Requirement Analysis for Personal Autonomous Driving Robotic Systems in Urban Mobility

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Abstract. Urban mobility is changing due to the emergence of new technologies like autonomously navigating robots. In the future, various transport operators and micro mobility services will be integrated in an increasingly complex mobility system, potentially realizing benefits such as a reduction of congestion, travel costs, and emissions. The field of personal robotic transport agents is projected to increasingly play a role in urban mobility, hence in this study, prospective target groups and corresponding user needs concerning human-following robots for smart urban mobility applications are investigated. Building on an extensive literature review, three focus groups with a total of 19 participants are conducted, utilizing scenario-based design and personas. Results show clearly definable user needs and potential technological requirements for mobile robots deployed in urban road environments. The two most mentioned potential applications were found in the fields of leisure applications and in healthcare for elderly people. Based on these focus group results, two personal automated driving robots which differ in function, operation and interaction were designed. The focus group-based results and derived requirements shed light on the importance of context-sensitivity of robot design.

Keywords: Autonomous driving · Human-machine-interaction · Personal human-following robots · Urban mobility

1 Introduction

In a rapidly urbanizing world, autonomous driving has gained a lot of attention and importance in recent years and has created new opportunities for city dwellers. Self-driving cars are considered as a well-known and widely noted forthcoming driving technology. However, outside of the broad public view, other forms of smaller automated vehicles are becoming more attainable and reachable for personal use [1]. These automated driving robotic vehicles can potentially support users by carrying goods and thus minimize physical load of humans [2]. While robots are already increasingly integrated in daily and

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social life [3], there is a need to further investigate beneficial product characteristics for smooth and effective human-robot-interaction (HRI) for personal autonomous driving robotic vehicles. However, the assessment of demands and the actual users' standards for personal self-driving robots are often speculative due to varying operational challenges [1, 4–6]. Although a number of studies have evaluated technical-functional and HRI requirements of personal robots, a consensus of distinct features and characteristics has not been reached [1, 4, 6, 7]. Thus, it is questionable how the market for personal mobile human-following robots will manifest and how these autonomous systems would be developed. The current research body [1, 3] focuses on technical issues dealing with how to create safe and functional person-following behavior. Only a few studies [2, 5, 8] included user surveys that indicate the number of potential users or record the personal needs from the user's perspective. Honig et al. [3] identified this gap in current research activities in terms of social interaction and user needs. Considering these limitations in the knowledge on personal human-following robots, the goal of this study was to define optimal conditions for a potential personal robot vehicle launch from a user's point of view by conducting focus group surveys. After the requirements of potential users are identified and considered, a human centered product design is developed incorporating the identified user needs.

2 Current State of Research

2.1 Autonomous Mobility

Small automated driving vehicles such as human-following robots were developed by two major research disciplines: Autonomous driving and Robotics. The research object represents an (electric) human-following robot operating in urban mobility applications. Thus, this personal vehicle includes characteristics of the field of research of *Autonomous driving systems* and *Robotics*. Both terminologies are consolidated and the actual state of current research on various human-following robots are examined.

Humans are already increasingly confronted with self-driving systems in the road environment. Some vehicles are already equipped with technologies that enable supervised autonomous driving. For these types of vehicles, there are a number of applicable definitions in the field of autonomous driving and robotics. According to the norm SAE J3016 (Society of Automotive Engineers), automated systems are classified in six different levels of automation depending on the area of application. These six levels encompass the following: No automation (level 0), driver assistance (level 1), partial automation (level 2), conditional automation (level 3), high automation (level 4) and finally full automation (level 5) [9].

For each level, the autonomy of the driving system increases while the need for surveillance through the user decreases. Autonomous systems consist of components of sensor technology, artificial intelligence, and actuators. Sensors such as cameras and radar systems, capture the environment surrounding the vehicle. Artificial intelligence is used to evaluate the recorded data and subsequently to change the state of the environment in order to achieve the objectives via actuators [10]. However, while first automated vehicles are tested on public roads, aspects concerning the liability for damages and the role of data privacy protection have not been sufficiently clarified.

