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Abstract:

This deliverable consists of the paper:
E. Chin, A. Chazoule, C. Toscano, V. Krüger, Testing of a human-user interface of a Cyber-Physical System, Journal of Intelligent Manufacturing, submitted.

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Testing of a human-user interface of a Cyber-Physical System

Estelle Chin, Arnaud Chazoule, Cesar Toscano, Volker Krüger

Abstract

ISO-norms for Human-Machine interaction (e.g. ISO 9241-210) require a constant human involvement in the development process of a human-machine interface. For cyber-physical systems (CPS), good human-machine interfaces are of particular importance. In this paper, we report results of experiments carried out at the company PSA Peugeot Citroen under realistic conditions that suggest a number of challenging improvements that are unique to CPS and that engineers, working with CPS, will need to take into consideration.

1 Introduction

Cognitive robots, able to adapt their actions based on sensory information and the management of uncertainty, have begun to find their way into manufacturing settings. One of the characteristics of such robots is their cyber-physical structure: While having a physical embodiment for manipulating the physical environment, such robots are usually vertically integrated into existing IT infrastructures, such as the manufacturing execution system (MES) and other data-structures. In [1] we have discussed such a cyber-physical system, the STAMINA robot that is able to autonomously complete *kitting tasks*: to navigate through a factory hall and collect parts from a warehouse, to assemble the parts into a dedicated kitting box and to deliver the kitting box to the tight spot at the manufacturing line. The STAMINA robot consists of a physical embodiment as well as a cyber part that provides access to the MES and to dedicated data-structures. These data-structures can hold the relevant factory hall knowledge such as

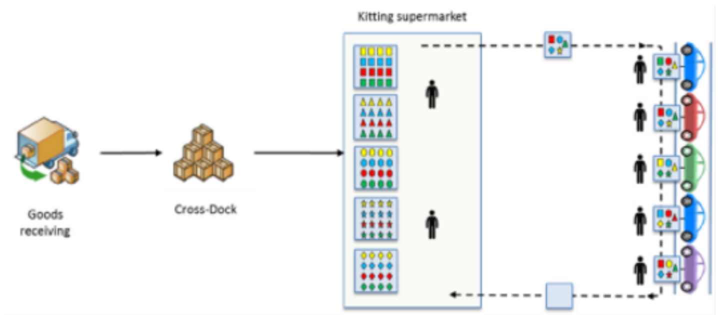

Figure 1 shows the kitting principle: Parts are delivered via a cross-dock into a kitting area. A kitting area is setup and organized by a kitting technician. Based on requests from the MES, parts are collected into kits and delivered to the manufacturing line by kitting operators and autonomous transports. The aim of the STAMINA project is to automate the kitting process.

- maps of the shop-floor and the warehouse
- locations of pallets, shelves and containers on these shelves
- associations of pallets and containers with specific parts that are to be collected.

In other words, the data-structures hold the concrete knowledge the robot needs for its logistic tasks. While the floor maps are 2D, the maps for container and pallet locations are 3D since shelves can have several levels (see Figure 4).

In addition, the data-structures also hold *state-information* such as filling levels of the containers.

With this information available, the tasks of the STAMINA robot are programed automatically [1,8]: The MES requests the robot to collect a set of specific parts into a kit (*kitting order*). Based on the knowledge from the database and the state-information, a task planner identifies the right sequence of *robot skills* [1,7] the STAMINA robot needs to execute in order to complete the task.

It is clear that for such an automatic task programming to work the correctness of the information in the database is crucial. However, while the filling-levels can in principle be kept updated using information from the MES, all the other pieces of information need to be provided by dedicated shop-floor workers. This means that user interface design is vital: a good design minimizes the chances for errors by supporting the human user when inserting the knowledge into the database. In fact, numerous errors during testing of our STAMINA system were due to faulty information in the database. The cause could clearly be backtracked to bad interface design which we hadn't initially payed any attention to. The result was that even the programmers made mistakes when inserting the data into the databases, and a lot of time was lost due to debugging the data.

Most often, the expects for human-machine interaction are usually not experts in robotics, while roboticists usually lack the insight into human-machine interaction and UI design. Therefore, within the STAMINA project, we have paired up with human-machine interaction experts from PSA Peugeot Citroen in order to optimize the user interfaces for inserting the data into the databases.

