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MHK70LT

Anti Pääro

Juhtmevaba andurite võrgu kasutamine autoparkla hõivatuse jälgimisel

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Utilization of Wireless Sensor Networks at the Car Parking Lot Occupancy Tracking

MSc thesis

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AUTHOR’S DECLARATION

I declare that I have written this graduation thesis independently.

These materials have not been submitted for any academic degree

.All the works of other authors used in this thesis have been referenced.

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Assignments to be completed and the schedule for their completion:

No.	Description of the assignment	Completion date
1.	Research existing systems, different used sensors and methods Decide on sensors based on this, the basic method of sensing	29.02
2.	Choose the needed wireless components and other electronical components such as controllers, batteries, general idea of the electronical components involved.	11.03
3.	Solve mechanical issues. Decide dimensions, installation and weatherproofing techniques, installation methods. .	20.03
4.	Algorithm for chosen method, basic layout of the wireless network. Installation of test application, programming the controllers, developing the mobile phone application	30.04
5.	Testing of the system, the application, evaluating the performance of the system, finalization of conclusion	15.05

Engineering and economic problems to be solved:

Developing wireless sensor demo system

Providing cost effective solution for existing car parking lot occupancy systems

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Confidentiality requirements and other corporate terms and conditions shall be set out on the reverse side.

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PREFACE

The subject of this thesis was provided by the Department of Mechatronics in Tallinn University of Technology. The aim of the thesis is to create a viable wireless network demo system that shows off the capabilities of the National Instruments WSN series of products. The demo system is to demonstrate the technical aspects of the WSN series while also providing a conceptual model of a solution to a practical problem, which can be solved using wireless sensors.

The chosen practical problem / demo system is a car parking lot occupancy counter/system. Usually car parking lot occupancy systems are incorporated into new parking lots or buildings that have underground parking lots, or they require heavy modifications or high costs in order to add an occupancy system to the parking lot. This is due to the nature of commonly available sensors and system being wired or using gates in conjunction with access control/barrier systems. Therefore using wireless transmitters and sensors can help reduce the cost and improve the availability of occupancy systems.

EESSÕNA

Antud lõputöö teema sain Tallinna Tehnikaülikooli Mehhatroonikainstituudilt. Töö eesmärk on luua juhtmevaba andurite demosüsteem, mis näitab National Instruments'i WSN tooteseeria võimalusi. Disainitud süsteem demonstreerib juhtmevaba andurite süsteemi WSN tehnilisi aspekte ning annab kontseptuaalse mudeli ühele kindlale praktilisele probleemile, mida on võimalik lahendada kasutades juhtmevaba andureid.

Valitud tehniline probleem on autoparkla hõivatuse jälgimine kasutades juhtmevaba andureid. Traditisiooniliselt on parkla hõivatuse jälgimise süsteemid uute parklate, rajatiste või maaaluste parklate uute hoonete osa. Teise variandina lisatakse olemasolevatele parklatele selliseid süsteeme, mis on liiga kulukad või vajavad suuri muudatusi parklale. Seda eelkõige seetõttu et enamus kättesaadavaid andureid ja süsteeme kasutavad kaableid või väravaid koos läbipääsusüsteemidega. Juhtmevabade andurite ja saatjate abil on võimalik neid kulusid kokku hoida ja suurendada parkla hõivatuse jälgimise süsteemide kättesaadavust olemasolevatele parklatele.

LIST OF ABBREVIATIONS

VNI - *Visual Networking Index*, a term used by Cisco Systems to display and forecast global IP traffic

WSN – National Instruments(tm) *Wireless Sensor Network*, the wireless sensor platform used in this thesis

NI – *National Instruments(tm)*, the developer of the WSN platform

IR – *infrared*, light spectrum

mAh – *milliampere-hour*, a measure of capacity for batteries

IDE – *integrated development environment* - software application that provides facilities to computer programmers

GLOSSARY

LabVIEW – Software by National Instruments for modeling and programming

1 INTRODUCTION

1.1 Problem statement

The chosen practical problem is important due to the rapid increase of vehicles and at the same time, the need to increase the efficiency of parking lots meant to cope with this increase. It is an everyday sight in parking lots today, here numerous cars are literally driving in circles trying to locate a vacant parking lot, even though one may not exist. These cars tend to also obstruct cars that are trying to exit the parking lots, thus making the overall movement speed in the parking lot slower.

Conventional parking management and occupancy systems use physical wires and as such, it is very difficult and costly to add those systems to already existing parking lots. It is difficult because typically the cables need to be installed underground which requires the use of heavy machinery to remove the pavement thus removing the ability to use the parking lot while construction is in progress. The other reason preventing the addition of these systems to existing parking lots is the cost. Removing the pavement, installing cables and then reconstructing the surface to the previous state is costly and it just is not cost effective for developers to do it.

One solution for this problem would be to use wireless parking lot occupancy systems. This chapter will go over the nature of wireless system overall and their growing trend in everyday use. Justification by cost of wired versus wireless systems will also be covered.

1.2 Background

As technological advances are made more of these are introduced into every day life, we see more and more devices connected to the Internet. In 2003 the number of devices connected to the Internet was 0.08 devices per people (according to Cisco[x]) and between 2008 and 2009 the number of devices exceeded the human population. This is commonly referred to as "The Internet of Things". In 2015 it was estimated that the number of devices connected to the

Internet exceeded 25 billion, thus bringing the number of connected devices per people up to about 3.47 connected devices per capita. Figure 1 below shows the progression and forecast for the coming years.

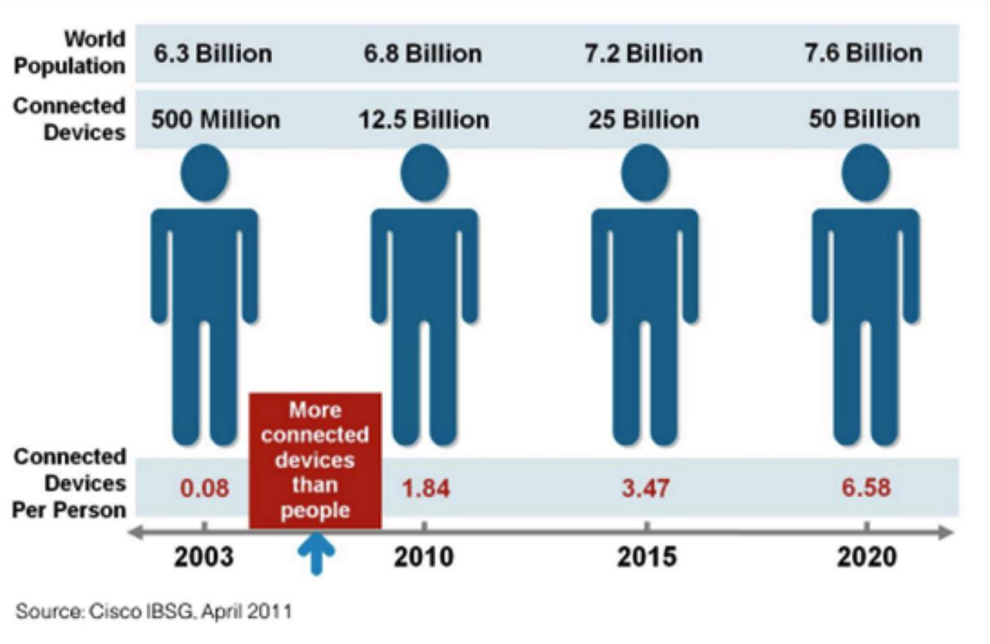


Figure 1. Devices connected to the Internet[1]

This increase in connected devices also means that there is an ever-present need to build new networks, but also provides new methods of transferring data to the end users. There is no longer a need to build dedicated displays since the information can be displayed on devices already connected to the internet. All that needs to be done, is to connect the new network or system to the Internet, and it is already available to the end user using the Internet.

The data traffic of wireless connections is estimated to surpass wired traffic in 2018, according to Cisco VNI[2]. According to different articles and reviews [3], [4] there are several advantages and disadvantages to using wireless networks. The main advantages of wireless networks over the older wired network are displayed in the Table 1 below.

Table 1. Wireless networks versus wired networks

Wireless advantage	**Wireless disadvantage**	**Wired advantage**	**Wired disadvantage**
Less installation time	Devices can't be	Cables are less	More installation

(no cables involved)	placed near electrical noise sources	susceptible to electrical noise	time (each individual computer has to be connected via cables)
Connectivity possible beyond physical boundaries	Lower transmission speeds	Faster transmission speeds	Connectivity possible only to and from physical locations where the physical connections extend to
Excellent mobility, users and devices can move around within covered area	To reach longer distances, more devices are needed, or more expensive ones	Wired connections lose less connection quality less over long distances	Limited, devices need to be connected physically to the network at all times
No need for hubs or switches	Devices typically more expensive	Devices are common and cheaper than wireless	Need for hubs and switches

Even though wired networks are usually cheaper indoors, since the cost of wired switches, hubs, routers and cables are lower[3], cables outdoors are installed in the ground. Installing cables in grounds brings about increased costs, including but not limited to: use of heavy machinery to dig, use of insulated PVC pipes, permits when crossing other infrastructure elements (water supply, drainage, gas lines etc.) and restoration of surfaces (such as pavement). Taking this into account, the cost of wireless networks for outdoor use should be far cheaper. The rough price estimation for the wireless system (compared to wired) used in this work will be included in later chapters.

1.3 Reasons for wireless system

To properly analyse if a wireless system will be more cost effective for use in the practical problem, some parameters are needed. The parameters will be based on an example parking lot and costs for different components and services for the system installation are taken from Estonian websites and construction company price catalogues.

The example parking lot is going to be the TUT inner campus parking as shown in the Figure 1.1 below. The Figure is an extract from the Maa-amet Flash based online map. It allows the measurement of distances fairly accurately and also displays other infrastructure elements such as electrical cables (dark purple), gas lines (light purple) and central heating pipes (dark blue).

Figure 1.1 Satellite image of parking lot

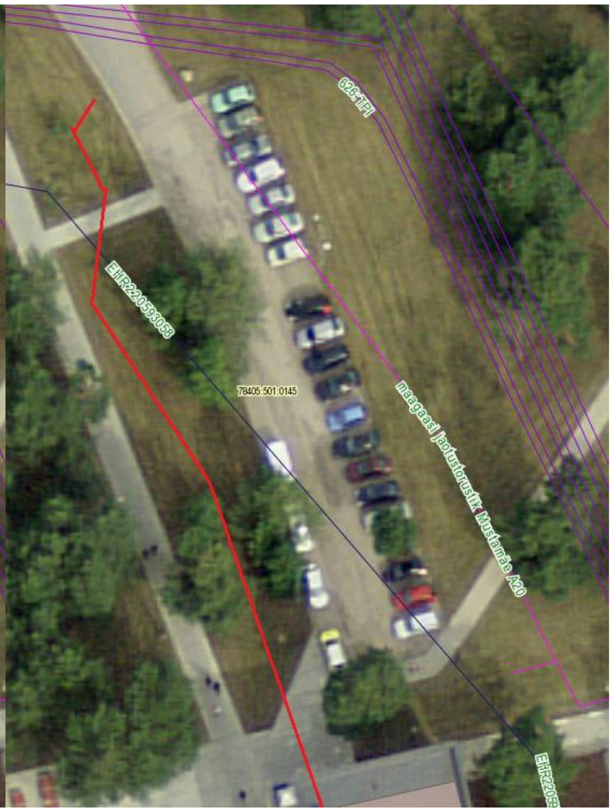


Figure 1.2 Added needed cable in red

This parking lot has a single entrance/exit, so we only need to add one gate to the system. For the conventional system, we need to place an underground cable along the red line as shown in Figure 1.2. The cable will be intersecting a central heating pipe which means that there are additional costs for coordinating with the owner of the pipes. Installing the cable along the other side of the parking lot would incur even most costs as there are more intersecting infrastructure elements. The distance along the path of the cable is roughly 74 meters. This means that the surface will have to be restored in a 74 m^2 area around the cable path, in addition since the cables need to be at least at a depth of 0.8 m and the cable should not be under tension - the total amount of cable needed (not including the indoors) will be around 80 m. We are going to assume that this will have the same price for different surfaces (although placing back tiles is probably more expensive), according to the price of regular grass/greenery restoration price.

Table 1.1 below shows the rough estimation of the cost of different main elements of a wired (conventional) system for a parking lot occupancy system and Table 1.2 an equivalent of wireless systems.

Table 1.1 Parking lot occupancy system cost wired system

Material/service	**Amount**	**Cost**
Controller Unitroncis Vision V230	1	453 €
Parking gate Sommer ASB-6010A	1	928 €
Cable cat5e	80 m	36.32 €
Cable MCMK 3x2,5	80 m	135 €
Cable trench digging	75 m	400 €(1)
Coordination with heat pipe owners (typical price)	1	80 €
Placement of Cable	75 m	380 €
Restoration of surfaces	75	370 €
Rough total		2783.32 €

Note. 1. Estimated work time 8 hours (including backfilling), rent of small machine and workforce

Table 1.2 Parking lot occupancy system cost wireless system

Material/service	**Amount**	**Cost**
Gateway	1	1078 €
Node	1	510 €
Enclosure for node	1	108 €
Rough total		1696 €

Although these are only the rough numbers and prices of the devices can vary a lot over different series and different manufacturers, the price for cable trench digging stays in the same price class. The devices for a wireless system indeed cost a lot more but it also means that there is no need to dig cable trenches or place cables underground. This can have several benefits such as preserving the environment or economically the maintenance of wireless systems is much easier. Based on the information above i conclude that wireless systems justify themselves in cost-effectiveness.

2 ANALYSIS OF EXISTING SYSTEMS

This section covers examples of some existing parking lot occupancy systems, both wired sensor and wireless sensors ones, although mains focus will be on systems similar to the one planned for this research. We will briefly cover the working principles, number of different components and the advantages and disadvantages of such installations.

2.1 Conventional systems

For the purpose of giving an overview of a conventional system, an example of the indoor parking lot in the Solaris shopping centre in Tallinn, Estonia.

The indoor underground parking lot[5] uses a single entrance/exit, with gates for both the incoming and outgoing cars. Cars and vacant spots are counted based on how many pass the gate by acquiring a parking ticket. In addition each parking space has a wired sensor installed in an overhead configuration totalling in 233 sensors. The occupancy status of each parking lot is displayed by a light indicator for quick reference for the incoming drivers in order to find a parking spot quickly. The number of vacant parking spaces is displayed on a display outside the building, seen when approaching the entrance.

This occupancy system is installed along with the building of the parking lot and includes controllers, access control systems and wired sensors. This is a typical system that requires the installation of cables under floors for the access gates and a very large amount of cabling for all the sensors.

2.2 Frogparking[6]

Frogparking is a company that provides complete parking management systems. This includes occupancy and guidance solutions using wireless sensors and minimalistic status displays. The company also markets full management with ticket processing, permits, enforcement application and user mobile phone applications, third party integration and cloud based services.