In addition to existing taxonomies on autonomous cars, the field of robotics has also conducted research on smart mobility [6, 11]. In general, robots are artificial technical objects designed and built by human beings [12]. In literature, the distinction between industry and service robots is commonly used [4, 6, 12]. A first definition of industrial robots was given according to the VDI 2860 (The Association of German Engineers) [13]. According to the research of Hertzberg et al. [12], mobile service robots differ from industrial robots in the fact that all their actions depend on the actual environment. Since the surroundings are constantly changing, the programming of the robot has to be adaptive to a wide array of environments. Thus, mobile robots have to record their environment by using sensors, evaluate their data and finally choose their action accordingly. A major challenge in designing robot systems is achieving a seamless interaction between humans and machines as social and technical constraints are to be taken into account.

In robotics research, mobile robots are often referred to as personal service robots [3]. The ability of tracking and following users is projected as a main task for personal service robots and the design of human robot interaction in for these robotic systems has been evaluated (e.g. [14, 15]). In general, tracking is defined as following or detecting of a target, e.g. a human that can occur in different application areas such as in traffic systems. A specific application comprises the assistance of people and contribution to their daily life system by ground service robots. These robots are able to transport goods (e.g. groceries) by following their users and hence participate in urban mobility scenarios. Most of the existing human-following robots that are identified in literature represent simple first prototypes that were built and tested mainly for research purposes [2, 7, 16]. In order to develop user-centric robots, the specific market and user requirements of potential user groups have to be further analyzed.

2.2 Legal Background

However, the question arises which legal market peculiarities have to be respected for the implementation of mobile robots as traffic attendees in urban mobility. In principle, vehicles are only permitted for use on public roads if they meet the requirements of the Road Traffic Licensing Regulations (StVZO). This regulation regulates the conditions for registration of all vehicles on the road in Germany according to §16 Sect. 2 StVZO, excluding certain vehicles such as wheelchairs, baby strollers and similar transport vehicles equipped with an auxiliary drive system that do not exceed a maximum speed of six km/h nor are motor operated [18]. In order to obtain registration approval for an automated driving robot, it must be clarified whether the robot qualifies as a vehicle in terms of road traffic law and, if so, what specific registration requirements would apply to it. As per §1 Sect. 2 of the Road Traffic Act (StVG), ground vehicles which are moved by engine-power without being attached to railway tracks are considered as vehicles. Thereby, the type of motion and purpose of use are irrelevant. Moreover, pedestrians must use sidewalks according to §25 of the Road Traffic Regulations (StVO). Only in cases where pedestrians are accompanied by a vehicle that obstructs others, the roadway must be used (§25 Sect. 2StVO). The electrically operating parcel delivery robot of a project in Hamburg represents an example for registration. The robotic system was classified as a vehicle in the sense of §1 Sect. 2StVG and thus was licensed for use in traffic. The delivery robot moved on the sidewalk with a maximum speed of six km/h [19].

Furthermore, if mobile robots as examined in this work are classified as small electric vehicles (similar to e-scooters), they have to meet the legal requirements and regulations of the Ordinance on Small Electric Vehicles (eKFV). Vehicles that move at no less than 6 km/h and not more than 20 km/h plus are electrically powered could be considered as micro-electric vehicles according to § 1 Sect. 1 eKFV. However, micro-electric vehicles are explicitly not allowed to be operated on the sidewalk, as stated by the Federal Ministry of Transport and Digital Infrastructure [20]. Moreover, micro-electric vehicles must comply with the corresponding speed limits or, for instance, must install a handlebar. In addition, the legal basis for autonomous driving must be taken into account. In line with the framework for autonomous and automated driving [21], assisted and semi-automated driving, representing level 1 and 2 are currently in conformity with German traffic law. Due to legal changes at a national and international stage, the implementation of high-level and fully automated driving functions at levels 3 and 4 are now enabled [21]. Autonomous driving according to level 5 is not covered by the German Road Traffic Regulation. Depending on the concrete requirements identified by the users, appropriate legal prerequisites must be met.

2.3 Existing Personal Robot

To better understand existing mobile companions that could influence the transportation infrastructure in urban cities, best practice use cases are given. Not only automotive manufacturers promote advanced digital solutions for self-driving technologies, but also other technology and mobility service providers like Piaggio Fast Forward [27], Microsoft [22] or Toshiba [23] have developed mobile robotic vehicles that follow humans and assist with various services. Only a few are available for sale and the majority represent prototypes for the purpose of research.

