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Digital based Pedestrian Counting

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Abstract:

The here presented master thesis is divided into three separate parts. Part I is a scientific paper, part II an according process report, and part III holds an appendix. The sum of these three parts are meant to constitute an equivalent to a traditional master thesis, regarding the quality and detail.

The possibility of detecting MAC addresses of Bluetooth and Wi-Fi devices, motivated transport researchers throughout the last years, to use this data for several applications in transport engineering. Especially the estimation of travel times for the motorized transport, by using these data sets showed promising results. The increasing usage of mobile devices, equipped with Bluetooth and Wi-Fi interfaces throughout the last years, creates new possibilities in using the mentioned sensors also for pedestrian data collection. This study is about to examine the usage of Wi-Fi and Bluetooth sensors for pedestrian counting, especially in urban areas.

A literature review has been conducted, to get a better understanding about the technical background of the system. Scientific studies, dealing with the usage of Bluetooth and Wi-Fi sensors for traffic detecting and counting were studied to get an overview about the current state of the art in this area of transport engineering. As a next step the sensor equipment was about to be tested in urban surroundings. The gained knowledge from the literature analysis was used, to set up open field tests. Besides these test runs, parallel manual counts were done to different times of the day and during peak and non-peak hours, to investigate the coverage of the generated data compared to the manual counts. To evaluate the data sets, detected by the sensors, a data processing methodology was developed and used for the further data evaluation.

The results indicated especially the suitability of the Wi-Fi Sensors, for following the structure of the comparatively done manual counts. Due to the suboptimal hardware settings of the used sensors, the generated data sets could not be used for distinguishing between the observed modes of travel. Further recommendations were given, how a speed based distinguishing between different modes of travel can be implemented by using Bluetooth and Wi-Fi sensors.

As a last part of the work, the processed data sets were used to estimate the manual counted pedestrian volumes out of the sensors produced data.

Keywords:

1. Pedestrian counting
2. Digital traffic counting
3. Bluetooth and Wi-Fi
4. MAC address scanning

Part I – Scientific Paper

Evaluating the usage of Wi-Fi and Bluetooth based sensors for pedestrian counting in urban areas

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Evaluating the usage of Wi-Fi and Bluetooth based sensors for pedestrian counting in urban areas

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Abstract

An improvement of the pedestrian infrastructure, as well as a higher amount of people walking in inner city areas are desirable. Pedestrian volumes are one of the key performances to argue for an enhancement of walkability. Information about the amount of pedestrians, walking in urban areas are often based on annual counts or traffic model estimations. For the increasing needs of sustainable inner city infrastructure planning, a wider range of available data can encourage policy makers for an enhancement of walkable infrastructure. Automatic measurement systems like infra-red beams or cameras are mostly used and designed for indoor environments like shopping malls or airports. The growing number of mobile devices, equipped with Bluetooth and Wi-Fi interfaces, creates new possibilities in pedestrian data collection in indoor and outdoor situations. An automatic, cost-effective pedestrian counting approach, operating with Wi-Fi and Bluetooth data to acquire pedestrian information is highly welcomed.

The research question of this study is whether the usage of Bluetooth and Wi-Fi sensors is suitable for a reliable estimation of pedestrian volumes in urban areas. The used sensor system is a measurement instrument which detects unique Wi-Fi and Bluetooth Media-Access-Control (MAC) addresses, sent from mobile phones, headsets or other hardware devices. First, a controlled test was arranged to validate the measurement equipment. In a second phase, several field tests were performed in order to evaluate the characteristics of different locations and their geometry. The generated data was analyzed in terms of its penetration rate in different locations and at different times, such as peak and non-peak hours. The penetration rate was determined by comparison of the sensor-detected data to manually counted pedestrian numbers. Data filtering techniques were developed in order to detect people's movements from the produced data sets. The measurement system is examined and discussed regard to its reliability, the further usage and its restrictions. Based on this study, the usage of especially Wi-Fi sensors can be recommend to estimate the amount of people in urban areas. An appropriate distinguishing between different modes of travel was not possible by using the available sensor equipment. Recommendations to implement a speed based distinguishing by using a specific sensor set-up with appropriate antennas are made.

1. Introduction

Pedestrian volumes are one of the key performances to evaluate the impact of pedestrian infrastructure improvements. Automatic counting techniques belong to the most promising strategies for enhancing the amount and the quality of pedestrian volume data.

Nowadays, most automatic counting approaches are designed for the motorized transport (Abedi, et al., 2015). Common methods therefore are the usage of inductions loops or automatic number plate recognition (ANPR) systems. The increasing amount of mobile devices, such as smartphones or mobile computers, in recent motivated transport researchers to evaluate the usage of that technique within the field of traffic engineering. Especially, the detection of Bluetooth (BT) and Wi-Fi Media Access Control (MAC) addresses was established as a new approach in automated traffic counting and for travel time detections. Several authors used and tested the systems for the motorized transport, both on urban roads (Abbott-Jard, et al., 2013) and on highways (Araghi , et al., 2012).

Compared to the motorized transport, methods for automatic traffic counting for non-motorized modes of travel have not been that widely investigated in transport research until the last years. Some techniques for automatic pedestrian counting, such as infra-red beams, laser scanners and piezo-electric pads, were examined and compared to each other by Greene-Roesel, et al., (2008). Most of these approaches are basically designed for indoor areas and are widely used to count people entering or leaving shops. Main drawbacks were figured out for the usage in outdoor environment, such as disturbances due to weather phenomena. Also video based camera systems were examined throughout the last years and their usage for counting pedestrians was tested. Advanced video surveillance has a good capture rate, but it's automatic data acquisition is highly sensitive to weather conditions, viewing angels and illumination changes (Liebig, et al., 2012). Also the relative high costs of video based approaches should be mentioned as a certain drawback.

The generation of accurate and reliable pedestrian volumes for urban areas is highly welcomed by urban planners and policy makers to argue towards a better walkability of urban areas. A reliable automatic pedestrian counting approach using Bluetooth and Wi-Fi MAC addresses could deliver continuous pedestrian volumes for urban areas and points of interests. The increasing amount of mobile devices equipped with Bluetooth or Wi-Fi carried by pedestrians and cyclists indicates the high potential capability of that system. Previous research investigations were done for Bluetooth (Malinovskiy, et al., 2012) and Wi-Fi (Abedi, et al., 2015) sensors to evaluate their usage for gathering information about pedestrians. Both of the studies used two sensors to detect the travel times and counts in between. A similar sensor equipment was used for the estimation of cyclists' travel times on varying gradients by Ryeng, et al., (2016). A one-sensor set-up was used by O'Neill, et al. (2008) to detected Bluetooth signals in several urban areas. This paper is focused on testing both, a one and a two sensor set up for the detection and counting of pedestrians in inner city areas. The raised research questions of this study is: *Is the usage of Bluetooth and Wi-Fi sensors suitable for estimating the amount of pedestrians in different inner city areas in a reliable and accurate way?*

The paper gives first an overview about technical issues, regarding the used detection technique with the particular sensor equipment. Afterwards, the developed data processing methodology is presented and a set-up process for the open field tests is considered. In the following chapter, the generated results are presented and discussed. Afterwards, the usage of the gained data sets for pedestrian volume estimations was examined. The study is concluded by giving further recommendations for the usage of the systems, as well as mentioning their boundaries.

2. Bluetooth and Wi-Fi Scanners for Pedestrians Counting

To understand how Bluetooth and Wi-Fi technologies can be used for automatic pedestrian counting, some technical aspects must be considered and are important to understand under which circumstances people can be detected. In particular, the following questions regarding the technical equipment were analyzed in the present:

- How can MAC address tracking be used for pedestrian counting approaches?
- What are the main characteristics of the sensors' equipment, and how do they operate?
- How is the collected data affected by the technical characteristics of the antenna equipment?

MAC Address Tracking Technology

MAC addresses are unique identifies, which are used for various types of communication networks. Bluetooth and Wi-Fi devices have their own personal MAC address code and can so doubtless be identified. Hence they can be traced by sensors, which motivates researchers for different applications in the field of transport planning. The generated data sets were so far mainly used for routing and travel time estimation approaches (Abedi, et al., 2015). The present study focuses on counting methods for pedestrians, based on MAC address data sets.

A main disadvantage of the presented technique is the discrepancy between sample size and the actual amount of road users. Especially pedestrians often carry several devices with them and might so be detected more than once. On the other hand, people who are not using any Bluetooth or Wi-Fi devices or who have turned off these functions, will not be detected by the sensors. Special user groups like children or elderly people might thus be underrepresented in the sample.

The characteristics of the sensors, and the design of the sensor antennas are important factors in terms of efficient data collection. The one-and the two-sensor set-up can be used for detecting MAC addresses of devices via BT and Wi-Fi sensors (Figure 1). In case of the one-sensor set-up, the passing devices are registered while they are in the sensor antenna's detection zone and manually counted while they are passing an imaginary line in front of the sensor. If two sensors are mounted, only devices passing two sensors are registered. The comparative manual counts can be done while devices are passing a line in between the sensors.

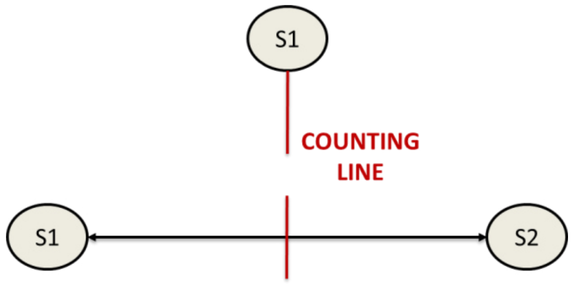

Figure 1 Sensor set up

The ideal site for a one-sensor set-up, is a long, relatively narrow corridor with no nearby junctions, where it is more likely, that discovered devices have actually passed the virtual counting line in front of the sensor. In very complex urban geometries, several nearby junctions or wide squares can increase the complexity of the manual counts done in parallel. In addition, more than two sensors can be used within a measurement approach. If two sensors are mounted, for example, along a highly frequented inner city road, a third sensor could be set up in addition along a nearby path, used only by cyclist and pedestrians. If only data sets, detected by all three sensors are included, the third sensor can operate as a filter for separating the cyclists' and pedestrians' data sets.

Antenna Characteristics

The probability of detecting a BT or Wi-Fi device is essentially dependent on the characteristics of the antenna equipment, such as signal strength, size and shape of the antenna's detection zone and the time an enabled device spends in the detection zone.

Characteristics of the antenna equipment should be tailored to the mode of transport, which is about to be analyzed. As an example, Table 1 shows the characteristic speed levels for common modes of transport in urban areas and the resulting residence time in an exemplary 50 m antenna detection zone. The minimum residence time is defined by the specific hardware based detection time of the traveling device. Previous research showed that Bluetooth devices are detected within a maximum of 10 seconds. However, the usual detection time is 5 seconds (Chakraborty , et al., 2008). Considering Wi-Fi devices, the detection time is shorter and around 1.4 seconds for a device (Abedi, et al., 2015).

Table 1 Characteristic speed levels and residence time in a 50m coverage area for different modes of transport in urban areas

Mode of travel	Speed	Time in 50 m zone
Car	50km/h; (13,9 m/s)	3.6 s
Bike	20km/h: (5,6 m/s)	8.9 s
Walking	5km/h; (1,4 m/s)	36.2 s

Table 1 shows that a 50 m detection zone is sufficient for pedestrians and also still acceptable for cyclists. Regarding the motorized travel, a bigger antenna range should be considered due to the short residence time in the zone. Therefore, sensors which are developed for operating along highways or arterial main roads should be equipped with antennas with higher gains and thus larger detection zones.

Operating with such powerful antenna equipment for the detection of non-motorized transport can have certain drawbacks. A wide antenna range in urban areas increases the complexity and the processing time of the data analysis. This is caused mainly due to the fact that bigger antenna gains collect more samples as they cover a wider area. If the antenna is mounted in crowded inner city areas, a lot of so called background noise may thus be detected. Background noise includes Bluetooth and Wi-Fi signals, sent by non-travelling devices, such as fixed units, mounted in buildings within the antenna's coverage zone, like Wi-Fi routers, smart TVs or stationary computers in offices or apartments. Hence, sensors which are about to be developed for the detection of non-motorized modes of travel should operate with smaller antenna ranges to avoid the detection of too many background signals. Due to the relatively slow speed levels of walking people, small antenna ranges are still sufficient for a satisfactory long resting time within the detection zone, to be reliably detected.

In addition to the size of the detection zone, the moving behavior of the observed user group should be considered as well for designing the shape of the antenna's detection zone. The two mainly used types of antennas in Bluetooth and Wi-Fi sensors are directional and omnidirectional antennas (Abedi, et al., 2015). Directional antennas concentrate their signal to a certain direction in a specific beam, while omnidirectional antennas spread their signal in a 360° zone around the antenna. Directional antennas are most useful for being mounted along a road, to detect devices, travelling along linear streets. The movement characteristics of non-motorized forms of travel are often more crowd-based. Pedestrians change their direction more often and are dwelling in certain areas. Therefore, omnidirectional antennas are considered to be more useful for these counting approaches.

Sensor Equipment

The equipment used in the present study was basically developed for the travel time measurements of motorized travel along roads. The sensors are operating with two Wi-Fi and three Bluetooth antennas. Table 2 gives an overview about the used antennas and their main technical characteristics. The antennas sending power is measured in decibel isotropic (dBi) units.

Table 2 Antenna characteristics sensors

Antenna type	Amount	Type	Sending power	Approx. range in m
Wi-Fi	2	directional	5 dBi	140m
Bluetooth	2	directional	20 dBi	130m
Bluetooth	1	omnidirectional	4 dBi	50m

Due to the main usage of the sensors for the travel time measurements along roads, the sensors are equipped with relatively strong antennas. The sending beam of the directional antennas is

70° and each sensor consists of two 180° opposite mounted antennas. Araghi , et al., (2014) determined detections ranges of up to 200 m with a similar Bluetooth antenna hardware set however the majority of detections was made in the range of 130 m and less.

The introductions into some important technical aspects showed, the high potential of the examined MAC address tracking technology for the detections of different modes of transport. Especially for the in this study investigated non-motorized modes, the choice of which technical equipment is used should be considered as important.

3. Methodology

The technical issues discussed above were used for finding suitable locations for field tests. In this context, the structure of the surrounded neighborhoods, as well as well as differences in local traffic volumes were taken into account. A method for processing the data sets generated during the field test was developed, in order to extract pedestrian volumes as well as some basic movement characteristics. This issue is of particular importance in the one sensor approach, as will be shown below.

Conceptual Approach

The first field tests were conducted by using a one sensor unit with the technical features described in Table 2. To investigate the reliability of the system, a comparison to the real number of pedestrians passing the sensor was needed. Hence, parallel manual counts were done at the test locations while the sensors were recording data. Both peak and non-peak hours were examined. Counting pedestrians in inner city areas can be rather challenging due to the crowd-based movement characteristics of walking people. For instance, pedestrians change their direction more often than cars and are dwell in certain areas. As presented in Figure 1, a virtual line was drawn in front of the sensor and people were counted manually, while they were crossing that imaginary line. The chosen test locations were bridges, due to the relatively low complexity of pedestrians' movement characteristics in these places.

The first field test took place at Gangbrua, a bridge across the Nidelva river in Trondheim. The sensor equipment was mounted in the middle of Gangbrua, with an approximate distance of 85m to the riverside. The bridge connects the city center of Trondheim with the residential area of Øya and is accessible for pedestrians and cyclists only. The bridge has a total length of 175m and is 3.8 m wide.

Traffic counts, which were realized by the municipality of Trondheim showed an amount of 232 pedestrians and 130 cyclists travelling across the bridge in the afternoon peak hour from 15:00 to 17:00 on the 9th of September 2014.

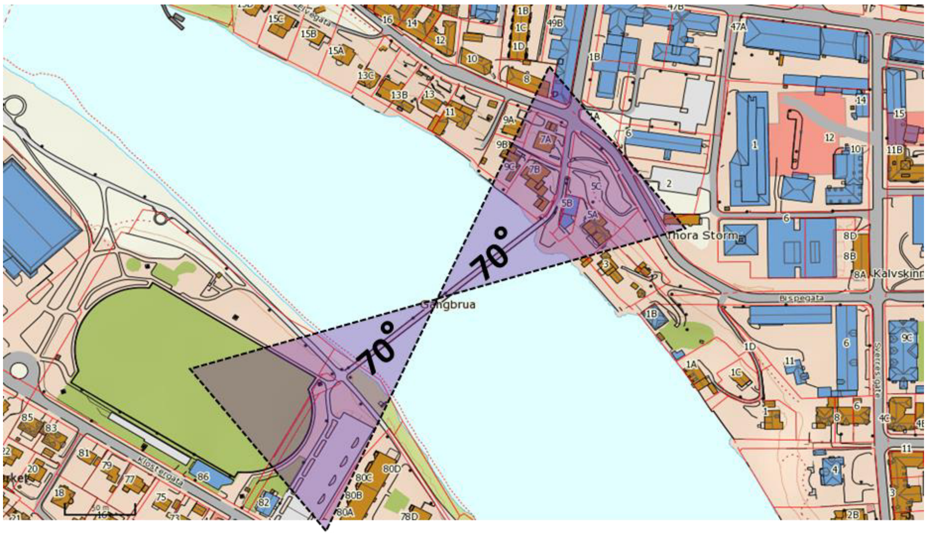

Figure 2 Study area Gangbrua (Source: norgeskart.no)

Figure 2 shows an overview of the study area at Gangbrua and the location of the sensors, as well as a sketch of their approximate detection area. The antennas' detections zones also cover areas around the bridge. Besides private houses, also office houses and a sports ground lies within the detection zone. The environmental complexity and the previously counted volumes seemed to be appropriate for a first test of the equipment for pedestrian counting.

A second field test was performed at Gamle Bybru for examining the suitability of one sensor to count passing pedestrians. This bridge (70m long and 8,5m wide) also crosses the Nidelva river and connects the inner city of Trondheim to the busy neighborhood of the Bakklandet district with many cafés, bars and restaurants.

The traffic counts mentioned above were also done for Gamle Bybru and resulted in 962 pedestrians and 785 cyclists crossing the bridge in the afternoon hours from 15:00 – 17:00 on the 9th of September 2014, showing a higher traffic volume as compared to Gangbrua.

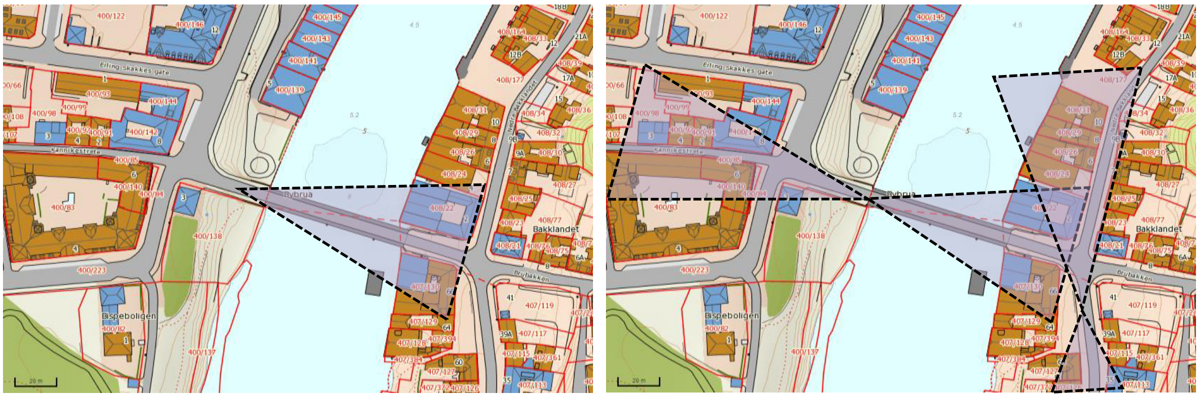

Figure 3 Study area Gamle Bybru for one- and two-sensor approach (Source norgeskart.no)

Figure 3 displays the investigated area at Gamle Bybru, the sensor locations for, the one- and the two-sensor test run and also includes sketches of the antennas detection zones.

Due to the shorter length of the bridge and the higher environmental complexity of the surrounded area, the positioning of the sensors was changed for the one sensor approach. The sensor was mounted at the Western end of the bridge and only one of the two antennas was used. The high sending power of the sensor equipment allowed a complete, coverage of the bridge by the antenna. In addition, parts of the Bakklandet area were within the detection zone of the antenna.

For the two-sensor field test, a second sensor was mounted in a street perpendicular to Gamle Bybru. To avoid direct overlapping with the antenna's coverage zone of the previously mounted sensor, the antennas were directed along the street in south / north direction. However, overlapping of the two coverage zones could not be avoided completely because of the high sending power and the relatively narrow testing area.

Data Processing

The raw data sets provided by the sensors had to be processed to obtain the required information. Especially for the one sensor set-up, a data processing method had to be developed, to distinguish between signals, created by fixed devices in the detection zone and those created by people passing by. If the detection zones of the antennas for a two sensor approach are not overlapping, fixed devices will not appear in the data set because only MAC addresses detected by both sensors are registered.

Table 3 shows a part of the sensors' raw data output for a particular MAC address, generated by one of the Wi-Fi sensors during the observations. The sensors convert the MAC address into a MAC address code, due to privacy reasons. Beside this code, the timestamp, an RSSI value and the antenna (3111_1 or 3111_2), with which the device was detected is registered.

Table 3 Exemplary RAW data set

TIME	MAXRSSI	MAC ADDRESS CODE	ANTENNA
15:40	-81	8848002331505450000	no.3111 2
15:41	-63	8848002331505450000	no.3111_2
15:42	-69	8848002331505450000	no.3111_1

The exemplary Wi-Fi data set in Table 3, was detected during 15:40 and 15:42. The signals were recorded by both of the sensor's antennas, with varying RSSI values. The filter method developed during the project, used the registered Received Signal Strength Indicators (RSSI) as a tool for distinguishing between moving and fixed devices. The RSSI value is sent from every detected Bluetooth and Wi-Fi device and indicates the strength of the received signal (Lui, et al., 2011). The higher that characteristic value is, the closer the detected device is to the sensor (Sauter, 2011). Devices, which are detected with a low RSSI value are in further distance to the sensor, than those with high RSSI values. The range of the observed RSSI values lies between -100 and 0. Values around -35 indicate a very close distance to the senor, while values of around -60 are characteristic for distances of around 35m (Lui, et al., 2011). The characteristic RSSI value of a device can also be dependent on the used Wi-Fi chip set. As mentioned in (Lui, et al., 2011), the RSSI signal is not only determined by the distance of the device to the sensor, but also by the type of chip set. Thus different RSSI values may result for two devices with identical distance from the sensor. This must be regarded as a certain drawback for the few-meter-precise localization of devices using RSSI signals. During this study, RSSI signals were used to identify the distance of the devices to the sensor on a non-meter-precise scale. The RSSI signal information was needed to distinguish the signals of a device passing by closely from the signal captured in the wider surrounding of the sensor. Therefore, the above mentioned lag of meter-precise local accuracy does not have a considerable effect for this particular approach.