The contribution of this paper is to

- provide a brief overview to roboticists about good UI, and how to achieve it
- explain what kind of experiments were done for the concrete *kitting* use-case
- what conclusions were taken from the experimental results.

Even though in this paper the cyber-physical system is developed for a concrete use-case, we are aim for general insights and conclusions beyond the specific use-case.

2 Background

In this section we will briefly summarize the structure of the STAMINA cyber-physical system (CPS) as far as necessary for this article. Please refer to [1] for further details. Figure 2 provides the overview: The red box marks the physical robot, the yellow boxes are related to the cyber-part where *Logistic Planner* is its main component. The Logistic Planner contains the *world model* which is the database containing all the above-mentioned data describing the shop-floor, incl. the state-information (*world state*). The arrows mark the flow of information. The MES (blue symbol) sends a kitting order to the Logistic planner. The planner forwards the kitting order, together with the world model (incl. the world state) to the Mission Planner. Based on this, the Mission Planner identifies a *task plan*, which is the right sequence of robot skills the robot has to execute in order to complete the kitting order. The task plan is then sent to the Logistic Planner which

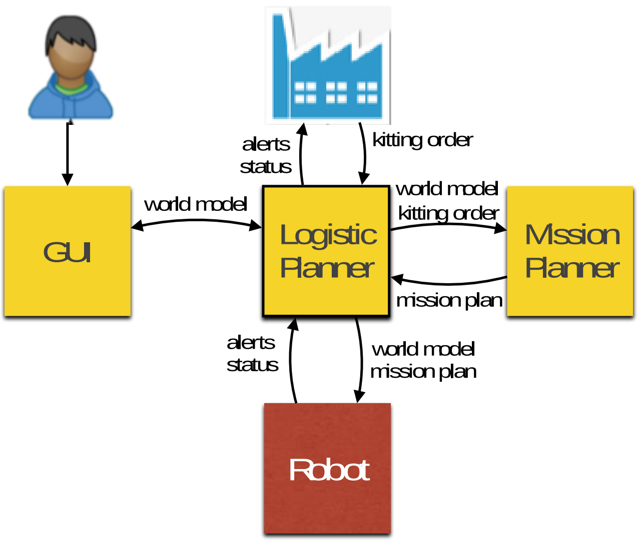

Figure 2 shows the relevant structure of the STAMINA-CPS : The physical robot is marked with the red box. The yellow boxes are related to the cyber-part, incl. the GUI, the Logistic Planner with the world-model and the Mission Planner.

forwards it to the robot, together with the relevant part of the world model[1]. The feedback of the robot to the Logistic Planner contains status information as well as updates to the world model and world-state [1,8]. A dedicated shop floor worker, a *kitting technician*, is responsible for setting up the kitting area, including the layout and all of its available physical objects. As such, he inserts the information into the world model by using a GUI. These persons are not manufacturing engineers but shop floor workers who know the layout, the structure and the kitting processes in their kitting area. Kitting technicians are not expected to have much experience with computers, and they do not have any experience with robots. In our opinion these kitting technicians are the typical shop floor workers who will have to interact with the future highly flexible robotic systems that are presently under research and development.

The present version of the GUI has been designed intuitively by the project partners who have a considerable amount of experience with shop-floor installations. In that sense the GUI is as good as possible without having had shop floor workers in the loop, and the question we want to answer is:

- How well are the kitting technicians able to use the GUI?
- What are the shortcomings of the present GUI layout and what are the typical errors that can appear?
- How can the GUI be improved?

In this paper, we present the GUI to the reader in Section 4, in the order and context they are seen during the experiments. We believe that this way the GUI can be easier related to the reactions of the volunteers.

The remainder of the paper presents the protocol and the preliminary results of the user testing of the Logistic Planner.

2.1 Human Machine Interaction 101

The objective of the user testing is to evaluate the acceptability by the user of the Logistic Planner, because if the system is not accepted by the user, it will not be used.

For the evaluation of the Logistic Planner, we consider the model of Acceptability of Nielsen [4] to be the most relevant one. According to [4] the acceptability of a system depends on several parameters, but refers to two main dimensions: social and practical acceptability (see Figure 3).

