DRIVE SWEDEN

Guidance for travels with autonomous vehicles for persons with blindness, deafness and deafblindness

Jonas Andersson
RISE RESEARCH INSTITUTES OF SWEDEN | 2021-06-30

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1. Summary

Autonomous vehicles can potentially enable new transport solutions where more people can travel independently and without accessibility issues. If new transport solutions are designed with a focus on inclusive design, then future transport systems can be accessible for more users creating large advantages for society. The project has explored how vibrotactile guidance devices can potentially improve the life of people with functional impairments such as blindness, deafness, and deaf-blindness by providing them with the means for more independent travel. Irrespective of the communication modality, devices used for orientation and navigation are one piece in the puzzle towards independent mobility for persons with diverse needs. Hence, a systems perspective is required to develop adequate solutions. The results show that vibrotactile guidance can improve orientation when locating a vehicle, receiving information along the way, and reaching the final destination, aspects that are important for independent travel and improved quality of life.

2. Sammanfattning

Autonoma fordon kan potentiellt möjliggöra nya transportlösningar där fler kan resa oberoende och utan tillgänglighetsproblem. Om nya transportlösningar utformas med fokus på inkluderande design kan framtida transportsystem vara tillgängliga för fler användare och skapa stora fördelar för samhället. Projektet har undersökt hur prototyper för vibrotaktil guidning potentiellt kan förbättra resande för personer med funktionsnedsättningar som blindhet, dövhet och dövblindhet genom att ge dem möjlighet till mer självständiga resor. Oavsett kommunikationsmodalitet är enheter som används för orientering och navigering en pusselbit mot självständigt resande för personer med särskilda behov. Därför krävs ett systemperspektiv för att utveckla adekvata lösningar. Resultaten visar att vibrotaktil guidning kan förbättra användarens orientering när man lokaliserar ett fordon, tar emot information längs vägen och når slutdestinationen, aspekter som är viktiga för oberoende resor, personlig frihet och ökad livskvalitet.

3. Background

In Agenda 2030 and the UN's Global Compact[1] are goals for increased equality in society. People with blindness (B), deafness (D) and deafblindness (DB) have diametrically different preconditions to travel compared to other people. This leads to unequal living conditions in society. With autonomous vehicles, there is great potential to radically increase the feeling of freedom and independence and to reduce the stigma related to B / D / DB. This proposal is further based on the feasibility study "Automation for increased accessibility?" funded by Drive Sweden which was carried out 2016-17.

Many persons with severe visual impairment, hearing impairment, D, B and DB have difficulty moving freely and travel as they are afraid of injuring themselves, causing injuries or getting lost. The problem is greater when the person has DB as sight and hearing cannot compensate each other. These persons are dependent on a companion who must walk next to and inform tactilely e.g. pat on the right arm while saying right, warn for a puddle of water or a branch in the road, or sign the information in the hand. The companions usually sign the information in the form of abbreviations or symbols instead of sentences. The problem is that assistants, especially those who know tactile sign language, are not always available, and it can sometimes be difficult to have a companion. Furthermore, aids that integrate all aspects of the trip (before / during / after the trip) are few and research takes place abroad based on local conditions.

As autonomous vehicles become more common, the question is how can they be used by D / B / DB in practice under Swedish conditions? A person who is D / B / DB will have great challenges in orienting themselves to locate their means of transport without a companion or driver / contact person in the vehicle. The challenges are found in several parts of a journey, e.g.:

- How can the traveler find the way to the vehicle?
- How can the vehicle be located at the pick-up point?
- How does the traveler know that it is the right vehicle?
- How does the traveler know if there are other people in the vehicle and where they are sitting?
- How does the traveler know that the vehicle is on its way to the correct destination and which road it intends to take?
- How does the traveler get information about disturbances / delays along the way?
- How does the traveler know that the destination has been reached?
- How does the traveler find the route to the final destination?

