Intuitive User-Centered Interaction Design for ATV

Stuart Chapman(✉), Thomas Kirks, and Jana Jost

Fraunhofer Institute for Material Flow and Logistics,
Joseph-von-Fraunhofer-Str. 2-4, 44227 Dortmund, Germany
{stuart.chapman, thomas.kirks,
jana.jost}@iml.fraunhofer.de

Abstract. The communication between the human and robot in the social networked industry plays a crucial role. Autonomous robots navigate freely through the warehouses and therefore need to convey their intentions and tasks in an intuitive and understandable manner for its human counterpart. This study examines the icons on the e-Paper display of the ATV EMILI. Tasks of EMILI are the transportation of goods and collaborating with its user by adjusting its height for a safer ergonomic use. The robot communicates its status and intention via its display. The icons transfer task or error messages to its users. The icons have been evaluated in an iterative process consisting of three test phases. Based on the results of the different test phases and the technical restrictions new icons have not been developed until the requirements of the users have been matched. The error icons have been standardized and did not cause any ambiguity in their meaning, whereas the task icons had to be removed and new icons had to be developed.

Keywords: User-centered design · Human-robot-interaction
Robotic interfaces

1 Introduction

The interaction between the two main actors – the human being and the machine – harbors new challenges and problems in the sociological questions of a company. These questions arise during the implementation and integration phase of new technologies. A central concept is the sociotechnical approach, which deals with the relationship between the user and the system. As soon as a machine acts autonomously, it affects human's behavior towards this kind of machines. However, the machine is programmed to interact with its user and to intervene in cases of error. The central question arises to what extent autonomous technology must be designed so that the user feels comfortable using the technology and can carry out his or her work safe and reliable. Intuitive operation and communication between the actors are challenges that need to be met.

This paper deals with a new kind of autonomous transport vehicle (ATV) which offers intuitive interaction methods for the human. EMILI (ergonomic, mobile, interactive load carrier for intralogistics) is a combination of ATV and a small load carrier

Published by Springer Nature Switzerland AG 2019
C. Bogdan et al. (Eds.): HCSE 2018, LNCS 11262, pp. 335–342, 2019.
https://doi.org/10.1007/978-3-030-05909-5_22

(SLC). It combines the compact design and standardized handling of a SLC with the capabilities of a modern ATV. EMILI can seamlessly be integrated into existing processes and systems thanks to the exact compliance with the external dimensions of a SLC (400 × 600 × 220 mm). From above you can see a load area, which has a recess for material transport and two horizontal handles, which are similar to the carrying handles of a normal SLC. There is a scissor lift under the lid, which can be extended up to 600 mm. It can adjust the height of the load-handling device as well as its storage area according to the height of the human worker. The current version of the SLC contains in front an e-Paper display. The display is 500 mm long, 137 mm high and is centered on the 400 mm wide front surface. In each case, 50 mm of the display are to both sides around the corner of the ATV and thus protrude out onto the two 600 mm long surfaces. The retractable running gear allows it for example to be stacked onto other SLC, transported using conventional conveyor technology and stored in an automated small parts warehouse. With EMILI the first ATV, which emphasizes on physical as well as psychological ergonomics, has been designed. EMILI is not restricted to certain areas in the warehouse and can be used without any external safety infrastructure. This allows real human-robot-collaboration. Further, it displays information about its state on the e-Paper display so that bidirectional interaction is possible. It can transport goods or tools to the human worker and function as a mobile picking station. Therefore, different applications like maintenance tasks as well as picking can be realized.

EMILI offers different interaction modalities. It can interact via web services with other machines and systems. Further, the human can cooperate with EMILI with smart glasses or smartphones. Natural and intuitive interaction is possible through recognizing gestures of the human worker. The physical demanding component and the exhausting procurement of goods is shifted to the robot. This new distribution of tasks increases the productivity and the user experience of the interaction. To set up a safe working environment, the icons and intentions of EMILI need to be comprehendible by everyone working in the warehouse. Therefore, EMILI has an e-Paper display that provides information about its status. This information needs to trigger intuitive action. Hence, the selection and composition of icons need to be analyzed.

2 Background

2.1 Human-Robot-Interfaces

For interfacing machines or robots, there exist different interaction modalities. Common solutions are PC-based programs or human-machine-interfaces directly at the machine control. Both are spatially limited, need special training and are therefore very inflexible. Some robots and machines offer interaction modalities via Apps on Tablets or Smartphone, which overcome the lack of spatial flexibility. Still the usage is not very intuitive since the feedback is not given directly at the robot or machine itself. In contrast, social robots e.g. Pepper [1] or Baxter [2] offer bidirectional feedback by using different colors or facial expressions to symbolize different states of the robot.

