Evaluating User Interfaces for a Driver Guidance System to Support Stationary Wireless Charging of Electric Vehicles

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Abstract. Stationary wireless charging could be a convenient alternative to wired charging of electric vehicles. The prerequisite for efficient wireless charging is that the charging components located under the car are precisely aligned. Drivers cannot observe the state of alignment from their perspective, which makes it challenging to identify whether the vehicle's position is accurate enough. In this paper, we present user interfaces that can support the driver in achieving the technically required precision. We provide three visualizations with different abstraction levels displayed on two screen types, which we evaluate experimentally in a user study. As part of the user study, we create a positioning scenario as it might occur with wireless charging. Participants must try to achieve the required precision by being guided by the user interfaces. The results of the user study indicate that, regardless of the visualization and screen type, drivers can position the vehicle within the defined tolerance range of 10 cm. However, the user experience differs significantly. In terms of usability and workload, drivers prefer a visualization that presents the positioning scenario from a bird's eye view. Moreover, the time to complete the task using the bird's eye view visualization took less than 44 s on average, which is probably shorter than parking and plugging in a charging cable. In contrast, an arrow-based visualization took in average up to 1.5 times longer than bird's eye view visualization to complete the task and was the most criticized by the participants.

Keywords: Visualization · Evaluation · Driver guidance · Wireless charging · User study · User experience · Precision · Pose estimation · Computer vision

1 Introduction

Electric vehicles are an interesting topic of our time because of a multitude of technological and ecological challenges associated with them. Since the air in many cities is contaminated by vehicle exhaust fumes [16], electric vehicles offer local air quality benefits due to zero exhaust emissions [7].

Although there are valid reasons for driving electric vehicles, initializing a wired charging process can be inconvenient. For example, drivers might need to

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leave the vehicle to establish a physical connection between the charging station and the car while risking exposure to severe weather conditions. In contrast, wireless charging could be a convenient alternative to wired charging as drivers can stay in the vehicle. Accordingly, Andersson et al. [1] indicate that there are benefits of inductive charging which might increase the attractiveness of electric vehicles.

Technically, wireless charging is enabled by a transmitter coil integrated into the floor, which transmits the energy through the air without contact to a receiver coil installed at the vehicle's underbody [25]. A constraint of wireless charging is that precise alignment of the charging components is required within a tolerance range that is defined by the technical properties of the charging system. Otherwise, the charging process cannot proceed efficiently [8]. Accordingly, the driver has to position the vehicle so that the charging components overlap as precisely as possible. A problem that arises is that many drivers are not used to precisely positioning their vehicle, such as observed in the studies from [3] where only 5% of the vehicles reached a position that could enable efficient wireless charging. Furthermore, the charging components are located under the vehicle and therefore outside of the driver's field of view. Various approaches could be applied to facilitate the positioning process. For instance, markings could be made on the ground, which can serve as an orientation during the positioning. Besides, parking stoppers that protrude from the ground can serve as a physical restriction. The limitation of these approaches is that they cannot be utilized universally for all vehicle types, since vehicle dimensions differ. Alternatively, mechanical systems can be utilized that align the charging components by moving them towards one another. The advantage of a mechanical system is that it might be used for different types of vehicles, for example by using multiple configurations. However, buying and installing a mechanical system is expensive. Besides, complicated maintenance work may be required since vandalism or street cleaning can cause damage if, for example, parts protrude from the floor.

As part of the research presented in this paper, we want to make efficient wireless charging of electric cars accessible in everyday use. There are already approaches that include concepts for positioning [5,12,15,18], however, the focus is often on the technical components. In this paper, we focus on the user's perspective. We aim to find a usable user interface for a positioning system that will help the driver to achieve the precision required for efficient wireless charging while ensuring a low workload. For this reason, we conduct a user study under realistic conditions in which participants have to position their vehicle as accurately as possible on a target point. To support the drivers, we provide various user interfaces composed of two screen and three visualization types.

The structure of this paper is as follows: In the following section we present related work. Subsequently, in Sect. 3 we define the goals for the user interface and our system design. The user study is presented in Sect. 4. In Sect. 5 we discuss the results and observations. Finally, in Sect. 6 we present our conclusions.