4. Project set up

4.1 Purpose

The goal of Drive Sweden is to identify, apply and evaluate new concepts and technologies. The project has done that by combining two relatively unexplored but promising branches of technology (vibrotactile guidance and autonomous vehicles) to create a new application and test and evaluate this combination in user groups where these technologies have potentially

[1] https://www.regeringen.se/regeringens-politik/globala-malen-och-agenda-2030/

life-changing effects. The project thus contributes to a sustainable and more equal society. The project contributes to the Swedish Transport Policy objectives working to improve accessibility for a large group of people who have difficulty using the transport system in an efficient and equal way. The consideration is addressed through increased safety and security for the target group, improved environment impact by reducing the need for specially adapted transportation and enabling travel on equal term in the same vehicle as other people, and improved health by radically increasing the feeling of freedom and opportunity to move in society for user group B / D / DB.

Early in the debate on autonomous vehicles, people with disabilities have been identified as a group where technology has great potential benefit[2,3] and as a target group where this technology could contribute to increased quality of life. Google has used the example of the possibility of driving visually impaired people to a restaurant as a visualization of what the technology can contribute. Automated vehicles have been seen as the efficient transport service of the future, but the emphasis is often on the development of the vehicles' own accessibility. The development has given the visually impaired high hopes for autonomous vehicles[4]. However, aids that integrate all elements of the journey (before / during / after the journey) are few. The conditions also differ between countries depending on e.g. local design of the street environment, travel services and public transport, which motivates Swedish research.

The current development of automated vehicles and mobility services also makes several of these expectations questionable. For example, automated driving systems are often installed in existing vehicle models that are not designed with the disabled in mind. Similarly, locating the vehicle, boarding and using seat belts in automated vehicles support. Services that address the "first and last mile" run along predefined routes, and to be able to use them, the traveler needs to get there in some other way.

The project, focus on identifying the benefits of being able to guide B / D / DB people to/from an automated vehicle corresponding to e.g. an automated on-demand service and/or autonomous shuttle bus that runs a predefined route. Together with the user groups, we have tested and evaluated both travel services in the form of autonomous shuttles, as well as guidance to and from these vehicles.

4.2 Objectives

The objective of the project is to study the preconditions for persons with B/D/DB to travel on their own in autonomous vehicles and autonomous public transport for increased freedom and quality of life. The goal is to identify needs for travel with autonomous vehicles and public

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[2] http://scholarworks.csun.edu/bitstream/handle/10211.3/203001/JTPD-2018-ID32-p274-283.pdf?sequence=1

[3] http://secureenergy.org/wp-content/uploads/2017/01/Self-Driving-Cars-The-Impact-on-People-with-Disabilities_FINAL.pdf

[4] https://www.technologyreview.com/s/602555/the-blind-community-has-high-hopes-for-self-driving-cars/?utm_campaign=socialflow&utm_source=facebook&utm_medium=post

transport and to test guiding technology for people with D / B / DB in different parts of a trip (before, during and after) to be able to complete trips without the presence of a driver or companion.

The following deliverables should have been achieved at the end of the project:

D1. A survey of B / D / DB needs before, during and after travel with autonomous vehicles under Swedish conditions.

D2. Existing prototypes for vibrotactile guidance of B / D / DB should have been tested in a new context - use with autonomous vehicles.

D3. Travel with autonomous vehicles should have been tested and evaluated with B / D / DB regarding user-friendliness and potential benefit for the individual and for society.

D4. An assessment of the scalability and need for technological development for the proposed solution for public transport and medical travel should have been carried out together with the project partners.

Overall research questions addressed in the project are:

RQ1. Can vibrotactile guidance enable people with D/B/DB to travel independently with autonomous vehicles?

RQ2. How should different solutions aimed at improving accessibility for people with D/B/DB be evaluated to highlight benefits for the individual and for society?