With regard to treatment applications, robot ROREAS [24], for instance, assists stroke patient constantly by providing walking exercises and guiding them. For senior care, a robot that follows, watches and monitors the safety of a patient by detecting falls was developed [16]. In addition, oxygen therapy patients that must carry their tank continuously can be remedied by a robot assisting as portable oxygen supplier [25]. Accompanying elderly people by providing walking assistance such as the cane robot [26] helps to prevent falls. Another application field comprises transportation, respectively cargo carrier uses. The most novel application is Gita [27], a robot that follows humans and supports them by carrying heavy items (e.g. groceries). Furthermore, robotic suitcases offered by various companies [28] assist people in carrying and thus enable hands-free operation. And finally, the company Smart be Intelligent Stroller [29] developed a stroller that moves independently. Moreover, several prototypes of personal service robots in the area of sports were developed to assist runners during training or while participating in a marathon [30] by carrying the runner's water, food or clothes. This idea is as well applied via a robotic golf caddy [31] which was designed to assist golfers by carrying their golf bags. Besides transportation of personal belongings, another application field is the communication sector. Microsoft enhanced the communication field by developing a telepresence robot that provides video conferencing. Remote users can participate as a presence-robot in any conversation anywhere [22].

The variety of different areas of application and related tasks emphasizes the need for context and task sensitive design. As the particular field of application sets general conditions of human users (e.g. homogeneity of healthcare workers in contrast to the heterogeneity of personal transport robot users) [6], it is crucial to learn more about the specific needs and requirements of potential users, multiple focus groups were consecutively conducted.

3 Methodology

The core part of this study comprises the implementation of three focus groups for which a total of $n = 19$ participants were recruited. All attendees were purposely selected according to specific socio-demographic data and assigned to either a heterogenous or homogenous focus groups respectively application field. A questionnaire prefilled from all discussion participants enabled the evaluation of various socio-demographic data. Due to the COVID-19 pandemic, the focus group format was changed from in-person meetings to an online format. The first focus group *($n = 6$)* explored possible applications and respectively user groups for automated driving small vehicles in general. The subsequent second *(cargo carrier group, $n = 7$)* and third *(healthcare group, $n = 6$)* focus group specified the most frequently discussed use cases, resulting from the first discussion. In each focus group, scripted questions were asked by the moderator to initiate the discussion. The guideline of all focus groups started with an introductory block where attendees introduced themselves. In addition, further specified possible application fields were investigated. Afterwards, this collection of ideas was evaluated and compared with existing application fields from literature by revealing a virtual flipchart via Google Docs, in which previous use case scenarios had been demonstrated. The question of the concrete need and added value of automated-driving robots was reviewed again by asking about the specific benefits of the technology. Furthermore, another question block explicitly referred to the research question regarding requirements in terms of function, interaction and operation. In addition, the second and third focus group subsequently illustrated individual scenarios in order to visualize the use-case of an automated robot more precisely based on results from the first focus group. An overview of the used methodologies is shown in the Fig. 1.

4 Result Evaluation

Possible use case scenarios and user requirements were generally and openly discussed in the first focus group. In order to accurately evaluate findings of the focus groups, the program MAXQDA was applied. Thus, data was systematically classified, and participants' statements were grouped for similar meaning in categories via codings and qualitative frequency evaluation. Moreover, the second and third focus group analyzed user desired requirements of automated-driving robots. After discussing openly various technical-functional, psychological and interactional needs, the users ranked the most relevant five requirements. With the help of ratings, a quantitative measurement was executed to analyze the gathered data.