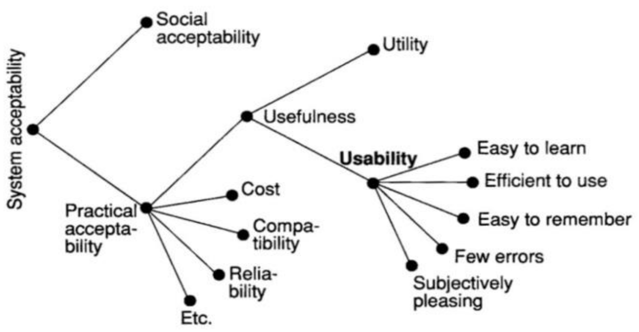

Figure 3 shows the Model of Acceptability by Nielsen [4].

In the presented user testing, we have focused on the *practical acceptability* in the first instance. In this case, we can focus on the GUI. To test the *social acceptability* requires the physical robot system to perform its task within the human social context. This, however, requires practical acceptability, first.

More broadly, during the design and the development of a new interactive system, following the user centered design approach is central to be sure that the system is accepted, as described in the document produced by ISO Group, ISO 9241-210[3]. It specifies that the future user should be

[1] For big factories with several ware houses, only a sub-part of the complete world model is usually relevant for the robot to complete the kitting order.

involved iteratively in the evaluation process of the system, from an early stage. This approach aims at taking into account throughout the entire development process the needs and requirements of the users, by applying Human Factors, Ergonomics and usability knowledge and techniques.
The *practical acceptability* of a system is subdivided into several aspects with the main one being its *usefulness*. *Usefulness* depends on the system's

- *Utility*: does the system meet an actual need and what kind of benefit does the system provide to the worker?
- *Usability*: how easy is the system to learn, to use, etc. ?

Usability is defined by the extent to which a system can be used by a specific user to achieve specific goals with effectiveness, efficiency, and satisfaction in a specific context of use (see ISO 9241-2010, [3]).
In the STAMINA project and this paper, the objective of making the Logistic Planner useful and usable is to reduce the training phase, to ensure the acceptability of the future users and to minimize the chance of inserting erroneous information and thus the need of subsequent corrections.

2.2 Description of new tasks for the kitting technician with STAMINA robots and the Logistic Planner

To evaluate the *usability* and *utility* of the Logistic Planner, it is important to explain the goals and the context of work of the present and the future kitting technician, in particular what the changes in the tasks will be if the robot takes charge of the kitting operations, and what the expected future manual tasks would be. In Table 1, we summarize 4 tasks of kitting technicians and how these tasks

Main kitting tasks	*Manual tasks currently done by the kitting technician*	*Tasks to be done by the kitting technician with Stamina robots and Logistic Planner*
1	Select the parts that can be placed in the kit (weight and height)	Select the parts that can be picked by the robot
2	***Define a new implantation or update an existing implantation in Autocad format***	***Configure the kitting zone (containers and parts) with the Logistic Planner and control the robot to scan the kitting zone in order to get its virtual map***
3	Define the operations of the kitting operator + training	Teach the robot how to pick the parts
4	Support the kitting operators in the kit creation in case of accidents or problems	Manage alerts raised by the robot and Logistic Planner (e.g. empty boxes). Resume the robot.

Table 1 summarizes the current and future tasks of the kitting technician

would change.

- Task 1 is concerned with selecting parts that can be assembled into a kit. For this, the kitting technician needs to identify which parts fulfill a set of specific requirements (e.g. can be picked with one hand). This task would change as one additional requirement will be that the object can be picked by the robot, which requires a certain amount of experience with the robotic gripper.

- Task 2 is concerned with the implantation of a kitting area, which is about a) designing the layout of the kitting area, incl. locations of pallets, shelves, containers and parts, b) to capture this layout using Autocad, c) to assure that this layout is not changed by mistake, e.g., when empty containers are replaced with full ones and d) to keep the Autocad specification up-to-date, if changes are required. This is the task that will change most because of Stamina. In the future, the kitting area needs to be modeled using the steps described in the following subsections: to use one of the robots to scan the area, and to build up a virtual map of the kitting area using the GUI of the Logistic Planner.
- Task 3 is concerned with teaching those shop floor workers who perform presently the actual physical kitting (*kitting operators*). The kitting technician informs the kitting operators about locations of parts, how to place them in the kitting box, etc. In the future, the kitting technician will have to teach the robot how to pick parts and where to place them into the kitting box. As for Task 1, a bit of experience with the robotic gripper will be required.
- Task 4 is concerned with supporting kitting operators in case of an accident or problems. In the future, the kitting technician will have to monitor simple run-time information of the robots such as alerts of, e.g., empty containers, and potential restarts of the robotic systems.