4.3 Project period

The project was originally planned for Jan 2019 to June 2020. Due to the COVID-19 pandemic, the project was extended to May 2021. The project was severely delayed by the COVID-19 pandemic since all user testing activities planned for the later part of the project had to be postponed. Planned participation in the IMC17 conference was also postponed to the spring 2021.

4.4 Partners

RISE Research Institutes of Sweden contributes to the project with extensive domain knowledge in the field of autonomous vehicles and cooperative systems. The researchers have expert competence in user studies and evaluation methodology. RISE has been project coordinator and project lead.

Audiological Research Center, Örebro University are experts in D / B / DB's special needs. Researcher at Örebro University are experts in aids for guidance with vibrotactile feedback.

Norconsult Astando AB contributes to the project with expertise in community, urban and traffic planning as well as accessibility for people with disabilities. Norconsult Astando AB contributes with extensive experience in areas such as public transport, ITS and accessibility for people with disabilities. There is also expertise on how the pedestrian network can be used for future navigation for pedestrians.

Västtrafik contributes with experience from the departments on-demand controlled traffic and strategic planning, based on its responsibility to procure and enable travel for a large part of the groups who for various reasons can not take part of public transport in full.

VGR Sjukresor, represents the public the actors responsible for community paid travel. These have a solid knowledge of the conditions for different transport solutions to be used to meet these needs.

The Swedish Association of the Visually Impaired pushes the issue of improved accessibility for people with disabilities in society and are experts in the special needs of the target groups. SRF's members are the target group for the solutions evaluated in the project.

Pariception AB develops aids for guidance with vibrotactile feedback and contributes with products and prototypes for testing.

5. Method and activities

The project has been performed using a user-centered design approach where needs and requirements has been explored and elicited based on blind, deaf and deaf-blind persons experienced when interacting with technology. The project has strived to evaluate human-technology-context interactions in real-life situations. Where real applications and situations has not been possible to achieve, situations have been simulated using stimulations to trigger close to real life experiences.

5.1 User studies

Five user studies were performed in the project:

Study 1: Expert review of autonomous pods in Stockholm and Gothenburg
Study 2: Usability testing of autonomous pods in Gothenburg
Study 3: Interview study with drivers and passengers
Study 4: Field testing of guidance technology
Study 5: Method development and online testing of travel aid using audially simulated trip

Study 1-3 are described in Publication 1. Study 4 is reported in in Publication 2. Study 5 is reported in Appendix 2.

5.2 Work packages

The project was organized in five work packages. Each work package contained a number of tasks. A summary of deliverables and answers to research questions are presented in chapter 6. Detailed results can be found in publications listed in chapter 8.

Work package 1: Project management
WP1 coordinated the work and called for work meetings and workshops. RISE performed the project management throughout the project.
<u>Task 1.1</u>: Project meetings and coordination. Project meetings has been organized in collaboration with the project partners throughout the project.

Work package 2: Identification of user needs
<u>Task 2.1:</u> Needs identification in relation to autonomous vehicles and autonomous public transport – need of guidance to and from vehicle, information needs in the vehicle during travel, positioning needs user-vehicle relative to each other. Needs identification was performed as part of the user studies and interviews performed in the project (Publication 1 and 2).

Task 2.2: Workshops on user needs. Internal workshops were performed throughout the project to plan user studies. In practice, needs elicitation was mainly done in the analysis phase of the user studies (Publication 1 and 2).

Task 2.3: State-of-art on existing guidance and positioning technologies. The state-of-art review was completed as part of the MSc thesis (Publication 2).

Work package 3: User studies – tests in traffic
Task 3.1: Trips together with the user groups in autonomous vehicles (real or simulated). Both real and simulated trips were performed in the project. The autonomous pods in public transport in Gothenburg and Stockholm were used as a platform for usability testing of autonomous transports (Publication 1). Further, autonomous vehicles were simulated with a manual car using the Wizard-of-Oz method (Publication 2). Also, travel aids were simulated using pre-recorded soundscapes to evaluate information needs in online meetings to achieve semi-realistic testing despite the COVID-19 restrictions (Appendix 2).