2.2 Automated Transport Vehicles

Automated Transport Vehicles are used to transport goods or people in a spatially limited space [3]. They belong to the group of discontinuous ground conveyors, are automatically controlled and move without any influence of the human [4]. According to [4] one or more ATV together with a control unit, infrastructure and components for data transmission, localization etc. build up an Automated Transport System (ATS). The usage of ATS started in the late 1950s in America [5]. From there on, they have changed regarding their flexibility and efficiency. Nowadays, there exist a variety of ATV which differ mainly in payload, navigation technology e.g. free navigation and control (centralized, decentralized or hybrid). A coming up trend in the field of ATV are low-cost ATV which enable small and middle sized companies to use ATV in their production systems or logistics facilities. Those ATV have lesser payload and drive with lower velocities so that for human-robot collaborated workspaces no external safety sensors are needed. Low-cost ATV are for example the LEO Locative of the company BITO [6] or the Weasel of the company SSI Schäfer [7].

3 Icon Description

EMILI has six different icons to display various states and in this way to provide information relevant to the user. The following sections distinguish between the warning icons and the task icons of EMILI. For the description of the warning symbols a comparison is given, as these represent a reference to already established symbols. The first three icons on the left display are for error messages and warning messages and appear in so-called “error” states. Error states are used to inform the user of error messages of any kind. The triangular symbol with an exclamation mark in the middle is similar to the street sign, immediately obvious and defined by the DIN EN ISO 7010 as a warning sign [8]. This icon lights up on the display as soon as an Error-state has occurred, for example if EMILI no longer has an internet connection, the accumulator is empty or a technical malfunction is detected.

The second icon is the battery. This makes an empty impression and contains an exclamation mark inside. This symbol appears as soon as the accumulator installed in EMILI reaches a critical battery level. In the operating systems of Android and iOS, similar icons are implemented to indicate a low battery level, usually with only an almost empty battery instead of an exclamation point. Finally, there is the icon for a missing wireless connection to the system. This consists of an exclamation point and a common symbol for a wireless internet connection, which is also widely used on mobile platforms. The three warning icons are deliberately based on already established symbols, so that EMILI users do not have to learn those icons and can immediately establish a connection between them. In addition to the three warning icons, there are three status icons indicating information about the current work task of EMILI. These icons are a square in a three-dimensional view and a circle, which in turn is divided into four quarter circles (see Fig. 1). The square represents a container. Being lit up on the display means that EMILI is currently executing a transport request.

Next to the container, a cogwheel icon has been implemented. There is an offset in the tooth position, while the gear itself remains in the same place. In this way, the illusion of a rotating gearwheel is created and the status “busy” is displayed. The rotating gear means that the robot is currently executing a task that does not necessarily require a transport request. For example, EMILI could participate in another place in a building and makes an empty run without a container. The circle with the quarters is the hint of a watch and is a qualitative statement about the theoretical duration of the task.

Fig. 1. Old task icons

4 Analysis of Icons

The information on the display of EMILI needs be comprehensive for the user and should not cause erroneous actions. Therefore, the technical as well as the human requirements have to be considered and implemented in the design of the icons. To guarantee an intuitive and safe interaction, a human-centered approach was chosen in which an online survey and interviews were conducted. These methods give straight feedback to existing icons and reveal how the icons have to be developed. By using this approach in the development stage, the costs are kept low and the users are involved.

The evaluation of the interface of EMILI took place in an iterative process. The aim of the analysis was to determine how much the icons match the expectations of the user and in cases of ambiguity and uncertain information influence the communication capability of the interface. The interface was first evaluated in an expert evaluation. An interdisciplinary team was formed, consisting of a graphic designer, computer scientists and a human factors engineer. States of EMILI consist of a composition of a facial expression, icons and text hints. In this work, we focused on the interpretation of the icons. By developing new icons, the technical compound had to be considered to ensure a smooth transition from prototyping to finally developing a new interface. The expert evaluation discovered misleading icons. In the beginning, each expert evaluated the states and the compounds of the interface on his or her own according to its meaning and how it is visualized. Afterwards, the experts came together in a meeting and problematic icons were reflected and alternative designs and compounds were developed. In particular, the time icon, the busy icon and the icon for transportation were not fully recognizable. Due to technical restrictions of the e-Paper display just a limited amount of segments was given. Therefore, the range of possible alternatives had to fit these technical requirements.