Considering their outdoor parking lot systems, there are two different wireless sensors, both of which have different mounting methods. The most relevant one to this thesis is the solar-powered wireless sensor used for occupancy detection, shown in Figure 2 below.

Figure 2 Frogparking occupancy sensor[7]

The sensor is designed to be installed directly onto the pavement and uses magnetic, active infrared and optical methods of detection [6]. The sensor is solar-powered and claimed to be working in all environmental conditions (snow, sun, smog, sand). A compiled comparison of the advantages and disadvantages of the sensor are listed in Table 2.

Advantages	**Disadvantages**
Solar powered, green	May become unrealiable if not exposed to sunlight for long periods of time
Small and discreet design	Needs pavement to be installed
Three methods of detection	Operating temperature -20° C to 80°℃, unsuitable for colder climates
Wireless connection, easy installation	

Table 2. Advantages and disadvantages of Frogparking Solar Battery[8]

An example of a typical architecture of the Frogparking system (using outdoor parking lot as an example) is as shown in Figure 3 below.

Figure 3. Frogparking structure[8]

The individual sensors connect to a nearby solar-powered gateway via wireless communication (433MHz, 868MHz, 915MHz depending on region[x]) when there is relevant data to be sent. The gateway in turn is connected to a cloud-based service which receives the data, handles report generation, ticket management and other parking services.

This means that the gateways and sensors can be quite simple and do not require a lot of computing power, thus allowing for less power consumption. The occupancy sensors are GPS located upon installation and connect to the nearest gateway. All the “heavy lifting” of tasks that require high computing power are done server-side.

From the information available at the time of writing this work, it is unclear how the third-party integration works.

2.3 AgilSense parking system[9]

AgilSense Wireless Vehicle detection system is a network of wireless sensors user in outdoor car parking lots [x]. The sensors used by this system use batteries and wireless communication. Similarly to Frogparking they are designed to be installed beneath the parking lot spaces and use Anisotropic Magneto-Resistive (AMR) sensors to detect the presence of vehicles. The typical structure of the system is as shown in Figure 4 below.

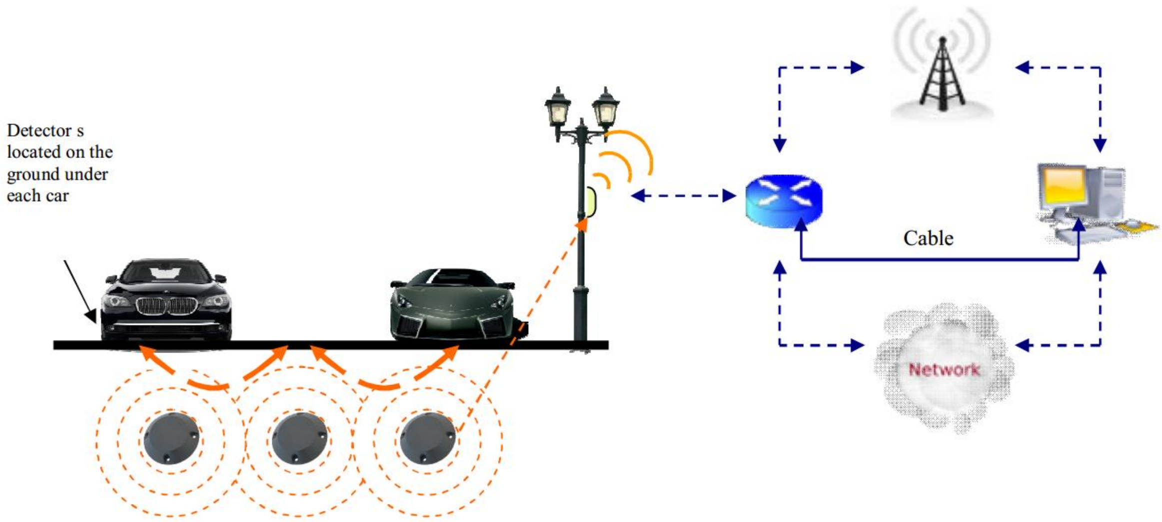


Figure 4. Typical AgilSense wireless network structure.[9]

Each of the ground mounted sensors can communicate with each other from up to 10 m away. At least one of the sensors needs to be connected in the same manner to a cluster controller device, typically mounted to a pole. It is possible to connect up to 120 sensors to each cluster and individual clusters can connect to each other from up to (typically) 200 m away. The clusters receive the data from the sensors. One of these clusters need to be connected wirelessly to a gateway (maximum number of clusters in each system is 31), that relays all the collected data to either a local server or cloud-based server. This server handles all the data and acts as a remote management centre.

Typical applications of this system occupancy detection, parking guidance, car parking lot utilisation monitoring and simple vehicle detection.
The advantage of such a system is the large number of connectable devices, sensor large detection range (over 1 m), ease of installation and long battery life (according to specifications

A compiled comparison of the advantages and disadvantages of the system are listed below in Table 3. Data for the table has been taken from AgilSense Wireless Parking Lot Detection System Technical specifications (see reference 9).

Table 3. Advantages and disadvantages of the AgilSense parking system[9]

Advantages	**Disadvantages**
Long battery life (~5 years)	Needs to be installed into pavement
Large number of possible sensors	Can be expensive for small parking lots because the number of needed clusters, gateways and relays stays the same from 1 to 120 sensors.
Sensors can act to relay data, significantly increasing range	Operating temperature -20° C to 85°℃, unsuitable for colder climates

3 METHODS OF DETECTION

This section covers most widely used methods for detection of large moving objects such as cars. Each subsection covers a method, the pros and cons of each method and the typical application area. The different subscribed methods are then compared and based on the results, a method will be chosen for the purpose of this thesis.

3.1 Video image processing

Video image processing is a method that employs the use of both hardware and software to obtain the required information using an imaging sensor. Usually these imaging sensors are either infrared cameras or regular analogue street and traffic cameras. Depending on the installation, it can also be possible to use pre-existing street camera feeds combined with image processing software to obtain the info.

In most cases, the camera feed is segmented into various zones by the operator, designating different lanes and then special algorithms and software methods are used by the image processor, to obtain information regarding the traffic in the camera's field of view.
Using image processing in such a manner, it is possible to detect:

- existence of a vehicle in the field of view
- number of vehicles (count) during a certain time frame or overall
- velocity of the vehicles
-

An example of application for detecting cars in a parking lot is described in Radovan Fusek paper "AdaBoost for Parking Lot Occupation Detection"[10]. Figure 5 shows their video image processing method in action at a university parking lot.

Figure 5. AdaBoost in action

As can be seen in the figure above, the video feed is segmented into different parking spaces and video image processing is used to determine whether the parking lot space is presently occupied or not. It is clear that this method is accurate in clear weather, optiomal angle and at close range (notice that parking space number 49 is falsely detected as free due to reflections and space number 41 is falsely detected as occupied due to the angle of the image). This method requires there to be a constant power source and being a high resolution camera, it also has significant power consumption.

Based on the information gathered, a table was compiled showing the advantages and disadvantages of the visual processing method, seen in Table 4 below.

Table 4. Main advantages and disadvantages of the visual image processing method[9]

Advantages	**Disadvantages**
Virtually possible (given sufficient resolution) to be applied to every image/video feed, even existing CCTV analogue inputs	Need to overcome detection artefacts caused by shadows, weather and reflections (can be overcome with improved hardware and software algorithms)

Possible to detect vehicle speed, occupancy, count and distance	Can be expensive for small parking lots, since high quality cameras cost a lot (cost per parking space will may be too high)
Can be combined with surveillance, since video feed is already provided	High power consumption
	Need for large bandwidth, constant feed of image

3.2 Ultrasonic

Ultrasonic sensors are two part sensors that act as transceivers. The first part of the sensor emits an ultrasonic sound wave towards a target object and the second part receives this reflected wave. The time it takes for the emitted signal to be reflected and received by the receiver is then converted into an electrical signal that is the sensor's output. Since ultrasonic sound waves travel at the speed of sound, it is possible to calculate the distance to the target object (which reflected the ultrasonic sound wave).

The main advantage of using ultrasonic sound waves for vehicle detection is that sound waves generally reflect very well off hard metal surfaces such as the body of a car. It is unlikely for a car to be made entirely of soft or "foamy" like materials, which could dampen the sound waves.

However, since ultrasonic sound waves are essentially sound waves means that the sensor's receiver part can also pick up random background noise and sounds, especially if they sounds are sudden. These are usually compensated by using various filters and algorithms to overcome the "background noise". An example of such a filter is the Discrete Extended Kalman Filter[13].

The main disadvantage is the constant power consumption of the sensor, because it needs to constantly emit ultrasonic sound waves in order to get a reflected signal. This makes it more difficult to be applied in a remote or battery-powered application.

An example of ultrasonic sensors being used for car detection in wireless network sensor systems has been analysed in the Youngtae Jo and Inbum Jung paper “Analysis of Vehicle Detection with WSN-Based Ultrasonic sensors” [12].

The paper[12] proposes methodologies to reduce computational complexity and reduce power consumption while maintaining optimal vehicle detection rate.

Table 5 below shows the summarized advantages and disadvantages of the ultrasonic sensor detection method.

Table 5. Main advantages and disadvantages of the ultrasonic detection method.

Advantages	**Disadvantages**
Not dependant on surface colour or reflectivity	High power consumption (can be improved with different methodologies[12])
Can detect distance to object, meaning it is possible to detect on which lane the car is on	Limited sensing range (most commercially available products up to 4 m), limiting the use on >2 lane roads
Fairly immune to background noise when applying filters[13]	Can be affected greatly by weather (changes in temperature or humidity for example)
Suitable for detecting large metal objects such as cars	Ultrasonic sensors have a minimum detection distance

3.3 Optical (infrared)

Optical sensors are the type that use both visible light and invisible (to the human eye) light. This chapter focuses specifically on infrared light, which is outside the visible spectrum of the human eye. This is because we do not wish for the detection signal to be visible as it may disturb the drivers. Furthermore, we will be covering both active and passive infrared sensors.

3.3.1 Passive infrared

Every object with a temperature above absolute zero emits a heat signal in the form of radiation emission. This is outside the visible spectrum, usually at infrared wavelengths and cannot be seen by the naked human eye. Passive infrared sensors rely solely on this infrared radiation of the heat signal and do not emit an energy signal of their own. This means that they have a low power consumption and no visible signs of detecting. Because of this, they are often used in PIR motion detectors such as for burglar alarms or outdoors lights.

Whenever an object that has a higher emitted infrared signal (meaning it's warmer) than the background in the sensor's field of view, passes the detection area of the sensors, it triggers and output. As such, this can possibly be used to also detect moving cars, because they generally have a higher temperature compared to the background.

However, because passive infrared sensors detect anything with a higher temperature, they will detect humans, animals, birds and other targets that have a higher than ambient temperature.

Because of this, passive infrared sensors for vehicle detection are mostly used in locations where movement is restricted to vehicles only, such as parking lots with separate entrance and exit lanes for vehicles, on highways and other vehicle exclusive areas. In such applications, they are usually used in overhead configuration, further reducing the chance of false detection.

The typical detection range and corresponding output signal of a PIR motion sensor is shown below in Figure 6.

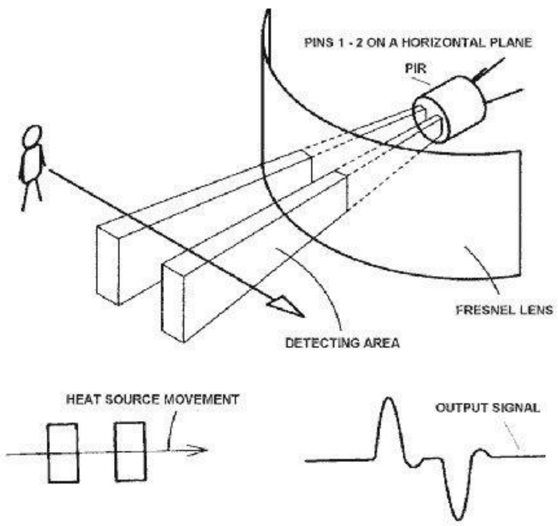


Figure 6. A typical PIR motion sensor detection area[14]

As the heat source (in this case depicted as a human) moves across there detecting area of the PIR motion sensor, the sensor gives an output signal depending on which sector the movement was detected in. When the heat source is on the right (as viewed from the sensor), the output is a positive voltage signal and when the heat source is on the left, the output is a negative voltage signal. This could also be incorporated into a vehicle detection application where there are no exclusive lanes (or they are hard to determine) for cars moving in different directions. Theoretically it will be possible to determine the movement direction of the vehicle.

The disadvantages of a PIR sensor is that it can be susceptible to weather (heavy reflections in case of a very bright and sunny day) or bright lights within the detection area. These can be overcome with better hardware or sophisticated software algorithms.

The advantage however, is that they can be used independently of the time of day - even at night without light sources (at night the signals are likely to be even clearer because the background and target temperatures differ more).

The summarized advantages and disadvantages of passive infrared detection method for vehicle detection are listed below in Table 6.

Table 6. Main advantages and disadvantages of the passive infrared detection method.

Advantages	**Disadvantages**
Can be used at day and night times	Can be susceptible to weather and bright sources of light
Low power consumption because it does not emit signals for detection	Limited practical maximum sensing range
	Detection of all objects with a temperature differing from background temperature, not just vehicles

3.3.2 Active infrared

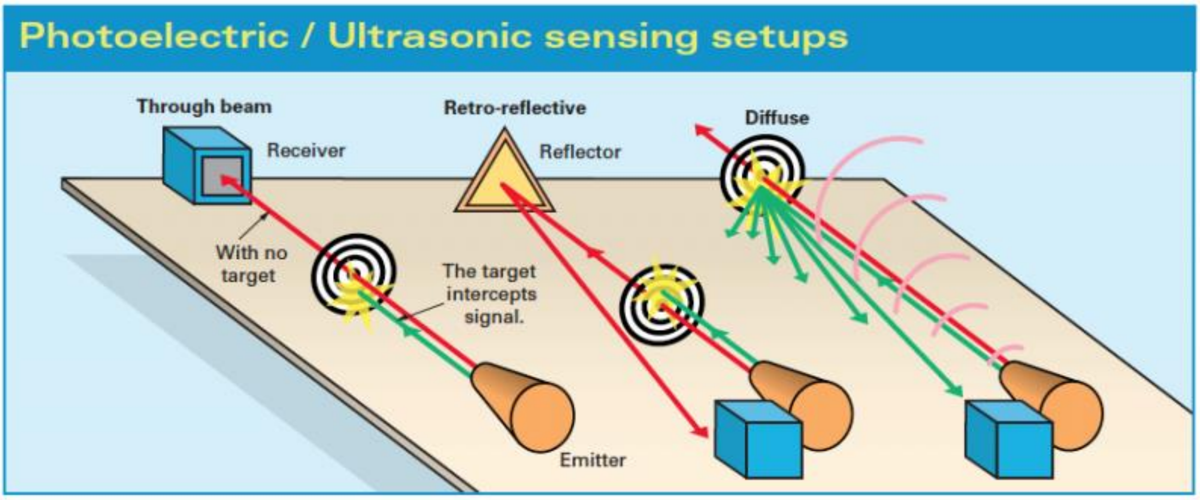
Active infrared sensors are similar to passive infrared sensors, but instead of relying on the radiation emission of the target object, they emit an infrared signal of their own. Depending on the type of setup, this signal is either sent to a receiver - forming a **through beam** sensor, sent to a mirror or reflector - making it a **retro-reflective** sensor or reflected off the surface of the object back to the sensor - making it a **diffuse-reflective** sensor.

