A prototype for robot assisted navigation for blind and visually impaired people

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***Abstract*—This paper presents the Boston Dynamics robot Spot in its application as a prototype for a navigation aid. Adapted to the needs of blind and visually impaired people, the developed assistance system will navigate through an unknown environment in the future. With its sensors, the Spot robot is developed to safely escort the operator to the desired destination. A survey conducted with the target group of blind and visually impaired people is presented. The navigation process is described in detail. The system and the interaction between hardware and software via a graphical user interface on a user's standard smartphone is introduced, along with network and hardware components. Usability and performance are examined. The behavior and capabilities resulting from this application are discussed. In the end, knowledge gained, and future directions are highlighted.**

***Index Terms*—Navigation, visual impairment, robotics, navigational aid.**

I. Introduction

When blind and visually impaired people move through an unfamiliar city environment with unknown dangers, they often experience orientation problems. Approximately 216 000 people in Austria are permanently visually impaired, representing 3% of the total population over the age of 15 in private households.[1] Worldwide, approximately 36 million people are blind and 217 million people are affected by severe or moderate visual impairment.[2] Major causes of visual impairment and blindness, however, are age-related diseases such as macular degeneration, glaucoma and diabetic retinopathy, all of which commonly occur above the age of 50. However, due to the aging of the population and the demographic trend, the number of incidences will soon increase significantly.[3] When blind and visually impaired people move through an unfamiliar city environment with unknown dangers, they often experience orientation problems. Some very effective everyday aids for blind and visually impaired people already exist. So far, along with white canes and human companion, guide dogs are commonly used for helping. To own a guide dog a lot of different aspects must fit together. Guide dogs are not very numerous and cost about €30 000 in training.[4] Waiting lists are long and not every dog can complete the training. Furthermore, the animal can perform its service for a maximum of 10 years.[5] To develop a technical aid, which can cover the need of guide dogs as well as generally navigation aids by a little more is indispensable in the future. Robots can also be used temporarily, depending on the need. As well, the acclimatization period only takes place on the side of the human. The robot agrees with every human and only needs breaks when the battery needs to be charged. No training phase is necessary, and the robot can be used immediately after production. Time and a lot of money is saved in the long run. As a result, more blind and visually impaired people can be provided with a navigation aid in a shorter time. The use of a proper navigation aid in the everyday life of a visually impaired person strengthens self-confidence as well as independence and opens many possibilities in the daily life with sighted people. Apart from economic benefits, this brings a social benefit and, in most cases, leads to successful integration into social life. Aim of this project was to develop a prototype of a robotic system to provide blind and visually impaired people with a navigational aid. It should be able to guide a person to a certain place safely and automatically.

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II. Methods

A. Survey

A survey with the target group of blind and severely visually impaired people was conducted to better understand their everyday problems with navigation aids. In addition, the aim was to find out how well a robot might be accepted by them. There were 29 respondents, with 39.3% out of them between 31 and 45 years old and 35.7% between 46 and 60 years old. The rest was divided between the 18 to 30 years age group with 14.3% and the group over the age of 60 years with 10.7%. Almost 79% of the respondents said they were completely blind, while 21% were severely visually impaired and still had residual vision. The use of daily living aids is strongly dependent on the employment status of the blind or severely visually impaired person. The busier the person, the more he or she usually has to leave the house and is dependent on assistance. 35.7% of all people asked stated that they were employed full-time, while 17.9% were employed part-time or marginally. Separated from the retirement category, 25% of the survey participants said they were not employed. 10.7% said they were studying at university, still at school or undergoing vocational training.

When asking about which navigational aid is used in daily life, 19 people responded with smartphone apps. Google Maps was mentioned numerous times in this context. Next, the white cane also received 17 mentions. With 4 responds each, guide dogs and human companions were mentioned comparatively little, as well as trust in one's own hearing. Other navigation aids mentioned were the sense of touch, ultrasonic obstacle warning devices and a compass. The survey participants were asked to name their favourite function of all navigation aids for blind and severely visually impaired people available on the market. A sense of direction of a human companion was the most frequently stated feature with 18 mentions.