Pedestrians travel with a relatively low speed level, while they are in the sensor's detection zone. Thus, the probability of a detection close to the sensor, with a relatively strong RSSI value, is high. Hence, only signals above certain RSSI levels were used in the presented study. Several tests with minimum RSSI levels of -60, -70 and -75 were done. Operating with a lower RSSI cut-off will deliver more signals, but also increases the probability of including fixed devices from the closer surrounding. A relatively high RSSI cut-off of -60 might decrease the amount of detected devices, but it delivers also a higher certainty of capturing only devices close to the sensor. In order to evaluate the validity of this technique, data sets of certain MAC addresses were analyzed in terms of their RSSI characteristics. An RSSI cut-off value of – 70 was figured out as the most appropriate one for the implemented field tests.

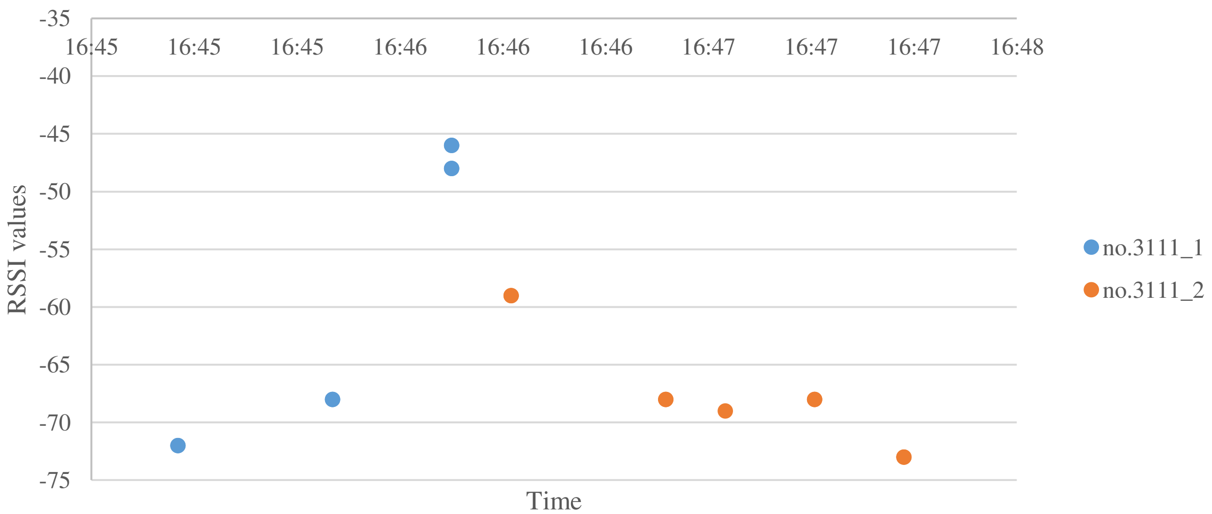

Figure 4 RSSI values of an exemplary moving Bluetooth device in the one-sensor approach at Gangbrua (probably carried by a person crossing the bridge from Øya to Trondheim city center)

Figure 4 shows the RSSI values received from a certain Bluetooth MAC address in the afternoon of the 10.03.2016 at the Gangbrua study area. The RSSI values indicate that the device entered the detection zone of antenna 3111_1 at 16:45. The increasing values imply, that the device was travelling closer to the antenna. At 16:46 the device leaves the detection zone of antenna 3111_1 and appears within the zone of 3111_2. Further on, the RSSI values of the device decreases gradually. The last signal sent from that device was detected at 16:47 with a relatively low RSSI value. The positioning of the sensor explains the movement behavior of the observed MAC address. Antenna 3111_1 was directed to the West (the Øya district) and 3111_2 towards the East (Trondheim's city center). The observed Bluetooth device was probably carried by a person, crossing the bridge from the Øya district, towards the city center of Trondheim.

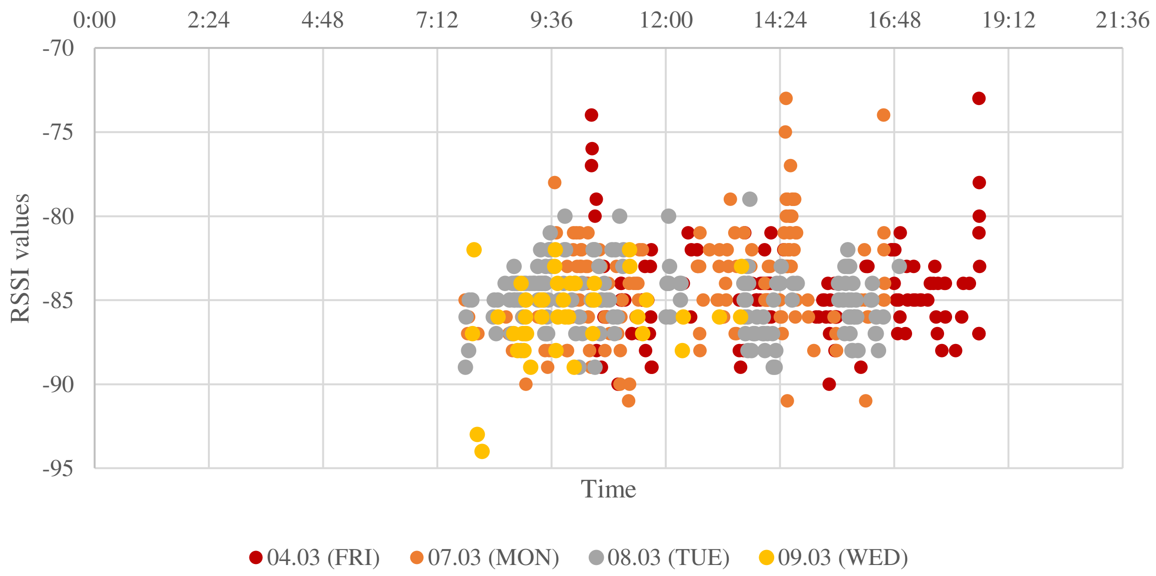

Figure 5 RSSI values from an exemplary stationary device in the one-sensor approach at Gangbrua (probably person with device moving within a building at the eastern end of the bridge)

The RSSI values of another specific Wi-Fi MAC address, shown in Figure 5 were detected during the period between the 4th and the 9th of March 2016 at the Gangbrua study area. In contrast to the example above, these were only discovered by antenna 3111_2. The regarded device was detected 603 times during the study period and had in generally lower RSSI values compared to the MAC address of the first example. The RSSI data points spread around the value of -85, with -94 as minimum and -73 as maximum. Furthermore, the device was only detected on weekdays (Friday, Monday, Tuesday, Wednesday) and between 07:30 in the morning and 18:30 in the evening. This specific pattern indicates, that the detected MAC address belongs to a device, which is located in the antenna's detection zone but does not pass the bridge. The shown MAC address might belong to a phone or a computer of a person working in an office in the antennas detection zone, who moves within the building but does not really come close to the sensor.

Next, the identification and extractions of those devices, detected more than once has to be considered. As shown in Figure 4 and Figure 5, a MAC address, passing by the sensors might be detected several times. To generate reliable counting data, each device should only be registered once while it is passing the sensors. Therefore, the RSSI filtered data set is segregated into particular timeslots like, the morning or the afternoon peak hour. Afterwards, duplicates should be extracted so that only one signal should remain for each registered MAC address. This extraction process should be limited to a possibly short time interval. If the duplicates are sorted out for a whole day's data set, a device which passes the sensor twice a day, for example during the morning and the afternoon peak hour, might afterwards appear only once in the filtered data set. Therefore, extraction of duplicates was performed within a three-hour interval in the present study.

Gangbrua, and Gamle Bybru were chosen as test areas for further field studies. Both bridges are only accessible for the non-motorized transport, but are different in their daily traffic volumes and the urban complexity of the surrounding neighborhoods. The data processing method developed for the data sets generated during the field tests, uses the registered RSSI values for distinguishing between mobile and fixed devices. The evaluation of particular MAC addresses indicated the suitability of this method, for filtering moving devices out of the raw data set.

4. Results and Discussion

The following chapter presents the findings of several tests done with the sensor equipment. Initially, a controlled test run was conducted, to examine the coverage of the antenna equipment, followed by several open field tests. Parallel manual counts were performed in order to evaluate the reliability of the equipment's detections. The positive results of these approaches, motivated the testing of estimations, based on the data sets generated by the sensors.

A controlled field test was arranged in order to investigate how many of the enabled Bluetooth and Wi-Fi devices passing the sensor are registered. The test was implemented on the early morning of Monday, March 14th 2016 between 02:10 and 03:10 at the Gangbrua location. A test person past the sensor (10 times back and forth) carrying four mobile devices in bags or pockets. Three of the devices were equipped with a Bluetooth interface and all four of them with Wi-Fi. 17 out of 40 potential Wi-Fi trips (43%) were registered by the sensors. Considering the Bluetooth sensor equipment, 19 out of 30 possible trips (63%) were detected. These results are in accordance with previous research by Ryeng, et al., (2016) dealing with the testing of similar Bluetooth and Wi-Fi sensors.

Subsequently four open field tests were implemented to test the equipment's performance for pedestrian counting. For both locations the majority of detections were made by the Wi-Fi antenna equipment. At the Gangbrua field testing location, 91 % [97/107] of the detected devices were Wi-Fi units and 9% [10/107] were Bluetooth devices. The results at Gamle Bybru were similar to the first field test. 94% [166/177] of all detected devices were Wi-Fi and 6% [11/177] were Bluetooth units. These detection rates are in accordance to the results, Abedi, et al., (2015) figured out, by using also BT and Wi-Fi sensors for pedestrian counting approaches.

The graph in Figure 6 shows an exemplary result of one of the Gangbrua field studies, which was done during the morning peak hour of Friday the 18th of March. Throughout the manual count, 236 people in total were detected while crossing the bridge between 07:00 and 10:00. One-hundred and ninety-two of them were pedestrians and 44 were cyclists.

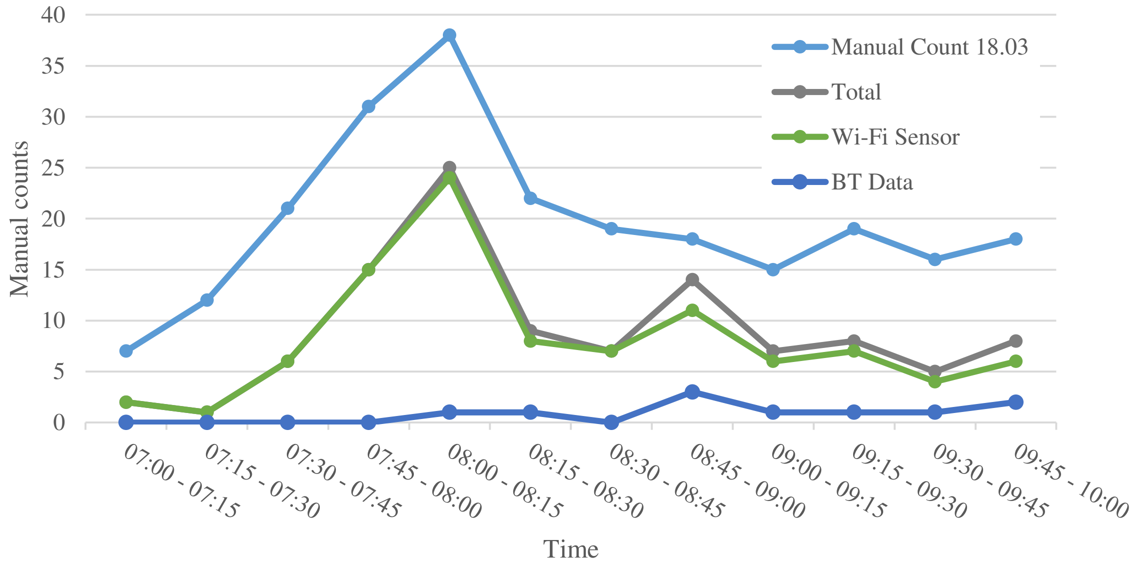

Figure 6 Results Gangbrua morning peak hour March 18th, (one-sensor approach)

Figure 6 shows the results of Bluetooth and Wi-Fi data sets separately and combined, comparing them with the volumes generated through the manual counts. As can be seen from the graph, the number of people passing by increases from 07:00 to 08:15, when it reaches a peak of 38 counts per 15 minutes and decreases afterwards to a plateau of around 15-20 counts per 15min. The detected Wi-Fi signals follow the structure of the hand counted pedestrian volumes better than the Bluetooth data set. The combined total number of detections is mainly determined by the Wi-Fi signals. The Bluetooth signals structure does not follow with the pattern of the manually counted data.

The second field test was implemented at the Gamle Bybru bridge. The exemplary results presented in Figure 7 were gathered during the morning of Saturday, April 23rd, 2016. The time period was chosen to collect data also in a non-peak hour time interval. The manual counting approach detected 378 people in total, crossing the bridge between 07:00 and 10:00. Of these, 323 were pedestrians and 55 were cyclists. The Wi-Fi data set again approximates the real amount of passing people better than the Bluetooth data set. The two peaks at 08.45 and 09:30 are detected by the sensors. Like at Gangbrua bridge, the Wi-Fi but not the Bluetooth data set delivers a similarly structured line graph compared to the manual counted volumes.

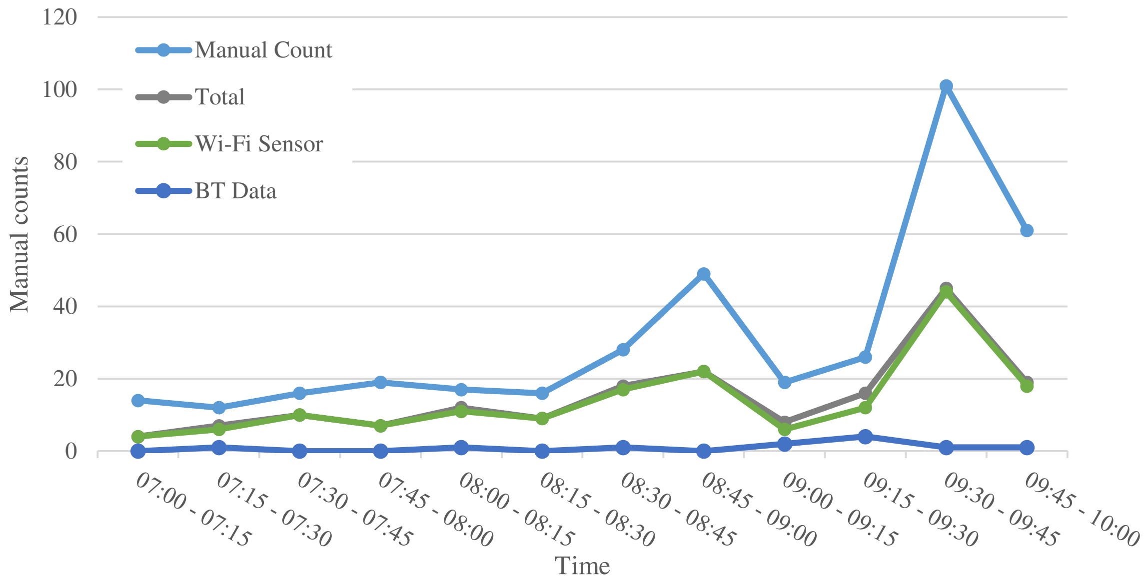

Figure 7 Morning on April, 23rd, Gamle Bybru

For the two-sensor approach, results were collected in the afternoon peak hour on Tuesday, April 19th, 2016 between 15:00 and 18:00. The hand counts during that time interval registered 2052 people passing by in total (596 cyclists and 1456 pedestrians).

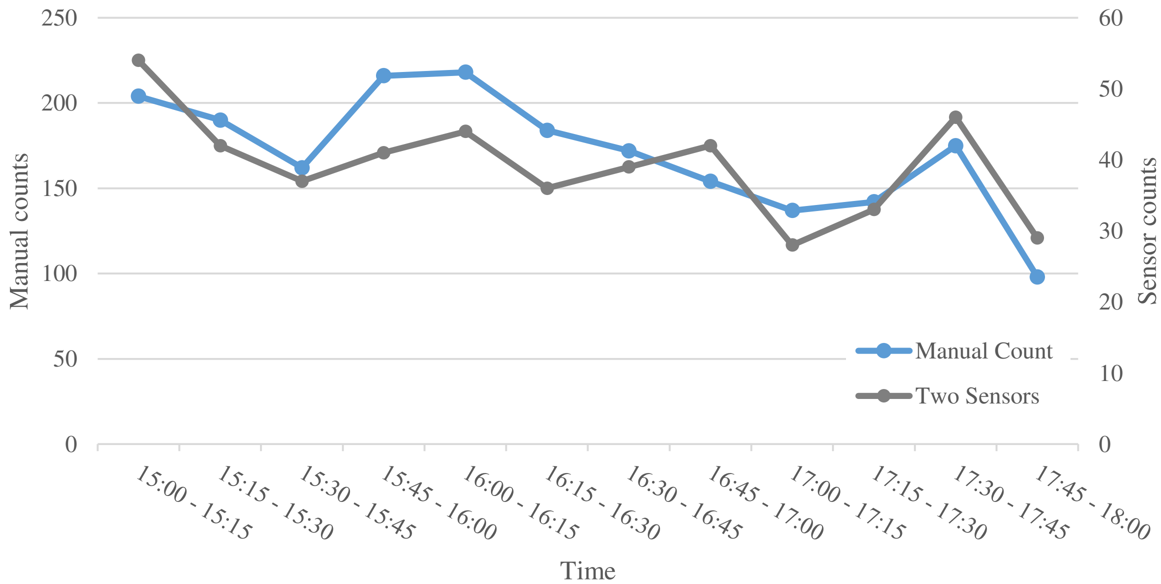

Figure 8 Afternoon peak hour April, 19th Gamle Bybru

During that two sensor field test, the sensors detected 477 devices in total, 99% [471/477] of them were Wi-Fi and only 1% [6/477] were Bluetooth devices. Due to the low number of BT detections, the results Figure 8 include only the Wi-Fi samples. The data is presented in a two-scale table to illustrate the equal structure of both graphs, including the main peaks. In the time interval between 16:45 and 17:00 the sensors' data indicates a small peak, which doesn't appear in the hand counted data.

The similar structure of manually counted and sensor-detected pedestrian and cyclist numbers motivated further investigations to estimate the real traffic volumes out of the generated data sets. To investigate whether this is possible, the penetration rate can be a useful tool for further estimations, based on the particular data sets. The penetration rate describes the coverage of a measurement result, compared to the hand counted pedestrian volumes. As mentioned, the majority of detections was made via Wi-Fi devices. The previous results indicated that the Bluetooth data sets are not having enough samples for precise pedestrian counting and were therefore excluded from further data analysis. For each field test, the Wi-Fi penetration rate was investigated and the results are presented in Table 4.

Table 4 Wi-Fi Penetration rates overview (Please note that the last measurement approach was made by using two sensors)

Testing day	Location	Absolute detections	Penetration rate
March, 10th	Gangbrua	206 / 390	53%
March, 11th	Gangbrua	137 / 242	57%
March, 16th	Gangbrua	111 / 233	48%
March, 18th	Gangbrua	97 / 236	41%
April, 19th	Gamle Bybru	616 / 2052	30%
April, 23rd	Gamle Bybru	166 / 378	44%
April, 24th	Gamle Bybru	108 / 320	35%
April, 24th	Gamle Bybru	437 / 1264	43%
April, 19th	Gamle Bybru	471 / 2052	23%

The penetration rates for the one sensor field tests vary between 35% (minimum) and 57% (maximum) coverage, while the two sensor approach only yields a coverage of 23%.

The generated penetration rates and the positive results of identifying the structure of the hand counted volumes on different times of the day are motivating for further investigations. A reliable estimation of the real amount of pedestrians out of the sensors generated data, would be a desirable approach to generate pedestrian volume data sets. To estimate pedestrian volumes out of the generated sensor measurements, the relationships between the two data sets was further investigated.

Two groups of data were formed in order to investigate whether the correlation of the data sets depends on the number of detections. The first group contains all tests with less than 350 manually counted pedestrians and cyclists during the three-hour field test time interval. To investigate whether also an estimation based on a larger and more scattered sample delivers reliable results, the second group included all data sets gathered during the field tests. Three different time intervals were examined to investigate potential differences within the data accuracy between regarded time spans. The relationship between the two data sets was indicated as linear and a linear regression was done. The results are presented in Figure 9 (< 350 counts) and Figure 10 (all counts). Please note that the data from March 18th (236 manual counts) were excluded from the analysis in Figure 9 and Table 5, as this data set will be used later on the test the validity of the linear regression model.