In case of a through-beam sensor, if an object is between the emitter and receiver, the signal gets interrupted and thus, an object has been detected.

In case of a retro-reflective sensor, if an object is between the emitter and receiver, the reflected signal from the emitter to the receiver (typically a photodiode next to the receiver) is interrupted, an object has been detected.

In diffuse-reflective setups, the signal is reflect off the surface of the object back to the sensor to a photodiode. If the signal gets reflected, there is an object in the detection area, if it does not - it means that there is nothing there.

The three types of sensor and setups are illustrated in Figure 7.



Lasers or sound waves serve as the signal in three setups. In through beam and retro-reflective, the signal shoots from the emitter to receiver until the target cuts it off. In diffuse sensing, the signal diverges until a target moves in and reflects some back to the receiver.

Figure 7. Different photoelectric optical sensor setups [15]

The simplest is the **diffuse-reflective** setup, using a sensor only at the location of the emitter. In theory the reflected light will be received by the receiver and there should be no reason to use anything on the other end, but in practical purposes using this kind of diffuse reflection can be tricky, because objects (suchs as cars) do not have a uniform shape or colour, meaning that the emitted signal may not be reflected to the photodiode or it could be absorbed.
Also, the further a light wave travels, the less energy there is to reflect back. This directly translates to less maximum sensing range for this method, unless the object is a mirror perpendicular to the emitter.

Retro-reflective sensor setups include a reflector behind the detection area, but this reflector does not have to be powered, therefore no cabling to it is not required and can be easily installed. This allows for better accuracy and greatly increased maximum sensing range.

Through beam sensor setups take this a step further and include a received behind the detection area that actively outputs the state of the detection area. It does need to be powered, but makes for the most reliable sensing method because even if background noise or other signals are introduced to the receiver, it will only output a signal if it does not receive the corresponding modulated signal from the emitter. Because this takes more powered components, it is also the most power consuming and is not efficient for use in wireless applications.

The relevant advantages and disadvantages of these three different sensor setups are summarized in Table 7 below.

Table 7. Main advantages and disadvantages of the photoelectric optical detection methods.

	Advantages	**Disadvantages**
Diffuse-reflective	Simple setup, does not require receiver or reflector at the other end	Detection accuracy is dependent on colour and shape of the target object
		Limited practical maximum sensing range, up to 4 m
		Susceptible to background noise
		Strongly susceptible to weather, because it alters the reflective properties of the target object
Retro-reflective	Sensing range up to 10 m	Requires a reflector on the other end of the detection area
	Modulated output, detects only emitted signal	
Through-beam	Modulated output, detects only emitted signal	Requires a powered receiver on the other end, increased power consumption

3.4 Acoustic

Acoustic sensors essentially act as microphones which detect any sound waves. Depending on the type of sensor, these can have either a discrete (ON/OFF) or analogue (4...20 mA) output.

Discrete acoustic sensors give an active output when a sound source near the sensor generates a sound wave with a decibel value above a certain threshold. Analogue acoustic sensors output a continuous analogue signal depending on the received sound waves.

Although rarely employed for vehicle detection, acoustic sensors have certain advantages that can be employed together with another type of detection method. The advantages an disadvantages are listed in Table 8 below.

Table 8. Main advantages and disadvantages of the acoustic detection method.

Advantages	**Disadvantages**
Fairly independent on weather conditions at close range	Unable to detect movement direction with a single sensor
Low power consumption	Limited practical sensing range
Moving vehicle sounds are easily distinguishable from background noise	Unable to discern distance
	Susceptible to sudden loud sound bursts such as sirens, alarms etc.

3.5 Chosen method

In order to choose the most suitable detection method for the demo system, some criteria has to be established. For this, the following of properties will be reviewed.

Power consumption

In wireless sensor networks it is very important to keep the power consumption to a minimum, while still maintaining optimal detection accuracy. While compromises cannot be made in the main functionality of the system, everything unnecessary should be discarded.

Installation complexity

The reason why wireless sensor networks are attractive is due to the low number of components and that there are physical connections required between the devices. The installation simplicity should not increase or should increase minimally with the chosen method. Otherwise, the use of a wireless sensor network is not justified.

Sensing range

The sensing range has to meet the standard two-lane (one in each direction) entrace/exit road of a parking lot. This means that the practical sensing range should be at least 5 meters - 4 meters for the roadway and 0,5 m for typical clearance from the side of the road. Since the maximum sensing range is usually in lab-like ideal conditions, a sensing range of at least 6 meters ill be used as the criteria.

Table 9. Comparison of detection methods

	Power consumption	**Installation complexity**	**Sensing range (practical)** (3)
Video image processing	Very high	Moderate	- (1)
Ultrasonic	Moderate	Simple	2 m
Passive IR	Low	Simple	5 m
Through-beam IR	High	High	> 10 m
Diffuse-reflective IR	Moderate	Low	4 m
Retro-reflective IR	Moderate	Moderate	10 m
Acoustic	Very low	Low	- (2)

Notes: 1 The sensing range of the video image processing method depends on the resolution and quality of the video/image feed provided to it

2 The sensing range of an acoustic sensor depends on the sound source

3 Sensing ranges have been taken from products available in the Farnell [18] product catalogue.

Considering the criteria established for the demo system, the initial chosen method is retro-reflective infrared detection method. In order to further cut down the power consumption, acoustic sensing will also be used in order to wake up the sensor. This means that the retro-reflective sensor will only be active if there is an output from the acoustic sensor (if there is a moving car approaching the entrance/exit of the parking lot). This should allow cutting down the power consumption of the sensor by a significant amount.

4 WIRELESS NETWORK SENSOR

4.1 National Instruments WSN

National instruments WSN[19] is a wireless sensor network platform that comes complete with battery-powered nodes with industrial certifications. It's intended use is in a variety applications for measuring and monitoring. According to National Instruments it provides the same quality and accuracy as traditional wired measurement systems, but since it is a wireless system it also provides additional flexibility, lower costs and the ability to create smart WSN systems with National Instruments LabVIEW software[20]. Wireless sensor systems in overall provide solutions for remote applications where using wired systems is impractical or infeasible. The main advantages of WSN (according to NI[21]) are listed below:

1) **Measurement quality** - The WSN platform provides multiple types of high-quality measurements, from single-point to waveform, all within a single system.

2) **Rugged embedded hardware** - The NI WSN devices are designed to be used in harsh conditions, both indoor and outdoor, with a wide range of working temperature, relatively high shock rating (50 g) and different certifications for international safety, electromagnetic capability and environment.

3) **Node programmability** - The WSN nodes (and gateway) can be programmed with LabVIEW in a graphical environment, without the real need for embedded programming skills.

4) **Flexbility** - WSN allows to bring measurement or control with the use of nodes to hard to reach places and also since there is no wired need to wire back to the gateway, the nodes can easily be moved to new areas or reprogrammed to suit new needs if the requirements of the user change.

5) **Cost savings** - Since WSN is a wireless system it does not need to have wired infrastructure and as such eliminates the need to do cabling work, saving on both install costs, material costs and also install time.

The typical architectures of a NI WSN system is as shown in Figure 8 below.

Figure 8. WSN network architectures[22].

In essence, the various WSN End nodes are connected wirelessly to a gateway (or possibly several). The data from the gateway can then be viewed using a computer with LabVIEW or LabVIEW Real-Time [23] software. The programming of the different nodes and gateways is done using NI software. Since the nodes are also programmable, it is possible to set up different calculations to be done node-side and only send data over the wireless network when there is adequate. This helps conserve battery levels and thus reduce maintenance costs.

4.2 Stucture

The structure used in the demo system is relatively simple, using a wireless gateway and a single node with analogue inputs. The wireless gateway is for the main data management and display. Most of the computational power is focused on the gateway in order to prevent unnecessary power consumption for the node. Since the gateway will be located indoors and it will have a dedicated power supply, this is the ideal solution.

The node and sensors will have a dedicated battery, in addition the node will have batteries installed as a backup option. This will allow the node to notify the system of the status of the battery.

For data storage a MySQL database will be used because it is universal and allows display of the information on virtually any medium. The data storage is further discussed in chapter 6.

The structure of the system is shown on Figure 9.

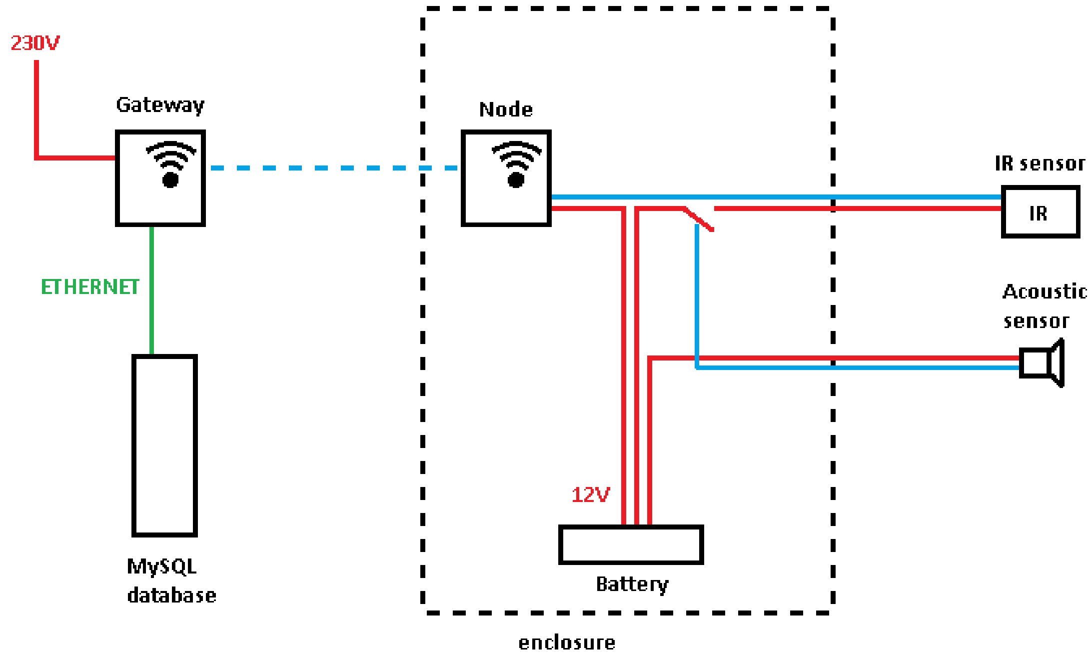


Figure 9. Structure of the wireless sensor network

The gateway is located indoors near the parking lot and has a dedicated power supply of 230VAC. In addition it is connected to the server running the MySQL database using a standard TCP/IP connection. This server can either be in the local network or in a remote cloud based server.

The node will be located near the parking lot entrance/exit in a weather-proof enclosure. In the case of multiple entrances or exists to the parking lot, each one will need it's own node, unless they are located in close proximity. The communicates with the gateway wirelessly, eliminating the need for cabling between the two devices.

The sensors will be located outside the enclosure, or if possible, in the case of the enclosure.

Both the node and the sensors will be powered by a battery that is located inside the enclosure.

4.3 Components

This section will focus on specific products or specific parameters for the electronic components in the structure. This will roughly determine the size of the node enclosure.

4.3.1 Gateway

The chosen gateway from NI WSN products is NI WSN-9792 Real-Time Gateway. This is a programmable gateway version with an Ethernet RJ45 port in addition to wireless capabilities. The main processing and logging with MySQL will be handled by this device. Illustration of the device can be seen in Figure 10 below.

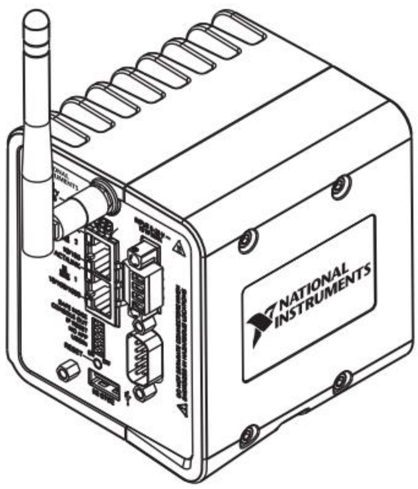


Figure 10. NI WSN 9792

4.3.2 Node

The selected node from NI WSN products is an analogue input and digital output node NI WSN-3202. Using analogue inputs increases the number of sensors that can be used for this application. This also enables the monitoring of the 12 V battery if necessary and the analogue inputs can also as digital inputs to a certain extent. The digital outputs allow the installation of other ON/OFF type devices if they are needed (perspective aspect).
Figure 11 below shows the dimensions of the node that are relevant for this work.