3 Setups for the Experiments

The experiments were carried out in PSA Peugeot Citroen Plant in Rennes, France (see Figure 4).

3.1 Volunteers of the Evaluation

The future kitting technician will be either the current kitting technician, as described in Table 1, or the *monitor* of the operators in the vehicle assembly line, who keeps under his responsibility the assembly (supervise and support the operators in assembly) and will , in addition, take charge of kitting tasks since the kit constitution will be more and more close to the manufacturing line.

Six volunteers have participated to the user testing of the logistic planner, two current kitting technicians and four monitors of an assembly line

Figure 4 shows the robot in front of racks with boxes. The racks are approached from the robot only from one side. The Logistic planner informs the robot about rack locations and rack directions. In addition, the Logistic Planner informs the robot about the containers on the racks and their contents.

3.2 Test Kitting Area

The test area is sketched in **Fejl! Henvisningskilde ikke fundet.**. It consists of a relatively small area of 700 m^2 with two aisles marked by the dotted line, and constituted by eight racks (white) and five EU-pallet sized boxes (red). Each volunteer sits near the instructor and facing the kitting area.

The sizes for the shelves are given in *cm*, and all shelves and boxes have unique identifiers (T1-T4, M1-M5, B1-B4). This graphic was provided to the volunteers.

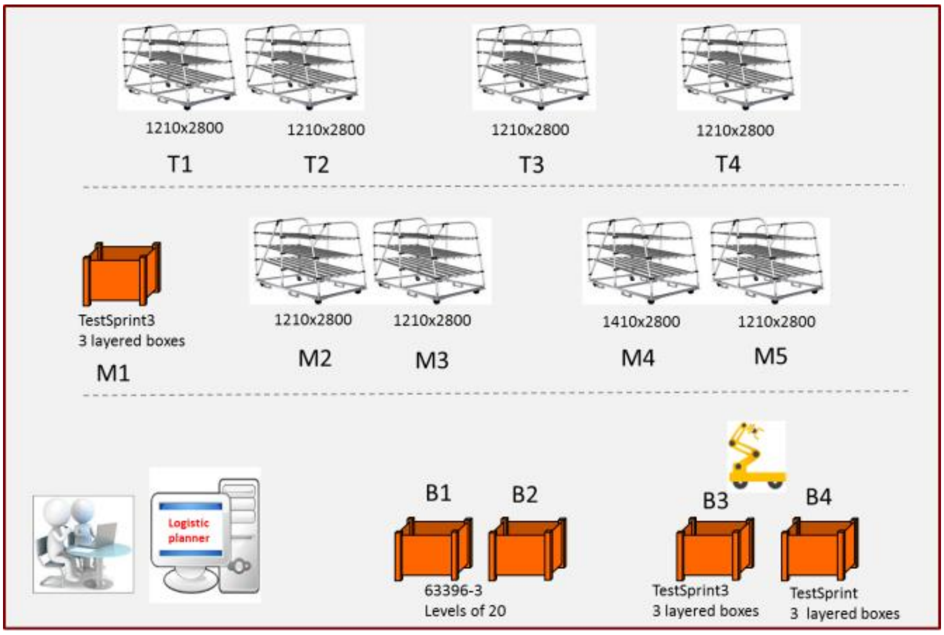

Figure 5 shows a representation (sketch) of the test area to be implanted with shelves and large boxes. The sizes for the shelves are given in cm, all shelves and boxes have unique identifiers (T1-T4, M1-M5, B1-B4). This graphic was also provided to the volunteers.