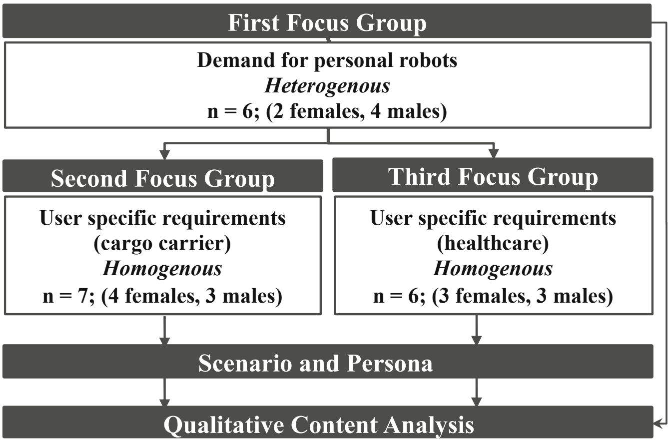

Fig. 1. Research methodologies overview

4.1 Need Assessment (1st Focus Group)

The main purpose of the first focus group was to prioritize prospective use case scenarios and to ascertain whether a demand for such mobile companions exists. The evaluated use case scenarios expected to show the most value are listed in Fig. 2, where most frequent mentions are listed in descending order. It can be observed that the respondents perceived the greatest need in the application of mobile cargo carrier in daily life or during leisure as well as in healthcare. Each of the six participants ranked the top three use cases, thus 18 total assertions resulted. Participants ascribed the greatest value in the application of mobile freight carriers such as *cargo carriers* for daily life of leisure ($n = 8$). Furthermore, the application field of healthcare ($n = 7$) was considered to be reasonably practical by providing e.g. medical support while carrying medical appliances or personal items of the person as well as the application sport ($n = 3$). Not considered at all during the evaluation were application fields with regard to children nor the telepresence robot despite the fact that use case scenarios of children were broadly discussed during the integrative session of the focus group.

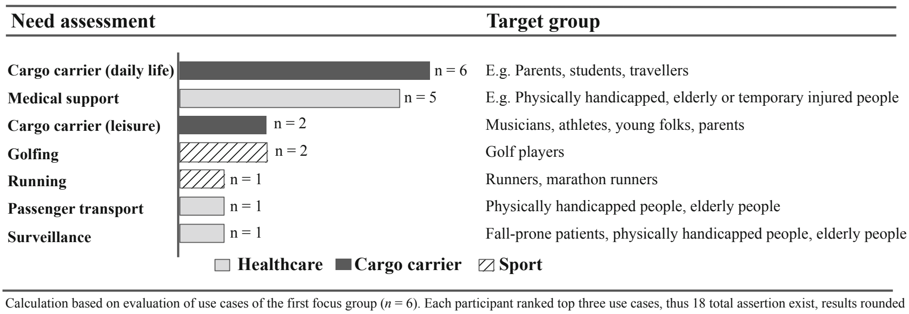

Fig. 2. Need assessment for automated driving human-following robotic systems

Therefore, the following target groups resulted for the two prioritized application fields:

- **For mobile cargo carrier applications:** Parents, students, travelers, elderly people, physically handicapped people, musicians, athletes and the young individuals
- **For healthcare applications:** Physically handicapped people, elderly people, temporary injured people, people after surgery, fall-prone patients

Particularly in the application field of a self-driving cargo carrier, the user group could represent people without having a car or a driver's license, especially in urban areas. This could lead to a replacement of the car in some situations. In this context, the topic of environmental pollution was mentioned by several participants. Many of the attendees perceived this technology as an alternative to transport cargo emission-free and considered mobile robots as an opportunity to not cause environmental pollution. Regardless of the application, the function ranked most valuable of the robot was to carry and transport items. Healthcare could therefore be considered as a separate subordination of cargo carriage. The subsequently conducted two focus groups explored specific scenarios and user requirements in the respective application area.

4.2 Requirement Engineering (2nd and 3rd Focus Group)

When designing urban self-driving cargo carrier, it is crucial to firstly understand the needs, desires and requirements of the users. Limited awareness in existing literature occurs as actual developments do not comprehensively provide sufficient user studies [1]. However, one major study worth mentioning conducts in-depth research about developing socially acceptable person-following robots [3]. The model is based on the premise that psychological needs are sorted and classified hierarchically, derived from Maslow's pyramid of needs which may serve as model for optimizing human satisfaction. Accordingly, a system should be developed in a manner that is primarily safe, functional and usable (ergonomic features) before it becomes pleasurable or even individualistic (hedonistic features) [32].

Thus, requirements from the focus groups were categorized into technical-functional, psychological and human-machine-interaction (HMI) needs. A total of 21 basis requirements and 11 application specific requirements (cargo carrier: 5, healthcare: 6) were elaborated within the conducted focus groups. An overview is provided in the following Fig. 3 and described in greater detail thereafter.

While a comprehensive list of potentially relevant requirements can be derived from the literature, it is unclear which priority is given to each individual need by potential users. To create a valid foundation, the results were quantified by a ranking. The evaluation was carried out by two subsequent additional focus groups. Thus, the seven cargo carrier participants of the second focus group and the six healthcare participants of the third focus group defined the five most significant needs. The conclusion of the evaluation results is given by the following ranking as shown in Table 1. On the one hand, the figure shows the requirements considered most important by both the cargo carrier and the healthcare group. On the other hand, large differences in preferences between the two user groups appear.