The white cane with its special tip was mentioned 16 times. Sense of direction of a guide dog, on the other hand, was mentioned only 4 times. This shows that there seem to be some disadvantages associated with guide dogs. Vibration, acoustic feedback and GPS location were also sporadically responded navigation aids. All people were also asked to rate their trust in technology in all their everyday aids on a scale from 1 with no trust to 5 with high trust. The result shows that 46.4% rated a medium level of trust with 3 out of 5 possible maximum points. 32% of the respondents even indicate a high trust in technology with 4 out of 5 possible points. However, 10.7% of the respondents stated that they have no trust at all in the technology in their everyday aids. Next, the participants where asked if they would trust a robot as if they would trust a human companion or a guide dog. 14 people responded with a yes and 11 with a no. 4 people did not submit a vote on this. The survey found that older people currently show the most distrust of technology when it comes to everyday aids. These figures are awaited to change in the future, as the next generation of elders is characterized to be more open-minded towards technical aids and the technical progress. The target group was also asked what bothers them most about the navigation aids currently available on the market. Imprecision of the navigation was mentioned by far the most by the respondents. According to the given answers, in the outdoor area, information about crossings is missing, and the GPS is often very inaccurate. Temporary construction sites and snow walls are not displayed at all. Another shortcoming of the current navigation aids is the high cost. An application for reimbursement by the health insurance is often very time-consuming and, unfortunately, often remains without success.

Another problem cited by survey respondents was that the current navigation systems available on the market require too many separate and exclusive devices for controlling them. Less equipment for all the different everyday aids would be desirable. As an overall result of the survey, it can be seen that the smartphone as an universal assistive device offers a great opportunity in the future. There are already many barrier-free usage options, on which various applications can build on. This is a clear statement and points in the direction of developing a smartphone app instead of an extra device for controlling a robot.

B. *The robot*

For the development of this navigation system for blind and severely visually impaired people the robot Spot by Boston Dynamics was in the center of attention. The quadruped, which is advertised as a manoeuvrable mobile robot, is able to move autonomously in any terrain in which a normal robot is can no longer operate, even off-road. During its operations, a wide variety of tasks can be conducted and data can be recorded continuously or only on demand. In figure 1 the robot Spot is depicted. The most important parts are highlighted.

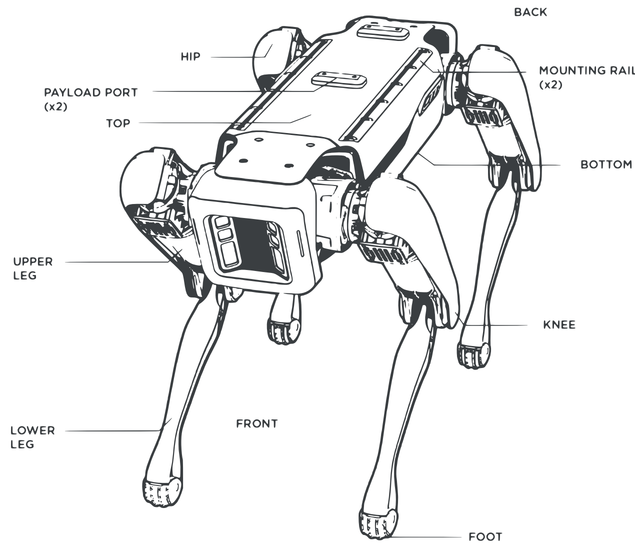

Fig. 1. The robot Spot with all its important parts highlighted.[6]

In addition, several other sensors and functions can be integrated into the system and controlled via the four-legged robot. With Spot, tasks can be carried out precisely and efficiently without having to put a human in danger. Equipped with various cameras, the robot can continuously see from all angles what is happening around it. The battery-powered Spot can be programmed and used in a variety of ways.[7]