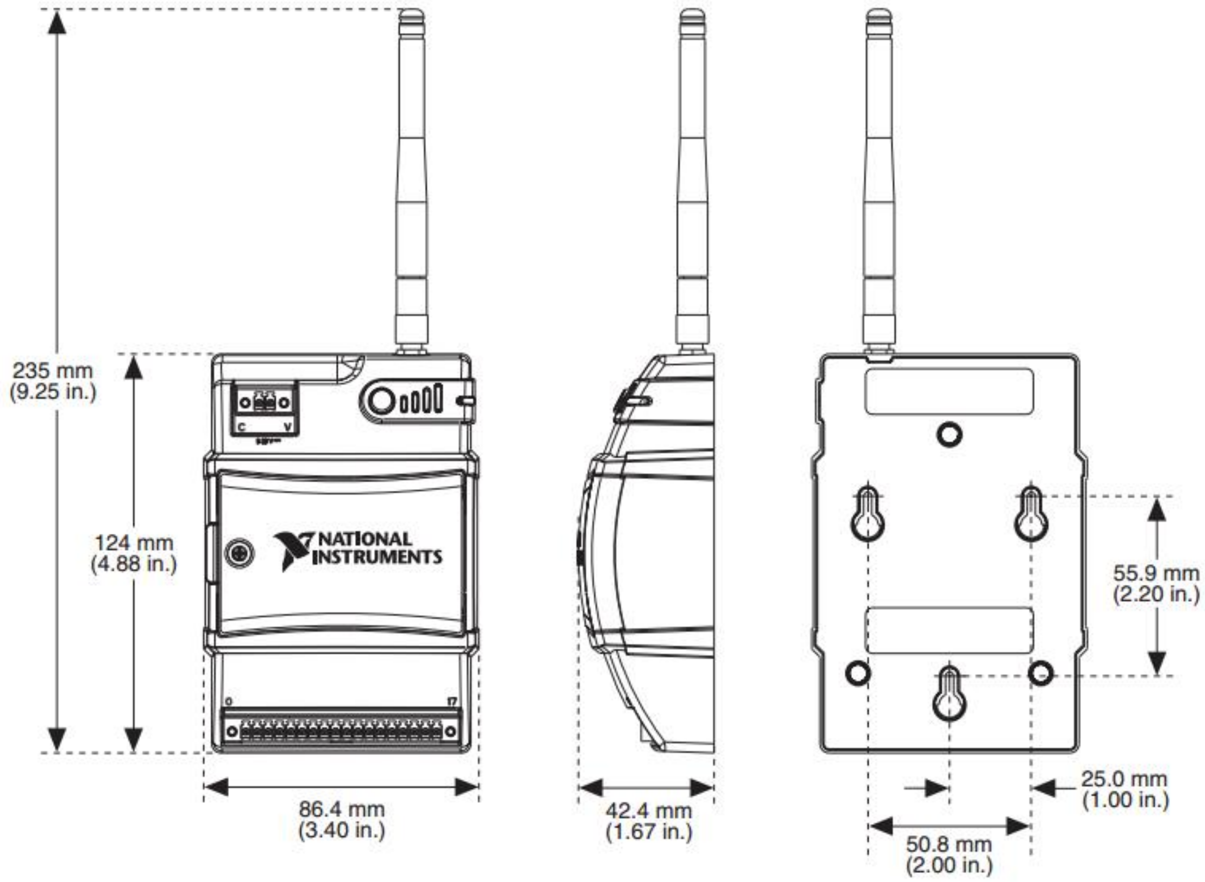


Figure 11 NI WSN-3202 dimensions

4.3.3 Infrared Sensors

In order to properly design a sensor bracket, a fixed size for the sensors need to be decided on. Most industrial grade optical sensors are in either cubic or cylindrical cases. For simplicity and due to dimension considerations, the sensor casing we will be using is cylindrical with outer threading. Although this significantly narrows the number of suitable sensors, there are still enough for the demo system.

The criteria for the optical sensor :

Sensing distance :	> 5 m
Sensing type:	Retro reflective
Rated operational voltage:	12 V
Light type:	infrared, >800 nm wavelength

Using Elfa Distrelec website's [24] search function, there are several sensors available. The chosen sensor is Carlo Gavazzi PA18CAR65PASA[25]. This is a retro-reflective sensor in a plastic casing with an M18 outside thread. Since this M18 outside thread is not unique, the sensor bracket will be designed around this type of sensors. The technical information and dimensions of the chosen sensor are shown in Figure 12 below.

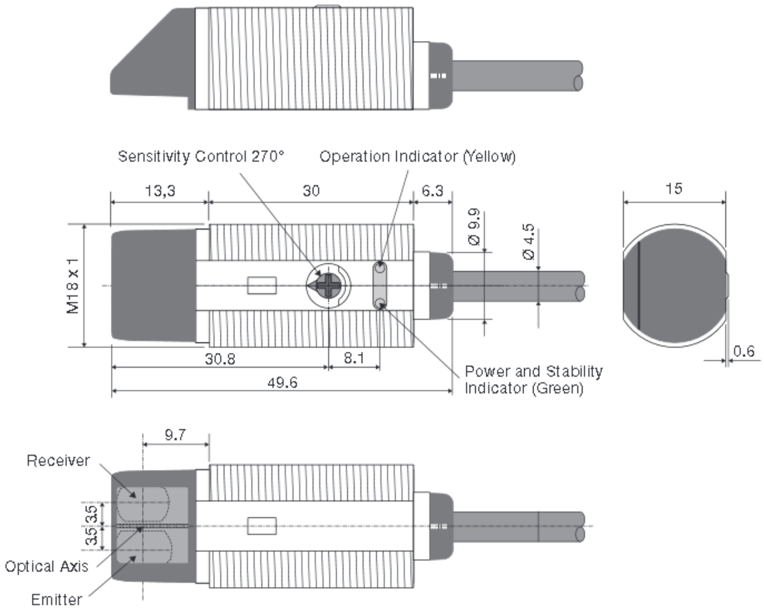


Figure 12. Industrial sensor PA18CAR65PASA[25]

4.3.4 Battery

Batteries are rather generic components but vary greatly in size. Since the width of the node is fixed, the enclosure width will be selected as the next (after node width) appropriate standard width of enclosures. Therefore, the battery length also needs to fit in this size. In turn, the width of the battery will determine the depth of the enclosure.

In order to properly choose a battery, criteria for capacity is important.
For our demo system, we want for the system to be able to run at least 2 months without the need for recharging.

The power consumption of the different main elements are:
Node (on standby): 5 mA
IR sensor (standby) 5 mA

IR sensor (active)	40 mA

Assuming the sensors are active 5 % of the time, over the course of 2 months, this is 2880 mAh consumption. The node and IR idle sensor comes to 7200 mAh.
This means that our battery has to be at least 10 080 mAh of 10 Ah capacity. The next size available is 20 Ah, so that is what we are going to be using as a baseline.

One appropriate battery with decent parameters is a Kingston PS20-12. It has a capacity of 20 Ah and the dimensions are 181x77x167 mm.

4.4 Schematic

Full electrical schematic of the designed electronical system, based on the chosen components and structure is shown in Appendix A 1.

5 MECHANICAL ASPECTS

5.1 Principle

In principle, the enclosure for the node an battery will be located as near as possible to the parking lot entrance/exit. Considering parking lots and roadways in general, inside settlements they are required by regulations to meet certain lighting requirements. Because of this, it is almost guaranteed that parking lot entrances and exists have lighting masts next to them.
For the enclosure fixtures, we are going to assume that there are indeed lighting masts available and that the enclosures will be installed on them.

The infrared sensor will also be attached to the lighting mast, but at a much lower height (so as to detect vehicles). The reflector will always be placed opposite of the roadway, at the same height as the sensor. This is going to be achieved using either wall connections where available or with a simple post that needs to be driven to the ground.

5.2 Enclosure

Considering all the information beforehand, we can determine the minimum size of the enclosure needed for our application.

The summary of the dimensions and enclosure are as shown below in Figure 12.2

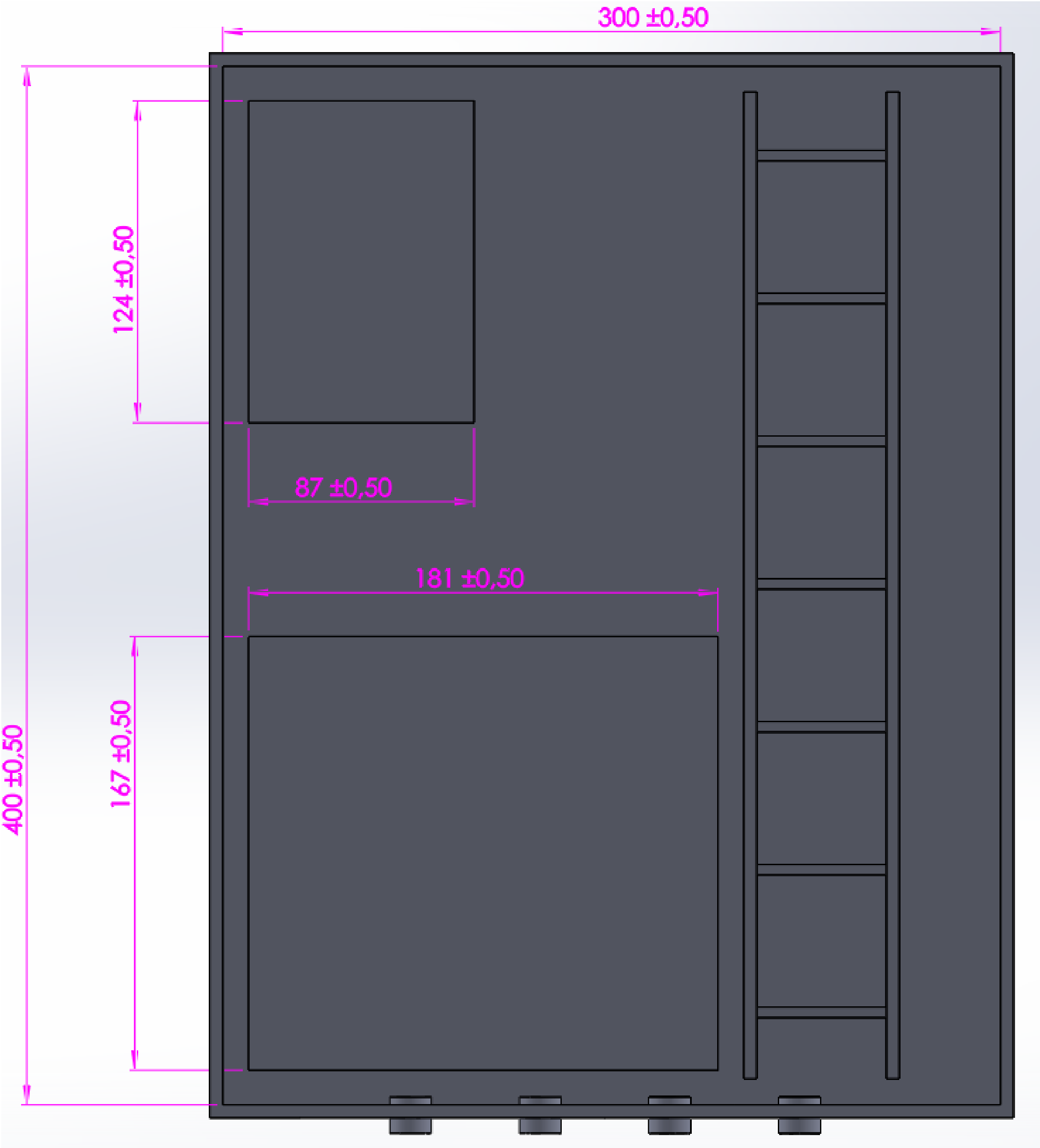


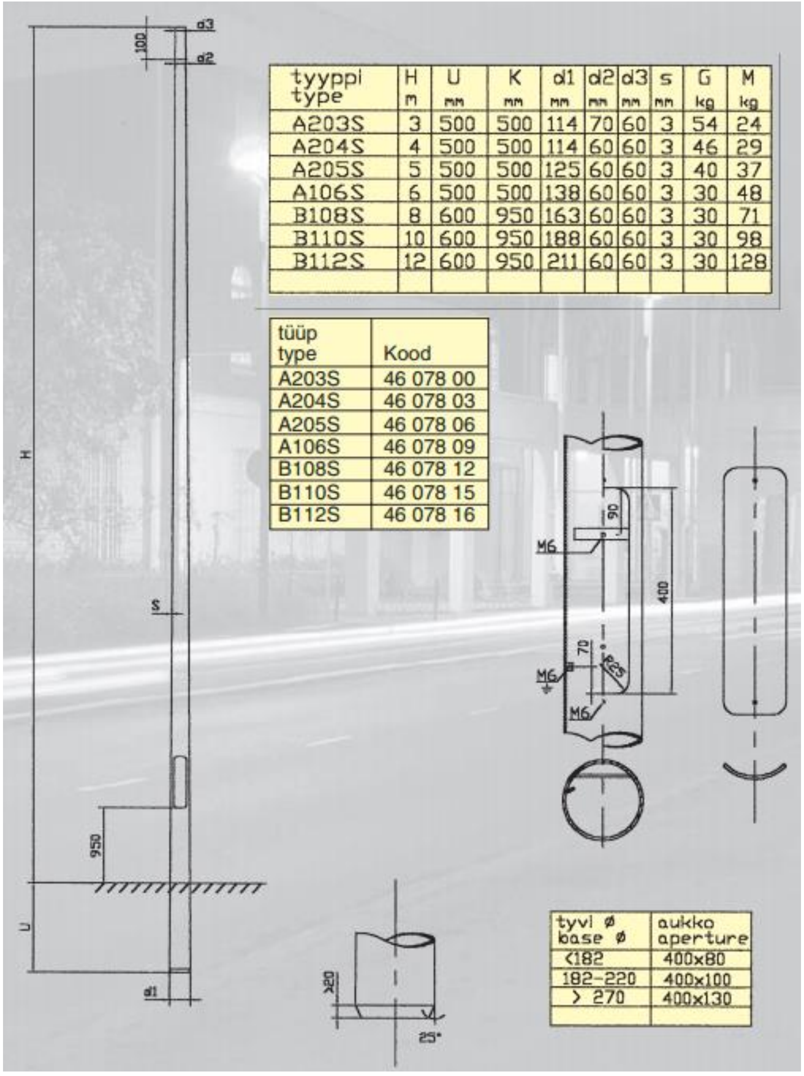
Figure 12.2 Enclosure with dimensions for battery and node

Since the enclosure size was chosen from standard sizes, the most fitting enclosure size is 300x400x200 (width, height, depth). The size smaller is too tight of a fit since there is also cabling required. In addition the above Figure 12.2 shows a cable rail installed on the right hand size. In accordance with good practice, enclosures should have 40% of free space after cabling, which this enclosure meets

The model 3D view is shown in Appendix A 2.

5.3 Sensor bracket

The sensor bracket is designed with the selected (chapter 4.3.3) sensors in mind. The lighting masts that it needs to fit for, are standard sizes and it has to be variable in size. Lighting mast information is taken from Elektroskandia product catalogue[26]. An excerpt from the product catalogue is shown in Figure 13 below.



tyyppi type	H m	U mm	K mm	d1 mm	d2 mm	d3 mm	s mm	G kg	M kg
A203S	3	500	500	114	70	60	3	54	24
A204S	4	500	500	114	60	60	3	46	29
A205S	5	500	500	125	60	60	3	40	37
A106S	6	500	500	138	60	60	3	30	48
B108S	8	600	950	163	60	60	3	30	71
B110S	10	600	950	188	60	60	3	30	98
B112S	12	600	950	211	60	60	3	30	128

tüüp type	Kood
A203S	46 078 00
A204S	46 078 03
A205S	46 078 06
A106S	46 078 09
B108S	46 078 12
B110S	46 078 15
B112S	46 078 16

tyvi ø base ø	aukko aperture
<182	400x80
182-220	400x100
> 270	400x130

Figure 13. Standard conical mast[26]

Figure 13 shows a standard conical mast. The diameter sizes of the base and tip for other masts are similar to the ones used on this mast. As we can see in the figure, the tip has a diameter of 60-70 mm. The base diameter varies from 114-211 mm. Most lighting masts for parking lots are 6 m in height, sometimes 8 m. Considering this, we are going to assume that the base diameter is 163 mm and the tip diameter is 60 mm.

This means that the diameter of the mast in it's entire length (including below ground length) changes from 60 to 163 mm. Because obviously the sensors will not be located underground or at the tip, further deductions are necessary. Considering that the average height of a car from ground to bottom of car wind shields is 1380 mm [27], the sensors need to be located below that value to ensure best possible detection. Figure 13 above shows that lighting mast connector plates are located at a height of 950 mm, so the sensor bracket should be fixed at a height of around 800-900 mm. Using simple deductions and assuming a linear relation we can determine that the at around a height of 900 mm, the diameter of the mast is around 140 mm. Considering the diameters mentioned above for both 6 m and 8 m masts, the bracket will need to be adjustable between Ø130-150 mm.