2 Related Work

In contrast to other positioning contexts such as automotive navigation and parking, accurate positioning is crucial for efficient wireless charging, since the charging components must be aligned precisely. Depending on the restrictions that result from the charging hardware, a maximum deviation between the charging components can be defined for energy transmission. A deviation in the range of a few centimeters can already lead to inefficient charging. As a result, the vehicle must be positioned an order of magnitude more accurate than it is required in the aforementioned contexts. Accordingly, different approaches attempt to solve the positioning from a technical perspective. For example, in [5,15] approaches are presented which utilize RFID for the positioning of the vehicle. There are also approaches in which the positioning is supported by mechanical concepts. In [12], an approach is presented in which the distance between the charging components is mechanically adjusted for dynamic charging. Also in [18] the charging components' misalignment is determined using wireless sensors, whereupon an electromechanical system automatically adjusts the position of the coil which is integrated into the floor.

In addition to the approaches that deal with technical positioning concepts, some authors present supporting user interfaces. Hudecek et al. [11] provide an assistance system for stationary wireless charging, which gives the driver visual feedback on positioning in three stages. The first stage illustrates the vehicle interior from the driver's perspective. This visualization should not distract the driver from driving and symbolizes the readiness of the system. As soon as the charging station is recognized by the positioning system, a path visualization takes place, which specifies a lane to the target position. If the distance to the target position is reduced to less than 10 m, the positioning scene is shown from the third perspective for a better overview. From the point where the distance to the target position is less than 3 m, the visualization changes the perspective to the bird's eye view with a high zoom level. The vehicle is displayed transparently so that the alignment of the charging components can be observed. An alternative to stationary charging is dynamic charging, in which the vehicle can be charged while it is in motion. Similar to stationary charging, deviations between the charging components can lead to inefficient energy transmission. A driver guidance system has been developed which can support to reduce the lateral deviation of the charging components [13]. The user interface developed for this purpose presents the current deviation in centimeters on a linear gauge, which encodes certain distance intervals with different colors. Besides, the authors of [14] present a lane-keeping assistant, which displays the misalignment in real-time on a colored linear scale. Also in [2] a user interface is presented, which is designed to guide the driver on a route where the charging power is high. A visualization of a green line is used for this, which is placed vertically in the middle of the screen. As soon as the position of the vehicle deviates laterally, a red arrow is drawn which points orthogonally to the center line in the compensation direction and has a length that is proportional to the degree of lateral deviation.

Although the presented works show various user interfaces, they are not evaluated in terms of user experience, precision and time in the context of stationary wireless charging. In order to find a usable user interface that can support drivers to reach the required precision in a reasonable time, we introduce a system with different visual user interfaces that we compare in a user study.

3 System

Driven by the motivation to find a suitable user interface for efficient wireless charging, we propose goals, followed by a solution system setup with various visual modalities.

3.1 Goals

In order to realize efficient wireless charging the user interface must achieve three goals which we roughly summarize in the following:

Precision. Accurate alignment of the charging components is an essential prerequisite for efficient wireless charging. The range of accepted misalignment is limited by the technical characteristics of the charging hardware. In contrast to vehicle navigation and parking, the precision required for positioning is an order of magnitude higher and is in the range of a few centimeters. Although the air gap between the charging components can also be a problem, in this paper we focus on the lateral and longitudinal offset, as these misalignment can be regulated by driving without hardware adjustment. Based on the misalignment tolerances of current inductive charging systems [3], we define a maximum distance of 10 cm in a radial area around the optimal position, without taking the air gap into account.

User Experience. The possible lack of attractiveness in the required vehicle positioning should not be the reason for drivers to reject the concept of wireless charging. Therefore, the user interface should be a valid and accepted tool to assist the driver with accurate positioning. The user interface should be intuitive to use. Ambiguity and confusion should be avoided so that no new problems arise that could make positioning even more difficult. Accordingly, the user interface must have a high degree of usability. In addition to positioning the vehicle for wireless charging, the driver has additional tasks in parallel, such as avoiding dangerous situations in traffic. In order to not distract the driver from the other tasks, the workload that arises when being guided by the user interface must be as low as possible. Moreover, when interacting with the user interface the driver must not be frustrated so that the positioning process is not perceived as unattractive.