Spot has so far been used for many different applications helping humans to not expose them to danger. Some of the main applications involved construction site operations to view the progress made, walking through oil and gas facilities or applications in the mining industry to perform measurements under dangerous conditions.[7]

C. *Navigation components*

- **Map**
  A map [8] represents a route that Spot has walked before. The saved map contains all the necessary data for moving around the recorded environment. For subsequent recognition of the route, all necessary details of distinctive points along the way are stored in the data as well. Anything beyond the recording is unknown to the robot and therefore the robot cannot orientate itself therein. If there is no orientation due to unknown terrain, the navigation is aborted immediately. At Boston Dynamics, navigation is always referred to as graph navigation, since the recorded maps are topological graphs.[8] Topological means a systematic description of spatial relation.
  Maps have to be recorded manually. When recording a map, Spot automatically creates waypoints along the route, which are connected by so-called edges. Therefore, maps are graphs with waypoints and edges.[9]
  In the following figure 2 the overall concept of a map for autonomous navigation provided by Boston Dynamics is shown.

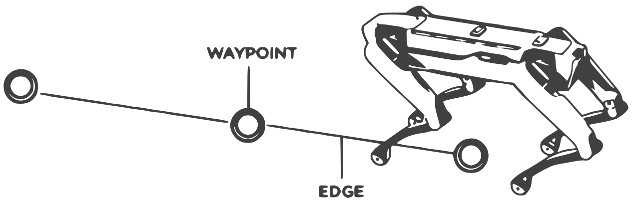

Fig. 2. The overall concept of a map for autonomous navigation by Boston Dynamics. A map consists of waypoints connected by edges.[9]

- **Waypoint**
  Waypoints demonstrate orientation points along the path, which Spot approaches step by step during navigation to its target destination. A single waypoint stores a bundle of data gathered from the route during the recording process. Waypoints are automatically created during map recording and store relevant details for navigation. The points are placed according to the route extent and the number of prominent details in the environment. The basic distance between automatically created waypoints is 2m. If there are more significant details in the environment, additional waypoints are set automatically or can be set manually.[8]

- **Edge**
  The connection of two neighboring waypoints is done by so-called edges. In mathematical terms, this transformation contains the information about the position of a waypoint in relation to another waypoint. In addition, the properties with which the robot moves between two waypoints are specified in the edges. An example of such a property is whether the robot uses stairs.[8]

- **Fiducial**
  Fiducials are special visual two-dimensional images placed along the captured map at specific points. With these, Spot can verify how its position in its world is compared to the surrounding environment during a navigation process. To be able to start a recording, at least one fiducial is required within sight of one of the five cameras of Spot when the robot is standing.[10]
  Subsequently, as needed, numerous fiducial markers can be placed along the path to further assist Spot in navigating, maintaining correct initialization between the robot world and the ambient world. Additional fiducials can also trigger more actions as desired. Fiducials can have many different looks. Boston Dynamics in fact already provides a file[11] with 19 different fiducials for Spot. In this file, so-called April tags are used, which are visual fiducial markers often used in robotics as well as augmented reality applications and camera calibrations. [12] In the following figure 3 an example for a suitable fiducial provided by Boston Dynamics is shown.

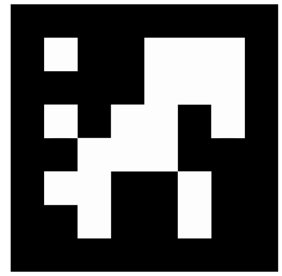

Fig. 3. An example for a fiducial tag which can be used for navigation.[11]