3.3 Executed tasks with Logistic Planner

In the present study, we are focusing on task 2 from Table 1 to find out how easy it is to use the Logistic Planner to create a new kitting zone (see Figure 6). Each participant is requested to set the map and to create a new implantation that results in a 3D world model of the kitting zone (see Figure 6) and the right correspondences between boxes and parts (see Table 2). This results into the following implantation work-flow:

1. Setup the map
2. Set the containers on the map (see Figure 5) and
3. Associate the parts to containers (see Table 2)
4. Check the 3D world model generated for the robot (see Figure 6)

Reference of large box	Associated parts
M1	Starter V7645594800
B1	Air Conditioning 967 80389
B2	Starter 98016677
B3	Alternator V757695
B4	Starter 965456

Table 2 shows the associations between each large box (left column) and the parts it is holding (right column).

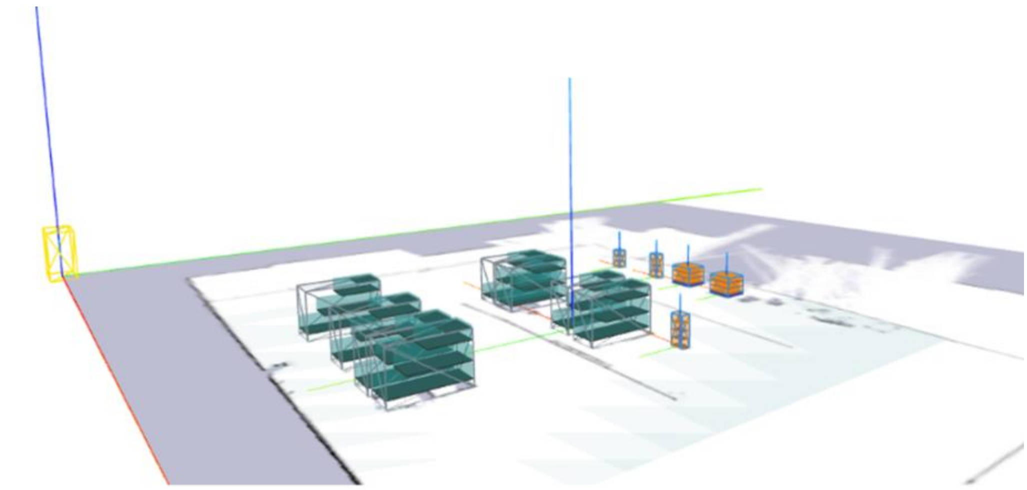

Figure 6 shows the 3D representation of the kitting area as defined through the GUI of the Logistic Planner. This is the result each volunteer should achieve.

3.4 Running the experiments

The experiments were done in separate sessions for each individual. Each session started with a 10 min introduction to the STAMINA project and its project goals, followed by a brief look into the kiting area and a very brief introduction to the GUI of the Logistic Planner. Then, each volunteer was given 30-45 min time to work through steps 1-4 of the workflow. Paper documents are provided to the participants with the information described in **Fejl! Henvisningskilde ikke fundet.** (sketch) and Table 2 (parts to associate). The individuals are requested to complete the tasks on their own without any help. Only in case of any difficulty, the instructor intervenes and provides some support.

Each experiment was concluded with an interview.

Phase	Description	Duration (min)
Introduction	Presentation of STAMINA project Presentation of user testing objective: evaluate the utility and usability of Logistic Planner Presentation of the kitting test area and the different objects (containers and parts)	10
Tasks execution	Set the map Set a new implantation Visualize the 3D world model	30-45
interview	Open discussion on positive and negative points	10
Total		40-55

Table 3 summarizes the duration in minutes of each block of a single individual experiment.

4 Experimental Results

In the following, we go through the different tasks and subtasks the volunteers were asked to complete. For each task the GUI is presented, the reaction of the volunteers are discussed and improvements are suggested.
Upon start the volunteers are presented with the initial menu of the GUI (Figure 7).

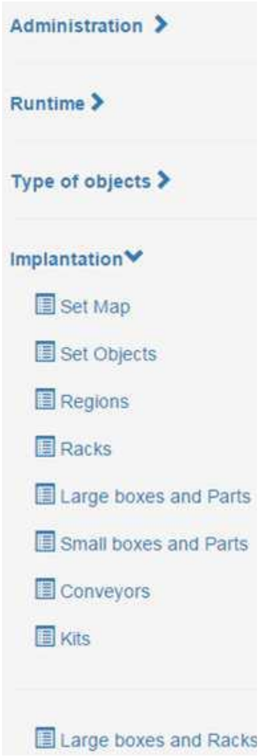

Figure 7 shows the top menu of the GUI (shown on the left side of the GUI window). Runtime *is concerned with runtime- and feedback information from the robots and the Logistic Planner.* Types of objects *allows the user to insert new objects, their ID, their CAD-model, visual appearance and grasping poses for the robotic gripper.* Implantation *is concerned with implementing the 3D map of the kitting area. This is the element the users are mostly concerned with in this experiment.*