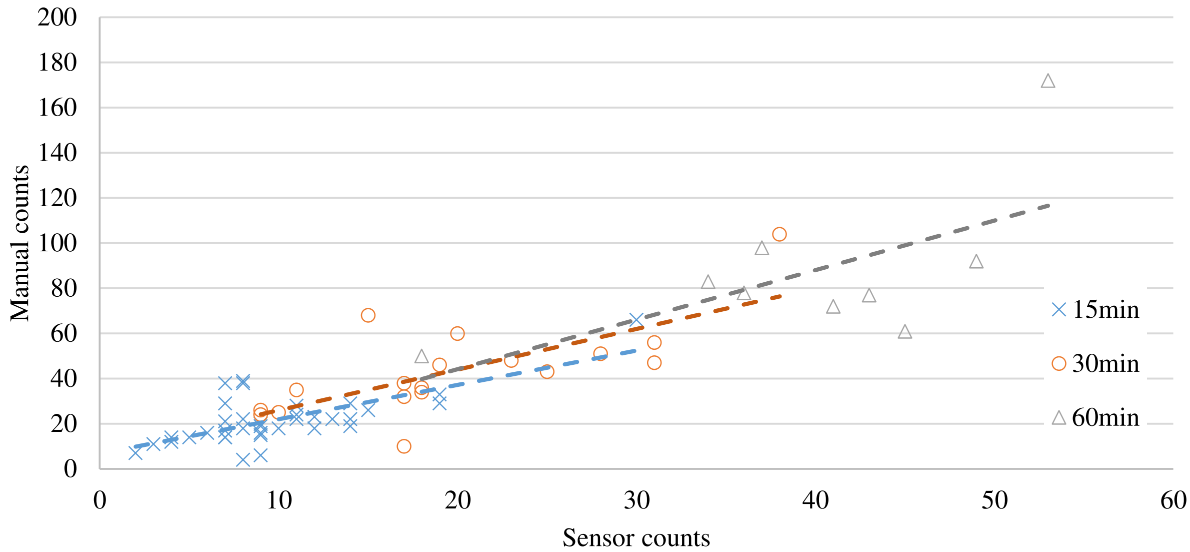

Figure 9 Linear regression analysis between manually and sensor counted pedestrian volumes for samples <350 manual counts

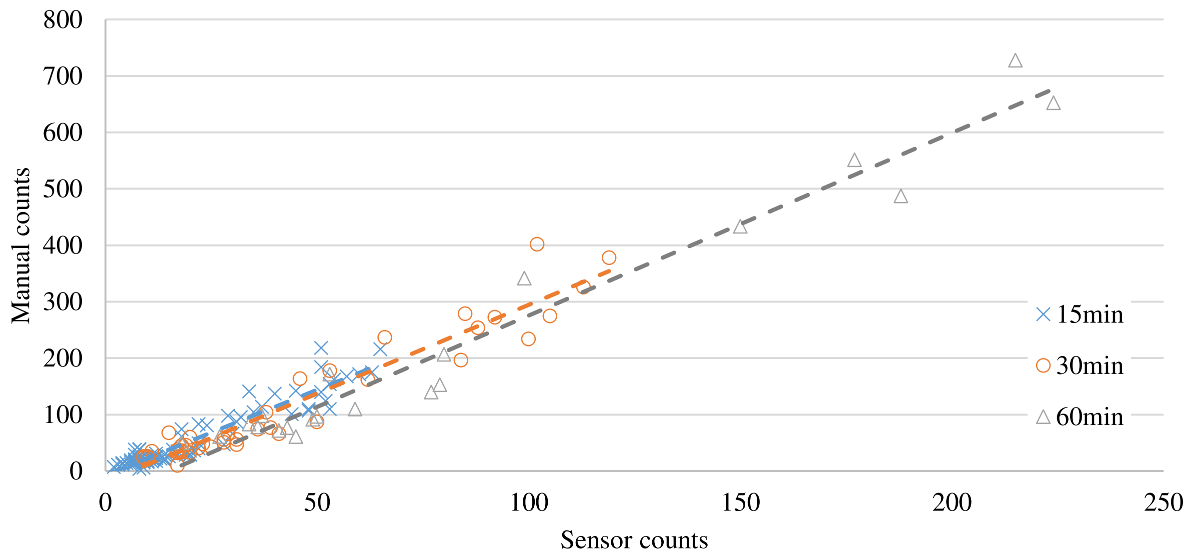

Figure 10 Linear regression analysis between manually and sensor counted pedestrian volumes for all manual counted samples

Both figures indicate a linear relationship of the respective data sets. A positive linear trend, between the detections of the Wi-Fi sensor equipment and the parallel done manual counts can be concluded out of Figure 9 and Figure 10. The corresponding linear regression functions are presented in Table 5 and Table 6.

To proof the suitability of used linear regression functions for estimating pedestrian and cyclist volumes, the developed method was applied for the data set of March, 18th. The field test of March, 18th was performed at the Gangbrua bridge. Two-hundred and thirty-six passing people were manually detected and the equipment's penetration rate was 41%. The field test is so sorted in the group of less than 350 detections in the chosen three hour intervals. The data set of March, 18th was, as mentioned, excluded from the for the estimations used data sets. The so generated estimation functions are based on the in Figure 9 shown graphs and presented in Table 5.

Table 5 Linear regression analysis for the data from Fig. 9

Function	Time Interval	R^2	Total Deviation
y = 1,5184x + 6,7346	15	0,485	-3%
y = 1,8002x + 7,8966	30	0,581	-6%
y = 2,1926x + 0,2686	60	0,405	-10%

The goodness of fit of the used functions is described by the coefficient of determination R^2. It illustrates the correlation between the two data sets and is for each time span in a satisfying range. The total deviation describes the percentage divergence between the estimated total number and the manually counted pedestrian volume for each time interval. All estimation functions are lightly underestimating the real amount of people passing by, but are also within an acceptable range.

Also the usage of more general estimation functions, based on all data sets, without pre-filtering them according to their specific volumes were examined and tested. Table 6 shows these functions for the equal time intervals. In this case are the shown functions, based on the graphs shown in Figure 10.

Table 6 Linear regression analysis for the data from Fig. 10

Function	Time Interval	R^2	Total Deviation
y = 3,0311x - 7,7422	15	0,897	-15%
y = 3,1463x - 20,372	30	0,925	-22%
y = 3,2386x - 48,569	60	0,964	-29%

The R^2 values are also quite promising, but the higher total deviations are indicating a less reliable estimation of the pedestrian volumes, compared to the previous data set. The regression functions from Table 5 and Table 6 were, as mentioned used to estimate the pedestrian numbers from the sensor-counted data at Gangbrua bridge on March 18th. The resulting graphs are presented in Figure 11.

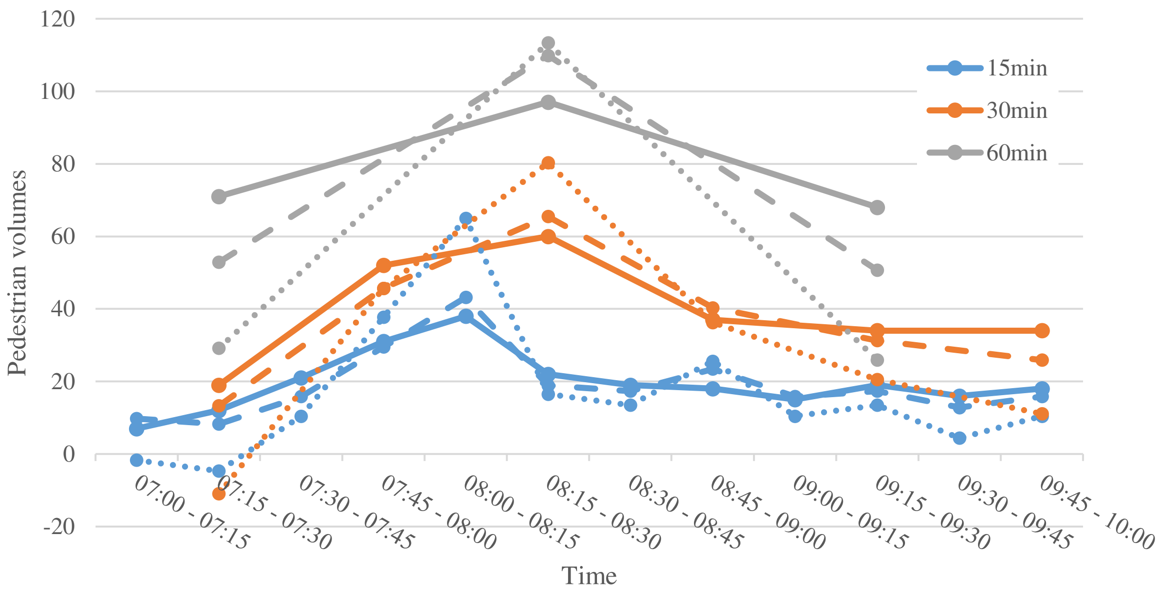

Figure 11Estimations March, 18th

The solid lines in Figure 11 represent the manually counted numbers of each time interval, while the dashed and dotted lines are the results of the estimation functions based on the data, generated by the sensors. The dashed lines refer to the functions presented in Table 5, using the data sets with less than 350 observations. The dotted lines refer to the more general estimations functions presented in Table 6 and including all detected data sets.

The estimations based on the grouped data set fit closer with the manual counted traffic volumes. The estimations based on the non-grouped data set also follow the structure of the manual counts, but are more vulnerable to over- and underestimations of particular data points.

5. Conclusion and Recommendations for further research

Throughout the implemented field studies and the following data evaluation and processing approaches, the suitability of especially the Wi-Fi sensors for counting non-motorized travel users was confirmed.

The controlled test runs showed the specific probabilities of detecting passing, enabled Bluetooth and Wi-Fi devices. One of the main challenges of the study was the development of a data processing strategy for the one-sensor approach in order to distinguish moving from stationary devices. The developed method proposed the RSSI values as a main tool to select moving devices out of the generated data sets. Further research approaches should include further examination of the raw data set to gain additional information about movement or behavior characteristics of the detected devices.

The evaluated data sets showed that most detections during the following field studies were made by the Wi-Fi antennas (91 to 99% of all detections). This was particularly true for the . two-sensor field experiment. Based on this observation, we conclude that the main focus for monitoring pedestrians should be put onto Wi-Fi data sets. The popularity of utilizing Wi-Fi can play a substantial role in the predominance of Wi-Fi devices in the present study. As Wi-Fi is often used for the internet access of mobile devices, users may tend to keep their devices in the enabled mode to increase the chance of getting connected to any nearby Wi-Fi network, while Bluetooth might rather be used on demand. The comparison of the generated data sets indicated the ability of the Wi-Fi data to follow the structure of manual counts done in parallel, by detecting peak and bottom points according to the corresponding manually counted numbers.

Beside the concluded general suitability of Wi-Fi sensors for counting approaches, discrimination between different modes of travel could not be further investigated within this study. As the used sensor equipment was basically designed for the detection of travel times for the motorized transport, the antennas were operating with relatively high sending powers. When using this equipment in narrow inner city areas like the present study, the overlapping of the antennas coverage zones is hard to avoid. For reliable travel time estimations, the detection zone of the sensors should be segregated with a certain distance in between. Travel times are defined as the time the devices need to travel from one sensor to the other. If the sensor coverage zones are overlapping, the devices are detected by both sensors at the same time. Nevertheless, pedestrians travel times can also be detected in narrow and dense inner city areas. To do so, the characteristics of the antenna equipment have to be adapted accordingly. For instance, smaller antenna ranges are sufficient for a reliable detection due to the slow velocities of pedestrians. Furthermore, the usage of omnidirectional antennas can be recommended. The circle form of these antennas detection zones is more appropriate for registering the crowd based movement characteristics of walking people along frequented corridors or at special points of interest in urban areas, like squares, bridges or plazas.

The estimations, based on the Wi-Fi data set approximate the manually detected volumes. Adjustment of the used linear estimation functions according to the expected amount of passing devices resulted in a higher accuracy of the estimations. The developed functions are based on the field tests at the two observed testing locations. Ongoing field tests and the inclusion of more and different locations can further improve the quality of the suggested estimation functions.

During this study the general ability of Wi-Fi sensors as tools for counting non-motorized travel users was confirmed. Their usage can be recommended considering several boundary conditions. The sensor equipment applied in this study was not tailor-made for pedestrian counting approaches and hence had several drawbacks. Especially the not possible distinguishing between the observed modes of travel by using the mentioned sensor equipment in the chosen field test locations has to be mentioned. The presented alternatives, especially for the antennas should be recognized for further research approaches. Considering this, reliable travel time data can also be collected, which is an essential data base for the speed-based distinguishing between pedestrians, cyclists and the motorized travel.

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Part II – Process Report

Digital based Pedestrian Counting

Maximilian Franz Böhm

Preface

This master thesis is written during the spring semester of 2016 at the Department of Civil and Transport Engineering at the Norwegian University of Science and Technology (NTNU).

The master thesis constitutes a total of 30 credits and was written during an exchange semester. The thesis is the final work of a two-year master program in transport engineering, studied at the University of Wuppertal in Germany. The thesis is submitted at the Department of Civil and Transport Engineering at the NTNU and will be acknowledged as a master thesis, and part of the final degree in transport engineering at the University of Wuppertal, as well.

Unlike a traditional master thesis, this thesis consists of a scientific paper (I), a corresponding process report (II) and an appendix (III). The sum of these parts is the equivalent to a traditional master thesis. The process report gives a more detailed overview about the done practical and theoretical work, which could not have been included into the scientific paper. Additional tables or data sets are included in the appendix. The paper was chosen to be put ahead of the process report, because of the so followed logical structure of the work.

The article “Evaluating the usage of Wi-Fi and Bluetooth based sensors for pedestrian counting in urban areas” is going to be presented during a breakout session at the walk21 conference in Hong Kong in the beginning of October 2016.

I want to thank everyone who has contributed to this project, the Statens vegvesen Vegdirektoratet in Trondheim, my supervisors and my family and friends. A special thanks to Eirin Ryeng, Torbjørn Haugen and Jürgen Gerlach, for their given inputs and the valuable guidance.

Summary

The possibility of detecting the MAC addresses of Bluetooth and Wi-Fi devices, motivated transport researchers throughout the last years, to use this data for several applications in transport engineering. Especially the estimation of travel times for the motorized transport by using these data sets showed promising results. The increasing usage of mobile devices, equipped with Bluetooth and Wi-Fi interfaces throughout the last years, creates new possibilities in using the mentioned sensors also for pedestrian data collection. This study is about to examine the usage of Wi-Fi and Bluetooth sensors for pedestrian counting, especially in urban areas.

A literature review has been conducted, to get a better understanding about the technical background of the system. Scientific studies, dealing with the usage of Bluetooth and Wi-Fi sensors for traffic detecting and counting were studied to get an overview about the current state of the art in this area of transport engineering. As a next step the sensor equipment was about to be tested in urban surroundings. The gained knowledge from the literature analysis was used, to set up open field tests. Besides these test runs, parallel manual counts were done to different times of the day and during peak and non-peak hours, to investigate the coverage of the generated data compared to the manual counts. To evaluate the data sets, generated by the sensors, a data processing methodology was developed and used for the further data evaluation.

The results indicated especially the suitability of the Wi-Fi Sensors, for following the structure of the comparatively done manual counts. Due to the suboptimal hardware settings of the used sensors, the generated data sets could not be used for distinguishing between the observed modes of travel. Further recommendations were given, how a speed based distinguishing between different modes of travel can be done by using Bluetooth and Wi-Fi sensors. As a last part of the work, the generated data sets were used to estimate the manual counted pedestrian volumes out of the sensors data sets.

Contents

List of Tables

List of Figures

List of Abbreviations

BT: Bluetooth

Wi-Fi: Wireless Fidelity

dBi: decibels-isotropic

Ghz: Gigahertz

Mhz: Megahertz

USB: Universal Serial Bus

IEEE: Institute of Electrical and Electronics Engineers

RSSI: Received Signal Strength Indicator

1 Introduction

1.1 Motivation

An improvement of the pedestrian infrastructure, as well as a higher amount of people walking in inner city areas are desirable. Urban areas with a high amount of walking people are often an indicator for a livable neighborhood. Promoting the walkability of cities has many positive effects and can be an indicator for a cities vitality.

Pedestrian volumes are one of the key performances to argue for an enhancement of walkability and to evaluate the impact of pedestrian infrastructure improvements. Probably the most promising strategy for improving the amount and the quality of pedestrian volumes data are automatically counts. Automatic traffic counting techniques are nowadays mainly used for the detection and counting of motorized modes of travel. Unfortunately, units for automatic pedestrian counting in outdoor areas are not very well developed and further investigations in that particular field have to be done. Especially some research result about the effectiveness and the reliability of devices for automatic counts are missing. The so far existing techniques for the detection of pedestrians are mainly used and designed for indoor environments and are often not suitable for urban outdoor areas. Like in other modes of transport, a reliable and permanent source for generating automatic counts would also be highly welcomed in the field of pedestrian counting.

Especially in developed countries, the usage of mobile devices such as smartphones or other communication units increased throughout the last years. Many of these gadgets are equipped with the wireless communication interfaces Bluetooth and Wi-Fi. Within the last years, sensors were developed to detect such devices while they were passing. Researchers used that equipment as a tool to estimate travel times between two mounted sensors in the field of transport engineering. Also first approaches towards the usage of the mentioned equipment for traffic counting were made. Unfortunately, most of these techniques were used in the field of motorized transport and sensors were mounted along highways or main arterial roads. The knowledge about the usage of these approaches for the non-motorized travel has to be further investigated. During this study, especially the suitability of Bluetooth and Wi-Fi sensors for counting pedestrians in urban areas, is about to be tested.

1.2 Research Question

As mentioned above, further approaches towards a better understanding of the usability of Bluetooth and Wi-Fi sensors, especially for pedestrian travel issues, are desirable. To gather information about pedestrian volumes the sensors have to be tested, whether they are suitable for counting passing pedestrians. The suitability and accuracy of such counts may differ between particular locations and due to the sensor set up. The during the study used BlipTrack sensors were developed by the Danish company Blip Systems and have been provided by the NTNU. That study is about to examine the following questions:

- Are Bluetooth and Wi-Fi Sensors suitable for counting pedestrians in inner city areas?
- Is the BlipTrack equipment suitable tool for doing theses counting?
- How can the equipment be set up due to the particular testing location?
- How do the results alter due to the different examined testing locations and due to different days and various peak and non-peak hours?

To summarize these research goals, the following research question for the master thesis project was raised: "Is the usage of Bluetooth and Wi-Fi sensors suitable for estimating the amount of pedestrians in different inner city areas in a reliable and accurate way?"

1.3 Objectives & Limitations

The main objective of this project is to answer the research question and to figure out, whether the usage of Wi-Fi and Bluetooth sensors are suitable for estimating the amount of pedestrians in urban areas, in a reliable way.

Therefore, field tests were conducted and the resulting data sets were analyzed. The generated results were used for estimating pedestrian volumes, based on the generated sensor data. In a further usage, the equipment might be mounted in a particular urban area and the generated data sets could be used for an estimation of the real amount of passing people.

It has also been an objective to submit the results (scientific paper) for presentation at an international conference. The paper was accepted for being presented during a breakout session at the walk21 conference which will take place in Hong Kong in October 2016.

Besides the generated results and the concluded findings, also the limitations of the sensor equipment were considered. The restricted time horizon of five months for the master thesis project, was one of the main limitations. A wider time span would have improved the generated results, by conducting more open field tests, to increase the reliability of the results. Also some technical limitations of the used sensor equipment had to be mentioned. Especially the discovered boundaries of collecting reliable travel times for pedestrians, by using the BlipTrack sensor system during the conducted field tests has to be seen as a technical limitation in the usage of the system.

1.4 Structure of Work

The process report of this master thesis consists of 6 chapters.

Chapter 2 two gives an overview about the used methodology during the study.

Chapter 3 introduces into important technical basics, which should be understood by using Bluetooth and Wi-Fi sensors for traffic counting approaches.

In chapter 4 suitable open field test locations are examined and a data processing technique is presented, to evaluate the through the sensors generated data sets.

Chapter 5 presents and discusses the results of the conducted field tests, using the previously developed data evaluation method. Based on the generated data sets a pedestrian volume estimation technique is developed.

In chapter 6, conclusions based on the done work and the gained knowledge are made. Also recommendations for ongoing research approaches within the field of digital pedestrian counting are given.

2 Research Methodology

A main part of the master thesis project was the development of the used methodology for answering the given research question

2.1 Investigating the technical background and literature analysis

For a better understanding of the current state of the art situation in automatic motorized and non-motorized traffic counting, a detailed literature analysis was implemented. Due to the importance of gaining a technical understanding for the used system, a focus of the literature study was the investigation of the Bluetooth and Wi-Fi technology as well as the technical characteristics of the used antennas. Furthermore, special characteristics of pedestrian movement are examined and technical conclusions due to special requirements for the technical system were made.

The literature analysis was also used to gather information about the current state of the art in automated traffic counting. After an introduction into that topic and the presentation of current approaches for the motorized traffic, the focus was put onto methods of automated detections and counting of non-motorized traffic users. Several international scientific papers were examined and knowledge about current research approaches in that particular field were accumulated.

Main sources for the literature analysis were the google scholar search as well as the Oria system which is provided by NTNU university bibliotheca. The following words and combinations were mainly used during the searching for relevant literature:

- Automatic pedestrian counting
- Pedestrian detection
- Bluetooth and Wi-Fi
- Bluetooth and Wi-Fi MAC address scanning
- Travel time estimations

Most of the used literature was written in English and also a few publications in German were mentioned. The wide accessibility of scientific papers for NTNU students was a very helpful circumstance for collecting a broad literature data base.

The results of the done literature analysis are included in many parts of the study. The gained information was used for an appropriate set up of the open field studies, as well as for earning important knowledge about many technical issues. Especially during the development of the used data evaluation and processing method, the knowledge gained throughout the literature review was required.

2.2 Conceptual Approach to Field Tests

To evaluate the suitability of the used BlipTrack sensor equipment for automatic pedestrian counting, the sensors were about to be tested in urban areas. The usage of different sensor set ups for counting passing devices were further examined. Tests by using only one sensor, as well as two sensor set ups, were conducted.

To evaluate the accuracy of the used equipment a controlled test during the night was implemented. The mounted sensor was passed with a known amount of Bluetooth and Wi-Fi devices to figure out how many of them are detected.

The basic idea of the mentioned one sensor approach is to detect the devices while they are in the sensor's detection zone. To figure out whether the BlipTrack system is suitable for that methodology, only one sensor was mounted in previously chosen locations in the inner city of Trondheim. Afterwards, also experiments with a two sensor set up were done at these locations. In this case, only devices were registered, which were detected by both of the mounted sensors. Benefits and drawbacks of the mentioned different set ups are discussed in the study.

The field test locations were chosen due to their local characteristics and the expected pedestrian volumes. To investigate the reliability of the sensor counts, generated during the field tests, parallel manual counts were done. These took place at all field test locations and were done during the morning peak from 07:00 – 10:00, the afternoon peak from 15:00 – 18:00 and around midday from 12:00 – 15:00. Both, peak and non-peak hours were observed, to examine potential differences within the sensor's counting accuracy.

2.3 Data Evaluation and Analysis Techniques

All sensors have a mobile internet connection to send the detected data sets to a Blip Systems web portal. The raw data sets generated by the sensors are further processed by Blip Systems and are afterwards available, to be checked or downloaded from a web page. The counting data can be downloaded as a Microsoft Excel spreadsheet for further own data reprocessing. The provided online dashboards are not used during the data evaluation process. Instead, the data processed by Blip Systems was downloaded and furthermore Microsoft Excel was used to compare the previous done manual counts with the sensor detections.

Due to poor results of the gained data sets, an own data filtering technique was developed. Therefore, the raw and not further processed data output from the sensors was requested from Blip Systems. The data was sent in a *.dsv data format, which was converted into a Microsoft Excel spreadsheet. The precise data filtering technique is described in chapter 4.4 within the process report, as well as in the scientific paper.

3 Theoretical Framework

For a better understanding of how Bluetooth and Wi-Fi sensors can be used for automatic pedestrian counting, some technical basics must be considered. Moreover, it is important to understand how and under which circumstances road users can be automatically counted. This section is meant to give a more detailed overview about technical aspects, than it was possible to give in the article. Certain questions which are about to be examined in the following chapter are:

- How do the wireless interfaces Bluetooth & Wi-Fi basically work?
- Under which technical circumstances can BT & Wi-Fi devices be detected by sensors?
- How can MAC addresses be used for traffic detection approaches?
- Which effects can the technical characteristics of the used antennas have on the collected data?
- What are the basic technical characteristics of the BlipTrack sensors and how do they operate?