  Similar to QR codes or barcodes, April Tags store information with a data volume of 4 to 12 bits.[13] Likewise, a position estimate of the fiducial in relation to the camera can be made in six dimensions, divided into 3 translations and 3 rotations.[12][13] The provided fiducials from April Tag family in Tag36h11 format match the perfect size and appearance for Spot's recognition. Boston Dynamics offers the user the possibility to choose other fiducials with different looks and sizes.[10]
  In order to start recording a map, at least one fiducial must be in sight of one of Spot's five cameras. Fiducials are well attached to the wall before the map is recorded and should not be moved from there on. They remain stuck to the wall even during every single navigation thereafter. The placement height of the fiducials should be set to allow Spot to see them in his cameras at the expected standing height at that moment. Fiducials do not need to be used at prominent points in the room such as corners, objects such as furniture, as these are prominent enough for the cameras. Exceptions to this are when a navigation starts there. There must always be a fiducial at the start of the navigation. The same fiducial can only be used once in a map. However, if multiple maps are included, the same fiducial can be used across multiple maps as long as it still occurs only once in each map.[10]

D. Navigation process

In the following paragraphs, all steps for navigation are explained in detail step by step. Navigation is done by a command to move the robot towards a specific waypoint.

- **Initialization**
  At the beginning of the navigation, Spot must first orient itself on the map that is loaded onto it. To find out where Spot is on the map at the moment, an initialization is performed. There are several possibilities for this. The used method involved triggering a localization upon detection of a fiducial in one of Spot's cameras.[9]
  Here, not only is a fiducial placed at the beginning of navigation, but numerous ones are placed along the route, clearly visible to at least one of Spot's five cameras, especially at each final destination. For the entire navigation, 17 fiducials were used along the way in this project. This of course leads to the disadvantage of having to place many markers along the path, which is not possible in every application environment. When

starting the navigation, Spot stands up and looks around for fiducials and can thus orient himself. The fiducials must not only be present when the map is loaded, but absolutely also at exactly the same position for each navigation afterwards. Small changes already lead to wrong initialization and thus also to wrong navigation. This means that there must be a fiducial at least at each final destination in the navigation environment, as Spot starts the next navigation from there. At this point, the robot is initialized to the route and can orient along its way.[9]

- **Localization**
  After initialisation, the robot must be located on the map. The feedback is an object with the pose of the robot in relation to a waypoint on the map.[14]

- **Navigation to a destination**
  Now Spot can start the navigation to desired destination on the pre-recorded and loaded map. Spot was programmed to choose the route with the least number of edges[15], thus the shortest route to the destination. If Spot has successfully navigated to the destination, the robot then sits down and signals the end of the route with an additional voice feedback for the user.

III. RESULTS

A. *The system*

In figure 4 an overview of all important components of the system can be seen. The robot receives commands from the processing unit. By using a smartphone the user can communicate to the robot where he or she wants to go to. Via a dog leash the user gets feedback from Spot. An additional voice feedback is realised to keep the user updated about what is going on.

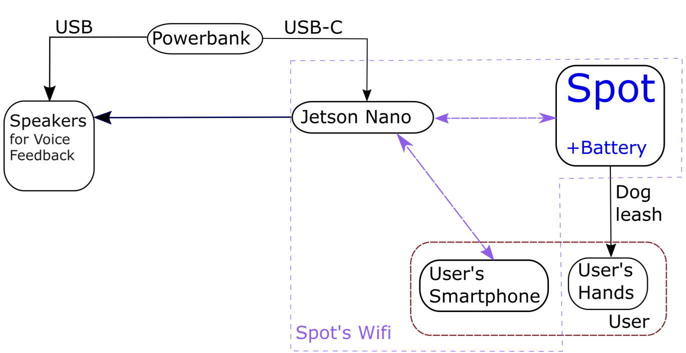

Fig. 4. The key components of the system concept.

All components will be described in the upcoming paragraphs.

*1) **Dog leash**:* One of the most important roles in the system has the leash, which was developed on the basis of special leashes for guide dogs. In the following picture the overall concept of using a leash to establish a connection between the robot Spot and the human is shown. With the handle of the leash, the user stands at the right or left rear end of the robot, depending on personal preference. The special leash, when in motion, provides the user with a sense of guidance and stability with a degree of flexibility for more room to manoeuvre when used in narrow indoor spaces.