These issues were addressed in the second phase, which consisted of testing the icons with alternate icons. The used method was an online survey conducted at the Fraunhofer Institute for Material Flow and Logistics (IML). The focus lied on the

ambiguous icons of the e-Paper display, discovered in the expert evaluation. Participants were given the possibility to propose other icons and give their meaning to the current and alternative designs. A total of 191 anonymous respondents took part. The interval coefficient was 95% and the error of margin was 6%. The respondents were mainly young and nearly 70% were in the range from 18–31. Continuing with the iterative process, the new icons were implemented and tested in a last test phase. Ten interviews were conducted at the Fraunhofer IML. Six participants were female and the mean age was 27. The aim of the interviews was examining if there are still issues concerning the meaning of the icons. The interview was structured and the questions were based on the results of the questionnaire and the additional comments of the participants. Participants were shown all icons without and with text hints. Afterwards participants should determine what the icons mean. The result was that all participants preferred icons with text hints. Reasons were that especially in the newly created icons, participants could better comprehend what the meaning of the icons are. The warnings signs are standardized icons, used on smartphones to illustrate the same problem statements occurring on a smartphone than on the interface of EMILI. Concerning the warning triangle, the design referred to the DIN EN ISO 7010. The idea behind using familiar icons is to mitigate confusion and to accelerate the learning stage.

The success of the combination of familiar and new icons and a new display design has been evaluated by using the User Experience Questionnaire (UEQ). The UEQ consists of six scales. Our study focused on the three scales attractiveness, perspicuity and efficiency. The three scales are of interest because our design should be easier to comprehend, more efficient and should generate an overall positive impression. The UEQ has been conducted after the interview session with ten participants. The users rated EMILI on these three factors on a 7-point Likert scale. The Likert scale consisted of semantic differential word pairs (e.g. attractive – unattractive). The benchmark analysis of the e-paper display results in a very positive outcome. The indicators for attractiveness (mean: 2.4), perspicuity (mean: 2.1) and efficiency (mean: 2.4) are located in the upper tenth of the range of values, leading to the grade: "excellent" (see Fig. 2). The results of the UEQ are presented in Table 1.

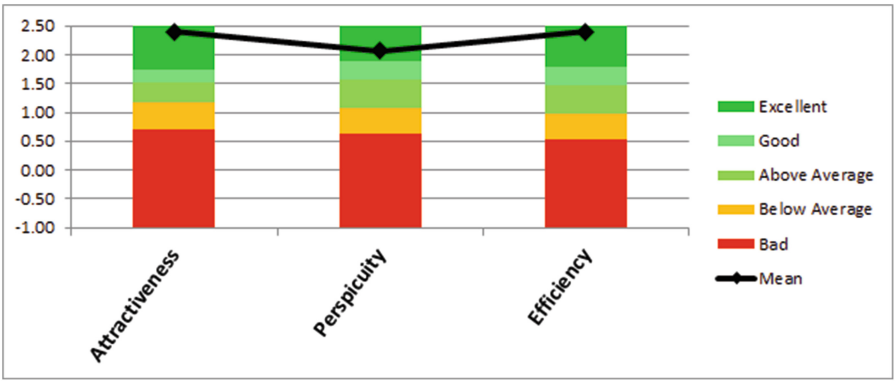

Fig. 2. Benchmark analysis of the UEQ

Table 1. Results of the UEQ

Scale	Mean	Standard deviation	N	Confidence	Confidence interval
Attractiveness	2.400	0.337	10	0.209	2.191–2.609
Perspicuity	2.067	0.306	10	0.190	1.877–2.257
Efficiency	2.400	0.516	10	0.320	2.080–2.720

The warning signs remained due to their universal meaning and were understood by all participants. On the other hand, the task icons were exchanged. Figure 3 illustrates that the cogwheel and the time icon were replaced with the three arrow icon and the avatar icon. These changes were necessary due to ambiguous understanding of the old icons and more important states to cover. The box icon is the only remaining icon in the new interface and has been adjusted due to its additional functions. The reasons for these changes are a result of the qualitative results of the questionnaire and interviews. Participants were reminded of the settings button on a smartphone when confronted with the cogwheel rather than seeing EMILI "in progress". Besides the cogwheel, the time icon became redundant. The time icon is not standardized and its period of time may vary depending on the length of the task. This leads to the conclusion that users cannot be sure of how long EMILI has been executing a command or how long the task will take. The implementation of the "Follow – Me" function led to the design of the avatar icon in combination with the arrow icon, indicating that EMILI is following its user. The arrows above and beneath the box icon illustrate that EMILI is adjusting its height and were added. Further, the three icons can interact with each other to give more reliable and precise information of the state of EMILI.

Fig. 3. New task icons.

Further, different icons were tested on their meaning. The requirements of the participants from the online survey were that transportation state of EMILI had to include motion. This requirement was tested with different icons. As an example, Fig. 4 shows the development of the transportation icon.