3.1 Wireless communication technologies

3.1.1 Bluetooth

Bluetooth is a since 1998 developed industrial standard according to the IEEE 802 classification for wireless data exchange in short ranges, between mobile or fixed devices (Chakraborty , et al., 2008). It is a standardized network protocol with mature benefits, like a worldwide spread usage, a high cost effectivity and a relatively easy development architecture. Each device has its own globally unique 48-bit Media Access Control (MAC) address.

Bluetooth uses short wavelength radio waves in the industrial, scientific and medical (ISM) radio band between 2.4 and 2.485 Gigahertz (GHz). The radio band is shared with other short radio applications, like Wi-Fi or microwave ovens, which can cause disturbances (Araghi , et al., 2014). To achieve a high robustness against disturbances a frequency hopping system is used. The frequency band is divided in 79 1 Megahertz (Mhz) large sections. The devices are changing between these 79 channels up 1600 times per second (625 µs per channel) to avoid interferences with other devices (Abbott-Jard, et al., 2013). Figure 1 shows the principal of frequency hopping.

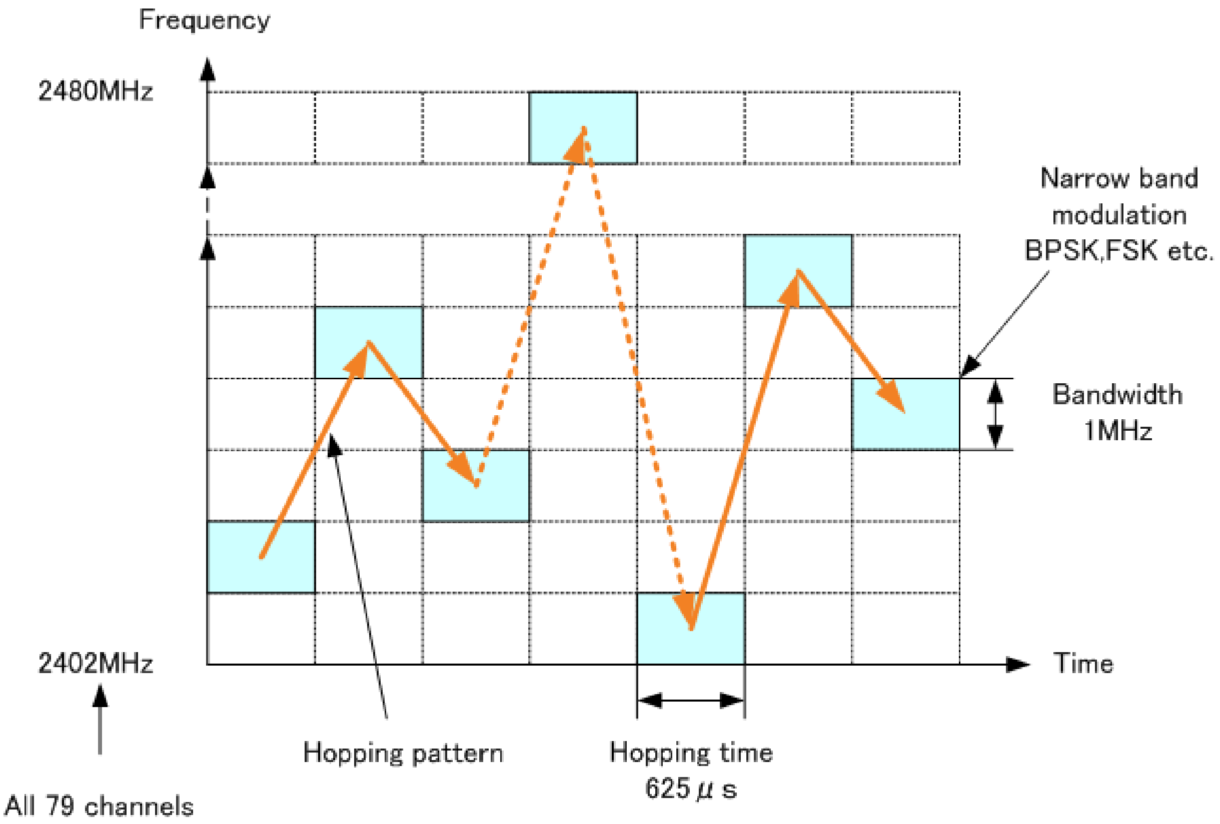

Figure 1 Bluetooth frequency hopping (www.cdt21.com)

The operation range of a Bluetooth device depends on its BT classification. The range of the signal differs between the 3 BT classes, from 1 over 10 up to 100 meters (Chakraborty , et al., 2008). A further important aspect is to understand the different states in which Bluetooth devices can operate and how they can get connected. The simplest form of a BT network is a so called piconet, consisting out of a master and a several number of slave devices. The connection process is basically divided into the inquiry and the paging phase. The inquiry phase is used to discover other, available devices which are willing to join a network within the range and to exchange the therefore necessary information to set up a connection. The master device tries to invite other devices to the piconet by transmitting a standard inquiry packet on different hop channels and waits for response packets, send by the slave devices. If the slave device answers after receiving the master's inquiry package, the master device switches into the page mode. Also in the page mode the master device will send a data package to the slave device which must also have switched to page mode. If the master device gets a response from the slave unit in the page state, a connection can be established (Abbott-Jard, et al., 2013). To clarify that procedure, Figure 2 gives a graphic overview about the BT connection process.

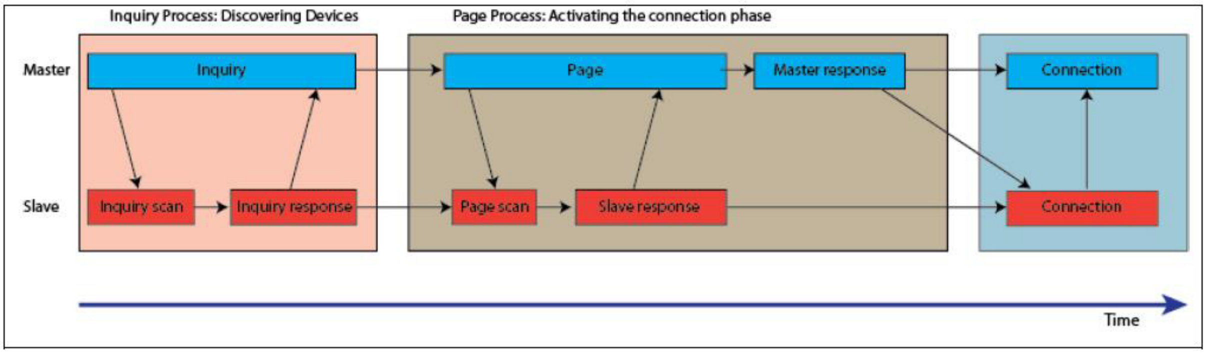

Figure 2 Bluetooth connection process (Abbott-Jard, et al., 2013)

In order to be able to track a passing Bluetooth enabled device, it is sufficient to conduct the inquiry phase to detect the device (Araghi , et al., 2014). Bluetooth scanners will never make a full connection with the available Bluetooth device (Abedi, et al., 2013). The in Figure 2 mentioned phases are therefore not needed. The required MAC address of the BT device is already transmitted in the inquiry phase. Due to the complex frequency hopping procedure, the inquiry detection time of a single device may take up to 10,24s, but the most devices are found within 5s (Chakraborty , et al., 2008).

3.1.2 Wi-Fi

Like Bluetooth, Wi-Fi is a wireless communication standard, designed for establishing local area network connections. Wi-Fi is a wireless local area network (WLAN), based on the IEEE 802.11 standard (Han, et al., 2012). Many daily used devices are equipped with Wi-Fi interfaces. Besides nearly all smartphones and notebook computers, also TVs and eBook readers do often have the possibility to establish a Wi-Fi connection.

Two basic operation modes are used by Wi-Fi devices to connect each other. The infrastructure mode uses an existing network infrastructure like a router to connect several Wi-Fi devices with each other. A second alternative is a connection between devices in the so called ad hoc mode. Devices in one of the mentioned modes will send beacon messages to announce the presence of the established network. The default set sending time of these messages is 100ms. The beacon message includes information about network specific characteristics like capability information and the networks service set identifier. The Wi-Fi interfaces of mobile phones operate in the ad hoc mode to find a potential network and are sending beacon messages while they are operating in this particular setting. Wi-Fi devices are also scanning the used wireless channels of 2,4 and 5 GHz to discover peers which are sending beacon messages. As modes of scanning, an active and a passive mode exists (Han, et al., 2012). During the passive scanning mode, the devices are listening to incoming beacon messages at regular time intervals and are switching between the two mentioned channels. In the passive mode, the device is not responding the beacon messages. Operating in the active scanning mode, the device actively searches for other devices by broadcasting probe a probe request messages and waits for responses. The sensors are using these scanning trials in the active mode to detect devices in their surroundings (Abbott-Jard, et al., 2013). The discovery time, using the presented procedure takes about 1s (Chakraborty et al 2010) for a detection, and is lower than the introduced Bluetooth discovery time.

3.2 MAC Address Tracking

MAC addresses are unique identifiers which are used for various types of communication networks and most of IEEE 802 network technologies, such as Wi-Fi and Bluetooth (Abedi, et al., 2013). Nowadays, the majority of smartphones and digital mobile devices uses Bluetooth and Wi-Fi technologies to exchange data between each other and for mobile internet access. Each of these devices can be doubtlessly identified via its unique MAC address. Hence, they can be traced, which motivates researches for several applications of data collection in the field of transport planning. Examples off a further usage, besides the detection of devices, are also routing, counting or travel time estimation approaches based on the MAC address data. The MAC address discovery time of the used wireless interface and the characteristics of the sensor's antennas are important factors in terms of efficient data collection.

Throughout the last years, especially Bluetooth scanners were used for detecting motorized vehicles along roads and to estimate their travel time (Abbott-Jard, et al., 2013). These scanners are a popular method for mainly detecting cars, due to the fact that a lot of the inner car communication is operated via Bluetooth wireless interfaces. Especially new cars are widely equipped with that technique. Toyota Germany confirmed, that in 2010 60 – 65% of all delivered cars were equipped with at least one Bluetooth interface (Margreiter, 2010). Time synchronized Bluetooth sensors, positioned along motorways and road networks have the potential to provide a live monitoring of passing devices with an enabled Bluetooth interface. Scientific studies investigated that technique and it was used along highways (Araghi , et al., 2014), as well as on inner city arterial main roads (Abbott-Jard, et al., 2013). The mentioned research efforts were mainly focused on the detection of motorized travel. The described MAC scanning method is a relative cost effective approach to gather several information about road users.

The success of using the Bluetooth interface for generating travel times has attracted further attention of exploring possibilities of Wi-Fi scanning sensors as a complementary or alternative data source (Abedi, et al., 2015). Previous research publications figured out, that the amount of Bluetooth devices along the users of non-motorized modes of travel is quite poor (Malinovskiy, et al., 2012) (Abedi, et al., 2015). So there might be a potential in the collection of Wi-Fi based data sets to improve the coverage among users of the non-motorized modes of travel.

As already mentioned in the scientific paper, several different sensor set ups for counting approaches are possible. Most common is the usage of a two sensor set up for measuring travel times of the in between moving devices. In this study, the potential usage of one sensor for counting approaches was examined. Besides these solutions, also three or even more sensors can potentially be mounted, to use them for filtering or routing approaches.

The main challenge of the one sensor methodology is the cooperativity between the sensors detections and the parallel conducted manual counts. While the manual counts are done along a distinct line in front of the sensor, the MAC addresses of Bluetooth and Wi-Fi devices are detected by the sensors when the wireless interaction space of the devices intersects the scanning area of the sensor (O'Neil, et al., 2006). Even in simple urban geometries, this approach is not completely predictable due to the variability of technical issues of the device and the potential coverage of surrounded BT and Wi-Fi devices. In urban areas the situation gets further complicated through the detection of devices traveling along covered adjacent streets or permanently located in the sensors' detection zones. Devices which enter the detection zone and leave it again, without passing the distinct line in front of the sensor, might be detected but are not included in the comparative manual count. The mentioned challenges do not affect a two or more sensor set up, because in this case only devices, which are detected by more than one sensor, are registered. If the detection zones of the sensors are not overlapping, only moving devices between the sensors are registered.

Another challenge of using MAC address data sets is, that their sample size does not represent the real amount of road users. It is possible, that people who carry more than one device with them might be detected more than once. People who do not carry any active BT or Wi-Fi device while they are passing a sensor will also not be detected. Besides this, Figure 3 shows that there is also an assured uncertainty whether people, carrying an enabled BT or Wi-Fi device with them and theoretically could be detected, are also discovered by the used sensor equipment. To investigate that question, a controlled field test has been set up, whose results are presented in chapter 5.1.

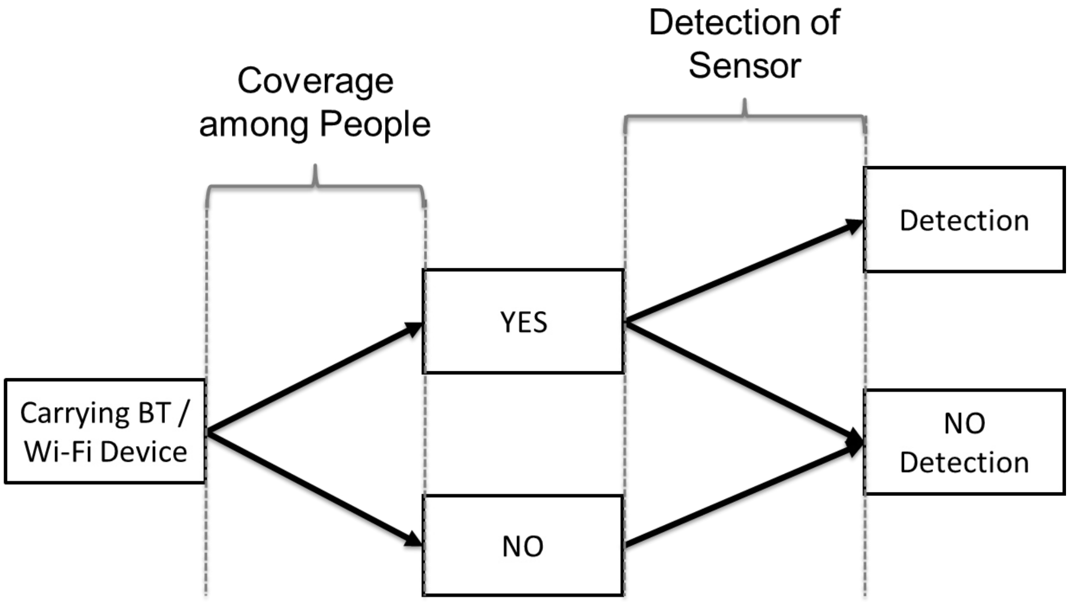

Figure 3 Detection probability of passing people

In addition to above mentioned concerns, the fact that special user groups might be underrepresented by using the technique of MAC address detection for traffic counting approaches has to be considered as well. Especially groups of people who should be intensely mentioned within the field of traffic planning, like children or elderly people, might be underrepresented in the generated data sets.

3.3 Wi-Fi & Bluetooth Antenna Characteristics

The probability of the detection of a BT or Wi-Fi device is essentially dependent on the characteristics of the used antenna equipment. Some aspects which are important to understand how the antenna hardware can affect a satisfying amount of detections due to the specific usage are the:

- Used antennas signal strength
- Size and shape of the detection zone
- Time in which the enabled transmitter is in the sensors detection zone
- Speed of the transmitting device

Especially in the regarded field of pedestrian counting with Bluetooth and Wi-Fi sensors the characteristics of the used antenna equipment should be intensively mentioned.

Which specific antenna is used, often depends on the mode of travel, that is about to be detected. The registration of cars along arterial main roads requires different antenna coverage zones than the often more crowed based movements of pedestrians in urban locations. For a successful detection it is necessary that the travelling device stays in the zone at least the amount of time the hardware based detection requires. As mentioned above, the detection time for Bluetooth is around 10 seconds in maximum but normally around an average of 5 seconds. Considering Wi-Fi devices, the detection time is around 1,4 seconds for a device. The probability of detecting a device is rising, the longer a device is stays within the antennas coverage area (Araghi , et al., 2014). Table 1 gives an overview about the residence time of a passing device in a 50m long corridor, due to its mode of travel.

Table 1 Mode of travel speed / time in detection zone

Mode of Travel	Speed	Time in 50 m Zone
Car	50km/h → 13,9 m/s	3,6 s
Bike	20km/h → 5,6 m/s	8,9 s
Walking	5km/h → 1,4 m/s	36.2 s

The velocities are chosen as typical speed levels of the mentioned modes of travel in inner city areas. The calculated times in which the users of a specific mode of travel are staying inside of a 50m wide zone are within a range between 3,6 and 36,2 seconds. Regarding the short time period of 3,6s for cars, staying in the exemplary 50m zone, it can be concluded that especially the probability of detecting Bluetooth devices (detection time approx. 5s) might be too short. To enlarge the chance of a successful detection of users traveling 50 km/h or more, the detection zone for catching these devices should be larger. An appropriate size for devices traveling with that speed would be at least 100m.

As a second user group cyclists are observed. There average speed is much slower, compared to motorized vehicles and therefore, the detection time within a 50m zone is higher. The calculated time of cyclists in a 50m zone is 8,9 seconds which is satisfying for the detection of Wi-Fi devices, but could be a bit longer, regarding the Bluetooth interface. For the group of pedestrians, a walking speed of 5 km/h is assumed. The resulting timespan in which pedestrians are in a 50m zone is 36,2 seconds which can be regarded as sufficient for both, an appropriate probability for the Wi-Fi as well as the Bluetooth detection.

Summarizing these information, recommendations for the optimal size of a detection zone due to the special usage can be given. While the detection zones for fast traveling motorized transport should be quite big, smaller sizes for non-motorized modes of transport are also suitable for achieving a satisfying probability of detecting such a device. In addition to the size of the detection area the moving behavior of different road users should be examined for designing the size and especially the shape of the antennas detection zone.

Regarding the hardware based antenna properties two main used antennas are introduced. The two types of antennas which are mostly used as Bluetooth and Wi-Fi sensors are directional and omni-directional antennas. Both shapes are presented in Figure 4.

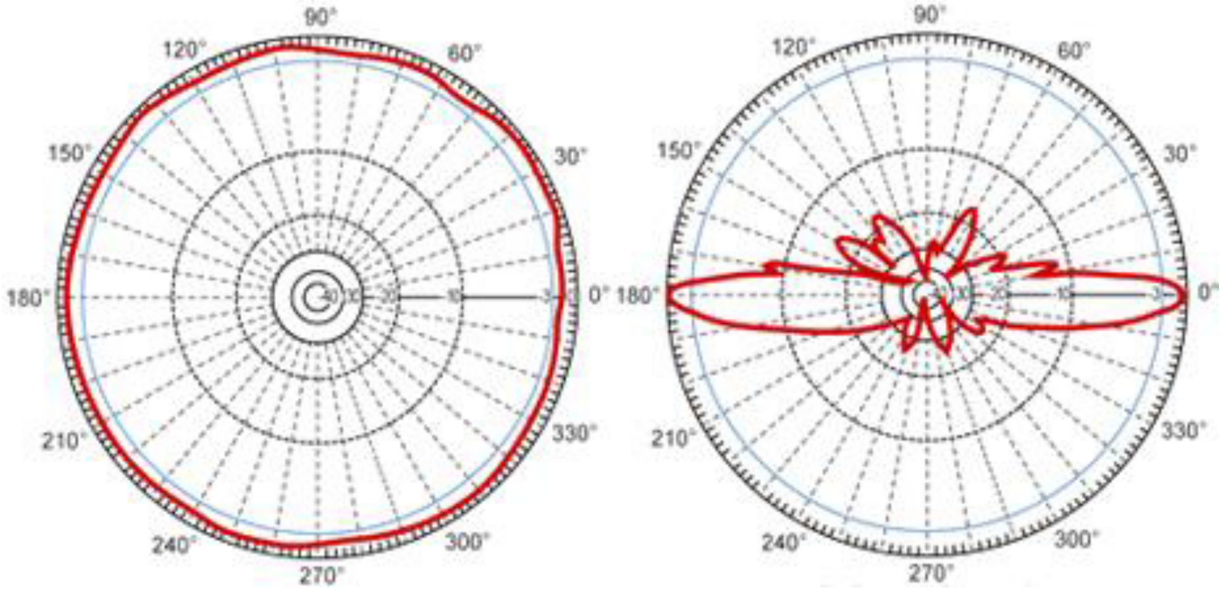

Figure 4 omni-directional antenna (left) / directional antennas (right) (www.bitstrom.com)

As shown in Figure 4 are directional antennas operating in a particular beam while directional antennas have a spreading of 360° and cannot be directed in any way. The right sided antenna characteristic in Figure 4 shows two directional antennas, operating in a 180° opposite direction with a directed sending beam of around 30°. Directional antennas can be used for detections along linear elements, such as longer, straight road sections. Omni-directional equipment can better be used to observe more complex geometries, such as a square or any point of interest.

As considered above, besides its type the ranges of particular antennas should be mentioned as well. The power gain unit of an antenna is expressed in decibel and is called decibel-isotropic (dBi). To get an impression about the particular ranges of different antennas Table 2 shows the results of range tests due to different gain strengths (Abedi, et al., 2015).

Table 2 Antenna radius and dBi (Abedi, et al., 2015)

Antenna gain (dBi)	Wi-Fi radius in m	BT radius in m
2	85	55
5	130	100
7	140	110
10	145	120

Basically higher antenna gains provide larger scanning ranges but working with a larger scanning area has also an effect on the local accuracy of the detected device. While there are more detected devices in a larger scanning area, the quality of the data in terms of the local accuracy of a single detection can be less satisfying compared to data, which is collected with smaller antenna ranges. This situation can be regarded as a tradeoff between a high sample rate, which means detecting many people due to the high antenna range, and the local ambiguity of the detections. The price of having a large covered area is then a lag of accurate information due to the precise location of the detected device. Figure 5 clarifies the above mentioned circumstance as a graphic.

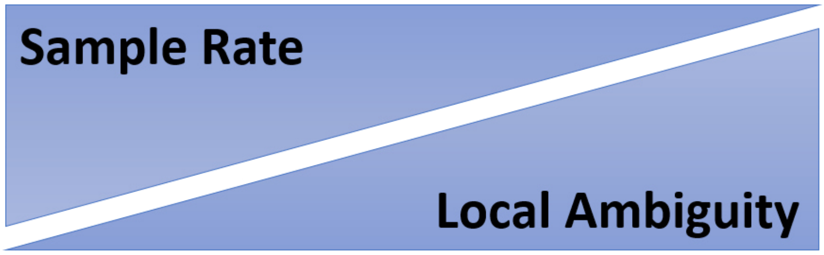

Figure 5 Tradeoff sample rate / local ambiguity

In addition to the previous mentioned aspects, another disadvantage of using a larger scanning area for pedestrian counting is, that the data may include more so called background noises. Background noise signals are created by fixed BT or Wi-Fi devices like Wi-Fi routers or computers, standing in the sensor's coverage zone and are detected by the sensors. They are included in the sensor's data set but are not indicating a moving device. A possible small amount of fixed devices within a sensors data set is desirable and facilitates the following data processing. Due to the fact, that pedestrian counting approaches are mostly done in dense populated urban areas, a certain amount of background noise signals within the data set is hard to avoid.