Fig. 5. The robot Spot with a dog leash to guide the blind or strong visually impaired person to the desired destination.

*2) **Other hardware components**:*

- The central interface of the system consists of an Nvidia Jetson Nano, on which all the necessary software for controlling Spot is stored. Enough power is supplied to the Jetson Nano via a power bank.
- Another important component in the developed system is the end user's smartphone. With this, the user has access to the Graphical User Interface and can communicate with the robot. To do this, the user's phone is connected to Spot's WiFi.
- A voice output was implemented via speakers mounted externally on the robot, which transmits current information about the operation of the robot via a speakers on Spot's upper side.

B. *Software components*

The whole project was coded in Python 3.6.9. For developing a web application the framework Flask was used. A server has been set up in Flask through which the user can be connected to the robot for communication.

When booting the Jetson Nano, the navigation code is started immediately, which also starts the server. As soon as the end user connects to Spots' Wifi, the graphical user interface, short GUI, can be opened in the smartphone's browser. As soon as the user has successfully logged in inside the GUI, the navigation to one of the various destinations can be selected by simply pressing the respective button. The layout seen by the user after successfully logging in can be seen in following figure 6.

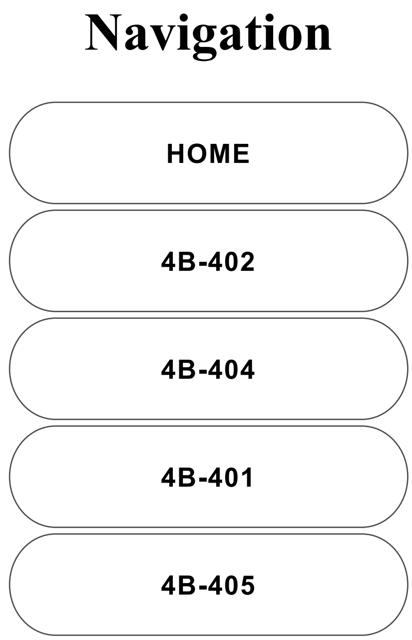

Fig. 6. The Graphical User Interface (GUI) on the phone of the user to communicate with the robot where Spot should navigate to

C. Accessibility

As a security precaution, it has been defined that only one end-user can be connected to Spot at a time. If a second end-user tries to log in, Spot will not let the second end-user execute any commands in order not to create any undefined situations for the actual end-user with the dog leash in his or her hand.

Regarding app use for blind and severely visually impaired people, there are already many tools available. No matter which operating system, Android or Apple iOS, both offer many operating aids for people with impairments. Enlarged font on the screen, stronger contrasts and fewer colours, colour inversions, as well as special voice controls are only a small excerpt of standard operating aids.

Thus, when developing a new app for a target group with visual impairments, the only thing that needs to be taken into account is simplicity of use and little graphic content such as images. The pre-installed operating aids already provide a great contribution to barrier-free operation. However, there is still a lot of potential for improvement, which can only be elaborated in constant exchange with the target group when testing the developed system prototype.

D. Usability test

In the following chapter, the developed robotic system will be evaluated by presenting results of a usability test. The test with seven healthy subjects consisting of some fellow students was intended to investigate a possible suitability for the target group of the blind and severely visually impaired with regard to system effectiveness.

Two different tests were performed. First, the subject was guided through a parcour. In the second part of the usability test, the user examined the entire robot system. Both tests were performed sighted. Main reason for that is that sighted people are not used to the condition of navigating in the dark compared to blind and severely visually impaired people. The purpose of this test is to evaluate the effectiveness of the system, as well as to obtain indications for further possible improvements. If the sighted user had to perform these tests blind, an additional barrier would be present, pushing the user into an additional uncomfortable and unfamiliar situation. The results would be biased.