Time. Drivers should be able to achieve precise positioning within a reasonable time frame. We define around 2 min as a reference value, as we estimate that parking and plugging in the charging cable could each take up to a minute. The suitability of wireless charging for everyday use depends on the time required for positioning the vehicle. Wireless charging may be convenient, but if positioning takes significantly longer than connecting the car by wire, drivers may prefer wired charging.

3.2 Overview

Figure 1 depicts an overview of the components of the system. For driver guidance the spatial relationship between the charging components must be tracked from a technical point of view. Accordingly, we utilize the approach from [19] in which the relative position of the primary coil is configured manually and the relative position of the secondary coil is derived from the position and rotation of the vehicle. In order to determine the position and rotation of the vehicle, the authors of [19] apply computer vision algorithms. Instead of the proposed camera, we utilize a lidar to acquire raw sensor data due to fewer configuration steps and increased accuracy. Furthermore, a backend computer processes the raw data and estimates the vehicle's pose, which is composed of the position and the rotation relative to the sensor device. A visualization software consumes the vehicle's last estimated pose via a REST interface to generate visualizations. There are two screen variants that present the visual information. A smartphone is used within the cockpit for visualization, which retrieves the positioning data via WiFi from the REST interface. Alternatively, outside the cockpit, the visualization is displayed on a stationary monitor, which is connected to the backend computer.

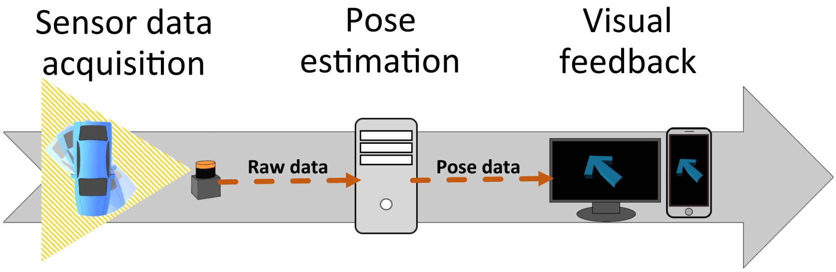


Fig. 1. Overview of the system components and processing pipeline.

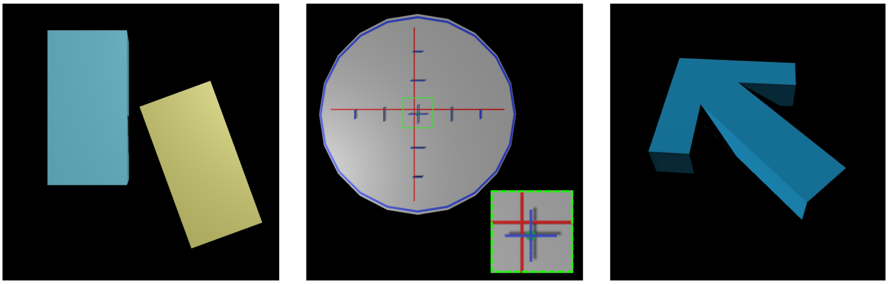
3.3 Visualization Types

This section presents the visualization types provided by our system. We present three visualizations with ascending levels of abstraction. The first visualization renders a spatial overview of the positioning situation. The second reduces the presented information to the two-dimensional relative distances to reach the target. Finally, the third prescribes the direction to be driven. To avoid visual over-stimulation and to compactly communicate the positioning information, we choose minimalistic visualization designs. Figure 2 gives an overview of all visualization types.