Group	Category	Requirement	Explanation
Requirement catalogue	Technical-functional	Filling volume	Filling capacity
		Robot weight	Total vehicle weight
		Load capacity	Maximum load
		Battery life	Duration or exchangeable battery
		Charging conditions	Charging time, station, usability, battery weight
		Safety and reactivity	Collision avoidance, independent traffic integration
		Elevation gain	Climbing altitude differences (sidewalk, stairs)
		Lock function	Robot closing and locking
		Weather resistance	Rain protection, rain cape
	Psychological considerations	Reliability and accuracy	No sporadic sheering off
		Social acceptance	Dispose of negative social stigma (shame), trust
		Adjustable following direction	Following from behind, side-by-side, front
		Height adjustability	Modular volume expansion, ergonomics
		Price	Moderate retail price
		Loss of autonomy	Free power of decision, appreciable enrichment
		Legal clarification	Traffic permit, liability
		Proximity setting	Situational geographical distance
		Theft protection	Unambiguous authentication, cyber security
		Data privacy and protection	Video recordings, surveillance
		Optics	Discreet, slim, practical, modern (vehicle-like)
	HMI	Handling	Intuitive, easy, self-explanatory operation,
		Connectivity	Smooth interaction with humans, robots, smartphones
		Mobile control	Charge status display, actual fill weight
Application field specific	Cargo carrier	Children seat	Folding seat
		Refrigeration	Cooling function (groceries, drinks)
		Installation of light	Installation of lighting / flashlight
		Modular coupling	Linking several robots
		Situational interface	Operator tailored user interface
	Healthcare	Seat	Rollator seat
		Emergency call system	Contact to a doctor/ambulance service
		Surveillance function	Intervention mechanisms, reminder, warning
		Medical data measurement	E.g. blood pressure, temperature by means of a bracelet or surface
		Entertainment	Communication (video, telephone), radio, news
		Haptic user surface	Large display, few buttons, activation by token or classic key

Fig. 3. Categorized requirements as resulted from the focus group discussions

Overall, a long-time battery life represented the most important requirement ranked by in total nine of all focus group participants. The battery must certainly last for a prolonged time as this ensures the operation of the vehicle. In addition, an intuitive handling $(n = 8)$ was expected to be met by all potential users of the healthcare robot. In contrast, this requirement represented a lower important need when examining the cargo carrier vehicle $(n = 2)$. Regarding the development of mobile cargo carries, six of those surveyed people considered a large filling volume to be important, for example, for stowing children, work materials, sports gear or groceries after shopping. Thus, the capacity volume must be sufficiently sized considering the specific use case that all personal belongings fit into the vehicle. For elderly or physically disabled people, the filling volume represented a lower value ($n = 1$). The ability of the robot to climb stairs was likewise interpreted differently. Respondents from the healthcare field regarded

Table 1. Prioritization of requirements between the cargo carrier and healthcare target group

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Requirements	Cargo Carrier (n = 7)	Health-care (n = 6)	Total (n = 13)
	Absolute	Absolute	
Battery life	4	5	4 5 n = 9
Handling	2	6	2 6 n = 8
Filling volume	6	1	6 1 n = 7
Safety and Reactivity	2	2	2 2 n = 4
Elevation gain	4	0	4 n = 4
Emergency call system	0	4	4 n = 4
Weather resistance	2	1	2 1 n = 3
Social acceptance	2	1	2 1 n = 3
Price	0	3	3 n = 3
Robot weight	2	0	2 n = 2
Reliability and accuracy	1	1	1 1 n = 2
Adjustable following direction	2	0	2 n = 2
Height adjustability	1	1	1 1 n = 2
Seat	2	0	2 n = 2
Entertainment	0	2	2 n = 2
Haptic user surface	0	2	2 n = 2
Load capacity	0	1	1 n = 1
Lock function	1	0	1 n = 1
Loss of autonomy	1	0	1 n = 1
Legal clarification	1	0	1 n = 1
Connectivity	1	0	1 n = 1
Refrigeration	1	0	1 n = 1
Sum	∑ 35	∑ 30	■ Cargo Carrier □ Healthcare