The designed bracket is shown below in Figure 14.

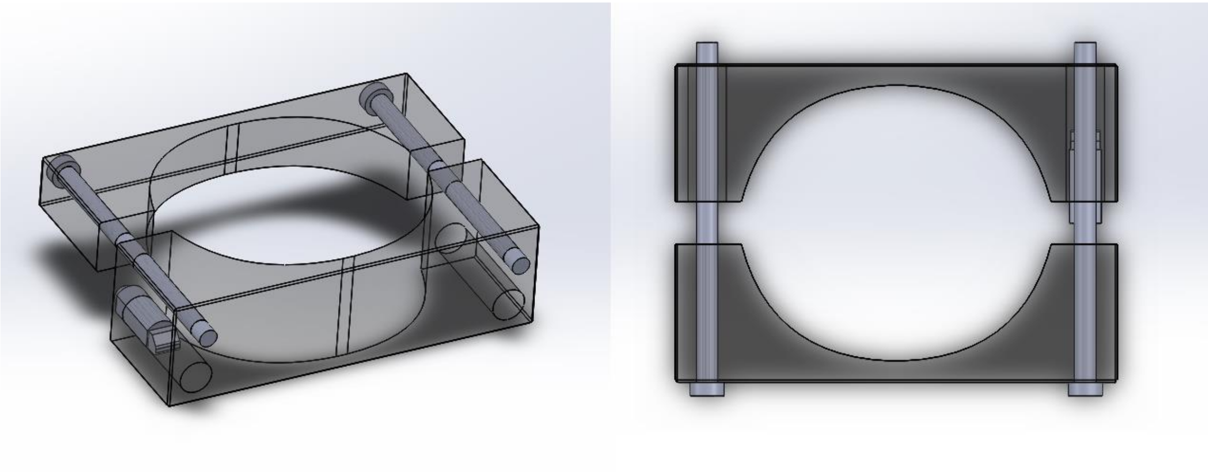


Figure 14. Bracket designed for Ø130-150 mm, for 6-8 m masts.

The adjustable feature comes from the elliptic shape of the bracket's inner area. The IR sensors will be inserted into threaded M18 holes in the lower part of the bracket, facing the roadway. Note that the sensor tip is not left out of the bracket, this is to decrease the chance of reflected beams from objects other than the intended reflector.

Technical drawings and adjustable feature proof are shown in Appendix A 3.

Since these industrial IR sensors have an IP-code of IP67, there is no need to consider separate enclosures and will be enough for the demo system.

5.4 IP-code

It is important that both the enclosure and all the devices that will be located outside are weather-proof. For both enclosures and devices, this is determined by their IP-code.

IP-code or International Protection Marking is a standard that classifies how protected a device has to be to intrusion of solid objects, water, dust or accidental contact[28]. The IP code is marked by IP and 2 digits. The two digits signify the protection degree - the first digit indicates the protection against solid foreign objects (such as dust or hand contact) to the objects hazardous parts and the second digit indicates the protection against liquids.

As an example, the most common IP-code value for indoor bathroom sockets is IP44. According to the standard, this means that the socket is protected against foreign objects over 1 mm in diameter and against splashing water against the enclosure regardless of it's direction.

First digit

Since the enclosure and sensors will be located outside, it is important that they are protected against both common and uncommon weather situations possible in the climate. The first digit shows the protection against dust or solid foreign objects. Assuming the weather is very dry and windy, dust particles can easily be flown from the roadway to the height of the enclosure of sensors. As such, the IP value should be at least 5, which means that the enclosure and devices are protected against dust to a certain amount, meaning that dust will not be completely blocked off, but certainly to an amount where the device would stop functioning. The code value 6 is practically airtight and is hard to achieve without using a special kind of enclosure, which astronomically increases the price of the system as a whole.

Second digit

The common weather situations occurring in a regular outdoors roadside environment is first of all rain, and secondly, splashing from cars on a wet day. Even though the speed is usually limited in parking lots and the enclosure is located fairly high, it is reasonable to assume that this can indeed still happen, even if it is uncommon. As such, the IP value of the second digit should be 4 - this means that the enclosure and devices will be protected against splashing from any direction. Rain in it's nature is dripping water or in case of a storm, it could also be splashing water, so the value 4 protects against both factors.

The overall chosen IP-code or IP class value is IP54.

6 DETECTION AND DATA MANAGEMENT

This chapter focuses on the application of the chosen detection method, acquisition of relevant data from the sensors, processing of that data in the gateway and storage into the database.

6.1 Detection principle

For the detection itself, two infrared retro-reflective sensors are used. The sensors are intended to be placed near the entrance or exit of a parking lot and mounted into the sensor bracket (described in chapter 5.3).

The two sensors when used together, are used to both detect the presence of a car in the roadway and to detect their moving direction. The principle is shown below in Figure 15.

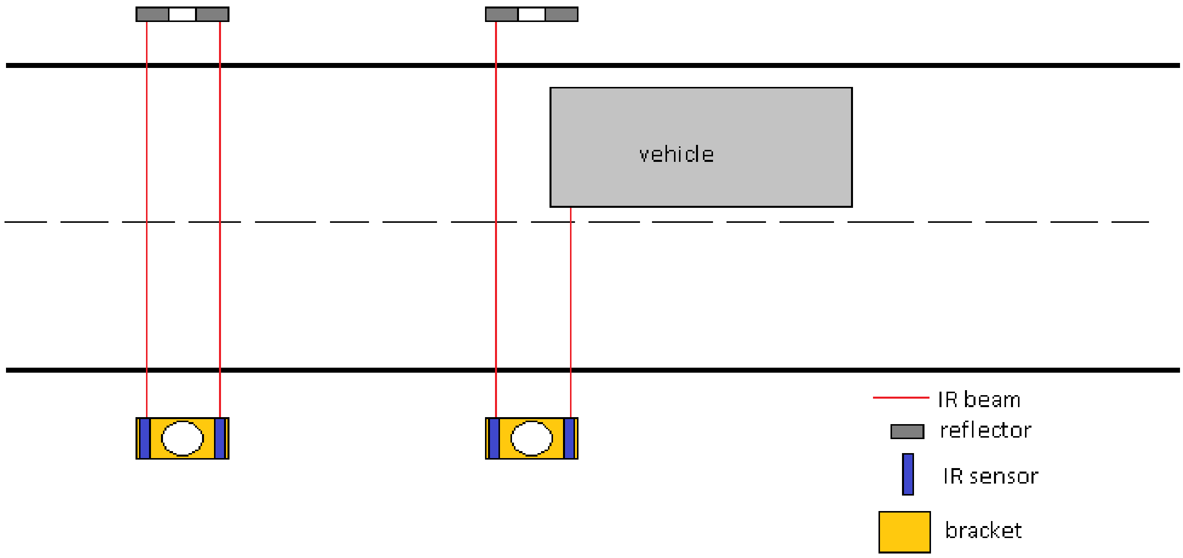


Figure 15. Detection principle.

In Figure 15, on the left we can see the normal condition, when no cars are in the detection area. In this case, the IR beams are unobstructed and are reflected back to the sensor.

On the right, is the case when a vehicle is moving from right to left in the sensor's perspective. This causes one of the sensor beams to be obstructed, while the other is not yet obstructed. Through this, we can determine that the car is approaching the sensor from the right. When the vehicle also hits the other IR beam (within a certain time frame) and the first IR beam is still obstructed we assume that a car is passing by the sensor. In addition, both of these sensor beams have to be obstructed for a certain amount of time. This provides the system with some degree of immunity against pedestrians unless someone is intentionally trying to mess with the system.

Furthermore, in order to decrease the power consumption, both of the IR sensors are switched off (no beam emitted) while there are no moving cars present in the vicinity. This is achieved by using an acoustic sensor (essentially a microphone) to only turn on the IR sensors when a sufficiently loud input is received from the acoustic sensor.

Ideally, the system should behave as shown in the Figure 16 below.

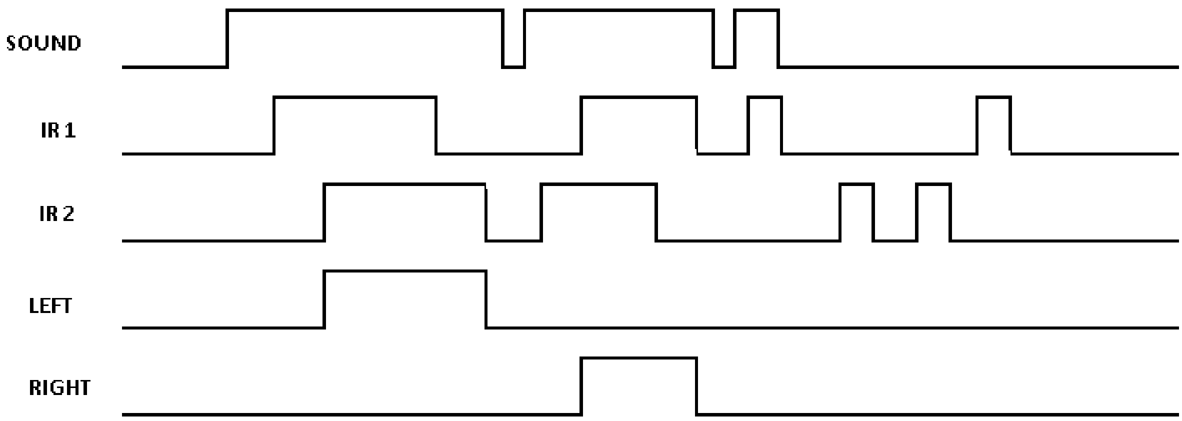


Figure 16. Ideal system behaviour

Explanation of figure 16:

1) IR beams only work when there is input in sound available

2) Sound input makes the IR beams active for a period after the sound input has ended.

3) Cars are detected based on moving direction (the sequence in which the IR sensors receive an input)

4) Both IR sensors have to receive a signal for a vehicle or object to he detected

Additionally, the impulses which should be sent to the gateway should be direction (left/right) falling edge triggered. This is because it is the point where the system has “reset” and a new vehicle can be detected again.

6.2 Algorithm

The algorithm used for the detection of vehicles is straightforward and illustrated in the Figure 17 below (Algorithm in full size can be seen in Appendix A 4).

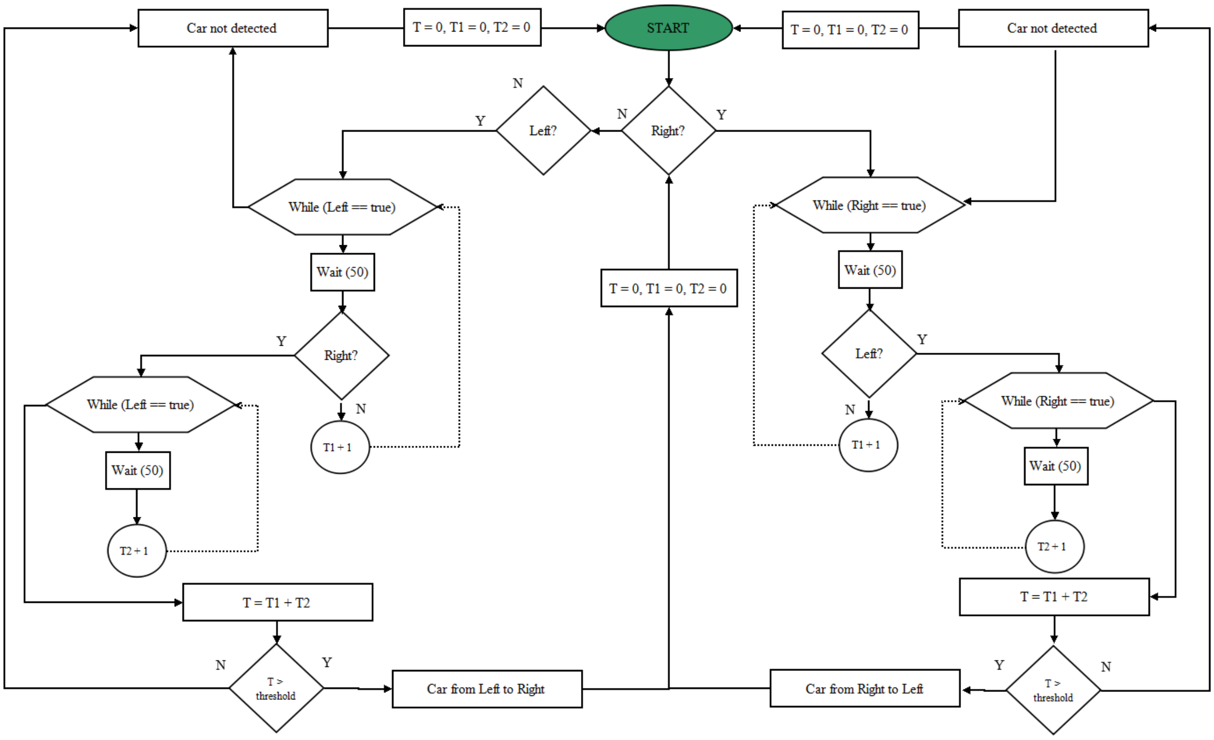


Figure 17. Algorithm for car detection

The algorithm works in a simple fashion:

1) Program starts

2) Check if right sensor is activated

a) If yes, while right sensor is activated, loop and check every 50 ms if left sensor is activated. If it is not, increment value T1 by 1. If it is, loop while right sensor is activated and every 50 ms increment value T2 by 1 until right sensor is not activated any more. Once deactivated, add T1 and T2 to get value T.

b) Compared value T to threshold

i. If higher, car detected **right to left**

ii. If lower, no car has been detected

c) Reset values

d) Restart check procedure.

3) Check if left sensor is activated

e) If yes, while **left** sensor is activated, loop and check every 50 ms if **right** sensor is activated. If it is not, increment value T1 by 1. If it is, loop while **left** sensor is activated and every 50 ms increment value T2 by 1 until **left** sensor is not activated any more. Once deactivated, add T1 and T2 to get value T.

f) Compared value T to threshold
   i. If higher, car detected **left to right**
   ii. If lower, no car has been detected
g) Reset values
h) Restart check procedure.

The algorithm is designed to prevent random objects (not vehicles) from registering as detection. This is done primarily by values T1 and T2 (if the final value T is too small it is unlikely that it was a vehicle that passed by, or it passed by with inconceivable speed for a vehicle in a parking lot). The other failsafe is the timeout - while in respective while loops, the respective sensor deactivates before the other sensor is activated.

It is noteworthy that this procedure is not activated until the acoustic sensor picks up a sound signal corresponding to that of a motor vehicle.