4.1 Set the map

All the participant go to the menu *Implantation* easily. Following the task “1. Setup the map”, the volunteers go immediately to *Set Map*, so that the screen in Figure 8 appears. The screen shows the range data as captured from the robot with the laser range scanners. To capture the range map, the robot was previously manually driven through the kitting area by an engineer. The volunteers have been informed that

1. the laser scanners are roughly 10cm above the ground and that obstacles 1 meter above cannot be sensed,
2. the laser scanners of the robot create the 2D-measurements on a plane,
3. A 2D-scan always depends on the pitch-angle of the robot so that the 10cm estimate of point 1 can sometimes be imprecise.

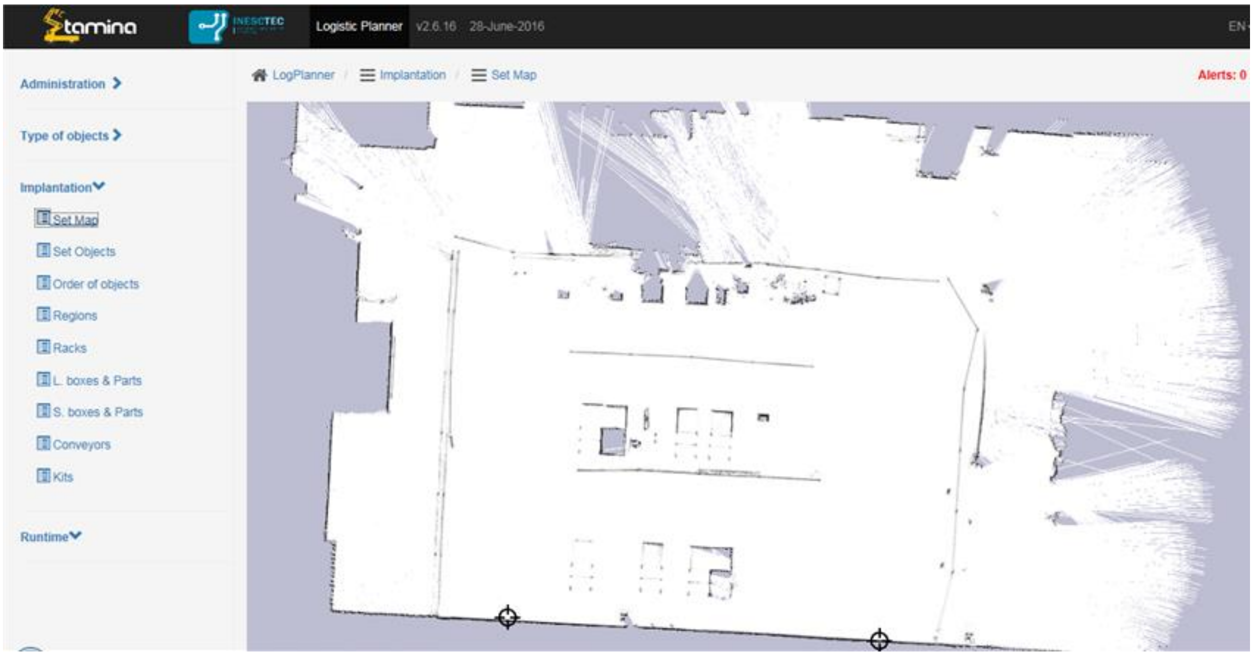

Figure 8 shows the “Implantation --> Set Map” screen. The screen shows the range data from the laser scanners of the robot. To capture the data, the robot was previously driven manually through the kitting area by an engineer.

From this, the participant has to recognize and identify the different containers (shelves and large boxes) present in the kitting area as visible in the front of them and as indicated in the paper document (sketch). Only one participant succeeds in identifying the large boxes in the image: he finds that the "grey squares are probably the large boxes", but not a single participant was able to recognize the shelves.
In addition, no one detected that the image is not in the correct orientation.