potential applications in e.g. nursing homes or clinics. This environment is barrier-free accessible, thus none of the users rated the robot's ability to climb stairs as of primary relevance. In comparison, four of the mobile cargo carrier users considered it as vital to overcome altitude differences, especially in urban areas. In addition, specific requirements could be distinguished, being only viewed as essential by the respective target group. In case of cargo carrying, these included, for instance, the robot's weight *(n = 2)*, the individually adjustable following direction *(n = 2)* or the installation of a refrigeration module *(n = 1)*. For the healthcare robot, this comprised the implementation of an emergency call system *(n = 4)*, an element of entertainment (e.g. telephone, radio) *(n = 2)* or the consideration of a haptic surface with few and big buttons *(n = 2)*.

5 Discussion

In this study, three focus groups were conducted to analyze potential demands of personal robots under consideration of user group heterogeneity [6]. After participants in a first focus group identified broad areas where robots could be useful, two subsequent focus groups identified potential requirements of a cargo carrier robot, and a healthcare focused personal robot. Overall, a majority of the 2^{nd} and 3^{rd} focus group attendees evaluated a high battery capacity as the most essential need *($n = 9$)*. However, the duration of the battery life affects the battery's weight. The greater the battery life, the heavier the battery becomes which ultimately affects the total weight of the robot. The provision of an additional portable battery could possibly offer a remedy. Another widely argued request depicts the robot's ability to overcome elevation. All applications identified in literature were not capable of climbing stairs, except one military robot developed by Boston Dynamics [33]. With regard to cargo carrying, urban areas were considered as especially conceivable terrain for mobile robots instead of rural areas. Thereby, according to the potential target group, the robot must either be able to climb stairs *($n = 4$)* or be handy and light enough *($n = 2$)* to be carried. Another restriction arises in respect to legal requirements and the robot's ability to follow humans. Regulations for registration approval must be addressed. By using focus groups, it became obvious that the robotic vehicle is intended to follow a human on the sidewalk according to the user's speed.

Consequently, the robot cannot be categorized according to the Ordinance on Small Electric Vehicles. Accordingly, micro-electric vehicles are only allowed to drive on roadways. It can be concluded that automated driving vehicles are permitted for operation if fulfilling the correspondent registration approval criteria that include e.g. a speed limit of more than six km/h. The development of this technology, however, would lead to a comprehensive registration procedure with no immediate guarantee for success. This could be remedied by a separate authorization regulation, similar to the current requirements for motor vehicles. In addition, no concrete road safety obligations exist regarding healthcare robots and legal clarification is still unclarified. Consequently, due to an uncertain legal situation, the approval of the to be developed robotic vehicle is classified as to be further investigated.

With regard to HCI it can be concluded that the user-robot interaction is perceived as an interdisciplinary field that investigates social behavior, communication and intelligence in natural and artificial systems. In other words, interaction requires interchange and communication (verbal or non-verbal) between the robot and humans. Thereby, interaction refer to direct and indirect human-robot communication, stated as explicit and implicit mode of interaction [1]. Furthermore, the appearance of a robot also has an effect on the interaction. Derived from this, it can be concluded that the mobile cargo carrier represented a functional vehicle, thus is only capable of displaying emotions via e.g. flashing lights or sounds. Potential users of the focus group described this robot as rather functional, practical and handy. The automated driving robot was perceived by the users rather as a means of automated transportation vehicle and less as robot providing social functions. On the other hand, the designed healthcare robot provided richer movement and gesture via voice control, speech or body language. In contrast, the healthcare robot aimed to simulate human cognition and interaction by basic physical gestures and facial expressions, thus representing a socially mobile companion. Likewise, if the robot gives warnings during the use. Natural human-robot communication was intended even if the majority of studies does not provide communication during the human-following interaction [3]. Moreover, the healthcare robot needs to be connected to a doctor, the emergency service or the retirement home in case the SOS button is pressed. Both robots must trigger an alarm in case of theft. A loud signal should appear when an unauthorized attempt is made to steal the robot. The cargo carrier should be capable of being linked to other robots. A smart, smooth connectivity must therefore be provided. The healthcare robot must follow, observe and monitor the safety of the patient as similarly being previously researched in a study by Tomoya et al. [17]. If the user falls and does not move anymore, the robot triggers a signal and contacts the pre-defined emergency contact. In general, simple voice control between robot and user has to be implemented to interact socially with the user or other road users. In conclusion, the healthcare robot not only takes on the role of a carrier but takes over the role of a supervisor by providing further direct human-robot communication. In both application fields, there exist interfaces between the robot and the user, as well as between other pedestrians, traffic participants, obstacles and additional appliances.