3.4 BlipTrack Sensor System

The BlipTrack Bluetooth and Wi-Fi sensors, used during the study, were developed by the Danish company Blip Systems. The set up for a measurement consists of a battery unit, a Wi-Fi and a Bluetooth sensor. As shown in Figure 6 are they mounted along an iron pole and can be placed in several urban surroundings. In this case, the upper sensor unit is the BT and the downer one the Wi-Fi sensor. The sensor unit is mobile and can be mounted in any urban surrounding. The sensors should be locked with a chain to an existing pole or a traffic sign, a tree or any fixed urban furniture.

Figure 6 BlipTrack sensor Øvre Bakklandet

According to the paper, an overview about the used antenna equipment is given in Table 3.

Table 3 Antenna characteristics BlipTrack sensors

Antenna Type	Amount	Type	sending power	approx. range in m
Wi-Fi	2	directional	5 dBi	140m
Bluetooth	2	directional	20 dBi	130m
Bluetooth	1	omni- directional	4 dBi	50m

The main unit of the BlipTrack sensor equipment is the Bluetooth sensor. It is equipped with two directional and one omni-directional antenna. The used omni-directonal Bluetooth antenna has a sending power of approx. 4dBi. The range of that 360° spreading antenna is approximately 50 m in an outdoor surrounding. The antenna is located in the middle of the used Bluetooth sensor. As shown in Figure 7, the two grey directional Bluetooth antennas (BT1 & BT2) are positioned on the opposite sides of the sensor. Their sending beam width is 70 degrees with a gain power of 20 dBi (Blip Systems, 2012). The resulting detection range of these two antennas is approximately 130 m. The communication unit for the live upload of the data is also integrated in the Bluetooth sensor.

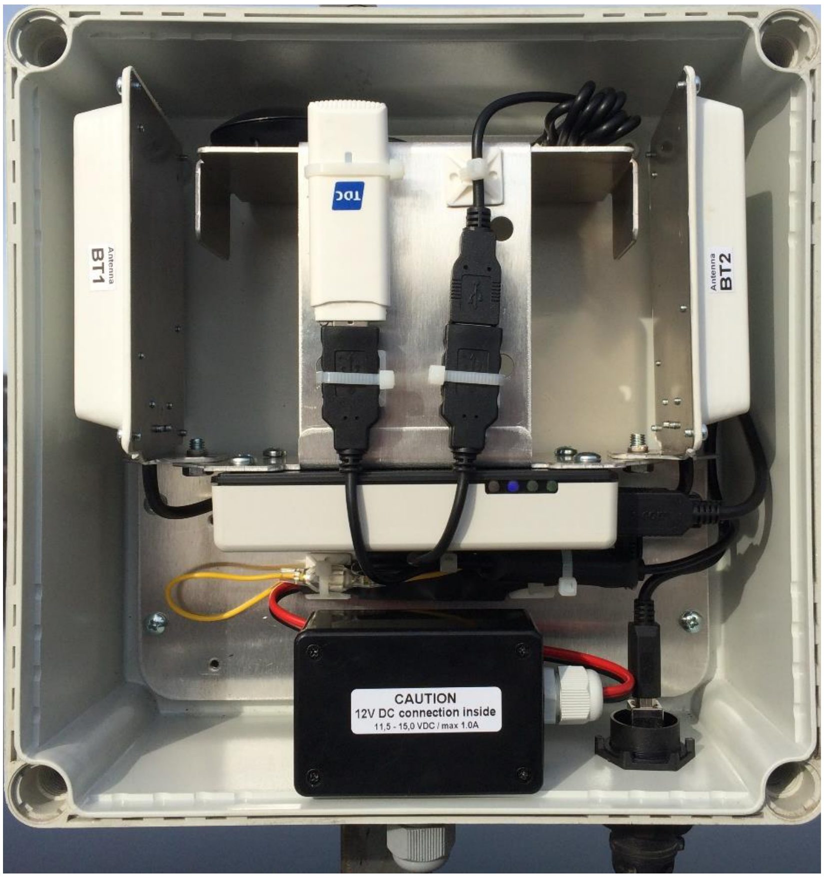

Figure 7 BlipTrack Bluetooth sensor

The used Wi-Fi sensor consists, as mentioned in Table 3, of two directional Wi-Fi antennas with a power gain of 5 dBi (Blip Systems, 2012). Figure 8 shows an opened sensor with the antennas WF 1 and WF 2.

Figure 8 BlipTrack Wi-Fi sensor

They are placed on the opposite sites of the sensor box. The width of the detection beam of these two directional antennas is 70°. The radius of the antennas is around 130m (Abedi, et al., 2015). The BlipTrack Wi-Fi unit cannot be used on its own and must be linked via USB to the Bluetooth sensor. The Wi-Fi unit has no own communication unit and only two antennas, which are connected to two operating dongle units. The collected data is sent to the Bluetooth sensor and through its communication unit further transferred to the internet. Both sensors are connected to a central battery unit. The battery unit consists of one lead accumulator with a capacity of 75Ah. A fully charged accumulator lasts for 5-6 days and has to be changed and recharged afterwards.

4 Measurement Approaches

4.1 One Sensor Testing Approach

In contrast to many other research approaches, in this study the usage of a one sensor set up was also investigated during the performed field tests. As mentioned in a previous part of the work, the used BlipTrack Sensor Equipment was basically designed for the measurement of travel times along roads for the motorized transport and rather for the counting of pedestrians and cyclists. To investigate, whether that particular Bluetooth and Wi-Fi equipment is suitable for counting pedestrians in different urban areas and therefore using only one sensor, several open field tests have been set up. Some certain questions which are raised and tried to be answered during the study, considering especially the one sensor test approach, are:

- Is the set-up of one sensor suitable for counting pedestrians?
- Can the direction in which the devices are passing the sensor be determined?
- Which boundaries has the usage of that system?

As further examined in chapter 4.3, suitable test locations for testing the equipment in open field tests have to be found, to answer the previously mentioned questions.

4.2 Two Sensor Testing Approach

Moreover, a two sensor set up is used within the study to investigate its suitability for pedestrians counting approaches. Therefore, a second sensor is mounted and the devices, are registered while they are passing both sensors.

Several benefits and drawbacks, compared to the previously introduced one sensor counting approach are about to be investigated. As well as for the one sensor testing, appropriate open field test locations were examined and had to be found.

4.3 Examine Suitable Test Locations

The locations for the conducted open field test had to be chosen carefully. In the study, pedestrian volume data, collected by the municipality of Trondheim is used for the decision making. The mentioned manual counts of pedestrians and cyclists in the inner-city of

Trondheim took place in September 2014. The eleven counted locations where chosen all over the city. Most counts were realized on bridges. Some which are only accessible for pedestrians and cyclists like the Gamle Bybru or Verftsbrua, as well as bridges of arterial main roads, like Elgeseter bru. Also the pedestrian volumes of two street sections at Kongens gate and at Nedre Bakklandet were counted.

Gangbrua above the Nidelva river was chosen for the first test run with the sensor equipment. The bridge connects the city center of Trondheim with the Øya district. Øya is a residential area with a sports ground and the Trondheim spectrum event hall, which is attracting people due to different events. The Øya district has no direct bus connection which makes walking across Gangbrua the fastest connection to the city center of Trondheim. Gangbrua is only accessible for pedestrians and cyclists and has a length of 175m.

As mentioned, in the paper a second field test location was chosen, to compare the results of the conducted field tests at both locations. The Gamle Bybru area was used as a second observed field test location due to the different usage of the surrounded neighborhoods, as well as due to the in general higher amount of pedestrians in this area.

4.4 Data Processing / RSSI

The scientific paper explains the implemented data processing technique and shows characteristics of detected fixed and moving devices. This chapter gives some additional information about the chosen data processing technique. In addition, the steps for the exemplary data processing of a chosen data set is presented.

The Received Signal Strength Indicator (RSSI) is an indicator, sent by every detected Bluetooth and Wi-Fi device to the sensor and was used as main tool to distinguish between fixed and mobile devices during this study. The RSSI is an indicator for the power level of the signal strength of a device, received by the antenna (Lui, et al., 2011). In wireless IEEE 802 surroundings the RSSI is a dimensionless unit which must be interpreted due to its special usage. The higher a RSSI value, the stronger is the signal of the sending device and the closer that one is to the antenna. The RSSI value is collected together with the MAC address of the Bluetooth and Wi-Fi device and a timestamp. Table 4 shows a data output from one of the Wi-Fi MAC address scanners. In that case the used Blip sensor equipment changed the MAC address due to privacy concerns, into an also unique MAC address code.

Table 4 Sensor output RSSI characteristics

TIME	RSSI	MAC ADDRESS CODE
12:40	-51	884800683150312
12:42	-63	45332023315064
13:42	-46	1231802531505450

Regarding the above shown table it, can be assumed that the device with the MAC code 8848… was detected closer to the sensor due to its higher RSSI value, than device 4533…. A RSSI Value of -100 indicates a very low signal strength, while values bigger than -60 are already indicating strong signals (Sauter, 2011) (Lui, et al., 2011). In case of the counting of pedestrians, the evaluation of the RSSI values in addition to the MAC address data is a very useful tool, especially for the distinction between mobile and fixed devices. Fixed devices, which are located within the antenna's detection zone, are sending a relative high and stable RSSI value. They can be filtered out, if a certain RSSI cut off boundary is used and for example only RSSI values higher than -70 are used for a further data evaluation. Because of the rather slow velocities with which pedestrians are traveling the probability of detection close to the sensor is relatively high. Therefore, pedestrians are staying within the sensors' detection zones for quite a long time. Thus, the probability of detection with a high RSSI value is bigger, than for other modes of transport.

The developed data processing method was used for evaluating the raw data sets, generated by the BlipTrack sensors. A detailed flowchart of the used method is shown in Figure 9. To get an impression of the amount of processed data, the method is exemplarily used for the data set of the 09.03 at the Gangbrua field test area.

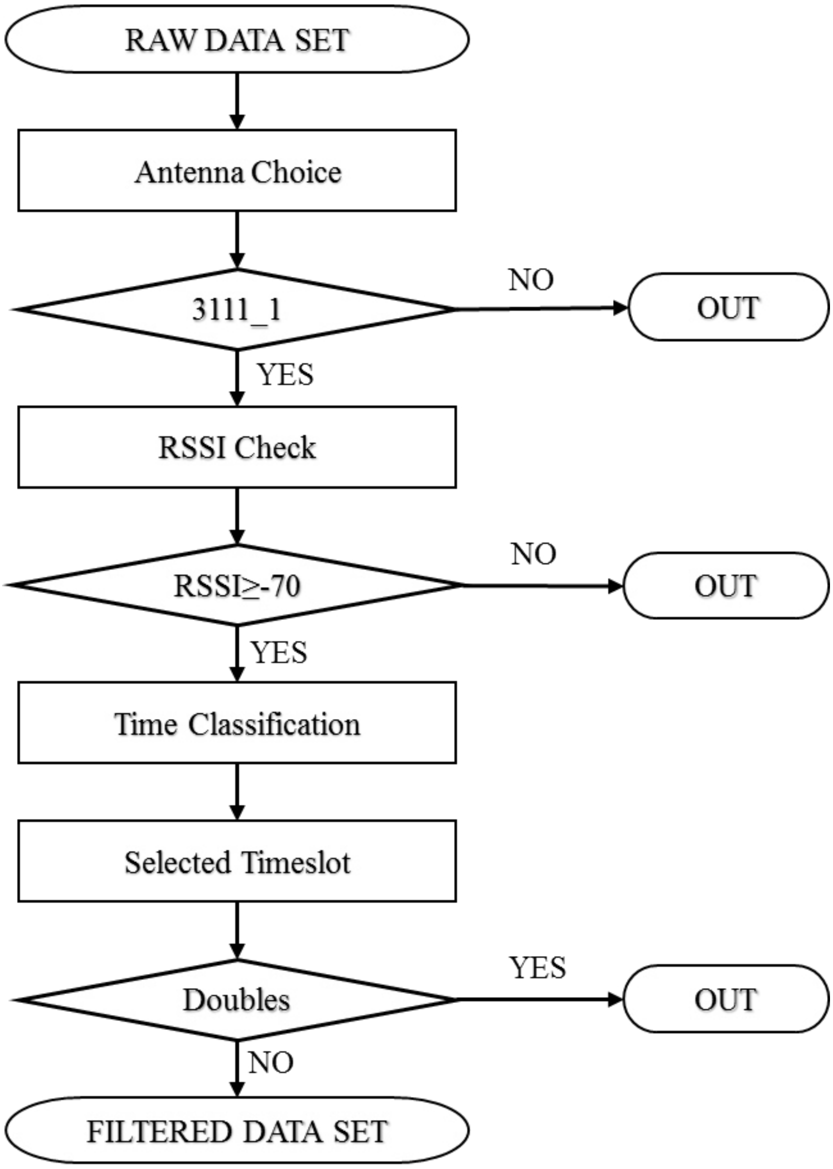

Figure 9 Data evaluation method

In contrast to the following field tests at the Gangbrua study area, the data set of the 09.03. was generated while the sensor equipment was located at the beginning of the bridge. For the following field tests, the equipment was moved to the middle of the bridge and both antennas were used. Hence, for this particular test only the antenna which was directed towards the bridge was considered for the data processing. On the 09.03. a total of 45.052 signals were detected by the two Wi-Fi antennas. Due to the location of the sensor during this time only antenna 3111_2 was chosen, which resulted in an updated data set of 22.032 signals. Subsequently, an RSSI cutoff of -70 was set to focus only onto the devices, which were detected in the closer surrounding of the sensor. After that filtering update, 857 signals remained for the whole day. The big gap between these two data sets can be explained by excluding the continuously sending fixed devices during this filtering step. The selected time interval of the morning peak hour contained 158 detections and the afternoon peak hour 202. As a last part of the data processing method, the double detected signals were extracted. For the morning peak hour 122 signals and for the afternoon peak hour 140 signals remained. All presented filtering approaches were done via the advanced filtering method of Microsoft excel.

5 Results & Discussion

Within this chapter, several additional results of some test situations are mentioned, which would have gone beyond the scope, regarding the published paper. Some results are presented in a more detailed way than it was done within the paper. Results for different tests, which are already mentioned in the paper are shown for further field tests within this report.

5.1 Controlled test

For a better understanding of the sensors and especially to examine the penetration rate of the BlipTrack sensor equipment, a controlled test was set up. The penetration rate describes the percentage coverage of the sensors' detections, compared with parallel done manual counts. Differences between the detection rates of Bluetooth and Wi-Fi devices shall be examined in that test as well as the total detections of the BlipTrack sensor system.

As testing location, the above introduced Gangbrua was chosen, thus only pedestrians and cyclists were about to be detected in the direct surrounding of the sensors. The test run was implemented in the early morning of Monday the 14th of March 2016 between 02:10 am and 03:10 am. Due to the early time and suboptimal weather conditions the test run was not influenced by any passing passengers, except the test person. The devices mentioned in Table 5 were carried in a common shoulder bag as well as in the trousers pocket of the test person.

Table 5 Devices controlled test

Number	Type	Modell	interfaces
1	mobile phone	iPhone 5s	Wi-Fi & Bluetooth
2	mobile phone	Google Nexus 5	Wi-Fi & Bluetooth
3	mobile phone	HTC XXX	Wi-Fi & Bluetooth
4	eReader	Kobo	Wi-Fi

The devices were carried back and forth for five times, so the sensor was passed in total ten times by all devices. Each of the five back and forth trips were started at the southern end of the bridge in the Øya district. The three mobile phones were all equipped with Bluetooth and Wi-Fi interfaces while the used eReader only had a Wi-Fi interface. The wireless interfaces of the devices were all enabled during the entire test run. Calculated of the amount of enabled devices and the number of how often the sensor was passed, a total number of 70 trips could have been possibly detected.

At first the ability to detect Wi-Fi devices of the Blip sensors is examined. Therefore, all four test devices presented in Table 5 can be used. Because of privacy concerns the MAC addresses, detected by the Blip sensors are converted, as mentioned, into unique hash codes, which shall complicate the re-identification of a single device via its MAC address (Blip Systems, 2012). Thereby the assignment of one of the codes to a special used device is not possible. Table 6 shows the converted codes of the particular devices and if they were detected during passing the sensor for each of the test runs.

Table 6 Wi-Fi controlled test detections

Device Code	02:20		02:36		02:45		02:56		03:04	
	1	2	3	4	5	6	7	8	9	10
-8178651828932550000			■	■	■	■				
5194441587845240000	■				■	■	■	■	■	■
-6133411596712450000							■	■	■	■
-4986342519594310000						■	■			

A green box indicates the detection of a passing device, while a white box shows a potential, but not registered detection by the sensors. As shown in Table 7, 43% of all Wi-Fi devices which were passing the sensor are detected by the Blip equipment. The table also shows the varying probability of the detection of the different used devices. While device 51944… was detected at 70% of all passes along the sensor, unit -49863… was only detected in 20%.

Table 7 Wi-Fi controlled test devices

	-8178651828…	51944415878…	-6133411596…	-4986342519…	Total
Detections	4	7	4	2	17
Percentage	40%	70%	40%	20%	43%

As mentioned, the Bluetooth data generated during the test run was evaluated, to gain information about the detections characteristics of the Bluetooth sensor equipment. Similar to the Wi-Fi generated results, also the Bluetooth data showed different detection characteristics due to the regarded device. The specific characteristics are presented in Table 8 and Table 9.

Table 8 Bluetooth controlled test detections

Device Code	02:20		02:36		02:45		02:56		03:04	
	1	2	3	4	5	6	7	8	9	10
-8178651828932550000										
5194441587845240000										
-6133411596712450000										

The probabilities of detection vary within a range of 60 -70% due to used device. In total, 63% percent off all enabled Bluetooth devices were detected by the mounted sensor equipment during the test run.

Table 9 Bluetooth controlled test devices

	-8178651828…	51944415878…	-6133411596…	Total
Detections	6	7	6	19
Percentage	60%	70%	60%	63%

Reasons for the different probabilities of detections for Bluetooth and Wi-Fi units might be caused by the devices' hardware settings. These circumstances were not further examined and can maybe be part of additional research studies.

5.2 Open field testing

Besides the in chapter 4.4 introduced and further on used data processing method, also the Blip Systems company is offering an online data evaluation approach, were the sensors generated data is processed and can be downloaded from a web page. The suitability of these data sets was also tested. The results were therefore downloaded from the Blip System web page and further investigated by using Microsoft Excel. The results are presented in the following diagrams. Figure 10 shows the results of the manual counts and parallel generated data set of the sensor unit during the morning peak of the 18.03, downloaded from the Blip Systems web page. The diagram is using two scales, one for each graph, to figure out potential similarities of data sets structures.

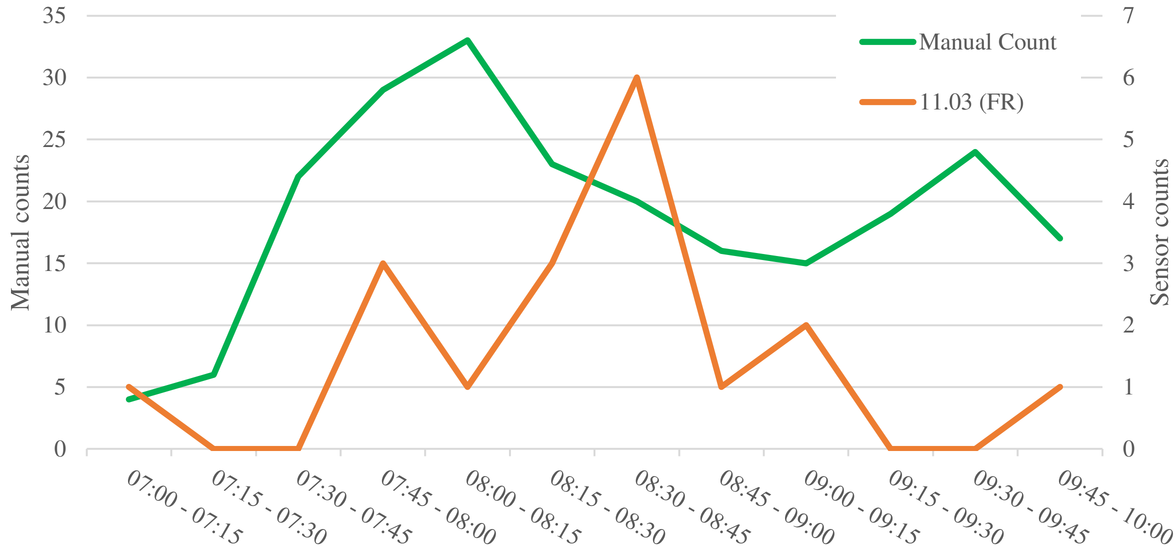

Figure 10 Manual counts Gangbrua 11.03

The sensors data set for the 11.03 is not following the structure of the manual counts. The data points for the 15-minute time intervals are shown in Figure 10 and indicate no fit between the two data sets. Table 10 presents the 15-minute precise penetration rates of the test approach.

Table 10 Penetration rates Gangbrua 11.03

Time	Manual Count	Wi-Fi Sensor	Pen. Rate
07:00 - 07:15	4	1	25%
07:15 - 07:30	6	0	0%
07:30 - 07:45	22	0	0%
07:45 - 08:00	29	3	10%
08:00 - 08:15	33	1	3%
08:15 - 08:30	23	3	13%
08:30 - 08:45	20	6	30%
08:45 - 09:00	16	1	6%
09:00 - 09:15	15	2	13%
09:15 - 09:30	19	0	0%
09:30 - 09:45	24	0	0%
09:45 - 10:00	17	1	6%
Total	228	18	8%

In addition to the inability of the data evaluated via Blip Systems to follow the structure of the manual counts, the total penetration rate of the used equipment is only 8%. For some of the evaluated time intervals the sensor equipment did not register any device, while up to 24 people were passing the sensor.

Due to the assumption of an approximately similar structure of the morning peak hours during weekdays at the Gangbrua study area, the generated data sets of the sensors from different weekdays were compared to the manual count of the 18.03 in Figure 11.