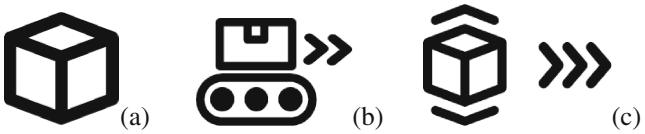

Fig. 4. Development of the transportation task icon (from a to c).

The first transportation icon (see Fig. 4a) consisted of a box. Participants stated that the box is loaded on EMILI, but did not mention that the box is moving. This led to the new designs (see Fig. 4b), which focused on adding dynamic elements or focusing on material flow, indicated by the box on the assembly line. This icon has then been evaluated as a tank or other misleading concepts. As a final icon (see Fig. 4c), we created an icon based on the box and additional implemented arrows as an icon, which in interaction with the box resembled a moving box. Due to the ergonomic height adjustment, one arrow above and beneath the box were added to simulate an upward or downward movement. Focusing on the interaction of the icons, the avatar icon in combination with the arrows display the "Follow – Me" function, whereas the box icon in combination with the aforementioned icons imply a transportation task towards the user.

5 Conclusion

The design of the new e-Paper display is based on the iOS mobile platform architectural structures. Whereas in the initial display, icons and text hints were strictly divided and the icons were placed on the left side and text hints on the right side, the icons are now placed above the artificial face in a horizontal bar (see Fig. 5). Further, the text hints and icons were divided due to their function. On the left side of the interface, warning signs and referring text hints were placed. On the right side, task signs and their referring text hints were implemented. The overall design reminds the user of a toolbar similar to a smartphone toolbar. Referring to the icons, the task icons were completely new designed and implemented. The new task icons are adapted to the needs of the user. In contrast, the warning icons were standardized and the results of the online survey and interview reveal no misleading or wrongly implemented icons.

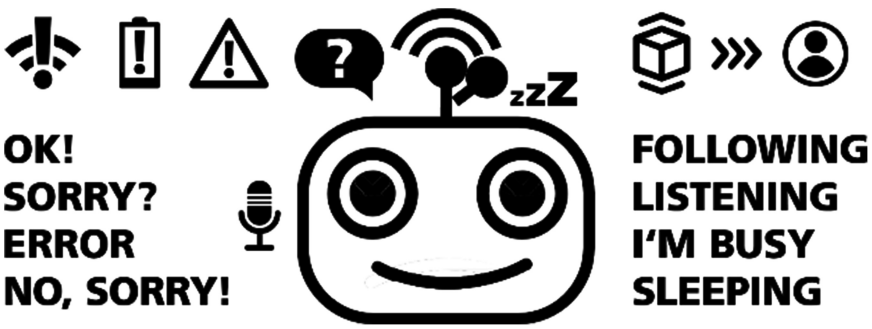

Fig. 5. Redesigned e-Paper display of EMILI

6 Outlook

The Future work will include an analysis of the display in a real working environment with actual workers. We plan to implement a virtual 3D avatar being projected on top of the ATV indicating the status and other interaction functionality by the use of augmented reality glasses. This approach will also be evaluated with appropriate analysis methods. The ATV already has inbuilt RGB LED stripes around the bottom outline intended for status feedback. We will also research on adequate color and light sequencing functionality.

Acknowledgements. We want to thank the Innovation lab Hybrid Services in Logistics, funded by the Federal Ministry of Education and Research (BMBF) and in the Center of Excellence for Logistics and IT funded by Ministry for innovation science and research of NRW, Germany.

References

1. SoftBank Robotics: Who is Pepper? https://www.ald.softbankrobotics.com/en/robots/pepper. Accessed 4 May 2018
2. CobotsGuid: Rethink Robotics Baxter. https://cobotsguide.com/2016/06/rethink-robotics-baxter/. Accessed 4 May 2018
3. Ten Hompel, M., Schmidt, T., Nagel, L.: Materialflusssysteme Förder- und Lagertechnik, vol. 3. Springer, Heidelberg (2007). https://doi.org/10.1007/978-3-540-73236-5
4. Verein Deutscher Ingenieure VDI: VDI Norm 2510: Fahrerlose Transportsysteme (1992)
5. Ulrich, G.: Fahrerlose Transportsysteme. Vieweg + Teubner Verlag (2011)
6. BITO-Lagertechnik Bittmann GmbH. LEO Locative Das Fahrerlose Transportsystem für Behälter und Kartonagen. http://www.leo-locative.de. Accessed 26 Sept 2017
7. SSI SCHÄFER FRITZ SCHÄFER GMBH. FTS Weasel®. https://www.ssi-schaefer.com/de-de/produkte/foerdern-transportieren/fahrerlose-transportsysteme
8. DIN EN ISO 7010: Graphische Symbole–Sicherheitsfarben und Sicherheitszeichen (2013)