A Case Study on Defining Infrastructure Sensor Positions with Consideration of Existing Infrastructure

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Abstract: Support by infrastructure sensors can be crucial to enable automated vehicles to safely navigate complex urban driving environments. Finding the suitable positions for infrastructure sensors is a complex problem with different demands and factors. This paper proposes a method of automating the process of selecting positions for infrastructure sensors in a 2D environment. The positions are selected using available data of the streets, for sensor placement suitable existing infrastructure and sensor coverage demands. This methodology is then applied to finding sensor positions in the neighborhood of Lausitzer Platz in Berlin, Germany. The sensor demands for this are to taken from a virtual roll out scenario of the U-Shift vehicle concept. This is done by first finding suitable sensor positions for the bigger streets with the highest cargo and person transportation demand and then covering of every street in the neighborhood. In this use case more than half the sensor could be placed on existing infrastructure, if there is a high density of existing infrastructure that is suitable for the placement of sensors.

1 INTRODUCTION

Although car manufacturers have made a lot progress in increasing the capabilities of their driving assistance systems in the recent years, eliminating the need of constant human supervision remains an unsolved challenge for production cars. This is especially true for urban and suburban traffic. The driving environment in these is highly complex with a lot of other traffic participants, some of which are Vulnerable Road Users (VRU) like for example pedestrians and cyclist. Another big challenge in these scenarios are occlusions of the field of view of automated vehicles by other traffic participants, buildings and other objects like trees and signs. One approach to enable save navigation through this complex urban traffic is the support by other automated vehicles and infrastructure to provide additional information. To exchange this information between traffic participants 'Vehicle to Everything' communication is used. as standardized by the European Telecommunications Standards Institute (ETSI) as ITS-G5 (ETSI 2020). ETSI defines messages over which perceived objects (CPM), information about the ego vehicle (CAM) and coordination of maneuvers and trajectories (MCM), can be communicated with other traffic participants.

A way to achieve a higher quality of information is the placement of sensors outside of vehicles. The acquired information is then shared with traffic participants via CPM messages.

Infrastructure sensor systems have an inherent advantage by being placed higher than vehicles and being able to have multiple perspectives of the driving situation. The extent of this sensor coverage can range from only on some points of interest, like for example especially dangerous intersections, to coverage of the whole area of operation, as proposed in the concept Managed automated driving (MAD) (Schindler 2023).

There are different coverage and economic, demands on the infrastructure. To cover a area of relevant size, many sensors have to be placed and a lot of factors have to be considered to find suitable positions. While there has been previous work on improving and automating larger scale placement of other traffic infrastructure like street lights (Baihaki et al. 2024; Ishak 2021) or infrastructure communication units (Huo et al. 2024). Work on the placement of infrastructure sensors is usually focused on finding an optimal sensor configuration, with the

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least number of sensors possible (Akbarzadeh et al. 2014; Argany et al. 2018; Geissler and Grafe 2019). In a real-world rollout however, the number of needed sensors is not the only factor to consider. The cost of constructing a pole, to place the sensor upon, can be multiple times the cost of the actual sensor unit. This paper proposes a methodology for finding a suitable infrastructure sensor configuration for a quarter, prioritizing existing infrastructure to place sensor units. The approach uses a 2D representation of the environment using geographic data in formats of the Geographic information system (GIS). Chapter 2 describes the methodology of placing the sensors, Chapter 3 then applies the methodology to the use case of a virtual scenario of an operation of U-Shift vehicles in the neighborhood of Lausitzer Platz in Berlin, Germany.

2 METHODOLOGY

In this section the algorithm for finding sensor positions is described. First the necessary input parameters are described, then the actual placement algorithm.

2.1 Input Parameters

The input parameters for the proposed automated finding of infrastructure sensor positions are: street data, sensor demands, candidate poles and loss function.

The required street data contains all streets on which sensors are to be placed. A street is defined as a polynomial path between two intersection points. This selection is based on spatial limits. Within these spatial limits single streets can also be selected or deselected based on preference.

There are two ways to define sensor demands. The first are fixed-point demands and define a maximum distance, within which an infrastructure sensor has to be placed. This can used to make sure a point of interest, like for example intersection points or bus stops have sufficient sensor coverage. The second way of defining a sensor demand is a sensor density demand. It is defined by a maximum distance between to sensor poles and can be varied for each street. Through this the sensor density can be varied to consider streets with higher risk of personal harm, like for example streets with unprotected bicycle paths or streets near schools.