*1) **Parcour**:* The first part of the test involves a parcour to allow the user to slowly become accustomed to the system of a robot with a leash. All subjects were guided through a parcour with 7 different sectors. On the parcour, the user was guided by the robot and the leash while holding the handle of the leash. Robotic control was performed manually by the operator of the test. Each sector focused on different aspects of an application of the robotic system during a navigation. The seven sectors involved are:

1) From home position to first left turn
2) Left turn
3) Straight ahead + left turn
4) Circular motion
5) Stopping after circular motion
6) Left turn
7) Straight ahead followed by 360° turn

A response to the course in the test was rated 1 as successful, 2 as reasonably successful, and 3 as unsuccessful.

*2) **System Test**:* In this part of the test the user was trying out the whole system. The mobile app in combination with the robot as a stand-alone device with all the necessary hardware was tested. After walking through the parcour, the user already had a better feeling for how the robot works and was more relaxed during the system test.

The user was first instructed to navigate to a few destinations. During and after the process the users were specifically asked subjective questions in order to obtain information about its suitability for everyday use and future improvements.

*3) **Test results**:* When combining both parts of the results it can be said that the results of the system so far have positively surprised many people. There was no user experiencing discomfort during the entire system process. Within a few seconds, every participant got used to the system. The system is very simple and thus does not require very long explanations. Therefore, users were also fond of the smartphone app, as no training in an extra device is needed. Speed and traction of the robot were generally found to be very pleasant. Accordingly, no adjustment should be made here.

In general, 4 out of the 7 people asked would like to see more leash stability. The others, however, are fully satisfied with the stability. The leash length of $71\,\mathrm{cm}$ has proven to be optimal for all different body sizes. A shorter leash would lead to problems of the robot recognizing the human as an obstacle which it tries to avoid. A longer leash would not have the same guiding effect and would be too loose.

Feedback came in that vibration feedback in the user's grip could be a detail which would greatly improve the lead quality of the leash even without more stability of the leash.

A request by some test respondents was to expand the audio feedback. It was found to be very pleasant. Hence, audio feedback could also be given during the process of uploading the map to the robot. By doing this, the user is aware of ongoing activity and that the connection between him or her and the robot has not been interrupted.

However, there are still shortcomings in the system. Starting or stopping abruptly poses challenges for the overall system with humans involved. The user mostly cannot react as quick as the robot does. This is why section 5 of the parcour was only conducted completely successful in 57.14% of the cases as it can be seen in table I. It was proposed by some users to include a soft-start and a soft-stop of the robot. Sharp turns also present a major challenge for the system. As it can be seen in table I, in sector 4 and 7 circular motion is included. Calculating the average, in only about 71.43% of all circular movements they were conducted completely successful. When observing the participants and their results, avoiding rotations at the beginning and end of navigation would bring added value as well. The robot is doing these movements to either park in or out at a destination. During the main walking part there are none of these unwanted circular movements. Additional audio feedback could help in all these situations, according to users.

The tests were conducted in a controlled area. In a free environment with, for example, glass doors, the system would be even more error-prone, as the robot cannot correctly identify them in most cases.

Furthermore, it was a challenge during the test to keep the server running all the time. The robot's battery and the process unit's power bank were constantly draining. In free operation of the system, this must be taken into account permanently.

Some test participants nearly bumped into the wall when doing turns with the robot. This is why some of them wanted the robot to include a margin which prevents the human from running into a wall. The wish was justified by the users by the example of a car with a trailer making a turn.

In order to obtain the overall accuracy of the system in the usability test, the mean of the optimal results must be calculated. An optimal result occurs when the system including the subject exactly operate in the exact imagined way. In the evaluation of the usability test the optimal result is represented by the number 1 standing for successful. The number 2 represents a reasonable results. The response was not as great as it should be but there was still a response to it. Number 3 represents a unsuccessful result.

Combining all results gathered from 7 users a confusion matrix has been created to conclude all results. Table I shows the confusion matrix highlighting the optimal results.