6.3 Data management

Overall the data management is divided into 4 separate areas:

1) Data acquisition
2) Data processing
3) Data storage
4) Data retrieval from storage / data display

Data acquisition

Data acquisition is solely done by the NI WSN nodes. The to IR sensors in combination with the acoustic sensor detect the vehicle movement and it's direction. The detection process and the algorithm are done in the node. This is to save the wireless node battery, because info is only sent wirelessly (the antenna is used) to the gateway, when there is relevant data to be sent. This means that the different kinds of background noise and false detections (non-vehicles) do not activate the antenna, leading to longer battery life.

Data processing

Once the gateway has received the data, it does all the necessary processing actions. The wireless messages is received, decoded into proper format, a timestamp is added and then stored in the database.

Data storage

In order to store data in the database, it is important to know how a database works.

Each database is made up of several data tables, that each store data similarly to a spreadsheet table. The tables have columns and rows with each row and column combination capable of holding information. The data type that is stored in each such element is defined by the column. This means that for whichever row, the data type across the whole column stays the same.

It is in our interest to use the fact that databases hold different tables, because we can use the different tables for different parking lots around a certain address or building complex. For our demo system purposes the database will be representing Tallinn University of Technology and each table will represent a parking lot in the campus. It is possible to use one main server and for each different address, another database. This kind of structure is illustrated in Figure 18 below.

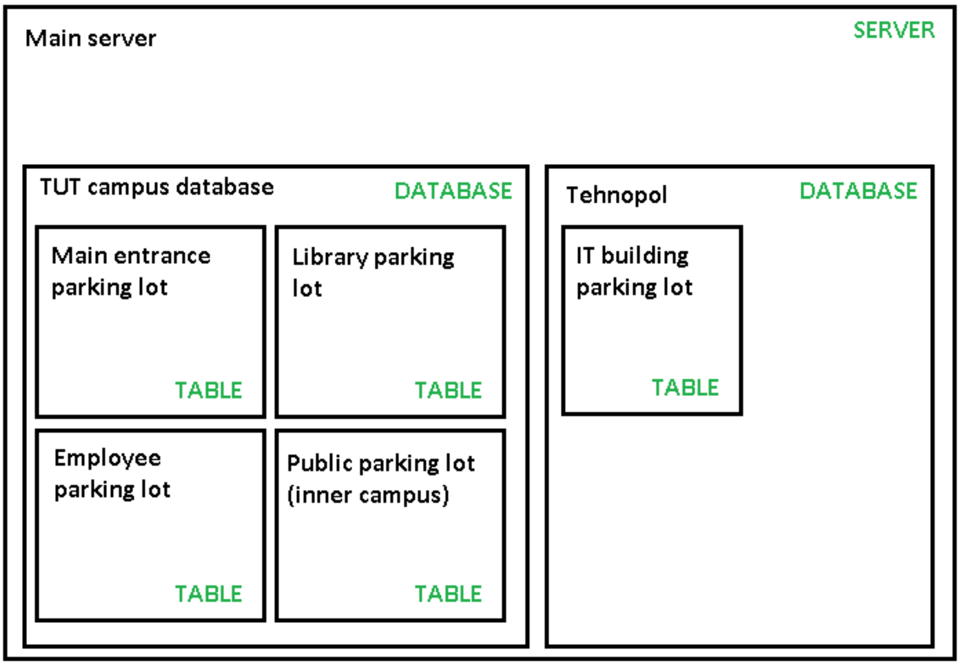


Figure 18. Data storage structure.

Each database will hold relevant information about the different parking lots. This information includes:

1) ID - ID of the parking lot (numerical representation)

2) Name - Identification of the parking lot (for example: “Main entrance parking lot”)

3) Address - Address of the parking lot, if it differs from the building complex address

4) Gates - number of entrances/exists in the parking lot

5) Spaces - total number of parking spaces in the parking lot

Each table in the database will then represent a parking lot and the table is where information about the occupancy is stored. In addition this allows keeping a log of arrivals and departures of vehicles. The main thing we want to store in the table is number of vacant slots, but there is some other information that will be stored alongside it. Each table will have:

1) **ID** - ID of the information, good practice to have

2) **Time** - timestamp for the movement of a car

3) **Gate** - through which gate did the movement occur

4) **Direction** - In which direction did the movement occur (arrival or departure)

5) **Old count -** Number of cars in the parking lot previously

6) **New count** - Number of cars in the parking lot after movement has occurred.

7) **Total** - Total number of parking spaces

8) **Vacant** - number of vacant parking spaces after movement

Visual representation of the table layout and example is shown in Figure 19 below.

ID	time	gate	direction	old_count	new_count	total	vacant
1	14:56	first	out	15	14	22	8
2	16:32	first	in	14	15	22	7
3	16:43	first	in	15	16	22	6
3	17:00	first	out	16	15	22	7

Figure 19. Table layout.

The ID is automatically incremented by the server and also the time is automatically recorded when the data is inserted in the database. The other slots are filled by the gateway upon insertion.

In order to store data in the database, a unified set of commands is required in order to bypass all version differences and data format incompatibilities. For SQL databases, the solution is to use SQL statements or queries. In essence, SQL is a standard language for database access.

An SQL statement is a command given to be processed by the computer or server running the database. The statement is essentially a line of code, that tells the server to perform an action using the parameters given. The line of code that is built up from statements is called a query.

For our data storage and retrieval operations we are going to be using several queries.
First, in order to retrieve the number of cars currently in the parking lot we use the following code:

SELECT new_count FROM parkla1
ORDER BY new_count DESC
LIMIT 1;

This query selects the column **new_count** from the table **parkla1** (parking lot id), orders the whole column in a descending fashion, and retrieves one element. This effectively retrieves the last entered number in the column, which is latest entered number, which is also the number of cars currently in the parking lot.

Similarly to the first query, the total spaces are also retrieved using the following query:

SELECT total FROM parkla1
ORDER BY total DESC
LIMIT 1;

Although we know that this never changes, it is easier to read a single number for use in LabVIEW (for gateway programming).

Secondly, in order to store a new line in the table, we use the query:
INSERT INTO parkla1 (gate, direction, old_count, new_count, vacant)
VALUES (value1 value2 value3 value4 value5);

This query inserts a new row into the table parkla1, and in that row, writes the value1 to column **gate**, value2 to column **direction**, value3 to column **old_count, **value4 to **new_count** and value5 to **vacant**.

Both of the queries are done by the gateway (programmed with LabVIEW) as seen in Figure 20 below. The complete gateway program in LabVIEW can be seen Appendix 2.

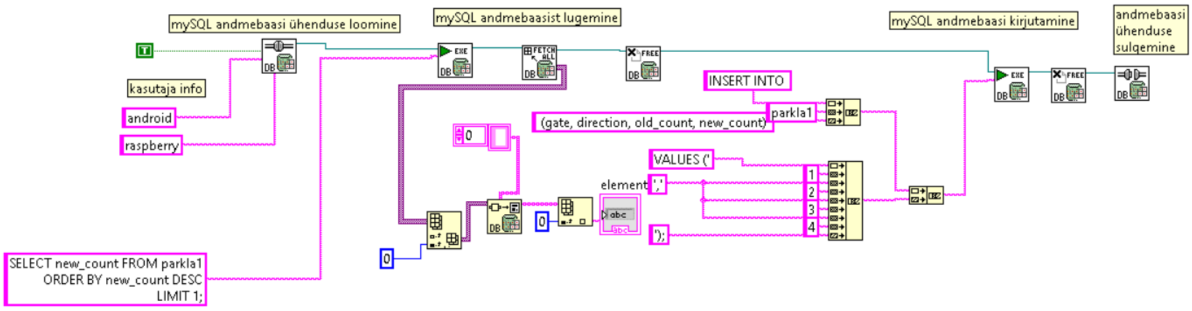


Figure 20. Use of SQL queries in LabVIEW.

Using SQL queries, there is no need to know in which data format the columns are, because the database itself will handle the insertion process. This means that programming in this way is more universal and bypasses version incompatibilities

Data retrieval

The data retrieval works similarly, using SQL queries. Further discussed in the next chapter (Chapter 7).

7 MOBILE PHONE APPLICATION

This chapter covers the basics of the mobile phone application, the used design, code and retrieval of information from the database to display.

7.1 Used software

Although the info can be easily displayed with the use of a website, it was decided to use a mobile phone application, because it goes well with the idea of Internet of Things and the whole concept of wireless connectivity. The used platform is Android, as it is widely used for both mobile phones and tablets.

The software used to create the Android application is Android Studio, which is the official IDE for Android application development. In addition to the default libraries, the java.sql library is used to provide methods for connecting to databases.

Android Studio uses the programming language Java, so the entire application is written using Java and it’s libraries.

7.2 Design

For testing the data retrieval, a very simple design was created. The design of the application is straightforward. The user view is divided into several tabs, each of which represents a location (in the demo system case, just the TUT is populated with information).
After choosing the appropriate tab, the user gets an overview where all of the parking lots and their vacant parking spaces are shown. This overview is shown in Figure 21 below.

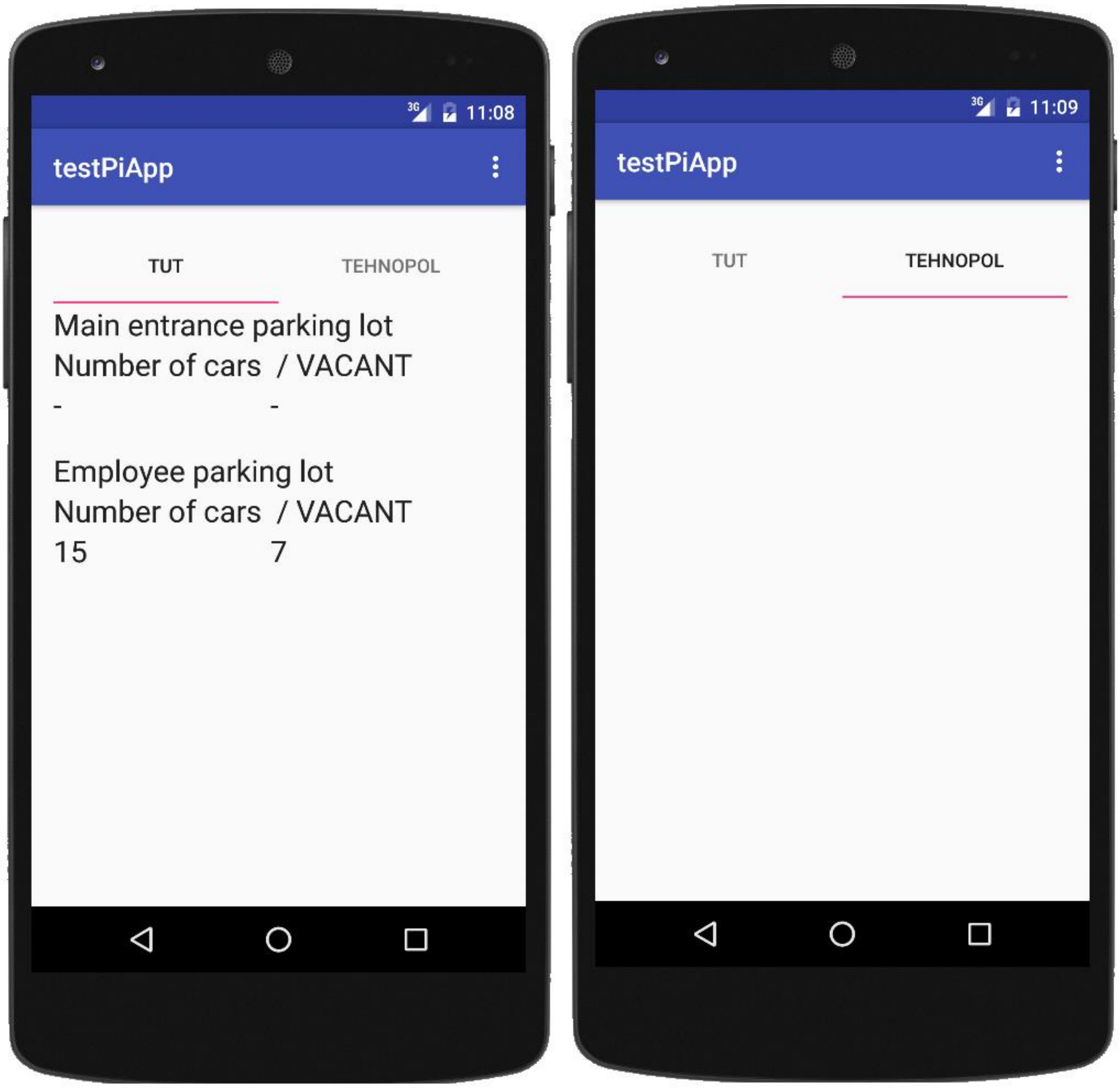


Figure 20. Design for testing purposes

As seen in the figure above, the design is simple and is only used as a “proof of concept”, to show that the data retrieval is possible.

For future and practical use, the design needs to be reworked entirely.

7.3 Data retrieval

Data is retrieved from the database using the java.sql library available for free online. The methods used for the connecting and retrieval process are:

java.sql.Connection con = DriverManager.getConnection

java.sql.Statement stat

java.sql.ResultSet rs1

stat.executeQuery

In essence the process is similar to that used in LabVIEW:

1) Connecting to the database
2) Creating a statement/query
3) Sending statement/query to database
4) Retrieving data

The full code used in the mobile phone application (in Java) is shown in Appendix B. Below is the code and explanation used only for the data retrieval.

//driver setup
Class.forName("com.mysql.jdbc.Driver");

This is used to set up the driver. Since the database uses ODBC format, the JDBC driver is used.

//connecting to database
java.sql.Connection con = DriverManager.getConnection("jdbc:mysql://192.168.1.213/TUT", "android", "raspberry");

Here we define a new connection for the sql connection using the driver. We give the address of the server (in here it is used in a local network), the name of the database (in this case TUT), the username and the password used to connect to the server.

//sql statement setup
java.sql.Statement stat = con.createStatement();

This line of code sets up a statement object, which will essentially contain the query later.

//execute the query, returns ResultSet object.
java.sql.ResultSet rs3 = stat.executeQuery("SELECT new_count FROM parkla1 ORDER BY new_count DESC LIMIT 1;");
java.sql.ResultSet rs4 = stat.executeQuery("SELECT vacant FROM parkla1 ORDER BY vacant DESC LIMIT 1;");

These lines execute the queries and write the returned data into a ResultSet data object (this is an object defined by the java.sql library). The query is sent to the server using the stat object which in turn has information regarding the connection to the server.

//writing the data from the Resultset object to the ResultTextView object (declared above, to be CountView1 object)
```
while (rs3.next()) {
    ResultTextView.setText(Integer.toString(rs3.getInt("count_total")));
}
```

Finally, the ResultSet object is read line by line. The value matching the column **count_total** is converted to an integer, then converted into a string and this string value is then used to overwrite the text field in **countView1**

A similar process is done for the vacant parking spaces :
//writing the data from the second Resultset object to the ResultTextView object, which we change to point to vacantView2 (for vacant parking spaces number)
```
ResultTextView = (TextView) findViewById(R.id.vacantView2);
while (rs4.next()) {
    ResultTextView.setText(Integer.toString(rs4.getInt("vacant")));
}
```
The setText function overwrites the text field that is ultimately shown to the viewer in the overview page (see Figure 20).