In some cases, existing infrastructure like lamp posts and traffic lights can be used to place sensors. This avoids the cost and planning associated with the construction of sensor poles in an urban environment. The input candidate poles is a list of the positions of all existing infrastructure suitable for placing sensors.

The fourth input parameter is the cost function. It defines what cost the placement of a sensor and pole has. This cost can be an economic cost, but also societal costs like use of public space. The function can contain per piece costs for sensors or poles but also for example cost dependent on the location of the pole.

2.2 Placement Algorithm

The algorithm starts by searching Sensor positions to fulfil all fixed-point demands. The algorithm checks, if there are any candidate poles that fulfil the maximum distance demands. If that is the case, the sensors are placed on that location. If there is no suitable candidate pole, a new pole is placed directly at the fixed-point demand.

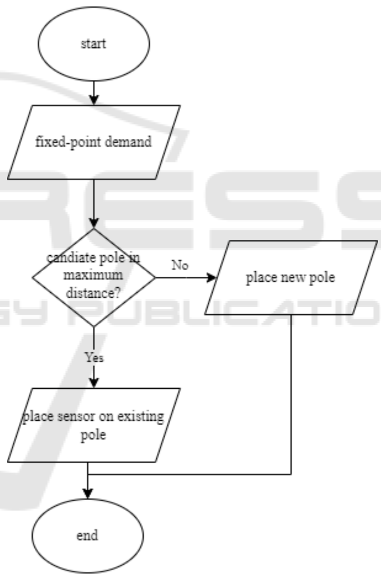

Figure 1: Flowchart of the placement algorithm to meet fixed-point demands.

In the next step the streets are separated into street sections. A street section is defined as the area between two fixed-point sensor poles. To find a suitable sensor configuration, the following process is done for each street section: In the first step, the minimum number of poles required for covering the street section are placed in a way, that the distances between all sensor pole on the street section is the same. This sensor configuration is then saved as configuration 1 and the cost of is determined through the cost function. In the next step the nearest pole candidate for each optimal sensor positions it is determined and then checked if the maximum distance requirements are still fulfilled for all distances between poles. If not, a candidate pole in between is searched in between the two poles, which don't fulfil the requirement. If none is found, a new pole is placed in the middle of these two poles. When all distances between poles are below the maximum distance, this sensor configuration is called sensor configuration 2 and its cost is calculated. Then the cost of both sensor configurations is compared and the configuration with the lower cost is picked.

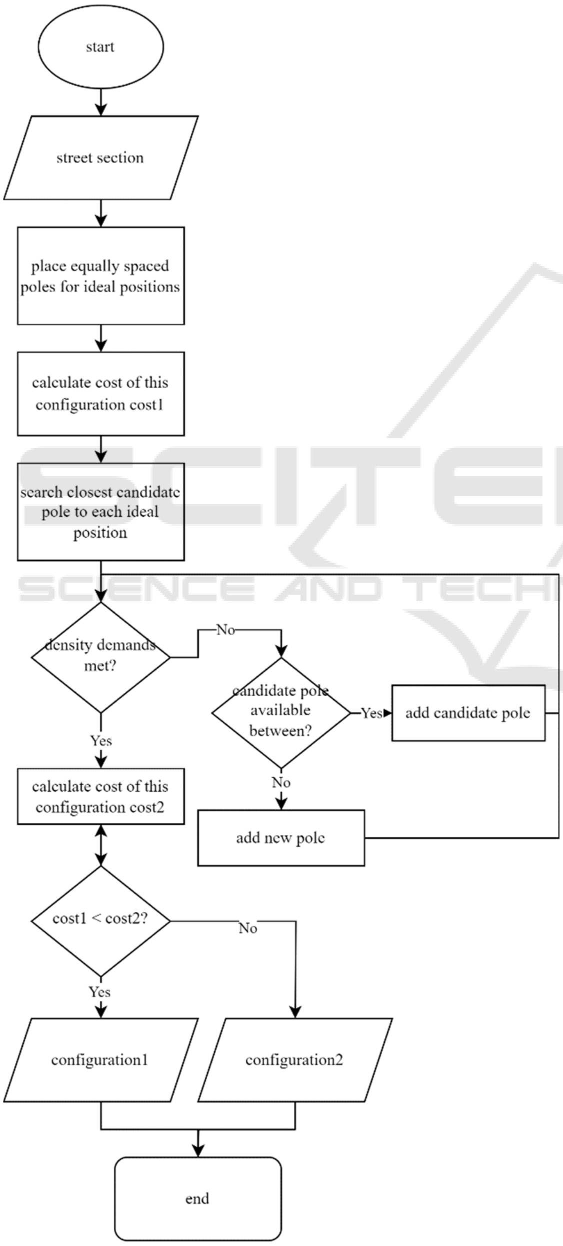

Figure 2: Flowchart of the placement algorithm to meet density demands.