TABLE I
CONFUSION MATRIX TO CALCULATE THE SYSTEM ACCURACY. THE STATES 1,2 AND 3 STAND FOR SUCCESSFUL,REASONABLE AND UNSUCCESSFUL.

Obstacle/ State	1	2	3
1	**100.00%**	0%	0%
2	**100.00%**	0%	0%
3	**100.00%**	0%	0%
4	**85.71%**	14.29%	0%
5	**57.14%**	42.86%	0%
6	**100.00%**	0%	0%
7	**57.14%**	42.86%	0%

As a result, the overall system accuracy amounts to 85.71%. On average 6 out of 7 parcour obstacles were figured out optimally by the subjects.

IV. DISCUSSION

The results of this project show that it is possible to successfully navigate a human to different places with a robot. An experiment was then conducted to quantitatively evaluate the system effectiveness and to find out future improvements.

There are still unresolved problems. One fundamental ethical dilemma in the use of this developed robotic system still remains. Actually, a robot must always be as far away from a human as possible. Ethical guidelines or standards on robotic navigation systems involving humans are still too general and mainly focus on industrial application, where the robot generally should be kept away from the user as much as possible.[16][17] In a robotic navigation system, robots should be as near as possible to the human companion. Still, Boston Dynamics does claim not to use the robot in the immediate vicinity of people. If in the future a hazardous situation with consequences were to occur, the question arises as to how far someone would be liable for the damage. The manufacturer of the robot Boston Dynamics would never admit guilt, as it already clarifies in advance not to use the robot in the immediate vicinity of people.

Every now and then, the screen automatically darkens and later enters lock mode. When the phone is unlocked again, it can sometimes be detected that the network connection was disconnected in lock mode. This means that the web app opened in the browser is no longer up-to-date and the user notices on the screen that the page has to be reloaded. However, the robot does not know this and, in the case of previously started navigation, continues to navigate. This can lead to troublesome situations. In the future there will be an emergency stop integrated into the GUI. In a situation of a needed page reload, the robot is no longer fully controllable, as the emergency stop on the mobile phone display can no longer be pressed spontaneously in the event of a problem. However, this is a problem on the mobile phone side, as this is meant for power saving. By resetting the network settings, this problem can be deactivated in some cases. Then, in most cases, a network connection remains even in lock mode. Alternatively, the phone can be set to not automatically switch to lock mode after a short period of time.

In general, some problems were considered in the development of the navigation. The fiducial markers to be used at the beginning and on the routes can develop into issues in some cases. Fiducials must always be in the same place and must not be removed or placed elsewhere since the beginning of the map recording. As soon as the placement is changed in the slightest, the map must be re-recorded. Furthermore, the height of the placement of the fiducials is essential for effectiveness and must always be at the perfect height for at least one camera. This adjustment to the camera can take some time and several map recordings until the perfect position is found. In addition, fiducials are not necessarily the most beautiful sight visually. With 10 or more fiducials in close proximity with few optical features around, this means a solution which is not very aesthetic in the long run.

An additional general problem with navigation is the fact that Spot is not aware of where it is in relation to the various possible destinations on the map as soon as it boots up. If a desired destination is then selected on the smartphone to start navigation, Spot does not know which map to select for navigation. Each recorded map contains an exact route from a defined final destination to the next final destination. However, with a dead battery, the robot may stop somewhere in the middle of the route. In this case, the robot cannot select a map to guide it to the desired destination when navigation is started. As a workaround, a universal map has been added, which guides through all possible positions in the total operating environment of Spot. By doing this, Spot has the advantage of being able to orientate itself at any time. The disadvantage, however, is that the route to the desired destination is significantly longer the first time after Spot is switched on. From the second navigation after Spot is powered up, everything is back to normal, and the robot takes the best possible route to the destination.