8 TEST SYSTEM

For the purposes of testing and providing proof of the described system and methods, a test system was built, that uses the described wireless sensor network structure.

The test system comprises of the following components:

1) Programmable wireless gateway
2) Programmable wireless node
3) Sensors for the node
4) Server for the database
5) Tablet for the application

Wireless network

All the components in the wireless network were connected to a local network, using cables and a router which has port forwarding functions. In order for the mobile phone application to be accessible to the outside network, port forwarding is needed. This ensures that when connecting from an outside network, the mobile phone application data retrieval requests are forwarded properly to the server hosting the database. Structure of the network is described below in Figure 22

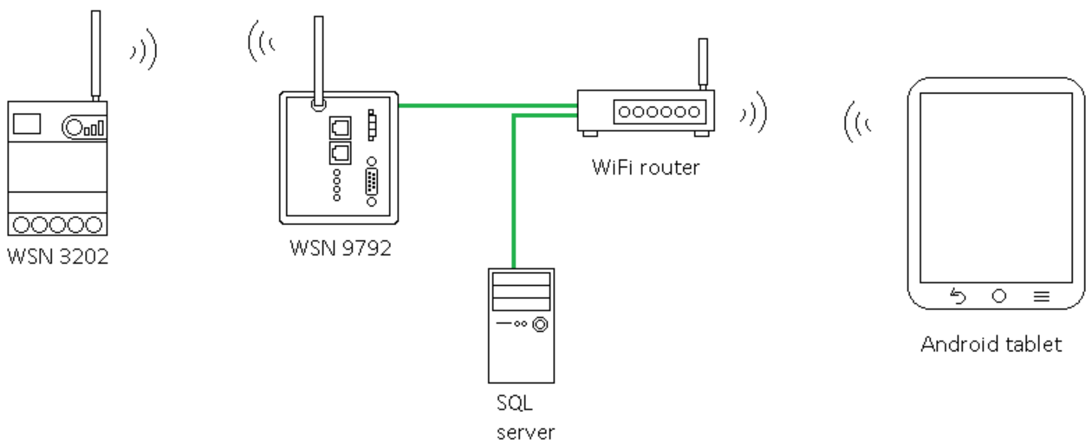


Figure 22. Test system setup

The programmable gateway NI WSN 9792 was programmed using LabVIEW 2015 using Real Time Module and the WSN Module. The final LabVIEW program for the gateway is shown in Appendix C 1.

The programmable node NI WSN 3202 was also programmed using LabVIEW 2015 and the necessary modules. The final LabVIEW program for the node is shown in Appendix C 2.

SQL database

The database server was set up on a Raspberry Pi B mini computer, using the following software:

Distribution:	raspbian-jessie-lite
Server software:	Apache
SQL software:	MySQL with phpMyAdmin

Tests

Using simulated signals (representing the IR sensors) within the LabVIEW environment, a number of tests were run. The data from the nodes was sent wirelessly to the gateway, where it as processed and using queries, the data was exchanged with the SQL database. The simulated arrivals and departures of cars from and to the parking lot were written properly and the data regarding occupied and vacant parking spaces was properly displayed.

It is noteworthy that these test were concluded in a lab-like environment, without any interference from weather or other potential sources of noise.

9 SUMMARY

The work in done in the thesis is a proof of concept for solving the practical problem of car parking lot occupancy. The problem is solved using a wireless sensor network and proving their cost effectiveness versus conventional wired systems.

In the process, the advantages and disadvantages of both systems were analysed and reviewed. For the wireless sensor system, typically used detection methods and sensors were reviewed and the most suitable for this kind of application was chosen.

Including the sensor, a suitable network structure and mechanical installation methods were developed. Based on the work done, a fully functioning system can be built. The data mangement system designed and tested for the purpose of the application are applicable for typical servers and hardware already available. Both the data stroage and retrieval methods work with any SQL databases and the application for displaying the information is both easily configurable and deployable for a very large number of different devices.

In conclusion, when using a system similar to the one described in this work, it is possible to create a more cost-effective system that traditional wired parking lot occupancy systems and also to make it more available by using the system for existing car parking lots.

KOKKUVÕTE

Antud lõputöös tehtud töö annab lahenduse konseptsiooni ja tõestuse autoparkla hõivatuse jälgimise süsteemile. Praktiline probleem on lahendatud kasutades arukat juhtmevaba andurite süsteemi ning on toodud selle süsteemi eelised ja kuluefektiivsus.

Töö käigus vaadeldi mõlema süsteemi eeliseid ja puuduseid. Uuriti ka enamlevinuid auto tuvastuse viise ja erinevaid andureid, mille põhjal valiti välja antud rakenduse jaoks kõige sobivaim.

Lisaks anduri ja meetodi valikule, töötati välja sobiv juhtmevaba võrgu struktuur ning mehaanilised lahendused, mille põhjal on võimalik välja ehitada töötav süsteem. Väljatöötatud ja testitud andmehalduse süsteem on rakendadav tüüpilistes serverties ja juba olemasoleval riistvaral. Nii andmesalvestuse kui ka andmepäringute meetodid töötavad mistahes SQL andmebaasides ning katsetuse eesmärgil loodud nutitelefoni rakendus on lihtsasti seadistatav ja seda on võimalik kasutada suurel hulgal erinevates seadmetes.

Antud töös kasutatud ja kirjeldatud süsteemi rakendamisel reaalse probleemi lahendamiseks on võimalik luua kuluefektiivsem süsteem võrreldes traditsiooniliste kaabeldusega autoparkla hõivatuse süsteemidega. Kirjeldatud süsteem võimaldab ka hõivatuse süsteemid muuta kättesaadavamaks, sest on rakendatav olemasolevatele parklatele.

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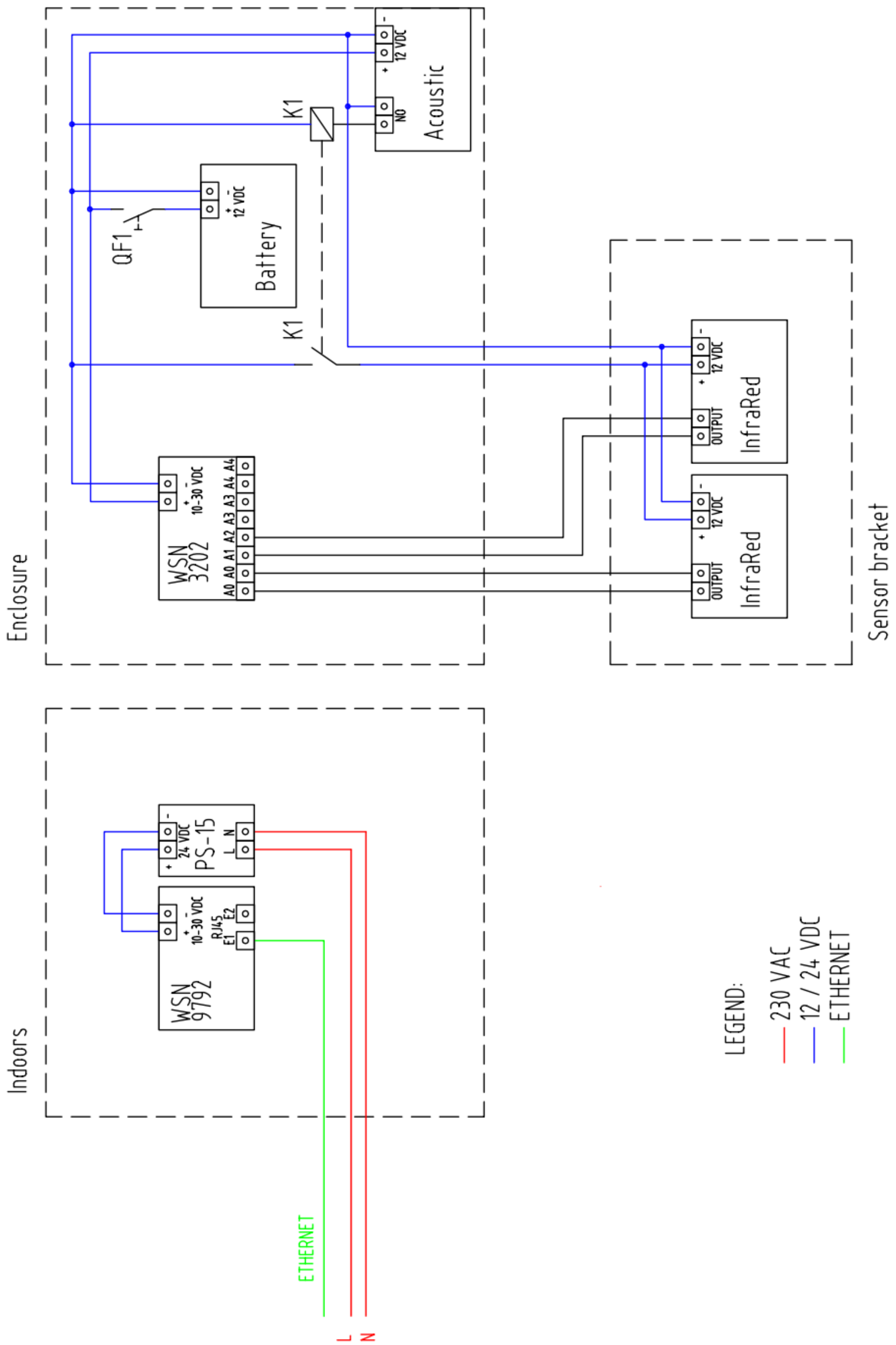
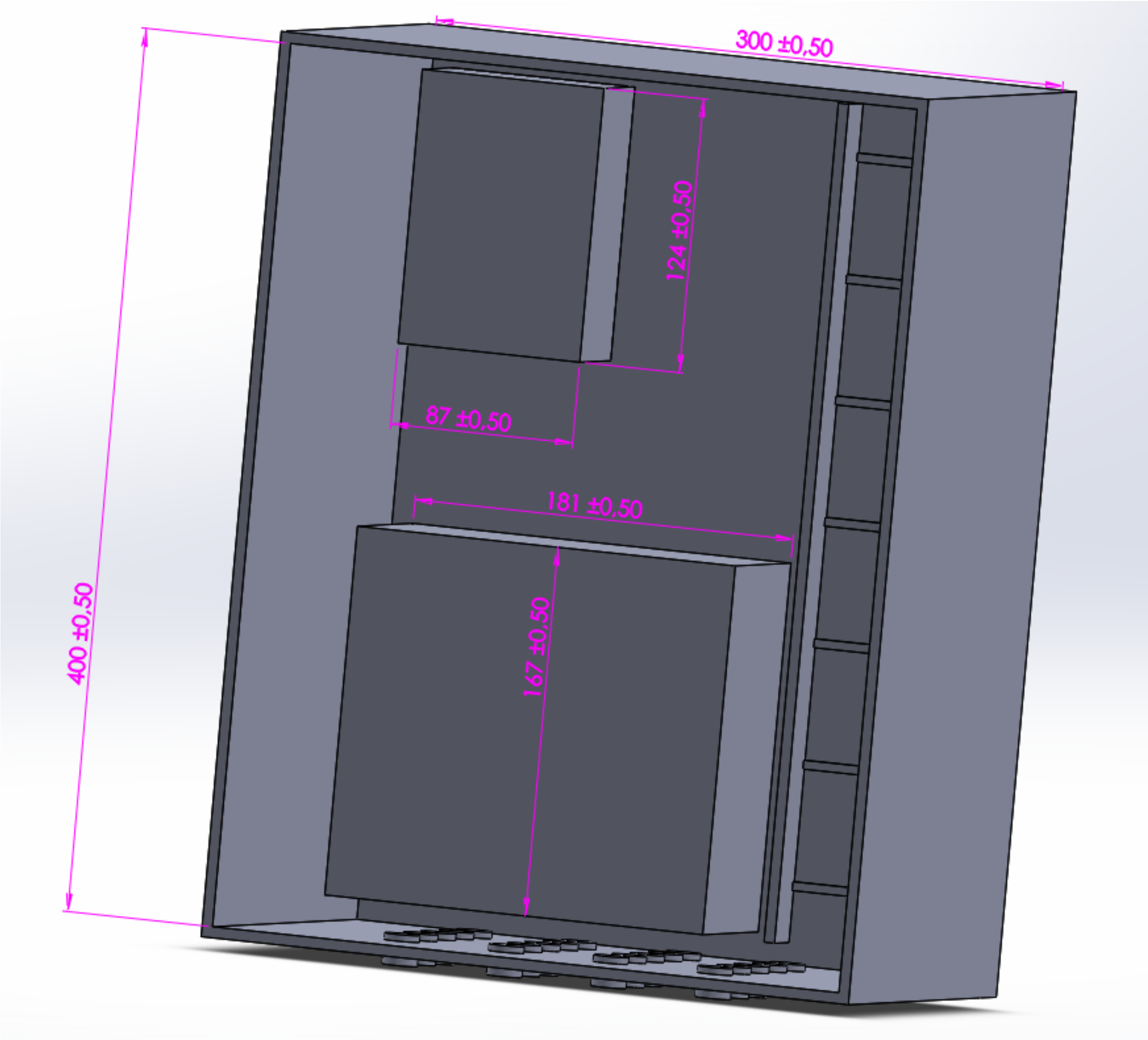
APPENDICES