Bird's Eye View. We aim to realistically reflect the current positioning situation, for the first type of visualization. Numerous parking assistance systems utilize cameras installed around the vehicle to give an overview of the surroundings such as presented in [9,22] to support the driver in the parking process. Inspired by this concept, we provide a visualization that supports the driver with an overview, that presents the spatial relationship between the vehicle and the target position from a bird's eye view. Based on the given overview, the driver can freely reason about the next vehicle maneuver in order to reach the target position. Figure 2a presents an exemplary state of the visualization during a positioning process. The yellow rectangle represents the vehicle and its position and the blue rectangle symbolizes the target position as a parking lot metaphor. Driver's task is to move the rectangle of the vehicle as precisely as possible into the rectangle of the target position by positioning the vehicle. The more the two rectangles overlap, the closer the vehicle approaches the ideal position.

Radar. For the second visualization, we increase the abstraction level by only showing the distance to the target. A linear gauge [13] or horizontal arrows [2] can communicate the lateral deviation from a target position in the context of dynamic wireless charging. Our application context is stationary wireless charging requiring the vehicle to be aligned longitudinally as well. Accordingly, we provide a visualization that presents the longitudinal and lateral offset between the charging components. Figure 2b illustrates the second visualization type, which is inspired by the aircraft's primary flight display such as illustrated in [6,17]. A round radar-like surface is utilized, on which two red bars move horizontally and vertically from the driver's perspective. The horizontal bar moves vertically and indicates the relative longitudinal offset between the charging components. The vertical bar moves horizontally and shows the lateral offset. An optimal alignment of the charging components is reached when the intersection of both bars is in the center of the visualization. There is a small green circle in the center of the visualization which represents the tolerance range of 10 cm. The rectangle in Fig. 2b illustrates an enlargement of the radars central area containing the tolerance range.

Arrow. The third type of visualization has a higher level of abstraction, since only the information of driving direction is given. For this purpose, a path visualization can be used, as shown in [11]. If the driver is too far from the screen, parts of the path may no longer be visible. An alternative is to visualize an arrow. Since numerous traffic signs display arrows, many people are likely to recognize them from a great distance. Furthermore, they are utilized in various navigation contexts to metaphorically indicate the relative location of a object such as in [20,23]. This is why our third type of visualization presents the driving direction from the driver's perspective using an arrow as depicted in Fig. 2c. By following the direction which is indicated by the arrow, the driver can reach a target location which enables efficient wireless charging. Since the direction is given, the driver is not required to extract the driving direction from the visualization himself, as it is required by the other visualization types.



(a) Bird's eye view (b) Radar (c) Arrow

Fig. 2. Overview of the visualization types of the proposed system.

3.4 Information Output Setup

In addition to the visualization itself, an essential part of the user interface is the screen modality. Drivers receive information concerning the current traffic situation from various sources. Within the cockpit, different parameters are presented that might be needed while driving, for example, via the speedometer, the navigation device, or a head-up display. Outside the cockpit, for example, traffic signs or lights communicate traffic information. Based on this assumption, the visualization is alternatively displayed inside the cockpit and outside of the cockpit.

Inside the Cockpit. An advantage of utilizing screens within the cockpit for driver guidance is that many drivers are used to getting information from monitors in the vehicle from other contexts while driving. Another advantage is that they are protected against environmental influences such as rain, and it is probable that the illumination conditions inside the vehicle do not severely restrict the readability of information. In the context of our application, the monitor must be integrable with little effort and low cost and be applicable regardless of the vehicle type. Since smartphones can be used with negligible effort regardless of the vehicle type, we decide to utilize one as a displaying device. The visualizations are implemented for Android devices using OpenGL ES [21].

Outside the Cockpit. While driving, drivers receive traffic information outside of the vehicle, for example via traffic signs. As an alternative to the screen inside the vehicle, we also install a stationary screen outside the vehicle, similar to a traffic sign. The advantage of a screen outside the vehicle is that the focus can remain outside the cockpit during positioning and does not require to look inside the vehicle as with other devices. This means that the traffic situation can still be kept in view and possible risky situations can be prevented. The visualization is rendered using software that was implemented using the Unity Engine [24] and running at the backend server. To protect the screen from environmental influences, we optionally use a waterproof casing.

4 User Study

In order to analyze to what extent the visualization modalities of the system can meet the requirements, we conduct an experimental user study, which is described in the following sections.