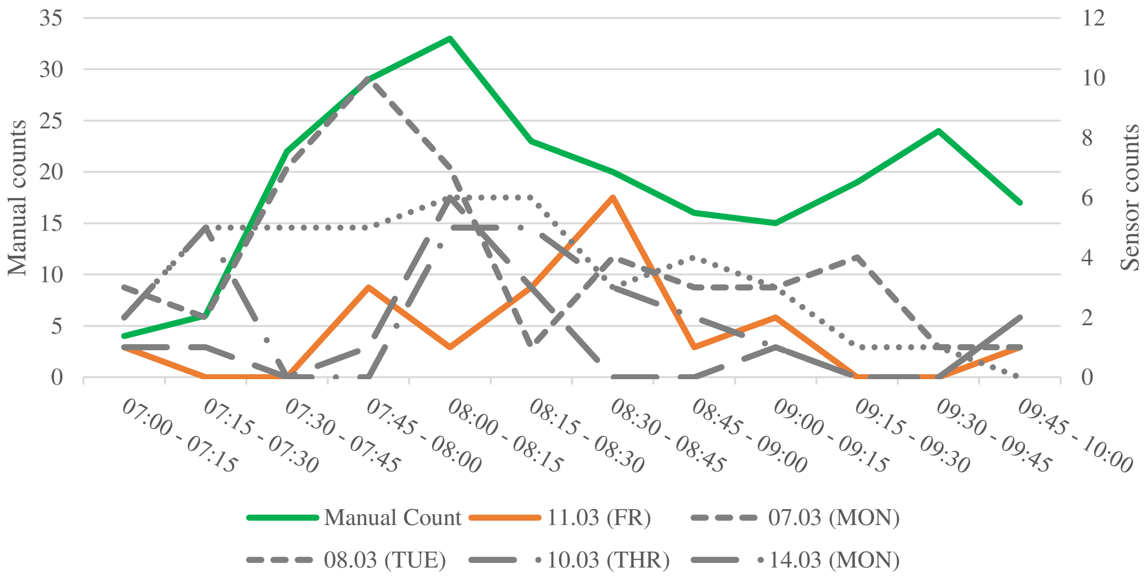

Figure 11 Manual counts Gangbrua 11.03 comparison

Also in this case none of the showed graphs is following the structure of the manual counts in a satisfying way.

As a next approach, the time interval for the observed peak hours was enlarged up to 60 minutes. Figure 12 compares the hourly time intervals of the sensor output and the manual counts.

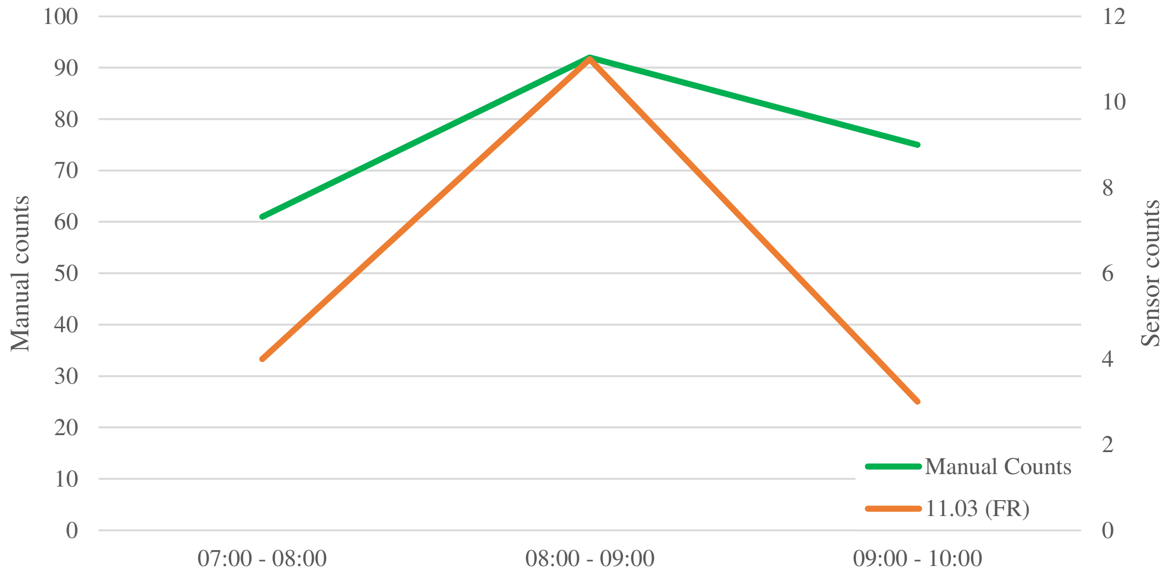

Figure 12 Manual counts Gangbrua 11.03 (60min)

Figure 13 uses the same method as previously done for the quarter hourly time intervals to compare the previously observed peak hour of the 18.03 to other morning peak hours on different weekdays.

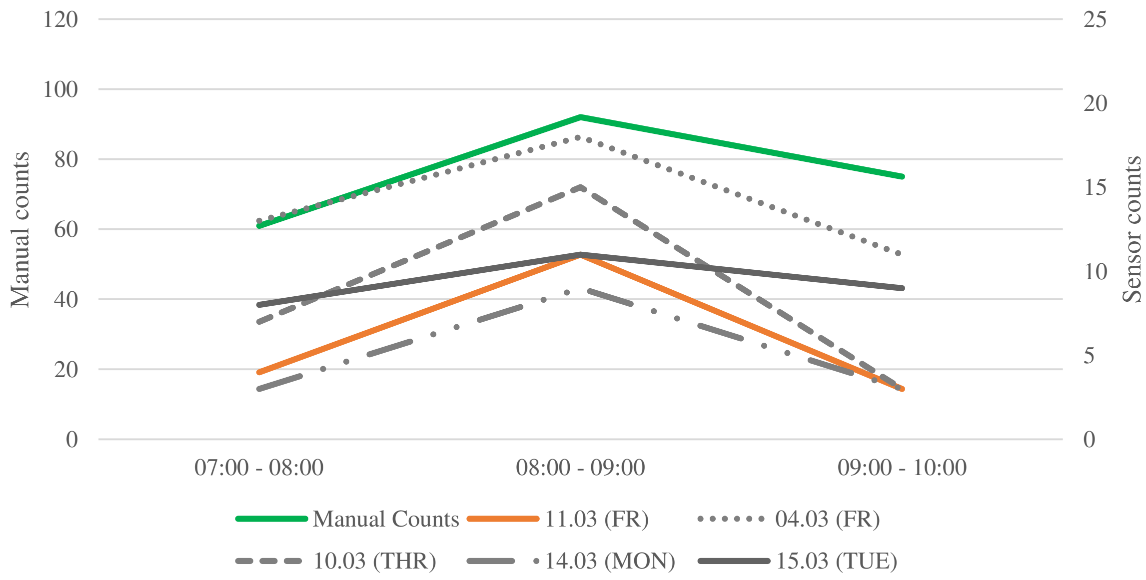

Figure 13 Manual counts Gangbrua 11.03 comparison (60min)

In this case, using an hourly time interval, the structure of the manual counts is better approximated by the sensors data. But still the poor penetration rate is not satisfying.

To generate more reliable results, also for the quarter hour time intervals, the above presented data processing technique is used for a further data evaluation. Besides the through the paper evaluated field tests of the 18.03. at the Gangbrua location and for the 23.04. at Gamle Bybru, the data for the mid-day time period of the 16.03. is mentioned here. This particular field test took place at the Gangbrua location. Using the developed data processing method improves the results essentially compared to the previous presented data sets, which were processed by Blip Systems.

Figure 14 shows the graphs of the manual counts, as well as the results of processed data sets of the Bluetooth and the Wi-Fi sensors.

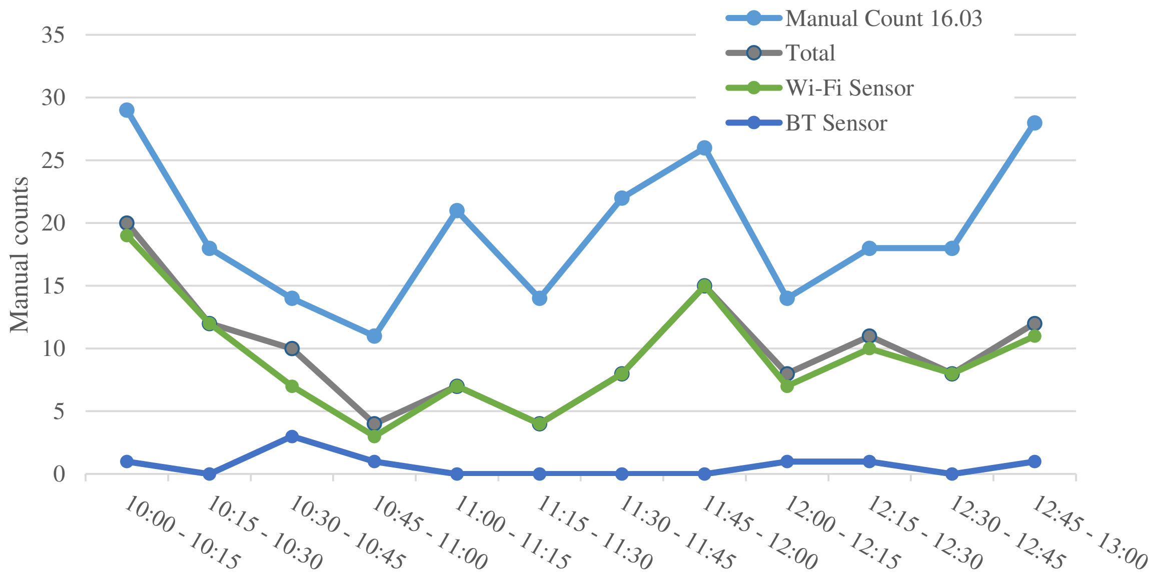

Figure 14 Results Gangbrua morning peak 16.03

Especially the Wi-Fi data sets, are approximate the manual counts in an appropriate way. The combined graph of the Bluetooth and Wi-Fi detections is mainly determined by the Wi-Fi signals. The amount of detected Bluetooth signals is quite low and the general structure of the manual counted data cannot be followed. In general, especially the Wi-Fi based graph mirrors the structure of the manual counts in a satisfying way. All peaks and low points are identified.

To identify the coverage of the Wi-Fi signals in quarter hour precise time intervals, their penetration rate should be mentioned. In Table 11, the detailed quarter hourly penetration rates for the field test on the 16.03 are listed.

Table 11 Penetration rates 16.03

Time	Manual Count	Wi-Fi Sensor	Pen. Rate
10:00 - 10:15	29	19	66%
10:15 - 10:30	18	12	67%
10:30 - 10:45	14	7	50%
10:45 - 11:00	11	3	27%
11:00 - 11:15	21	7	33%
11:15 - 11:30	14	4	29%
11:30 - 11:45	22	8	36%
11:45 - 12:00	26	15	58%
12:00 - 12:15	14	7	50%
12:15 - 12:30	18	10	56%
12:30 - 12:45	18	8	44%
12:45 - 13:00	28	11	39%
Total	233	111	48%

A total penetration rate of 48% indicates a much higher amount of detected devices compared to the previously introduced BlipTrack data sets.

As in the paper, also the results for the two sensor field study is presented. Within this report a closer investigation of the detailed penetrations rates is possible. As mentioned in the paper, due to the even poorer amount of Bluetooth detections compared to the one sensor field tests, only the Wi-Fi signals were used for further examinations. As presented in the two scaled Figure 15, for this measurement approach the Wi-Fi data sets follow the structure of the manual counts as a reference in a satisfying way.

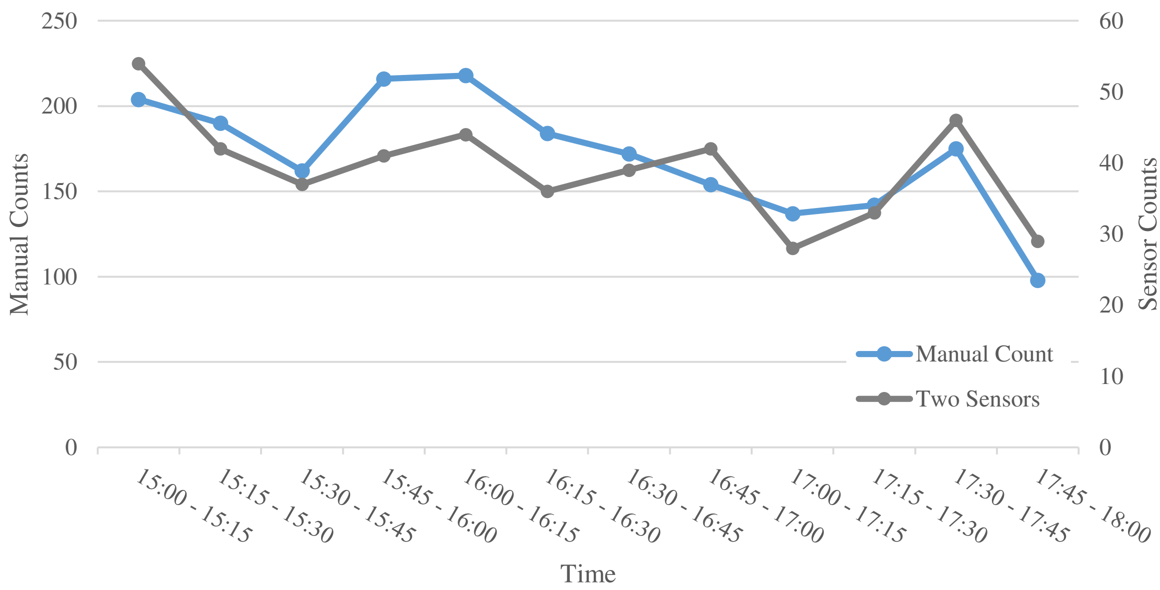

Figure 15 Two sensor approach 19.04

Table 12 shows the quarter hour precise penetration rates for the two sensor measurement set up.

Table 12 Penetration rates two sensor set up

Time	Manual Count	Wi-Fi Sensor	Pen. Rate
15:00 - 15:15	204	54	26%
15:15 - 15:30	190	42	22%
15:30 - 15:45	162	37	23%
15:45 - 16:00	216	41	19%
16:00 - 16:15	218	44	20%
16:15 - 16:30	184	36	20%
16:30 - 16:45	172	39	23%
16:45 - 17:00	154	42	27%
17:00 - 17:15	137	28	20%
17:15 - 17:30	142	33	23%
17:30 - 17:45	175	46	26%
17:45 - 18:00	98	29	30%
Total	2052	471	23%

The total penetration rate is, with 23% lower than the total rates of the one sensor approaches. The quarter hour precise values are quite stable and vary in a range between 19% and 30%.

Additional to the introduced comparison of the processed data output to the parallel done manual counts, the 24h data set output from two sensors is also compared while they were parallel mounted at the Gangbrua field test location.

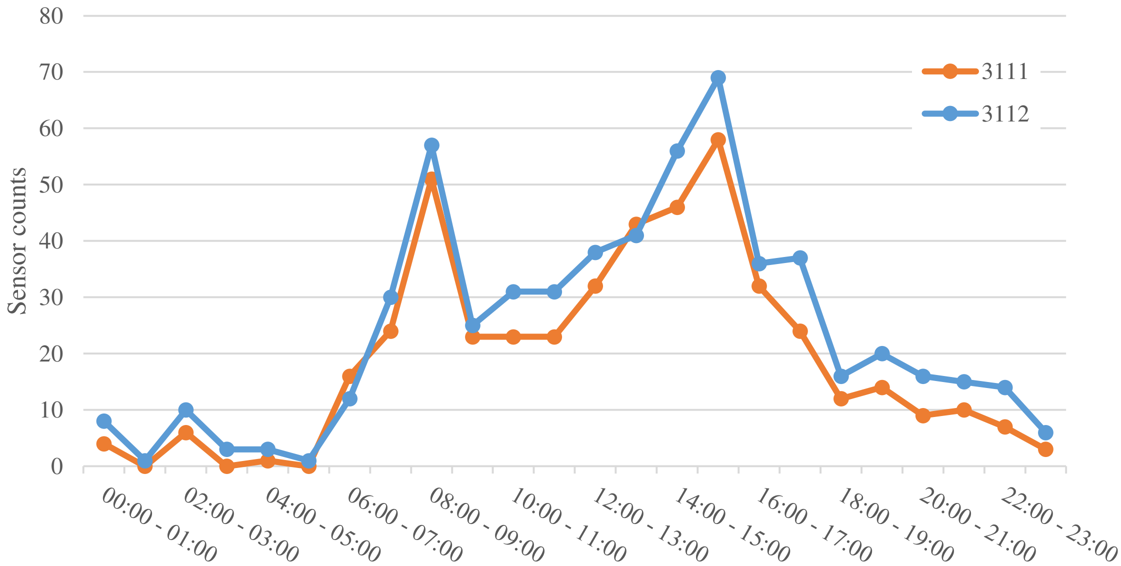

Figure 16 Whole day evaluation sensors 3111 / 3112

The two graphs in Figure 16 present the results of the developed data analysis method for a 24h observation period on the 18.03.2016. The structure of the data output of both sensors is similar, by detecting a morning and an afternoon peak hour, as well as the lower frequented time spans during the night. The reliability of the used data evaluation technique could be proofed. A parallel manual count over such a long time span was not possible due to limited resources, but could be an interesting approach for further research studies.

5.3 Pedestrian volumes estimations

Based on the positive results of the processed Wi-Fi sensor outputs, a further usage of the data, generated by the sensors, can be considered. The possibility of estimating the amount of pedestrians in particular inner city areas by mounting a Wi-Fi sensor and collecting the data of passing pedestrians would be a highly welcomed technique for producing automatic generated pedestrian volumes.

To further investigate this possibility, the data sets, generated by the sensors, are compared to the collected manual counts. Therefore, the data sets are investigated in the observed 15-minute time intervals, as well as summarized to 30 and 60 minute intervals. The main reason for this is to identify potential differences in the estimations accuracy for the different time spans. Figure 17 shows the resulting correlations for each of the chosen time intervals and includes the data sets of all open field tests and the parallel generated sensors' data.

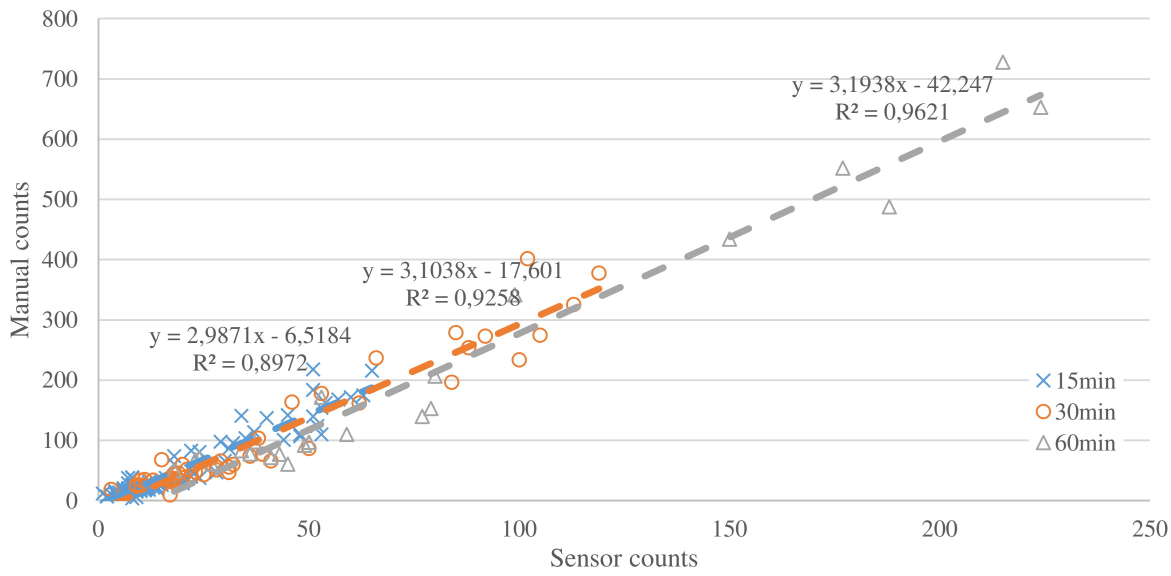

Figure 17 Correlation sensor / manual counts

Furthermore, Figure 17 shows the rising number of sensor counts by an increasing number of manually counted pedestrians. The relation between the two data sets is indicated as linear, and a linear regression graph was calculated for each of the time intervals. Besides the drawn graphs, the corresponding functions as well as the determination coefficient R^2, as an indicator for the goodness of fit, are mentioned in Figure 17.

According to the estimation technique, presented in the paper, a second estimation is done to gather further information about the suitability of the developed technique. Therefore, the mid-day time period of the 16.03. is chosen. This field test was conducted at the Gangbrua field test area. The estimation functions are based on two different data sets. The particular data set of the 16.03, for which the estimations are about to be done, is excluded from both of the mentioned data sets. The first one only includes data sets from field test with a similar range of manual counted persons (<350) during the time interval of three hours. The first approach is presented in Figure 18, including the relevant estimation function for every time interval, as well as the R^2 values.

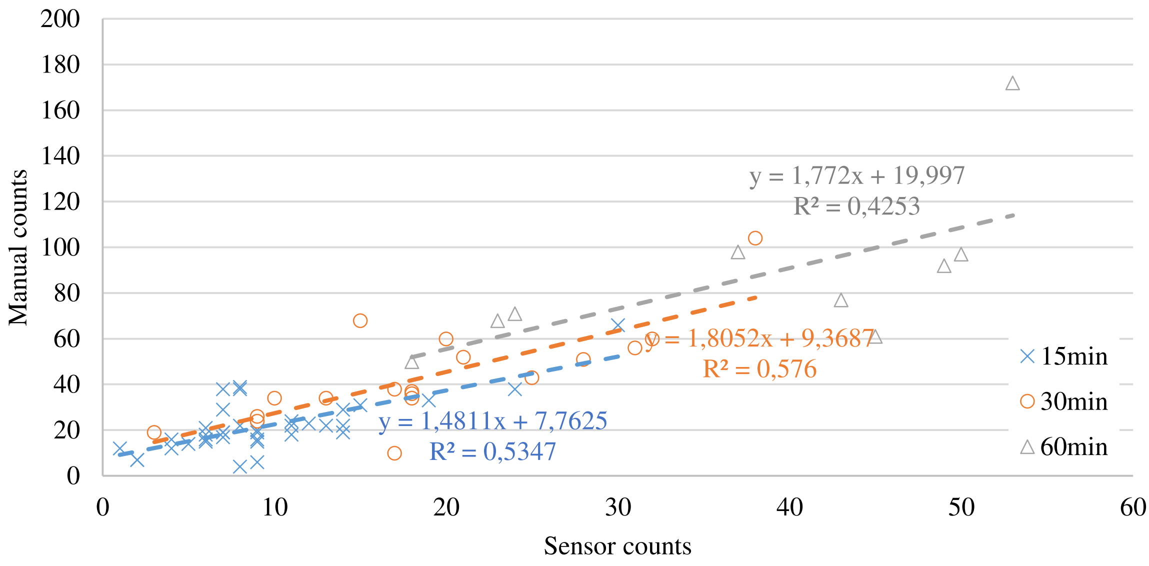

Figure 18 Comparison hand and sensor count <350 (16.03.)