Task 3.2: User testing with and without existing guidance technology in different situations with autonomous vehicles. The prototypes (Read Move, Ready Ride and VibroBraille) were tested in simulated autonomous vehicles in Study 4. The participants with D/B/DB experienced travelling with and without the aids. Each participant made an individual travel choice and the information provided was evaluated in three phases – before, during and after the trip (Publication 2).

Work package 4: Evaluation
Task 4.1: Specification of how guidance technology needs to be adapted and developed further. The implications for further development of guiding technology were assessed as part of the user studies (Publication 1 and 2).

Task 4.2: Assessment of how positioning of users and vehicles should be done in future applications. Based on identified needs – assess how road network information and vehicle sensors can be used. A set of workshops were made both within the project and with external partners to assess how the future transportation system and related system architectures may look like to realize the guidance functionality (Appendix 3).

Task 4.3: Method development for evaluation of personal- and societal benefit by building upon the results from the pre-study "Automation for improved accessibility?". The assessment framework developed in the pre-study was elaborated further and complemented with input based on data collected in Study 5 (Appendix 2).

Work package 5: Dissemination
The project has been disseminated in scientific and professional communities, as well as social media. See chapter 8 Dissemination and Publications for list of dissemination activities and publications.

6. Results and Deliverables

Extensive results from the studies can be found in the MSc thesis report, in the journal article and the Appendices to this report. Deliverable D1-D4 are summarized in Table 1. The answers to the overall research question RQ1 and RQ2 are summarized in Table 2.

Table 1. Deliverables

D1. A survey of B / D / DB needs before, during and after travel with autonomous vehicles under Swedish conditions. In summary, these include need for personalized modes of communication depending on type of impairment, accessible and easy to use emergency handling functions, accessible and easy to use and understand interfaces such as buttons and information, common platform for alerts and notifications, customizable information and services, reliable and accurate maps. Specifically, the vibrotactile guidance devices can be a useful aid in navigation, but as such, the devices are part of a system-of-systems that has to be well integrated to provide an appropriate service. More details on user needs can be found in Publications 1 and 2.
D2. Existing prototypes for vibrotactile guidance of B / D / DB should have been tested in a new context - use with autonomous vehicles. The prototypes Ready Ride, Ready Move and VibroBraille have been tested in the context of autonomous public transport and autonomous cars. The results show that Ready Move was the most preferred device by the research persons in the tested situations, due to its ease of use. Detailed results can be found in Publications 1 and 2.
D3. Travel with autonomous vehicles should have been tested and evaluated with B / D / DB regarding user-friendliness and potential benefit for the individual and for society. Travel with autonomous vehicles has been evaluated in five user studies that all address the usability and benefits of both existing autonomous vehicles in public transport and a system to support navigation to autonomous vehicles.
D4. An assessment of the scalability and need for technological development for the proposed solution for public transport and medical travel. The system architecture for navigation guidance technology have been assessed and elaborated in a series of project workshops. The results can be found in Appendix 3.

Table 2. Answers to the overall research questions

RQ1.	**Can vibrotactile guidance enable people with D/B/DB to travel independently with autonomous vehicles?**
The project has shown that vibrotactile aids can support personal guidance and navigation in a significant way. It has also highlighted the need for a systems approach and that the devices used for guidance is one part of a larger puzzle that needs to be in place for person with functional variations to draw full benefit of an autonomous transport system. Publications 1 and 2 provide in-depth analysis of benefits, challenges and user needs when using vibrotactile guidance devices.	
RQ2.	**How should different solutions aimed at improving accessibility for people with D/B/DB be evaluated to highlight benefits for the individual and for society?**
The project has used a variety of methods to highlight both benefits and challenges with autonomous vehicles for persons with D/B/DB. In study 1 and 2 expert reviews and heuristics usability evaluations pointed out points of improvement in human-vehicle interaction (Publication 1). Further, in-depth interviews and ride-alongs in autonomous pods in public transport gave a thorough understanding of the specific and diverse needs of persons with B/D/DB (Publication 1 and 2). In study 4, field testing using Wizard-of-Oz methodology to simulate an autonomous vehicle provided a way to stage future human-vehicle interactions and evaluate experiences that can be expected in the future (Publication 2). In study 5, the creation of soundscapes and staging of travel experiences via online meetings was explored. Despite not being able to meet physically (due to the COVID-19 situation) the method worked well to enable evaluation with participants under restricted circumstances.	