4.1 Test Environment

We set up a test environment, which we depict in Fig. 3. We visually mark the target position with a red adhesive point having a radius of approximately 1.5 cm. Furthermore, we utilize a lidar since lidars typically enable precise measurements. We adjust the lidar to face towards the defined target area to record it. By directly aiming to a target position in a distance of 3 m and a configured field of view of 90° the lidar can perceive the vehicle in about 3 m to the left and right of the target position. With an offset of 1 m in $+z$ and 11 ms in the -x direction, we select the starting position in a parking lot so that the driver has to make a slight curve while driving forward to reach the target position. We select a Dell P2311Hb with 23″ of screen size and install it at a height of about 1.4 m. We set up the device 1 m in the $+x$ direction so that the driver can observe it while positioning. Moreover, we provide each participant with a Samsung Galaxy S7 Edge, which can be freely placed in the cockpit of their personal vehicle, depending on their preference.

4.2 Task

The task of the participants is to move their own vehicle, guided by each visualization in combination with each screen modality, three times from the starting position to the target position within a radius of 10 cm. As soon as the condition is fulfilled, the background of the visualization turns green and the driver can end the positioning process. The vehicle's reference point is located in the center of the side directed towards the lidar. Since the vehicle type can differ among the participants, the length of each vehicle is configured in the system. Visualization and screen modality is being assigned in a random order. However, after utilizing all user interfaces, the driver must repeat the task without any user interface.

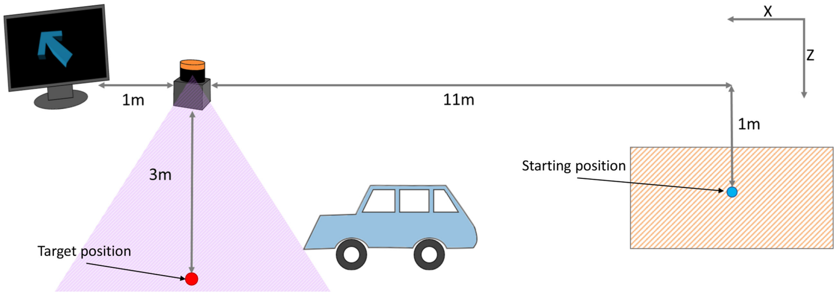


Fig. 3. Overview of the experimental setup with lines symbolizing the distances in the setup. The orange area represents a parking lot containing the starting position. The purple region symbolizes the lidar's tracking area containing the target position.

4.3 Data Acquisition

We provide digital questionnaires to each participant, which should be filled out on their smartphone, to obtain various information. The participants specify their gender, age and the number of years they own a driving license. Besides, the participants should rate their parking skills and IT skills on a scale from 1 for poor to 10 for very good. After every third repetition of using a visualization modality, feedback about the usability and workload is requested. To get a deeper insight into usability, the participants fill out a SUS (System Usability Scale [4]). We also provide a questionnaire that we derived from NASA-TLX [10] to measure the workload in our context. Since the user should fill out the questionnaire on their smartphone, we use a scale with a maximum of 5 points, whereby we equate the weighting of all questions. During the entire user study, each participant is motivated to express their experiences to evaluate the visualization modalities besides the questionnaires. Furthermore, we measure the end position when using each visualization modality to determine the resulting positioning error. The positioning error results from the distance between the vehicle's reference point and the target position. In addition, the time is measured during positioning to determine whether the required duration is within a reasonable time frame.

4.4 Results

In this section we introduce the set of participants and the collected measurement results of the user study.