APPENDIX A 1



APPENDIX A 2



Dimensions

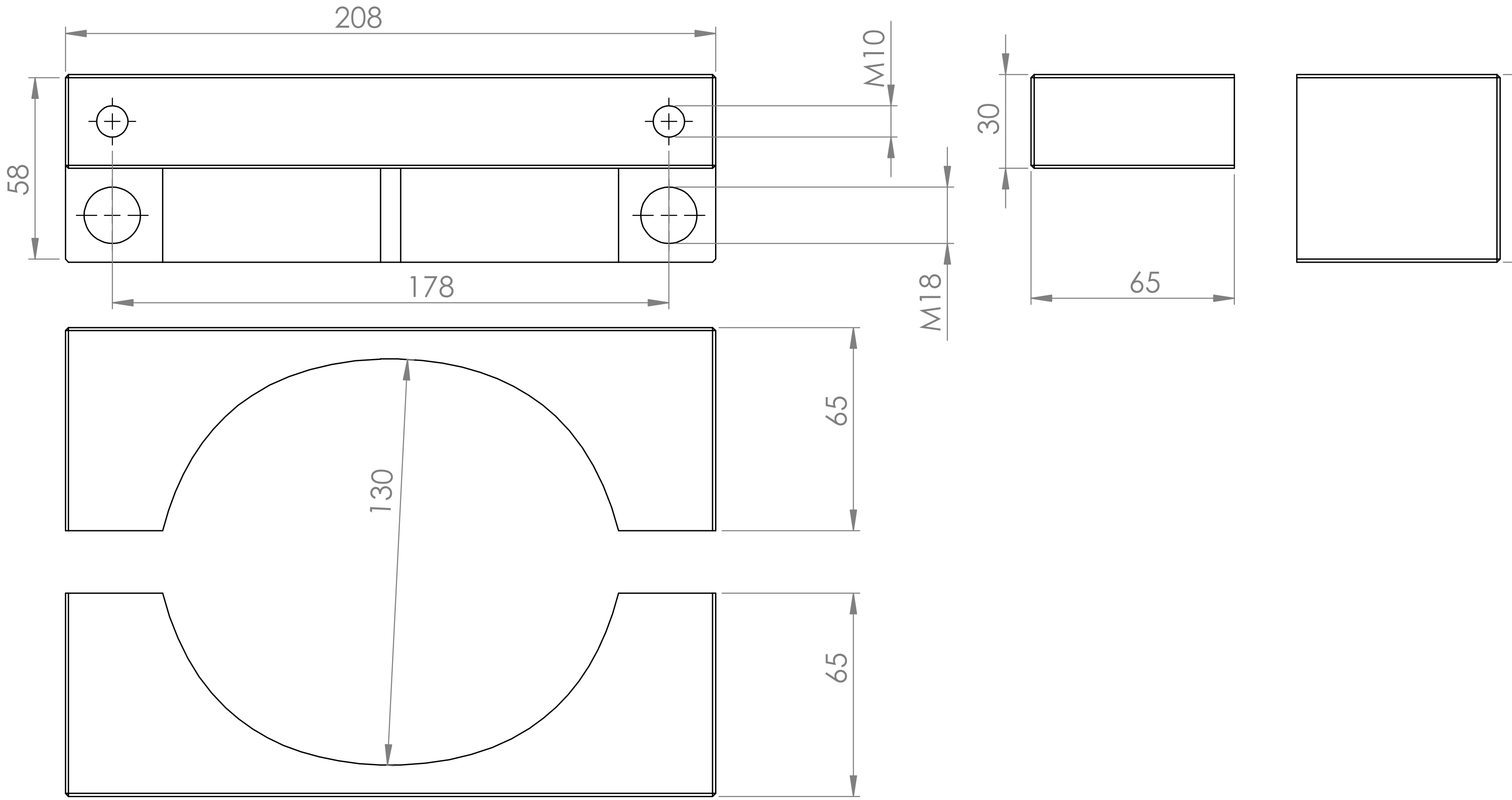
Enclosure 300 x 400 x 200 (width, length, depth)

Battery 181 x 167 x 77

WSN Node 87 x 124 x 43

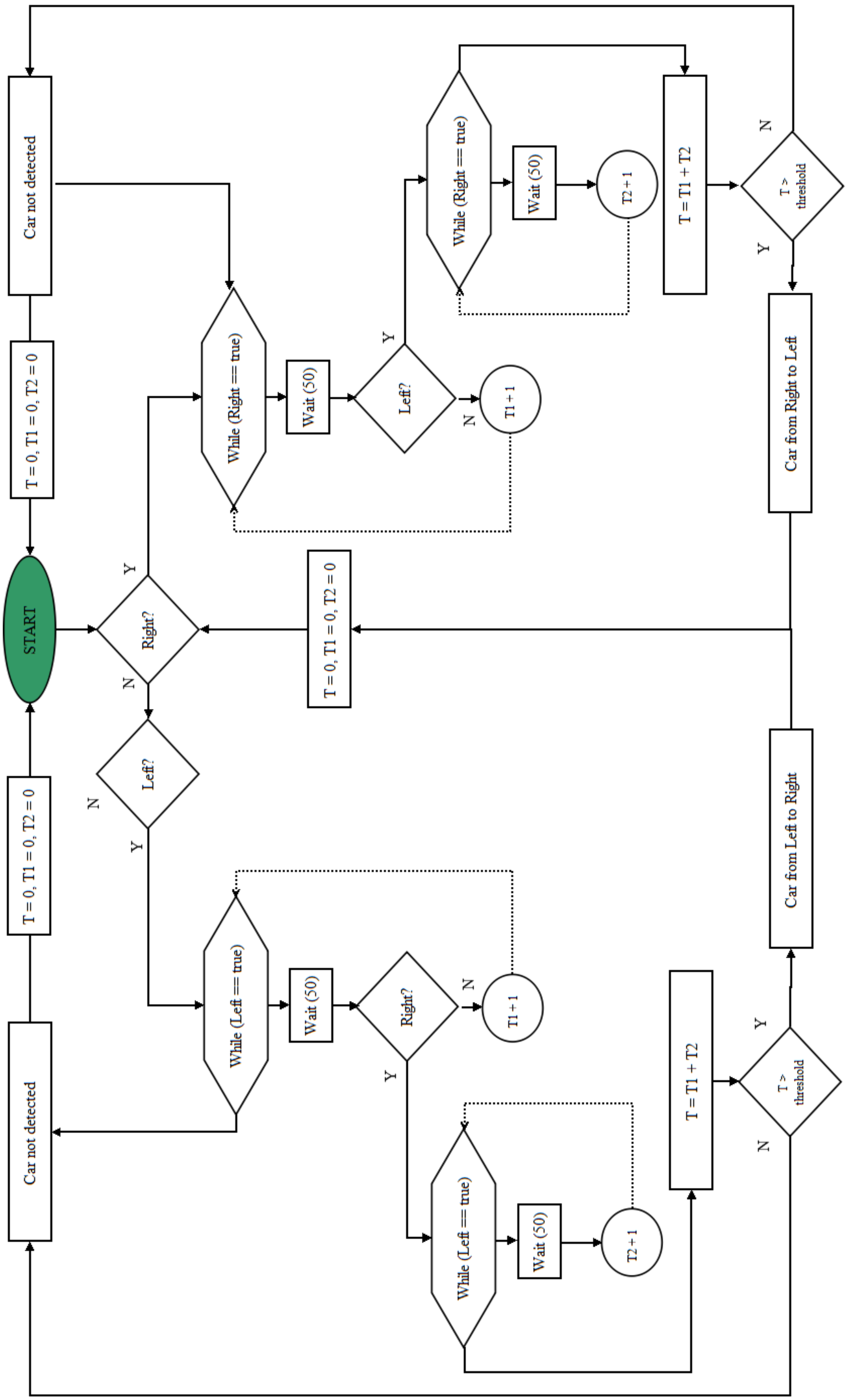
Dimensions are in millimetres.

APPENDIX A 3



	Material ABS		Unmarked tolerances ±0,05	Mass 0,115 kg	Mõõt 1:2
Designed	A. Pääro	Title BK1.001		Format A4	
Checked					
Approved					
		Sheet 1/1	Part no. Sensor bracket		

APPENDIX A 4 Detection algorithm



APPENDIX B Mobile phone application code

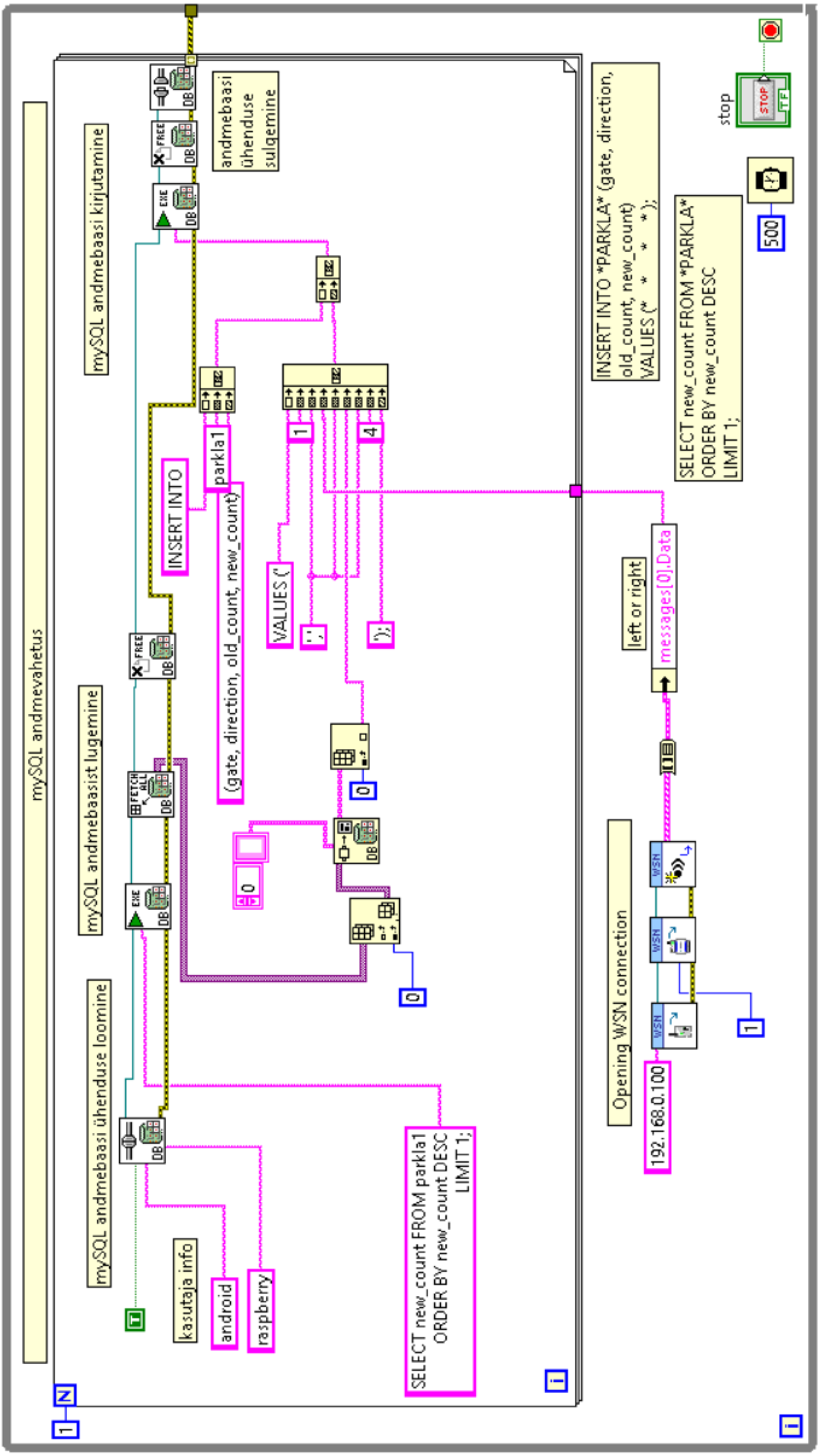
MainActivity.java

```
Package dolt.testpiapp;

import android.os.Bundle;
import android.os.StrictMode;
import android.support.v7.app.AppCompatActivity;
import android.support.v7.widget.Toolbar;
import android.view.Menu;
import android.view.MenuItem;
import android.view.View;
import android.widget.Button;
import android.widget.EditText;
import android.widget.TabHost;
import android.widget.TextView;

import java.sql.*;
import java.util.Vector;

public class MainActivity extends AppCompatActivity {

   TextView ResultTextView;

   @Override
   protected void onCreate(Bundle savedInstanceState) {

      StrictMode.ThreadPolicy policy = new
StrictMode.ThreadPolicy.Builder().permitAll().build();
      StrictMode.setThreadPolicy(policy);

      super.onCreate(savedInstanceState);
      setContentView(R.layout.activity_main);
      Toolbar toolbar = (Toolbar) findViewById(R.id.toolbar);
      setSupportActionBar(toolbar);

      ResultTextView = (TextView) findViewById(R.id.countView2);

      //creating the tabs
      TabHost tabHost = (TabHost) findViewById(R.id.tabHost);

      tabHost.setup();

      // creating the TUT tab
      TabHost.TabSpec tabSpec = tabHost.newTabSpec("TUT");
      tabSpec.setContent(R.id.TUT);
      tabSpec.setIndicator("TUT");
```

```
        tabHost.addTab(tabSpec);

        //creating the Tehnopol tab
        tabSpec = tabHost.newTabSpec("Tehnopol");
        tabSpec.setContent(R.id.Tehnopol);
        tabSpec.setIndicator("Tehnopol");
        tabHost.addTab(tabSpec);

        //Retrieving the data from the mySQL database
        ResultTextView.setText("after decl.");

        try {
          //driver setup
          ResultTextView.setText("in try");
          Class.forName("com.mysql.jdbc.Driver");
          ResultTextView.setText("driver done");

          //connecting to database
          java.sql.Connection con =
DriverManager.getConnection("jdbc:mysql://192.168.1.213/TUT", "android", "raspberry");
          ResultTextView.setText("connection done");

          //sql statement setup
          java.sql.Statement stat = con.createStatement();

          //execute the query, returns ResultSet object.
          //these are left commented, because in the demo system, the parkla2 is not used
(parkla2 is main entrance parking lot)
          //java.sql.ResultSet rs1 = stat.executeQuery("SELECT new_count FROM parkla2
ORDER BY new_count DESC LIMIT 1;");
          //java.sql.ResultSet rs2 = stat.executeQuery("SELECT vacant FROM parkla2 ORDER
BY vacant DESC LIMIT 1;");
          java.sql.ResultSet rs3 = stat.executeQuery("SELECT new_count FROM parkla1
ORDER BY new_count DESC LIMIT 1;");
          java.sql.ResultSet rs4 = stat.executeQuery("SELECT vacant FROM parkla1 ORDER
BY vacant DESC LIMIT 1;");

          //writing the data from the Resultset object to the ResultTextView object (declared
above, to be CountView1 object)
          ResultTextView.setText("executing");
          while (rs3.next()) {
            ResultTextView.setText("in while");
            ResultTextView.setText(Integer.toString(rs3.getInt("count_total")));
          }

          //writing the data from the second Resultset object to the ResultTextView object, which
we change to point to vacantView2 (for vacant parking spaces number)
          ResultTextView = (TextView) findViewById(R.id.vacantView2);
          ResultTextView.setText("executing2");
          while (rs4.next()) {
```

```java
                ResultTextView.setText("in while_2");
                ResultTextView.setText(Integer.toString(rs4.getInt("vacant")));
            }

        } catch (Exception e) {
            e.printStackTrace();
        }

    }

    @Override
    public boolean onCreateOptionsMenu(Menu menu) {
        // Inflate the menu; this adds items to the action bar if it is present.
        getMenuInflater().inflate(R.menu.menu_main, menu);
        return true;
    }

    @Override
    public boolean onOptionsItemSelected(MenuItem item) {
        // Handle action bar item clicks here. The action bar will
        // automatically handle clicks on the Home/Up button, so long
        // as you specify a parent activity in AndroidManifest.xml.
        int id = item.getItemId();

        //noinspection SimplifiableIfStatement
        if (id == R.id.action_settings) {
            return true;
        }

        return super.onOptionsItemSelected(item);
    }
}
```

APPENDIX C 1 LabVIEW gateway program



APPENDIX C 2 LabVIEW Node program