Another current problem is Spot's flexible routing. When the robot starts navigation, it moves in the direction of the destination. If it is more effective for Spot in its current position to go backwards or sideways, this can also happen. According to experience, this is most likely to happen in the first and last moments of navigation. The main route to the destination is usually carried out forwards, as it is also the most natural for the robot's joints. However, it can lead to undefined situations, as the blind person with the guide leash might be confused in case of possible backward movements. The pull of the dog leash changes completely in these moments. The visually impaired user does not recognise the situation without eyesight and has to rely completely on Spot. A real guide dog would not walk backwards. This is something that objectively distinguishes Spot from a real guide dog. In the future, the walking style of the robot could be adapted a little more to the natural walking style of a living being.

Overall, Spot is still an industrial robot with weaknesses. In general, even if the battery can be fully charged, the battery still has too little operating time from the current point of view. The battery would have to be charged too often to accompany blind and visually impaired people to their desired destination. With a fully charged battery, Spot has a maximum operating time of 90 minutes in full operation or about 4 hours in standby mode while sitting. When Spot is used to assist the blind and visually impaired, it may have a long standby time between its navigation missions. It might be the case that the robot accompanies the human to a doctor's visit. Spot then has to wait at the doctor's for several hours until the human has to be navigated back. The robot's battery could then accidentally run out in its waiting position. Spot could be in a place where it cannot be easily recharged. In this case, Spot must be found by an external person and brought to a charging station. Also, low battery operation is sometimes very error-prone, which is a big problem when operating in a crowded environment.

It was found out that Spot is still a bit too big and bulky to be used in everyday life. Other people, traffic participants and animals do not yet really know how to behave towards Spot. There is often uncertainty as to whether Spot will avoid them in time. The behaviour of such an aid for everyday life still needs to be communicated to the general public. However, Boston Dynamics still claims to always have a $2\,\mathrm{m}$ radius with no object or human around the robot in operation. This is already not complied within an application with a dog leash and a human in the near surrounding. If the robot is additionally used in a crowded urban environment, this is even more critical. Children, other animals or moving vehicles can be a big challenge for Spot, but also vice versa. Glass doors create another big navigation hazard indoors. Spot does not recognise them and crashes into them in most cases.

V. CONCLUSION

This project shows that it is possible to successfully guide a person to a desired goal with a robot, including if the person is blind or visually impaired. A promising solution was developed using a guide dog as an template of behaviour. In an experiment a system effectiveness of 85.71% was found out. For a few reasons, the navigation process was not fully successful. There are still unresolved problems. This navigation method for the blind and severely visually impaired is still in its infancy and needs to be further developed. On the part of the manufacturer of Spot Boston Dynamics, this robot is not recommended for use around people.

It is still an industrial robot with shortcomings which will be constantly evaluated and improved in the future. The system presented, intended as an everyday navigation aid for the blind and severely visually impaired, shows a promising direction for further developments in this area.

VI. FUTURE WORK

The efficacy of this project provides a solid base for a more sophisticated analysis tool in this field. It can be extended in the future with the following suggestions.

The next step should be to carry out more detailed tests on the system in order to collect more quantitative information. This should be done first with healthy subjects and later on with blind and severely visually impaired people. After that, the possibility of opening doors by means of a gripper arm mounted on Spot should be realised. Without the possibility of opening doors, Spot will only be of limited use indoors.

At the moment the navigation is thought to be conducted indoors in public buildings. Future work can focus on outdoor navigation functions as this was seen as a strong wish out of the conducted survey. There, a proper recognition of traffic signs, crossings and junctions as well as temporary obstacles like construction sites is important. GPS could also be tested for use with Spot.

As well, the navigation could be tried to improve by experimenting with a LIDAR on top of Spot. This could deliver an improvement to the difficulty associated with the non-recognition of glass doors.

VII. Acknowledgment

I want to thank the MCI, especially, Alexander Hörbst for giving me the opportunity to work on Spot. It has been a great experience to get the chance to work on a Boston Dynamics robot. I would also like to thank Ephraim Westenberger for his support in the case of software questions and Ruben von Stein for his support in the implementation of my hardware ideas.

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