The second, more general approach, includes all, observed data sets except of the 16.03, with no filtering due to the total volumes and is shown in Figure 19.

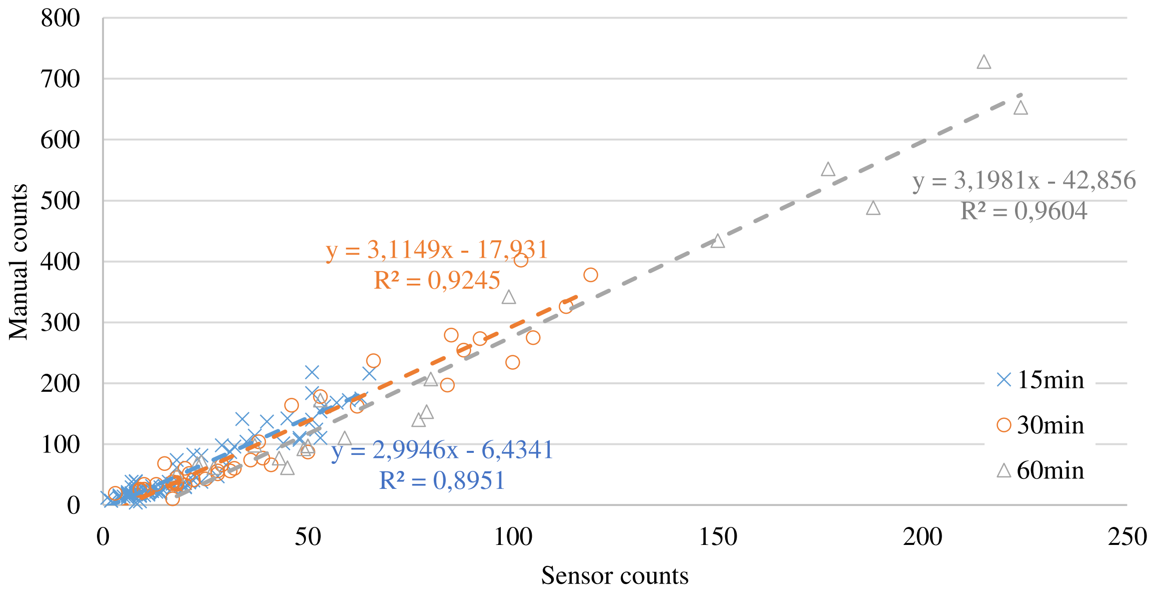

Figure 19 Comparison hand and sensor counts including all datasets except of the 16.03.

The resulting estimations, based on the sensors measured data sets, are presented for each time interval in the following figures and are compared to the conducted manual counts on the 16.03.

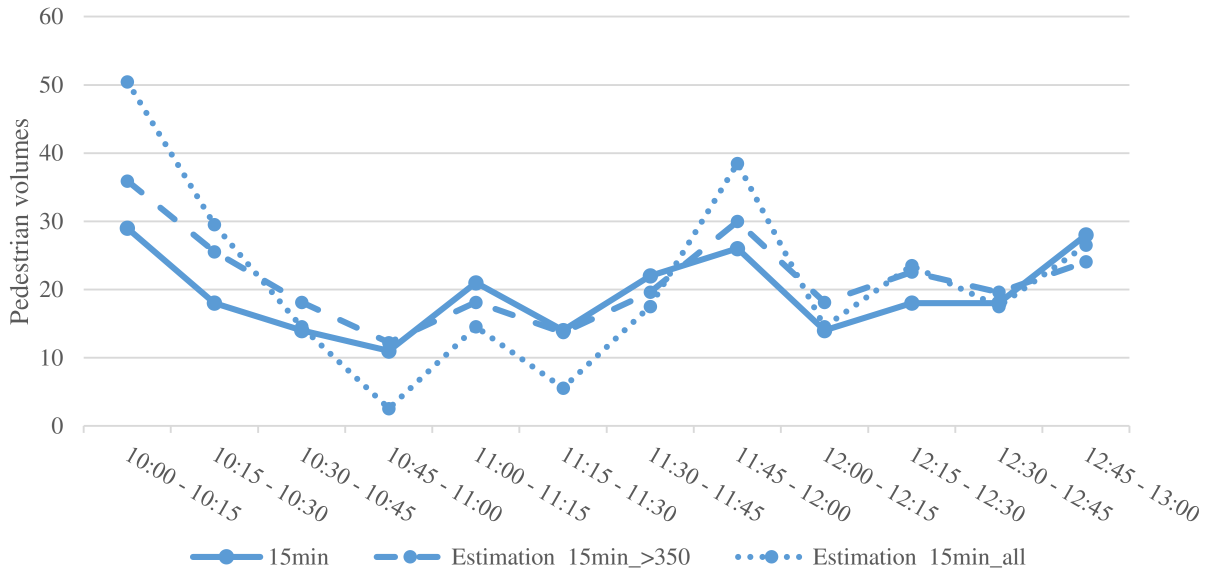

Figure 20 Estimations 16.03. 15min

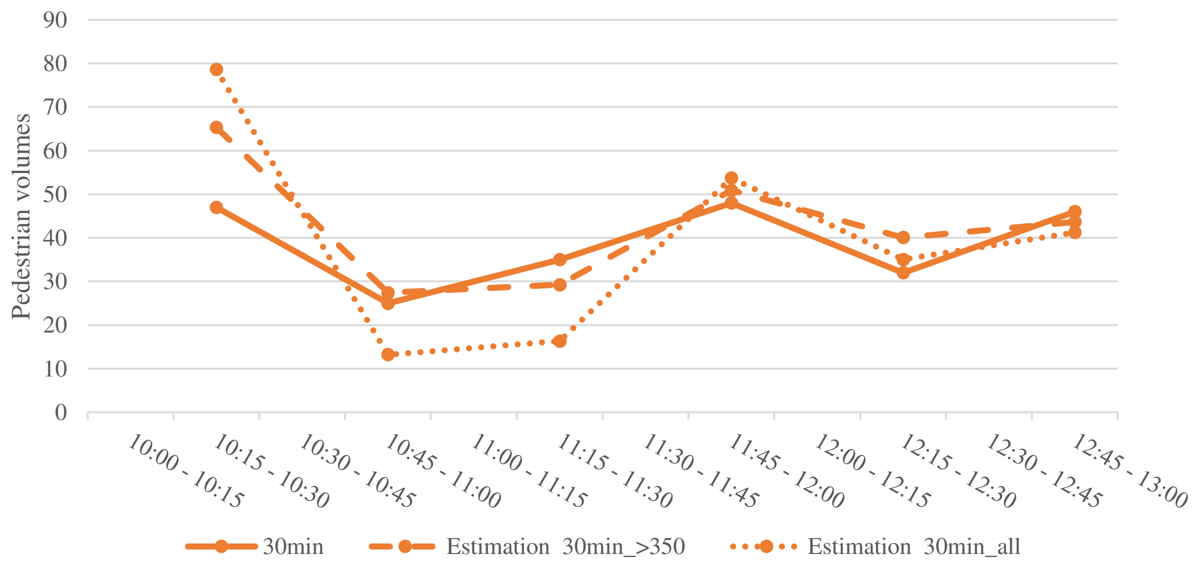

Figure 21 Estimations 16.03. 30min

For both of the regarded time intervals in Figure 20 and Figure 21 the results of the estimations are quite similar to the one presented in the paper. The estimations based on data sets, including only field test with less than 350 observed people, are presented as dashed lines. The ones including all data sets are presented as dotted lines. The estimation functions, based on the similar sized data sets which include only the field tests with less than 350 detected manual counts, are delivering a more precise estimation, compared to the more general functions which are including all data sets. Both of the used estimations are able to follow the structure of the manual counts, by estimating them based on the sensors detections. The results, based on the more general functions, including all data sets, are more vulnerable to over or under estimating the accurate amount of hand counted persons.

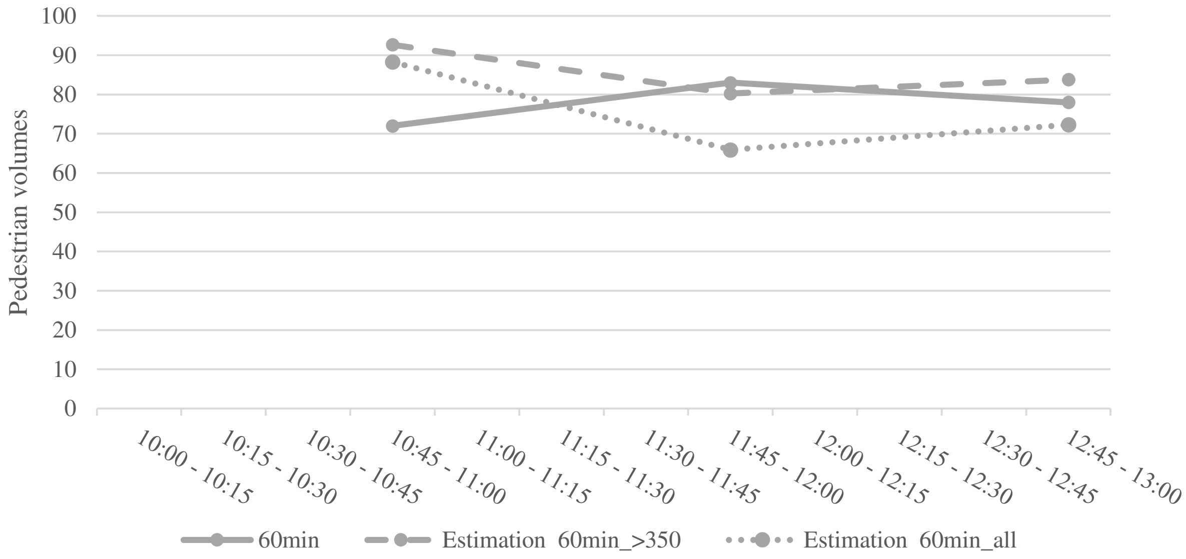

Figure 22Estimation 16.03. 60min

Regarding the graph of the 60 min time intervals the estimation functions do not hit the structure of the manual counts. In general, are the differences between the hourly time intervals not that wide, and the variations between the data sets are lower. The usage of 60min time intervals for a three-hour time period is also a quite rough description of the observed time period. While in this case, the midday time was observed, also no clear peak like e.g. during the morning can be expected. Nerveless, are the results of the used estimations not satisfying and is has to be concluded, that the fit of 15 & 30min estimation functions are more adequate.

6 Conclusion

The results of the study indicate especially the suitability of Wi-Fi sensors, for counting non-motorized modes of travel. The conducted controlled and open field tests, proofed the ability of the sensors to detect passing Bluetooth and Wi-Fi devices. A main challenge during the work, was the development of an appropriate data filtering and processing technique. Especially the usage of a one sensor set-up required the distinguishing between the signals of mobile and stationary devices.

While previous studies recommended the usage of Bluetooth signals for detecting motorized modes of transport, are Wi-Fi signals more appropriate for approaches among the non-motorized forms of transport, such as cycling and walking. This may be caused by a wider usage of Wi-Fi devices in the daily life of pedestrians and cyclists, as well as by differences in the daily utilization of these two interfaces among their users.

Out of parallel to the sensors recordings conducted manual counts can be concluded, that the generated and further processed Wi-Fi signals were following the structure of the manual counts. Peaks and bottom points were detected during different times of the day. Besides these promising results, a certain drawback of this study is the failed distinguishing between the observed modes of travel. Due to its hardware settings, the used sensors were not able to detect the devices travel times in the tested areas. Especially the large antennas detection zones of the equipment were inappropriate for the observed narrow inner city areas with high pedestrian volumes. A different hardware setting is therefore recommended and could deliver more reliable results for pedestrians' and cyclists' travel times, which would be an important characteristic for distinguishing between the captured modes of travel.

Interesting further research approaches could be the test of a different antenna set-up to detect the travel times of pedestrians and cyclists in urban areas. Especially the usage of omnidirectional antennas, operating with a lower sending power can therefore be recommended. Also additional testing approaches in different structured urban areas could lead to interesting results and could further push the usage of Wi-Fi sensors for pedestrian counting.

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Part III – Appendices

Appendix A

Problem description

MASTER DEGREE THESIS

Spring 2016
for

Maximilian Franz Böhm

Digital based Pedestrian Counting

BACKGROUND

The improvement of the pedestrian infrastructure, as well as a higher amount of people walking in inner city areas are desirable. In livable neighborhoods, people often choose walking as a daily mode of transport. Pedestrian volumes are indicators for the amount of walking people and can be used by policy makers to argue towards infrastructure improvements to support the walkability of urban areas. Unfortunately, are information about the amount of pedestrians, walking in inner city areas often based on annual counts or traffic model estimations. An automatic measurement system for the continuous generation of pedestrian volumes is a desirable approach. Throughout the last years measurement sensors for detecting Bluetooth and Wi-Fi devices were used in the field of transport planning. Especially their suitability for travel time estimations was investigated. The growing number of mobile devices, equipped with Bluetooth and Wi-Fi interfaces, creates new possibilities, using these sensors also for pedestrian data collection or counting.

TASK

The Thesis will test the suitability of the mentioned Bluetooth and Wi-Fi sensors for counting pedestrians in urban areas.

Task description

To answer the research question, the sensor equipment should be tested in controlled and open field tests. The generated data is about to be analyzed and further data processing methods should be developed.

Objective and purpose

The objective of this thesis is to determine, whether Bluetooth and Wi-Fi sensors can be used for counting pedestrians in urban areas.

Subtasks and research questions

- Perform a literature analysis on the usage of Bluetooth and Wi-Fi sensors for travel counting approaches
- Choose of appropriate open field test locations for further testing approaches
- Test the equipment's performance for the counting of non-motorized modes of transport
- Conduct manual counts at the field test locations, to evaluate the generated data sets due to its penetration rate
- Evaluate the generated results and give recommendations for a further usage

General about content, work and presentation

The text for the master thesis is meant as a framework for the work of the candidate. Adjustments might be done as the work progresses. Tentative changes must be done in cooperation and agreement with the professor in charge at the Department.

In the evaluation thoroughness in the work will be emphasized, as will be documentation of independence in assessments and conclusions. Furthermore the presentation (report) should be well organized and edited; providing clear, precise and orderly descriptions without being unnecessary voluminous.

The report shall include:

- Standard report front page (from DAIM, http://daim.idi.ntnu.no/)
- Title page with abstract and keywords.(template on: http://www.ntnu.no/bat/skjemabank)
- Preface
- Summary and acknowledgement. The summary shall include the objectives of the work, explain how the work has been conducted, present the main results achieved and give the main conclusions of the work.
- The main text.
- Text of the Thesis (these pages) signed by professor in charge as Attachment 1.

The thesis can as an alternative be made as a scientific article for international publication, when this is agreed upon by the Professor in charge. Such a report will include the same points as given above, but where the main text includes both the scientific article and a process report.

Advice and guidelines for writing of the report is given in "Writing Reports" by Øivind Arntsen, and in the departments "Råd og retningslinjer for rapportskriving ved prosjekt og masteroppgave" (In Norwegian) located at http://www.ntnu.no/bat/studier/oppgaver.

Submission procedure

Procedures relating to the submission of the thesis are described in DAIM (http://daim.idi.ntnu.no/). Printing of the thesis is ordered through DAIM directly to Skipnes Printing delivering the printed paper to the department office 2-4 days later. The department will pay for 3 copies, of which the institute retains two copies. Additional copies must be paid for by the candidate / external partner.

The master thesis will not be registered as delivered until the student has delivered the submission form (from DAIM) where both the Ark-Bibl in SBI and Public Services (Building Safety) of SB II has signed the form. The submission form including the appropriate signatures must be signed by the department office before the form is delivered Faculty Office.

Documentation collected during the work, with support from the Department, shall be handed in to the Department together with the report.

According to the current laws and regulations at NTNU, the report is the property of NTNU. The report and associated results can only be used following approval from NTNU (and external cooperation partner if applicable). The Department has the right to make use of the results from the work as if conducted by a Department employee, as long as other arrangements are not agreed upon beforehand.

Tentative agreement on external supervision, work outside NTNU, economic support etc.
Separate description is to be developed, if and when applicable. See http://www.ntnu.no/bat/skjemabank for agreement forms.

Health, environment and safety (HSE) http://www.ntnu.edu/hse
NTNU emphasizes the safety for the individual employee and student. The individual safety shall be in the forefront and no one shall take unnecessary chances in carrying out the work. In particular, if the student is to participate in field work, visits, field courses, excursions etc. during the Master Thesis work, he/she shall make himself/herself familiar with "Fieldwork HSE Guidelines". The document is found on the NTNU HMS-pages at http://www.ntnu.no/hms/retningslinjer/HMSR07E.pdf

The students do not have a full insurance coverage as a student at NTNU. If you as a student want the same insurance coverage as the employees at the university, you must take out individual travel and personal injury insurance.

Startup and submission deadlines
Startup and submission deadlines are according to information found in DAIM.

Professor in charge: Eirin Olaussen Ryeng NTNU

Other supervisors: Torbjørn Haugen NTNU / Statens vegvesen Vegdirektoratet

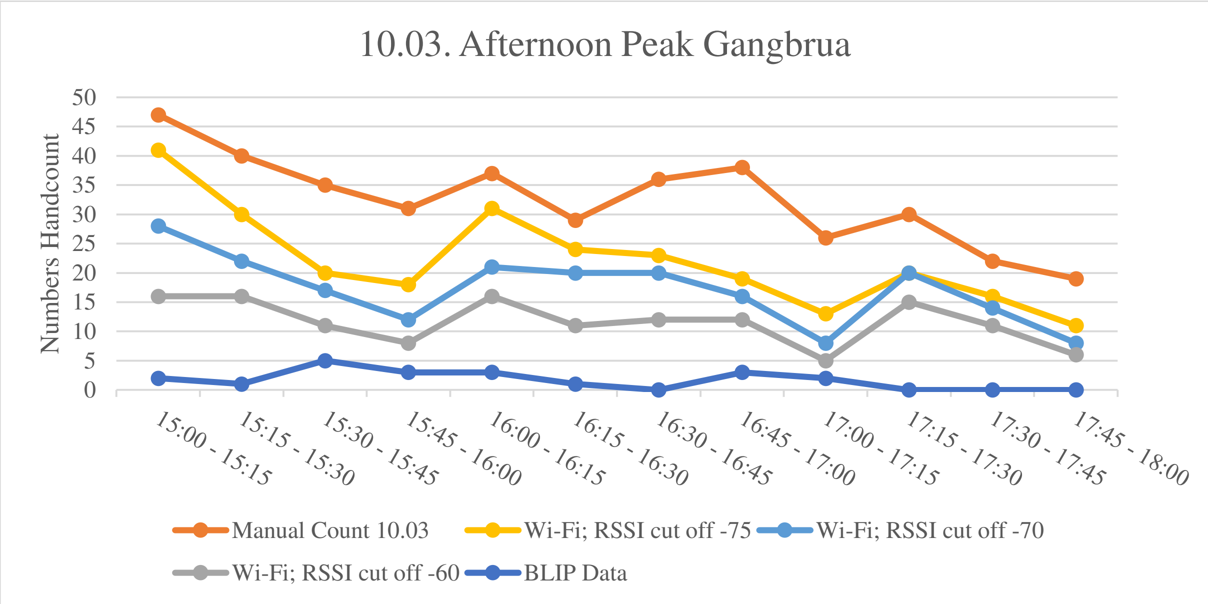
Department of Civil and Transport Engineering, NTNU
Date: 08.06.2016,

____
Professor in charge (signature)

Appendix B

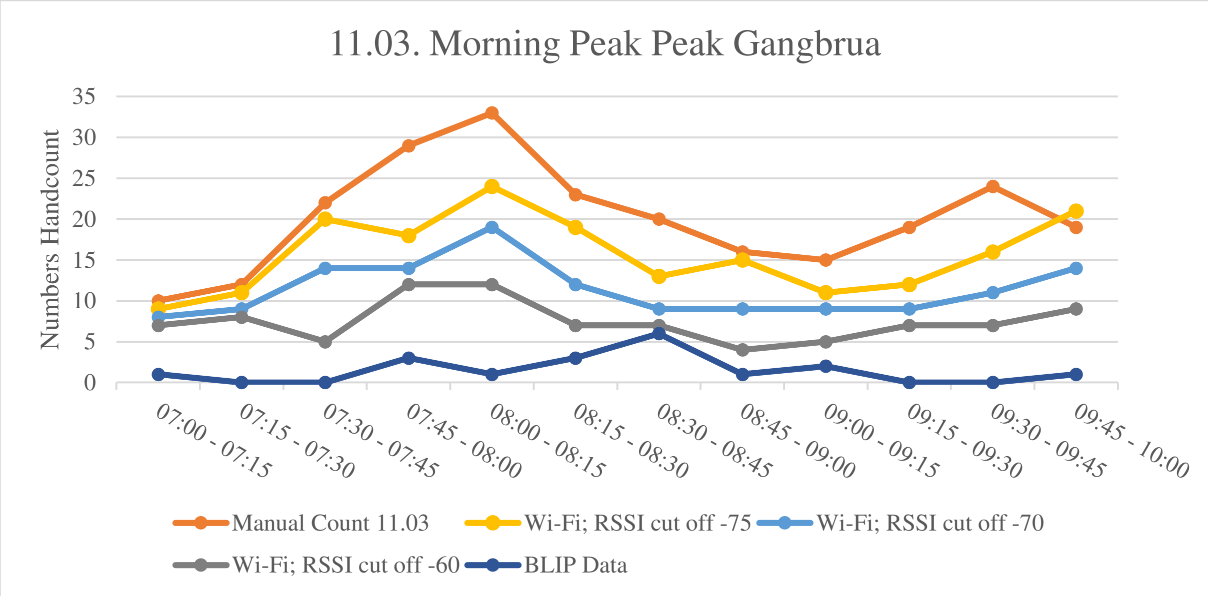
Additional Tables & Figures

Data open field test 10.03.