5.1 Conceptual Modelling

In order to get an impression how the robots could look like, two different mobile companions were conceptually developed, and modelling drafts were made. The aim of the subsequent modelling was to design two adequate robots that meet the main requirements and constraints as compiled in the focus groups. This can help future researchers to gain an understanding of interacting with the designed systems. Both design drafts were created as a result of the intensive dialogue with the potential users. The pencil sketches particularly incorporated requirements that were ranked as highly relevant in the focus groups. Thus, the second focus group desired a vehicle to transport goods and children for long excursions. In comparison, the third focus group desired a healthcare robot that assists and helps elderly people during their daily life. The following Fig. 4 illustrates the drawn pencil sketches of the designed cargo carrier.

A key characteristic of the robotic vehicle was its large filling volume as requested by six of the respective users. Thus, a seat for children including safety belts was also installed as demanded by the users. The robot can be locked via a flap. In addition, the attachable rain cape protects the transported goods as well as the children from rain or strong sunlight. The vehicle is mounted on several robust wheels which have the required grip to overcome curbs. The height of the robot can be extended via an axle and bar. At the bottom there is a kind of a drawer which represents a refrigeration system to cool for example food or beverages. The robot is equipped all around with cameras and sensors to capture the environment holistically. Inside the casing, a replaceable battery is located. The operation of the robot is executed by means of a smartphone. It can be concluded that the mobile cargo carrier is primarily functionally designed and resembles a mobile transport vehicle with heavily focus on family application fields.

In contrast, the healthcare robot had a minimalistic creature-like appearance and is illustrated in the following Fig. 5. Thus, the healthcare robot differs significantly from the mobile cargo carrier. Special attention was paid to ensure the surveillance functions as the robot was intended to accompany the user by giving warnings and by providing guidance. The healthcare robot should appear friendly and create humanity. Thus, the robot is able to use cues to interact and communicate with the user. At the back of the robot, a resting area was installed. Thus, the robot can drive the user back home while

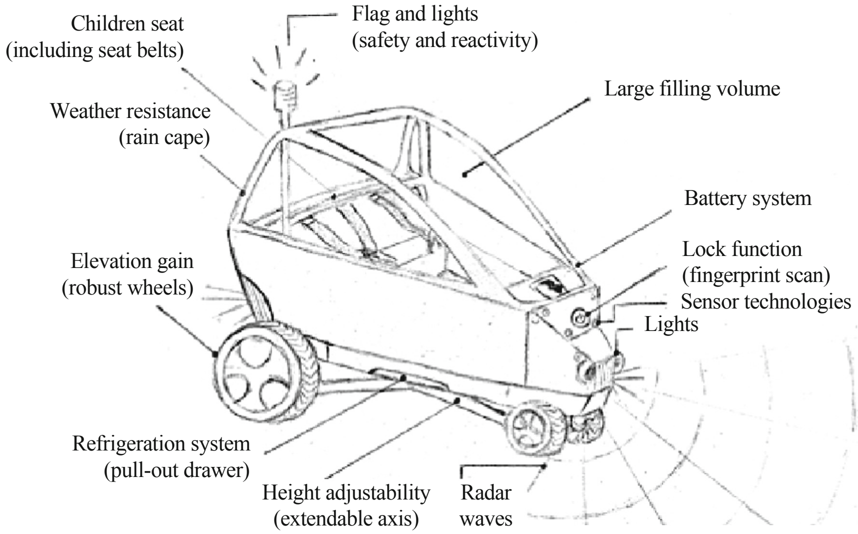

Fig. 4. Pencil sketch of the mobile cargo carrier robot

sitting. The operation is carried out with the help of an intuitive and easy to use operating panel, mentioned by all of the participants in the healthcare focus group *(n = 6)* as the most important requirement. The robot is further equipped with sensors and actuators in order to accurately perceive the environment and to react appropriately. A compartment for recording the user's health data (e.g. blood pressure) is also integrated in the armrest.