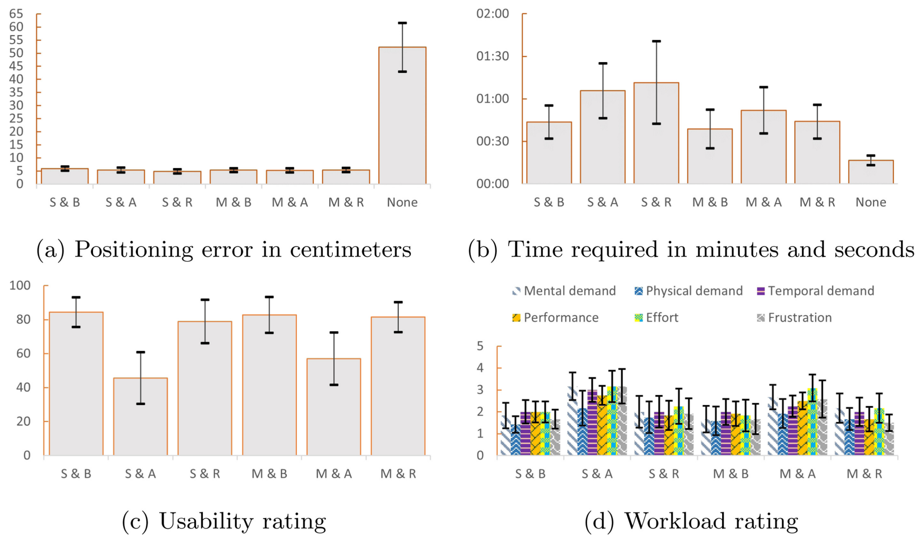
Participants. A total of 12 people took part in the user study, of which 7 are male and 5 female. The participants' age covers a wide range on the scale from 20 to 57 years with an average being around 37 years. Driving license ownership also spans a wide range from 0 to 38 years, with an average of 17 years. On the one hand, there are participants in the group who are novice drivers and on the other hand, there are participants who have been driving for decades.

Most drivers rated their parking skills with 5 or better, several with 10 and one with 2, resulting in an average of 7.3. Comparable with the parking skills, the IT skills were rated with an average of around 6.4. In contrast to the parking skills, more participants rated themselves with a value below 5, which leads to a balanced distribution within the range. In terms of age and driving experience, the participants form a relatively balanced group, while the self-assessed skills are mostly in the upper range.

Measurements. Based on the end position of the vehicle, we determine the average positioning error for each combination of visualization and screen. We calculate the average Euclidean distance symbolized by σ using Eq. 1:

$$\sigma = \frac{\sum_{i=1}^{n} \sqrt{(target_x - x_i)^2 + (target_z - z_i)^2}}{n} \qquad (1)$$

The constants $target_x$ and $target_z$ represent the coordinates of the target position. The variables x and z represent the coordinates of the end position. Figure 4 illustrates the data which was actively collected during the study. For a shorter notation we define the following: (Screen)&(Visualization) with Screen = [S = Smartphone or M = Monitor] and Visualization = [B = Birds eye view or A = Arrow or R = Radar].



(a) Positioning error in centimeters
(b) Time required in minutes and seconds
(c) Usability rating
(d) Workload rating

Fig. 4. A visualization of the study results using bar charts for mean values and error bars representing the 95% confidence intervals.

5 Discussion

This section provides a discussion of the findings and observations made in the context of the user study.

5.1 Precision

Without utilizing a user interface for positioning, the error lies in a wide range around 50 cm. In contrast, the use of one of the user interfaces leads to a significantly higher precision with each having a similar positioning error of approximately 5 cm. Accordingly, positioning procedures assisted by the user interfaces are about a factor of 10 more precise than without assistance, while the precision requirement is fulfilled at the same time. In terms of precision, significant differences between the user interfaces were not discovered.

5.2 User Experience

In contrast to the findings made in the context of precision, differences arise in terms of user experience. Figure 4c indicates a high rating in terms of usability for bird's eye view visualization followed by radar visualization. In contrast, the arrow based visualization, was rated significantly less usable in comparison to the others. As observed with the usability rating, Fig. 4d indicates a comparable ranking in the context of workload. Especially arrow based visualization was rated with a higher workload than with the other modalities. During the study, participants should report their personal experiences and impressions. Most of the participants prefer to be supported by a bird's eye view visualization, since decisions on next positioning step can be reasoned freely based on the overview provided. As the results in Fig. 4c and 4d indicate, the arrow-based user interfaces are the most criticized. The problem arising from this representation is that exclusively the driving direction is provided and no information about the relative offset to the target is communicated. Many participants were unable to estimate the distance to the target and drove past it, causing the arrow to rotate in the opposite direction, which was perceived as confusing. Furthermore, the radar visualization was rated in a comparable way as the bird's eye view visualization, however some users required a period of time for familiarization to understand how the visualization works.