7. Conclusions, Lessons Learnt and Next Steps

- The project has shown that vibrotactile guidance can give the possibility for improving orientation when locating a vehicle, receiving information along the way, and reaching the final destination, aspects that are important for independent travel.
- Design considerations for future guidance aid solutions have been developed and can be found in Publication 1 and 2.
- The vibrotactile devices used as prototypes in the project could only receive information. The studies point out the desire to also control the vehicle and trip. Future steps include exploring how users with functional impairments can communicate with, and control vehicles that do not have a driver.
- Irrespective of the communication modality, devices used for orientation and navigation are one piece in the puzzle towards independent mobility for persons with diverse needs. Future development should take the whole system perspective into account to create mobility solutions for independent travel and improved quality of life for persons with blindness, deafness and deaf-blindness.

8. Dissemination and Publications

The project has been disseminated in the following publications and presentations.

Publications

Scientific publication:

1. Ranjbar P., Krishnan P., Klingegard M. & Andersson, J.. Vibrotactile guidance for trips with autonomous vehicles for persons with blindness, deafblindness, and deafness: A qualitative case study. Submitted to Transportation Research Interdisciplinary Perspectives, 2021. Corresponding author: Jonas Andersson, jonas.andersson@ri.se

Master thesis report:

2. Krishnan Krishnakumari, P. (2019). Understanding the changes needed in the current existing technology for making autonomous vehicles more accesible to users that are blind, deaf or deaf-blind. Tesis (Master), E.T.S. de Ingenieros Informáticos (UPM). Universidad Politécnica de Madrid. http://oa.upm.es/55932/1/TFM_POURNAMI_KRISHAN_KRISHNAKUMARI.pdf

Articles in professional community press

3. Hur blir framtiden med självkörande fordon i trafik? Article in Strålkastaren #2, 2020. (Magazine for personell who work for or with Västtrafik)
4. Mobilitet med användarbehov i centrum – article in the report Innovation för Mobilitet, #1 2021, Almega Innovationsföretagen https://www.innovationsforetagen.se/2021/03/ny-rapport-innovativa-losningar-driver-framtidens-hallbara-mobilitet/

Social media

5. YouTube film presenting the project: https://www.youtube.com/watch?v=1CNVpimv0q8

Conferences

Presentation at Drive Sweden Forum 2020

6. Title: Guidance to autonomous vehicles – mobility for persons with deafness, blindness and deaf-blindness.

The International Mobility Conference IMC17 2021

Three presentations were given at the IMC17:

7. Andersson et al., User studies of self-driving vehicles for the visually and audially impaired: Ethical and methodological considerations
8. Cook et al., Autonomous transport systems for increased accessibility to societal functions
9. Ranjbar et al., Guidance for trips with autonomous vehicles for people with blindness, deafness and deafblindness

Conference presentation abstracts can be found in Appendix 1.

The project also participated in a panel session in the final summary of the conference where the implications of autonomous vehicles for persons with functional impairments were discussed.

Appendices

There are three appendices to this report as separate files.

Appendix 1 – Three conference presentation abstracts presented at International Mobility Conference 17 (IMC17), Gothenburg, Sweden, 2021.

Appendix 2 – Method development and online testing of travel aid using audially simulated trip

Appendix 3 – Proposed system architecture for personal navigation to autonomous vehicles