3 APPLICATION

In this chapter the proposed algorithm for finding a suitable sensor configuration is applied to a specific use case. The use case is a virtual scenario of an operation of a fleet of U-Shift vehicles in the neighborhood of Lausitzer Platz in Berlin. The scenario and the parameters and data inputs derived from it are specified in the following subchapter. Then the results for a partial and a full coverage of the streets with sensors are presented.

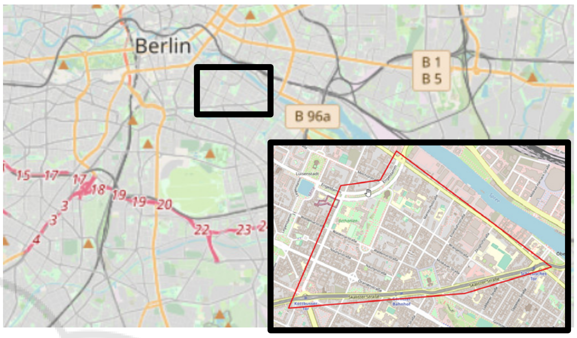

Figure 3: Definition of the Neighbourhood Lausitzer Platz.

3.1 Use Case and Input Parameters

The goal of the generated sensor configuration is the support of a fleet of U-Shift vehicles in the neighborhood of Lausitzer Platz in Berlin, Germany in a virtual scenario. The neighborhood is defined as the area marked in red in Figure 3 and covers around 1 square kilometer. The U-Shift vehicle concept is a modular and driverless vehicle. The driving module is separated from the transport capsule. This enables the vehicle to fulfill different driving demands by loading different capsules. Examples for this are a Cargo Capsule for the delivery of goods and a Person Capsule for transporting people.

The street data for the finding of sensors positions is taken from data provided through the data portal FIS-Broker(Stadt Berlin) by the city of Berlin. The data is filtered to enable two coverage scenarios to be investigated. In the first scenario, only the most important streets in the neighborhood are covered with sensors. For this scenario streets are selected by the following criteria. Firstly, Streets with a high density of shops and restaurants are picked to enable U-Shift to services Cargo demands. Streets with a high density of available candidate poles for sensor placement are also preferred, since this could reduce the cost of sensor placements. In the last step some streets not fulfilling the previous requirements to achieve a well-connected street network without any dead ends. The second scenario then covers all streets in the neighborhood.

The list of candidate poles is created using FIS-Broker data of traffic lights as well as street lights. The street lights data contains categories for each street light. These categories were then evaluated for suitability for sensor placement using samples from pictures in google street view. The results were used to filter out street lamps unsuitable for sensor placement.

The fixed-point demands on the infrastructure sensors are the following: All intersection points are set to have a maximum distance of 5 meters to the next sensor pole to provide additional safety. In addition to that all U-Shift Cargo and Person pick up points are set to have a maximum distance off 5 meters to the next sensor pole. This demand is set to assist the vehicles for the high precision backwards driving and give more security to passengers entering the person capsules.

To ensure safe operations of the U-Shift fleet, a complete coverage of the area of operation by infrastructure sensors is defined. The maximum distance between sensors units was defined as 80m, as proposed in the MAD feasibility study (Weimer 2020). For streets with bicycle lane a maximum distance between sensors of 50m was chosen, to give more safety to vulnerable road users.

For the cost function a cost of 1 unit or placing sensors on existing infrastructure and 10 units for placing a new sensor pole is chosen. The goal of this is to represent the additional cost of construction for a new pole. This results in the following cost function $cost_{section}$ for a street section with the number of newly placed poles n_{new} and number of candidate poles used $* \, n_{candidate}$:

$$cost_{section} = 10 * n_{new} + 1 * n_{candidate} \qquad (1)$$

3.2 Results Partial Coverage

As discussed, in the first scenario not all streets of the neigborhood of Lausitzer Platz are considered for the sensor configuration. The scenario contains 69 of the 97 total streets of the area. Figure 4 shows the considered streets in black, cases where new sensor posts would have to be placed in red and locations were sensors could be placed on existing infrastructure in blue.

