floor 2 Pressure

Figure 71. *Comparison between Floor 1 and Floor 2 Pressure Power maps*

Figure 71 shows a major difference in color pattern between floor 1 and floor 2 pressure power maps. Also, in the histograms, some pressure values were found to be useful for differentiating between both floors. Therefore, it is possible to use these values for floor detection.

6.4.4 Temperature

The histograms obtained for temperature from floor 1 and floor 2 can be compared to see if it is possible to use this parameter for floor detection. Figure 72 shows all the temperature histograms obtained from both floors. The blue bars represent the data obtained from floor 1 and the yellow bars represent the data obtained from floor 2.

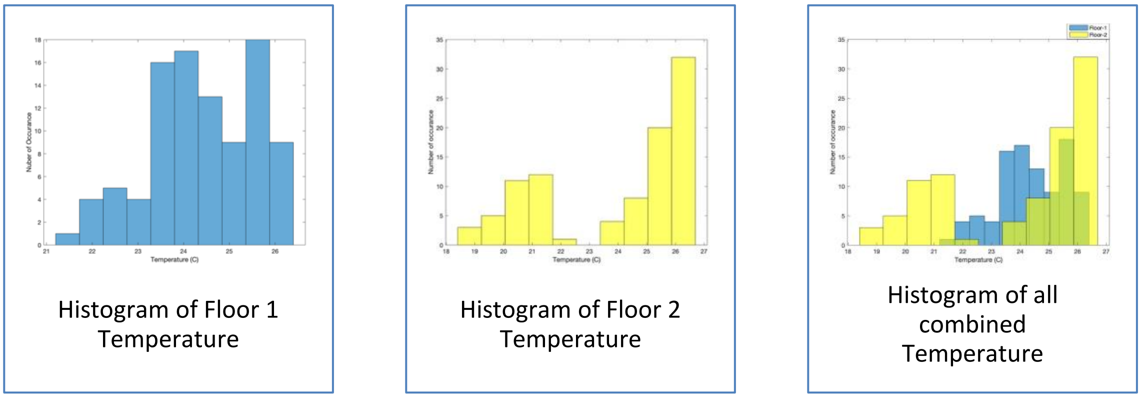


Figure 72. *Comparison between Floor 1 and Floor 2 Temperature Histograms*

Figure 72 shows that some portion of the temperature data might be suitable to differentiate between floor 1 and floor 2. In the combined histogram, some distinct yellow and blue bars are observed along with some overlapping. The distinct data could be useful for floor detection. Also, the lowest temperature value obtained from floor 1 and floor 2 is 20.89 C and 18.4 C respectively. The values between range 18.4-20.89 C obtained only in floor 2, which could be a useful information for floor detection. The overall power map obtained for temperature from floor 1 and floor 2 can be compared in Figure 73.

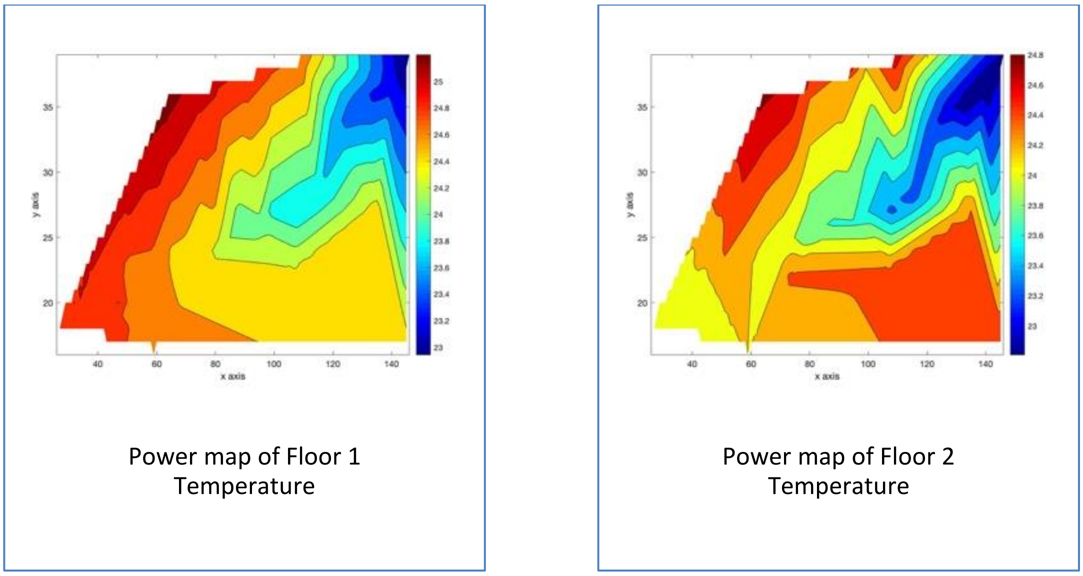


Figure 73. *Comparison between Floor 1 and Floor 2 Temperature Power maps*

Figure 73 does not show any major differences between the power maps of floor 1 and floor 2, which means almost identical temperature values were obtained from both floors. Therefore, only the values between 18.4-20.89 C are suitable for floor detection.