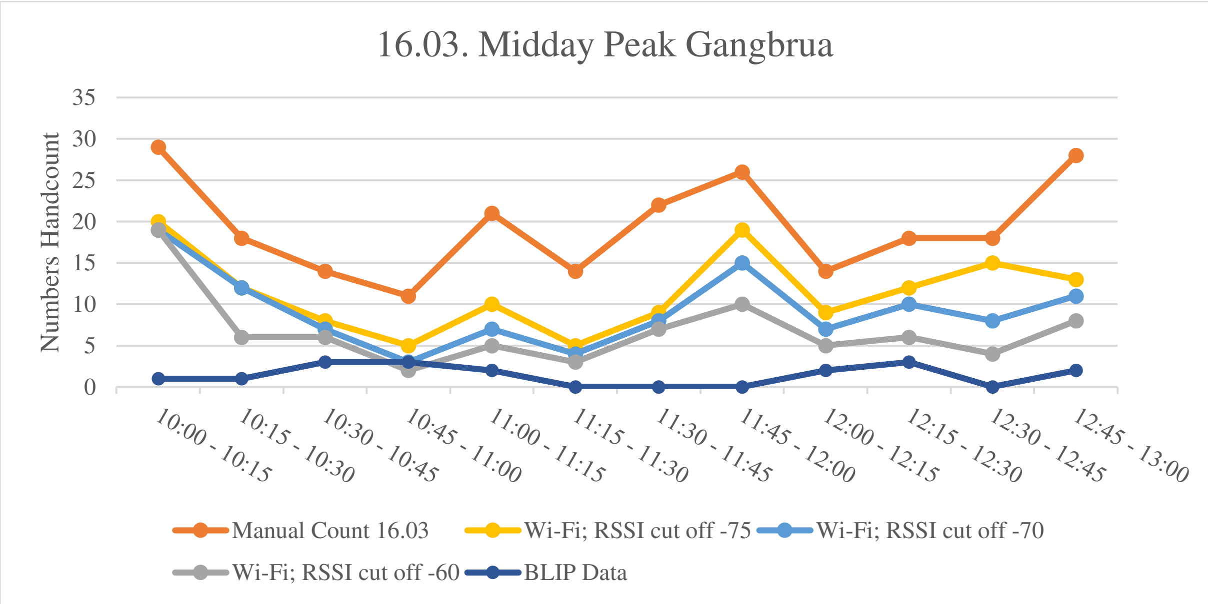
Time	Manual Count 10.03.	Wi-Fi RSSI cut off -60	Pen. rate	Wi-Fi RSSI cut off -70	Pen. rate	Wi-Fi RSSI cut off -75	Pen. rate	BLIP Data	Pen. rate
15:00 - 15:15	47	16	34%	28	60%	41	87%	2	4%
15:15 - 15:30	40	16	40%	22	55%	30	75%	1	3%
15:30 - 15:45	35	11	31%	17	49%	20	57%	5	14%
15:45 - 16:00	31	8	26%	12	39%	18	58%	3	10%
16:00 - 16:15	37	16	43%	21	57%	31	84%	3	8%
16:15 - 16:30	29	11	38%	20	69%	24	83%	1	3%
16:30 - 16:45	36	12	33%	20	56%	23	64%	0	0%
16:45 - 17:00	38	12	32%	16	42%	19	50%	3	8%
17:00 - 17:15	26	5	19%	8	31%	13	50%	2	8%
17:15 - 17:30	30	15	50%	20	67%	20	67%	0	0%
17:30 - 17:45	22	11	50%	14	64%	16	73%	0	0%
17:45 - 18:00	19	6	32%	8	42%	11	58%	0	0%
Total	390	139	36%	206	53%	266	68%	20	5%

Data open field test 11.03.



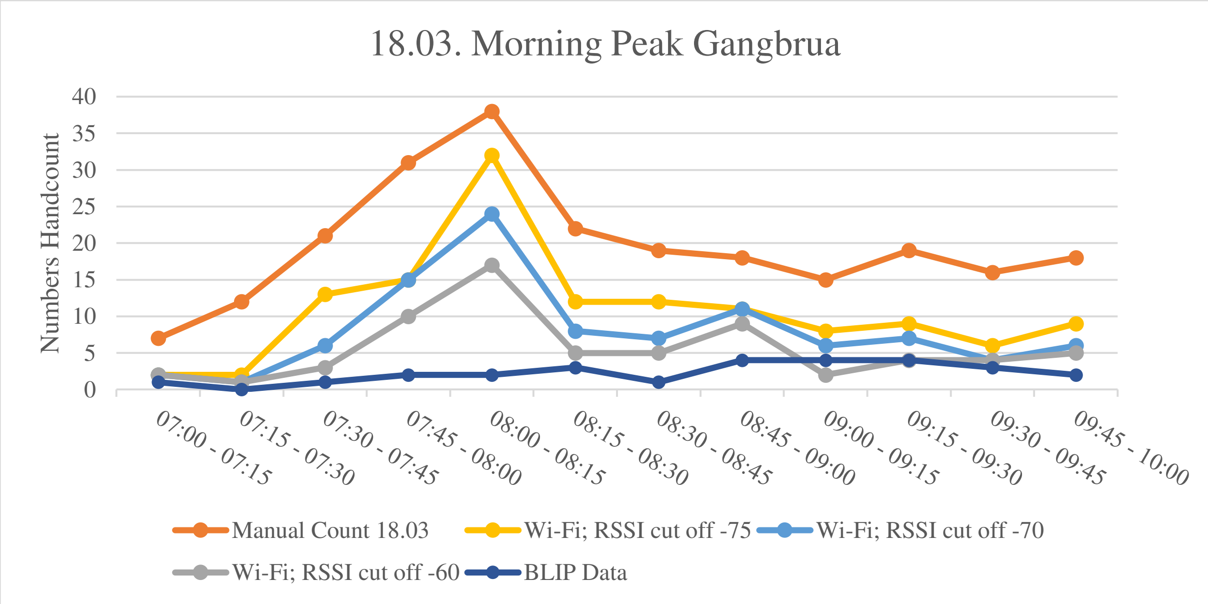
Time	Manual Count 11.03.	Wi-Fi RSSI cut off -60	Pen. rate	Wi-Fi RSSI cut off -70	Pen. rate	Wi-Fi RSSI cut off -75	Pen. rate	BLIP Data	Pen. rate
07:00 - 07:15	10	7	70%	8	80%	9	90%	1	10%
07:15 - 07:30	12	8	67%	9	75%	11	92%	0	0%
07:30 - 07:45	22	5	23%	14	64%	20	91%	0	0%
07:45 - 08:00	29	12	41%	14	48%	18	62%	3	10%
08:00 - 08:15	33	12	36%	19	58%	24	73%	1	3%
08:15 - 08:30	23	7	30%	12	52%	19	83%	3	13%
08:30 - 08:45	20	7	35%	9	45%	13	65%	6	30%
08:45 - 09:00	16	4	25%	9	56%	15	94%	1	6%
09:00 - 09:15	15	5	33%	9	60%	11	73%	2	13%
09:15 - 09:30	19	7	37%	9	47%	12	63%	0	0%
09:30 - 09:45	24	7	29%	11	46%	16	67%	0	0%
09:45 - 10:00	19	9	47%	14	74%	21	111%	1	5%
Total	242	90	37%	137	57%	189	78%	18	7%

Data open field test 16.03.



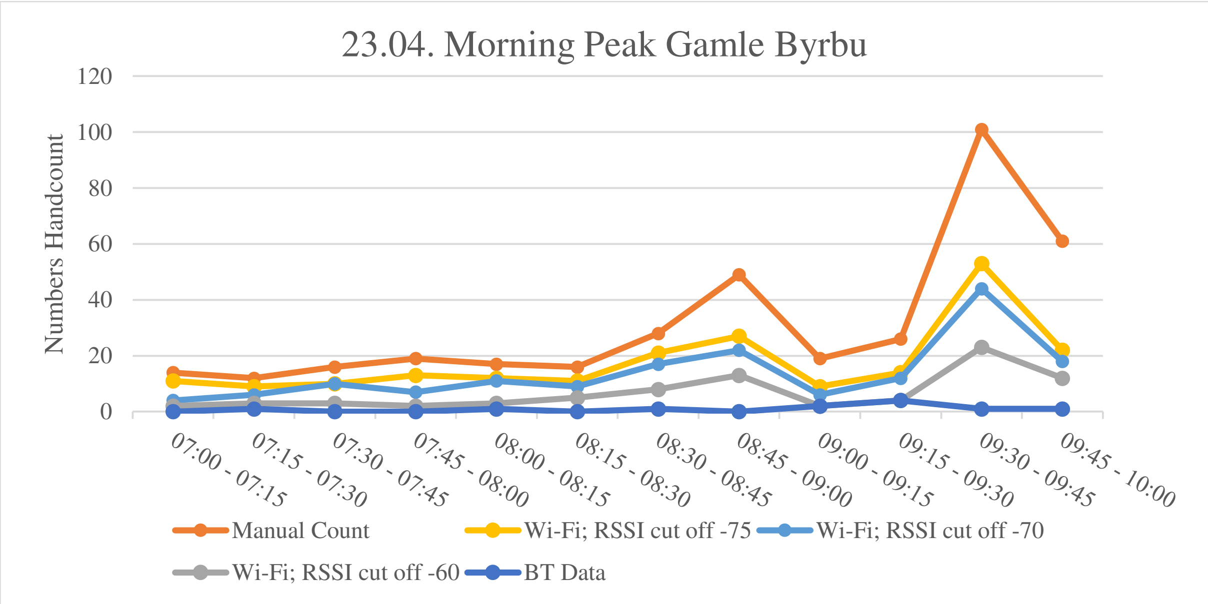
Time	Manual Count 16.03.	Wi-Fi RSSI cut off -60	Pen. rate	Wi-Fi RSSI cut off -70	Pen. rate	Wi-Fi RSSI cut off -75	Pen. rate	BLIP Data	Pen. rate
10:00 - 10:15	29	19	66%	19	66%	20	69%	1	3%
10:15 - 10:30	18	6	33%	12	67%	12	67%	1	6%
10:30 - 10:45	14	6	43%	7	50%	8	57%	3	21%
10:45 - 11:00	11	2	18%	3	27%	5	45%	3	27%
11:00 - 11:15	21	5	24%	7	33%	10	48%	2	10%
11:15 - 11:30	14	3	21%	4	29%	5	36%	0	0%
11:30 - 11:45	22	7	32%	8	36%	9	41%	0	0%
11:45 - 12:00	26	10	38%	15	58%	19	73%	0	0%
12:00 - 12:15	14	5	36%	7	50%	9	64%	2	14%
12:15 - 12:30	18	6	33%	10	56%	12	67%	3	17%
12:30 - 12:45	18	4	22%	8	44%	15	83%	0	0%
12:45 - 13:00	28	8	29%	11	39%	13	46%	2	7%
Total	233	81	35%	111	48%	137	59%	17	7%

Data open field test 18.03.



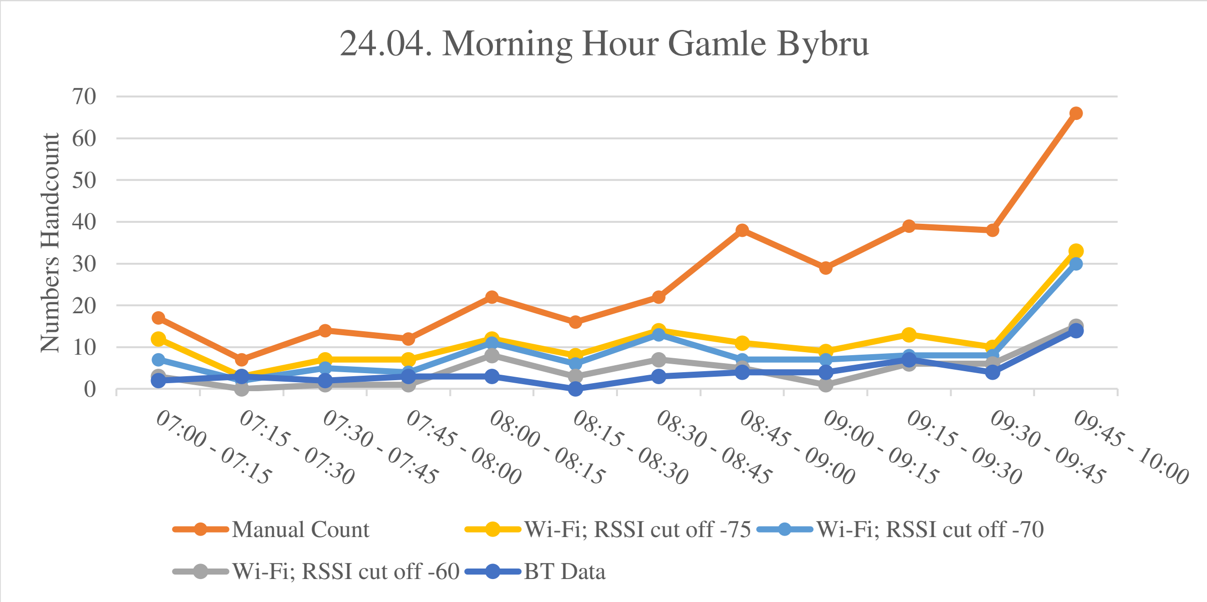
Time	Manual Count 18.03.	Wi-Fi RSSI cut off -60	Pen. rate	Wi-Fi RSSI cut off -70	Pen. rate	Wi-Fi RSSI cut off -75	Pen. rate	BLIP Data	Pen. rate
07:00 - 07:15	7	2	29%	2	29%	2	29%	1	14%
07:15 - 07:30	12	1	8%	1	8%	2	17%	0	0%
07:30 - 07:45	21	3	14%	6	29%	13	62%	1	5%
07:45 - 08:00	31	10	32%	15	48%	15	48%	2	6%
08:00 - 08:15	38	17	45%	24	63%	32	84%	2	5%
08:15 - 08:30	22	5	23%	8	36%	12	55%	3	14%
08:30 - 08:45	19	5	26%	7	37%	12	63%	1	5%
08:45 - 09:00	18	9	50%	11	61%	11	61%	4	22%
09:00 - 09:15	15	2	13%	6	40%	8	53%	4	27%
09:15 - 09:30	19	4	21%	7	37%	9	47%	4	21%
09:30 - 09:45	16	4	25%	4	25%	6	38%	3	19%
09:45 - 10:00	18	5	28%	6	33%	9	50%	2	11%
Total	236	67	28%	97	41%	131	56%	27	11%

Data open field test 23.04.



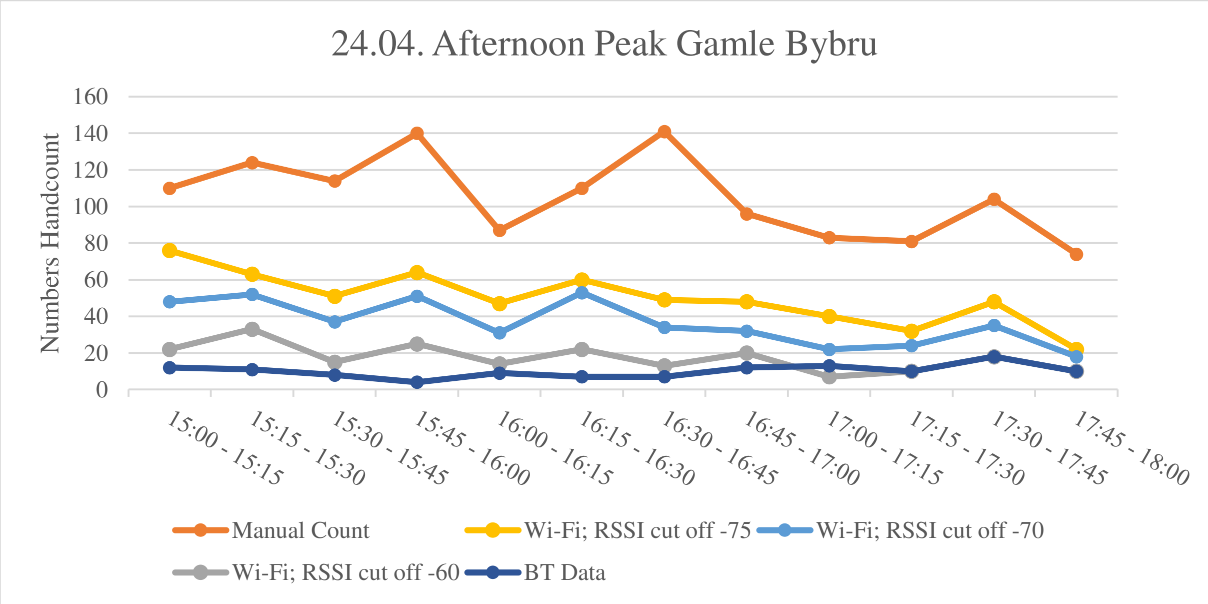
Time	Manual Count 23.04.	Wi-Fi RSSI cut off -60	Pen. rate	Wi-Fi RSSI cut off -70	Pen. rate	Wi-Fi RSSI cut off -75	Pen. rate	BT Data	Pen. rate
07:00 - 07:15	14	2	14%	4	29%	11	79%	0	0%
07:15 - 07:30	12	3	25%	6	50%	9	75%	1	8%
07:30 - 07:45	16	3	19%	10	63%	10	63%	0	0%
07:45 - 08:00	19	2	11%	7	37%	13	68%	0	0%
08:00 - 08:15	17	3	18%	11	65%	12	71%	1	6%
08:15 - 08:30	16	5	31%	9	56%	11	69%	0	0%
08:30 - 08:45	28	8	29%	17	61%	21	75%	1	4%
08:45 - 09:00	49	13	27%	22	45%	27	55%	0	0%
09:00 - 09:15	19	2	11%	6	32%	9	47%	2	11%
09:15 - 09:30	26	4	15%	12	46%	14	54%	4	15%
09:30 - 09:45	101	23	23%	44	44%	53	52%	1	1%
09:45 - 10:00	61	12	20%	18	30%	22	36%	1	2%
Total	378	80	21%	166	44%	212	56%	11	3%

Data open field test 24.04. I



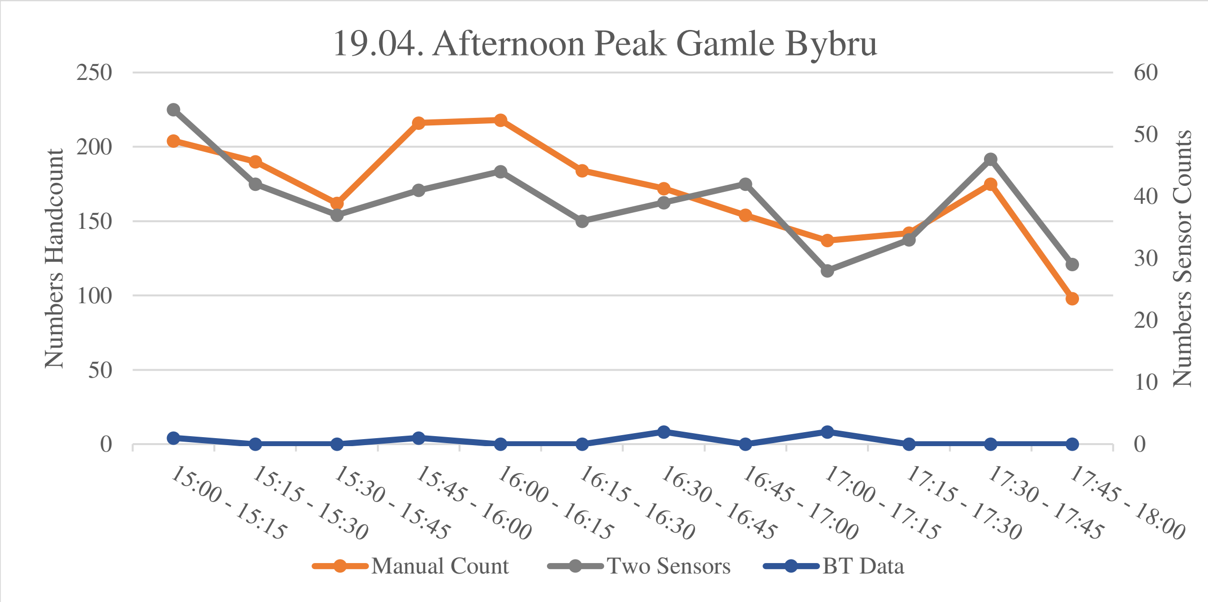
Time	Manual Count 24.04	Wi-Fi RSSI cut off -60	Pen. rate	Wi-Fi RSSI cut off -70	Pen. rate	Wi-Fi RSSI cut off -75	Pen. rate	BT Data	Pen. rate
07:00 - 07:15	17	3	18%	7	41%	12	71%	2	12%
07:15 - 07:30	7	0	0%	2	29%	3	43%	3	43%
07:30 - 07:45	14	1	7%	5	36%	7	50%	2	14%
07:45 - 08:00	12	1	8%	4	33%	7	58%	3	25%
08:00 - 08:15	22	8	36%	11	50%	12	55%	3	14%
08:15 - 08:30	16	3	19%	6	38%	8	50%	0	0%
08:30 - 08:45	22	7	32%	13	59%	14	64%	3	14%
08:45 - 09:00	38	5	13%	7	18%	11	29%	4	11%
09:00 - 09:15	29	1	3%	7	24%	9	31%	4	14%
09:15 - 09:30	39	6	15%	8	21%	13	33%	7	18%
09:30 - 09:45	38	6	16%	8	21%	10	26%	4	11%
09:45 - 10:00	66	15	23%	30	45%	33	50%	14	21%
Total	320	56	18%	108	34%	139	43%	49	15%

Data open field test 24.04. II



Time	Manual Count 24.04.	Wi-Fi RSSI cut off -60	Pen. rate	Wi-Fi RSSI cut off -70	Pen. rate	Wi-Fi RSSI cut off -75	Pen. rate	BT Data	Pen. rate
15:00 - 15:15	110	22	20%	48	44%	76	69%	12	11%
15:15 - 15:30	124	33	27%	52	42%	63	51%	11	9%
15:30 - 15:45	114	15	13%	37	32%	51	45%	8	7%
15:45 - 16:00	140	25	18%	51	36%	64	46%	4	3%
16:00 - 16:15	87	14	16%	31	36%	47	54%	9	10%
16:15 - 16:30	110	22	20%	53	48%	60	55%	7	6%
16:30 - 16:45	141	13	9%	34	24%	49	35%	7	5%
16:45 - 17:00	96	20	21%	32	33%	48	50%	12	13%
17:00 - 17:15	83	7	8%	22	27%	40	48%	13	16%
17:15 - 17:30	81	10	12%	24	30%	32	40%	10	12%
17:30 - 17:45	104	18	17%	35	34%	48	46%	18	17%
17:45 - 18:00	74	10	14%	18	24%	22	30%	10	14%
Total	1264	209	17%	437	35%	600	47%	121	10%

Data open field test 19.04. two sensors



Time	Manual Count 19.04.	Two sensor counts	Pen. rate	BT Data	Pen. rate
15:00 - 15:15	204	54	26%	1	2%
15:15 - 15:30	190	42	22%	0	0%
15:30 - 15:45	162	37	23%	0	0%
15:45 - 16:00	216	41	19%	1	2%
16:00 - 16:15	218	44	20%	0	0%
16:15 - 16:30	184	36	20%	0	0%
16:30 - 16:45	172	39	23%	2	5%
16:45 - 17:00	154	42	27%	0	0%
17:00 - 17:15	137	28	20%	2	7%
17:15 - 17:30	142	33	23%	0	0%
17:30 - 17:45	175	46	26%	0	0%
17:45 - 18:00	98	29	30%	0	0%
Total	2052	471	23%	6	1%