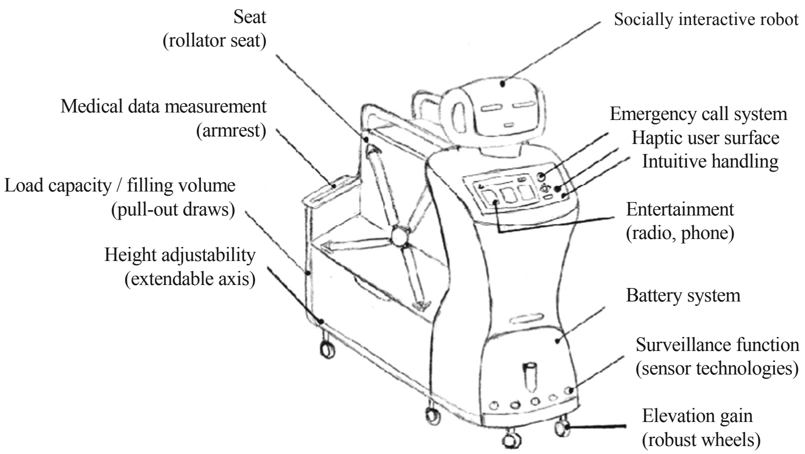

Fig. 5. Pencil sketch of the healthcare robot

Ultimately, it can be concluded that the automated-driving cargo carrier robot's primary function is to follow and carry the load (e.g. grocery shopping) of humans. In comparison, the healthcare robot additionally adopts further functions, as the robot not only carries the user's personal belongings, but also monitors, guides, supports and, if necessary, transports the user home. Thus, the healthcare robot no longer just follows the human, in fact it could autonomously drive the passenger home. The healthcare robot extends the capabilities of the initially examined research object (human-following robot) to rather an autonomously driving micro-vehicle, which can also carry and transport passengers. With regard to operation, it became clear that the two robots were dissimilar concerning the operating device and individual setting options. The automated driving cargo carrier was aimed to be operated via an app. Focus was set on a high usability and adjustability of the selectable parameters. In contrast, the interface of the healthcare robot seemed more tactical, conventional and was characterized by a large-scale display.

5.2 Mobility As-A-Service

In addition, it became clear that the function has to exceed the capabilities of the human beings as stated by the focus group participants. Urban areas are particularly suitable for the technology as stated by many interviewed users and as indicated in literature [34]. Therefore, electrically driven mobile robots could relieve the roads due to less car traffic and further could represent a new form of mobility for people that have no car. Extensive testing will be necessary for the implementation to ensure the required safety. In this context, economic efficiency calculations must be carried out in order to compare anticipated earnings with presumed expenses. Participants of the focus groups discussed from the very beginning that it would probably be less economically viable to purchase and own such an expensive technology. In addition, it must be ascertained whether the healthcare robot can be subsidized, e.g. by health insurance companies. However, the participants saw great potential in renting mobile robots, leasing them for a short time or using pay-per-use / pay-per-time models for only a limited period of time. In general, shared mobility such as bike sharing, e-scooters or carsharing already has a great impact on urban mobility. Thus, the range of different mobility options available needs to be aligned to the passenger's interest.

In addition, it is recommended to not only focus on automated driving systems but also to investigate autonomous driving scenarios. In each focus group, autonomous use cases made a subject of discussions. Furthermore, the scenario of linking a mobile cargo carrier with supermarkets so that they transport groceries home after shopping appeared to be full of potential. The use case of shopping was particularly further examined in a research study conducted by Dautzenberg et al. [34].

However, legal issues arising with regard to autonomous driving robots as previously mentioned have to be considered, as to date, the implementation of fully autonomous driving systems are in Germany so far not enabled [21]. The necessity of a manual vehicle control system persists, hindering the full roll-out of autonomous systems.

6 Conclusion

The present work was conducted to give researchers and providers in the field of user-centric personal robotic vehicles insights into potential user needs in two main areas of application, transport and healthcare. For this reason, the knowledge gained specifically in this work serves as a basis for further research activities. An evaluation and concretization of requirements have to be carried out by designers, technical specialists and further traffic stakeholders. To sum up, the vast majority of respondents recognize a benefit for small vehicles operating automatically. The way road users will use and access transportation will possibly change in the future. As consequence, self-driving private or commercial mobile robots could represent a completely new form of mobility for people living and participating in urban traffic.

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