7. CONCLUSION AND FUTURE ASPECTS

The aim of the thesis was to analyze the feasibility of using sensor data for indoor positioning through temperature, humidity, luminance and pressure sensors which are embedded into an IoT development device named 'Thingsee One'. At first, some key applications and challenges regarding Internet of Things were presented in this thesis, with a generic architectural overview and key technologies involved in it. Then literatures studies of some recent researches were described for indoor positioning, using other electro and non-electro-magnetic signals. Most of the studies have showed high accuracy and precisions in positioning. Then a detailed analysis for using sensor data which were captured by Thingsee One device was presented with the aim of developing an indoor positioning system. The measurements were taken from two different floors of a university building. The first challenge in this experiment was separating temperature, humidity, luminance, and pressure data from one file. A Python program was used in order to separate these data from one file and store them into individual files.

Different times and weather conditions were taken into account for the measurements and analysis. The analysis shows that it is not feasible to use environmental parameters for positioning purpose in indoor environment because of the inconsistency of values in different locations. The reason of this inconsistency was the high dependency of these environmental sensors on time and weather. Among all the sensor data, luminance shows better results which can be used for identifying few locations in both floors. Luminance, pressure and temperature data showed some suitable information for floor detection. Another problem which was found during this experiment was, identical values were capturing from different locations which makes it more difficult to identify the position from where it was captured.

However, the number of significant researches and implementation of indoor positioning using these parameters is very limited. Other non-electromagnetical approaches such as visible light, LED, sound, and smell/odour-based positioning are gaining increasing attention because of the high precision and accuracy, but most these approaches are very expensive. Using environmental sensors could possibly reduce the cost and the combination of environmental data, pattern recognition and machine learning algorithms can be used in order to increase positioning accuracy in deficient time which will lead to a stable and effective indoor positioning system.

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APPENDIX A: PYTHON CODE

```
def read_file(file_oj):

    for line in file_oj:
        row = line.rstrip().split(",")
        name = row[5].split(";")[1]
        print(name)
        value = row[7].split(":")[1]
        print(value)

        write_file(name,value)


def write_file(name, value):

    if name == "pressure":
        file_pressure = open("pressure.txt", "a")
        file_pressure.write(str(value) + "\n")
        file_pressure.close()

    elif name == "ambient_light":
        file_ambient_light = open("ambient_light.txt", "a")
        file_ambient_light.write(str(value) + "\n")
        file_ambient_light.close()

    elif name == "temperature":
        file_temperature = open("temperature.txt", "a")
        file_temperature.write(str(value) + "\n")
        file_temperature.close()

    elif name == "humidity":
        file_humidity = open("humidity.txt", "a")
        file_humidity.write(str(value) + "\n")
        file_humidity.close()



def main():

    filename = "CAUSES.LOG"
    file_obj = open(filename,"r")
    read_file(file_obj)


main()
```

APPENDIX B: MATLAB CODE (HISTOGRAM)

```
table = readtable('histo.xlsx');
nbins = 10;

luminance = table.luminance;
humidity = table.humidity;
temperature = table.temperature;
pressure = table.pressure;

figure
h1 = histogram(luminance, nbins);
xlabel('Luminance (lux)');
ylabel('Number of occurrence');

figure
h2 = histogram(humidity, nbins);
xlabel('Humidity (%)');
ylabel('Number of occurrence');

figure
h3 = histogram(temperature, nbins);
xlabel('Temperature (C)');
ylabel('Number of occurrence');

figure
h4 = histogram(pressure, 50);
xlabel('Pressure (hPa)');
ylabel('Number of occurrence');
```

APPENDIX C: MATLAB CODE (POWER MAP)

```
close all
clear all
clc
L = xlsread("measurements.xlsx");

x_map = [min(L(:,1)); max(L(:,1))];
y_map = [min(L(:,2)); max(L(:,2))];
interp_func = TriScatteredInterp(L(:,1),L(:,2),L(:,3));
grid_interval=1;

grid_vec_x = floor((x_map(1)/grid_interval))*grid_interval:grid_in-
terval:floor((x_map(2)/grid_interval))*grid_interval;
    grid_vec_y     =     floor((y_map(1)/grid_interval))*grid_inter-
val:grid_interval:floor((y_map(2)/grid_interval))*grid_interval;


[qx,qy] = meshgrid(grid_vec_x,grid_vec_y);
qz = interp_func(qx,qy);
figure
contourf(qx,qy,qz);
xlabel ('x axis')
ylabel ('y axis')
zlabel('Humidity')
figure
surf(qx,qy,qz);
xlabel ('x axis')
ylabel ('y axis')
hold on; colorbar
    colormap(jet)
```