The detailed distribution of the sensor position can be seen in Table 1. 52 sensor units were placed overall. For 133 of them existing infrastructure could be used, 119 new poles were placed. To fulfill the Whereas to fulfil the density demands 85% of the

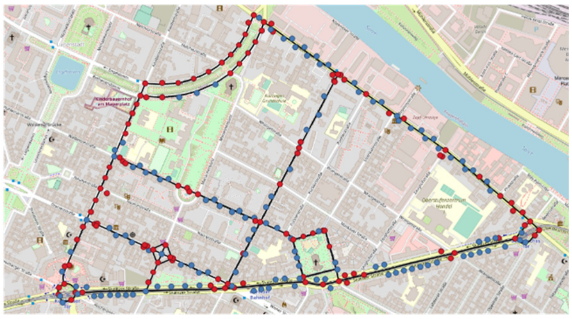

Figure 4: Infrastructure configuration to partly cover the streets of Lausitzer Platz.

Table 1: Distribution of placed sensors for the partial rollout scenario of Lausitzer Platz.

	infrastructure used	new poles
Intersection	8	46
Cargo	6	18
Person	3	35
density	116	20
overall	133	119

fixed-point demands (intersection, cargo and person), 12% of the poles were existing infrastructure. sensors were placed on existing infrastructure. This large difference can be explained by the low maximum distance parameters used for the fixed-point demands.

3.3 Results Full Coverage

The second scenario includes all 97 streets. The final sensor configuration contains 342 sensor poles overall. The streets and positions can be seen in Figure 5, using the same colours as Figure 4. The detailed distribution of the placed sensors can be seen in Table 2. To fulfil the fixed-point demands, most poles had to be newly placed. 58% of the sensors to fulfil density requirements could use existing infrastructure.

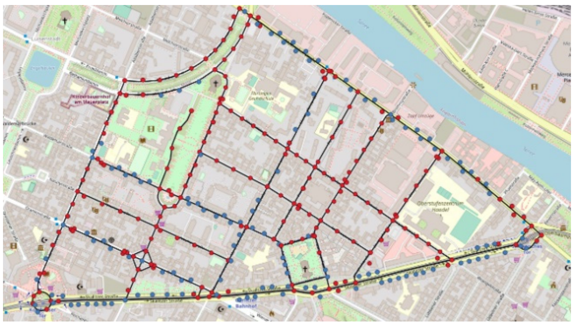

Figure 5: Infrastructure configuration to cover all streets of Lausitzer Platz.

Table 2: Distribution of placed sensors for the full rollout scenario of Lausitzer Platz.

	infrastructure used	new poles
Intersection	8	57
Cargo	6	25
Person	3	43
density	116	84
overall	133	209

Compared to the partial coverage scenario, all additionally placed sensors were newly placed. Most of these streets have historic gas-powered street lights. These are specific to Berlin and because of their low height not suitable for sensor placement. This shows that the suitability of the existing infrastructure for sensor placement can highly influence the number of sensor poles that have to be constructed and therefore the cost of covering an area with infrastructure sensors.

4 CONCLUSION AND FUTURE WORK

A method for automating the process of finding a configuration of infrastructure sensors for a large area was developed. It can fulfil both fixed-point and density demands. It considers existing infrastructure suitable for sensor placement and uses a cost function to compare different sensor configurations. This methodology was then applied to two virtual coverage scenarios for a neighborhood in Berlin, Germany. The first scenario covers only parts of the streets and the second all streets. For the partial coverage scenario around half the sensors could be placed on existing infrastructure and it could be shown, that the strictness of the sensor demands and suitability of the existing infrastructure influences the share of newly placed poles and therefore influence the cost in a real-world rollout. However, the methodology was only applied to one specific neighborhood. To verify and generalize the results the same methodology will have to be applied to more locations with urban or suburban traffic.

Since the methodology is based on a 2D model of the environment, it can't consider possible obstacles like trees, parking cars and buildings. Therefore, the method provides a first overview of the sensor placement and gives a starting point for cost estimation and exact pole positioning. For a real-world rollout however, every position will still have to be verified to consider all the additional restrictions in the real world or a highly accurately modelled 3D environment.

The placement of sensors in a real-world rollout can also have many cost factors and constraints not considered by the proposed methodology. Examples for that are the availability of electrical grid connection and cost of providing internet connection to the individual locations. To take this into account an extension of the cost function or additional constraints on sensor positions would be possible. The biggest challenge for that, is the availability of high-resolution data of these factors.

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