5.3 Time

Regarding the time required for positioning, Fig. 4b indicates that a time of less than 2 min can be achieved, which we consider to be suitable for every day use. However, the time required in the case of not utilizing a user interface for support is significantly less than in the other cases. This is caused by aborting positioning after a short period of time due to a lack of orientation. Without the support of a user interface, the participants were able to complete the positioning in just 1 out of 36 cases. Regardless of the visualization type, the average time required is consistently lower when utilizing a monitor. One reason for this result could be that we provided the participants with a smartphone, but no holder. Accordingly, most of the participants were not able to put the smartphones in a suitable location. However, three drivers were able to complete the task faster using the smartphone in at least 55% of their positioning attempts. These cases could indicate that the smartphone was in a suitable position in the vehicle. Comparing all visualization conditions, bird's eye view is the fastest regardless of the screen type.

5.4 Observations

At the beginning of the positioning task, some participants felt unsure, as this was the first time they had to position their vehicle with high accuracy. The average time required for each iteration indicates that uncertainty decreased when repeating the positioning since a learning and familiarization effect occurred. The first iteration took the participants an average of approximately 1 min, the second 50 s, and the third 40 s. Due to the measurement of time, some drivers felt compelled to perform well, but the measurement also unsettled others. In contrast to the smartphone screen, the stationary monitor is exposed to environmental conditions. Due to the problem that visualizations might be poorly visible caused by light reflections, we had to examine multiple angles for a suitable screen setup. To enable continuous operation of the outdoor screen setup, other influences such as rain and vandalism should be taken into account. In order to mitigate these environmental impacts, we have purchased a robust screen housing. Based on the experience gained in the user study, we conclude that a stationary monitor can only be used under certain conditions. Although the smartphone variant was rated to be more convenient, it was criticized for the fact that the device cannot be conveniently stored in every vehicle type. Such problems would not arise when displaying the visualization on screens that are integrated into the vehicle's dashboard. In order to improve the system, participants suggested that a combination of different visualizations could be helpful to benefit from the advantages of several visualization types. In addition, many participants mentioned that further information such as a numerical representation of the distance to the target should also be displayed. With regard to the sensing device, it was observed that the lidar occasionally produced inaccurate measurements. This effect occurred when the vehicle had reflective components such as chrome strips.

6 Conclusions

Wireless energy transfer for electric vehicles is conceived as a more convenient alternative to wired charging. For efficient wireless charging, the transmitter and receiver coil must be accurately aligned. Since charging components are often located under the vehicle, they are not visible to the driver, which makes precise alignment challenging. As part of our research, we provide a driver guidance system that supports the driver in fulfilling this task. Since in many cases the necessary positioning can only be carried out manually by the driver, a suitable user interface is required. Due to the novelty of this application context, there is a lack of experience in the design of such a user interface. In this paper, we try to identify a user interface for a driver guiding system that can support the driver to reach the required precision when positioning. Our system provides various visualization modalities, which we evaluated within a user study. A positioning scenario was simulated in which the study's participants should try to achieve a target precision using the system. The required precision could be achieved with all visualization modalities. However, the user experience differs significantly. The participants prefer a visualization from a bird's eye view, which gives an overview of the overall situation. In contrast, the participants were dissatisfied by using a visualization that presents an arrow pointing in the direction of the target position. The participants criticize that the spatial relationship between the current vehicle position and the target position is difficult to deduce. Moreover, the time to complete the task using the bird's eye view visualization took less than 44 s on average, which is probably shorter than parking and plugging in a charging cable. In contrast, an arrow-based visualization took in average up to 1.5 times longer than bird's eye view visualization to complete the task.

Although this paper focuses on stationary wireless charging, the user interfaces provided could be explored in the context of dynamic wireless charging. In addition to the driver guidance, the user interface could also send warning signals to the driver, to avoid collisions with objects in the surrounding.

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