Then, the instructor informed the participants that the image needed a 180° rotation to align with the viewing direction of the participant.
No participant was able to find the function of rotation, and the instructor needed to explain to place the horizontal line, by placing two points (see Figure 8 at the bottom).

Figure 9 shows the map rotated by 180°. The location of the participants is marked red.

The conclusions were that

1. *the image generated by the robot scanning has to be improved as even in the very simple test area of these experiments the participants are not able to recognize the different objects.*
2. *the GUI is required to provide a button in the user interface for rotation, and display the result of the action of rotation in real-time following to the user action.*
3. *Rotations of the map should be avoided as this type of operation is not easily seen in the 3D space by shop floor workers.*

Conclusion 1 is challenging. It says that the data from the laser range scanners is too abstract for the shop floor workers. In spite of being metrically and geometrically correct [5,6], the range data image cannot easily be improved without the interaction of experts. To the knowledge of the authors there are no ongoing attempts to automatically add semantic knowledge to the depth map that could aid the worker. The only present solution might be to supply dedicated training or to minimize the problem by adding opaque elements to the shelves so that its representation in the map is more visible. Conclusion 2 is also challenging: the aim is to identify in the range image the outer wall on the opposite side. In order to do that, however, the worker needs to have a basic understanding of what the range data means. Conclusion 3 is manageable as container boxes in a kitting area are organized as rows with the containers directed in the same direction. In this case, if the area scanning made by the robot is made in the same orientation as perceived by the operator, complex orientations (greater than 45 degrees) are avoided.

As the experiments have been carried out only once per person, it is not possible to say how difficult it might be for the volunteers to gain experience and to learn how to interpret the range data.

4.2 Set the containers on the map

Before setting the containers, the root region and the container region have to be defined in the image. All the participants find how to use the mouse to draw both regions in order to add them, and then how to complete the action by clicking in the button “done”.

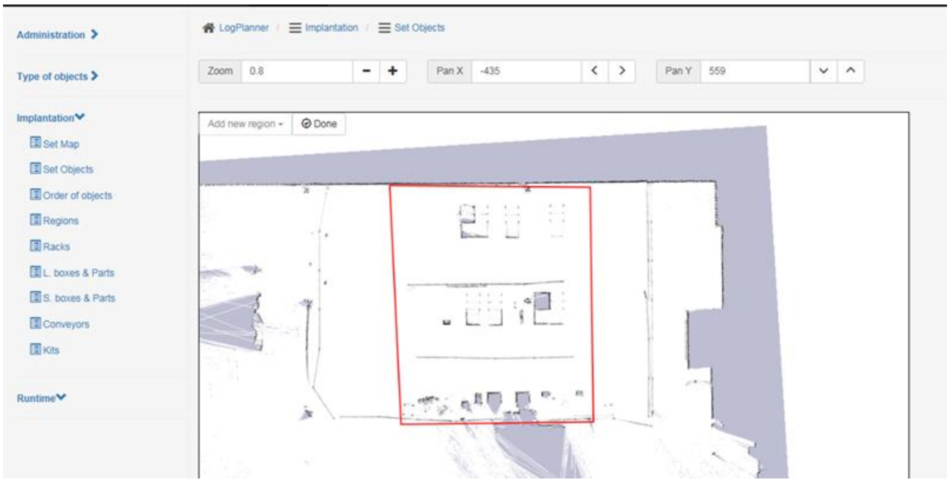

Figure 10 shows the kitting zone with the root and container region marked.

The volunteers observed that for completing a user action, the corresponding buttons were called either “done” or “save”, or it was marked with a “disk”-symbol. This variety caused confusion.
Furthermore, the current interface does not allow to come back or cancel an action. The user should always have the control of the system. However, these problems can be easily solved by software developers.
All the six participants were able to easily find how to create and place new containers with the mouse, but several difficulties are highlighted:

- the reference of the container to be placed has to be selected in a long list of references of containers. Here, the suggestion is to provide several levels of the list, e.g., level 1 having indicators to rack, large box or small box, and then level 2 holding the corresponding reference numbers. Alternatively, a field could be provided to write the type of container and then propose automatically a reference number.
- The representation for large box is at this screen very small compared to rack, and the suggestion is to display the large boxes bigger (see Figure 11).
- A newly created container is initially

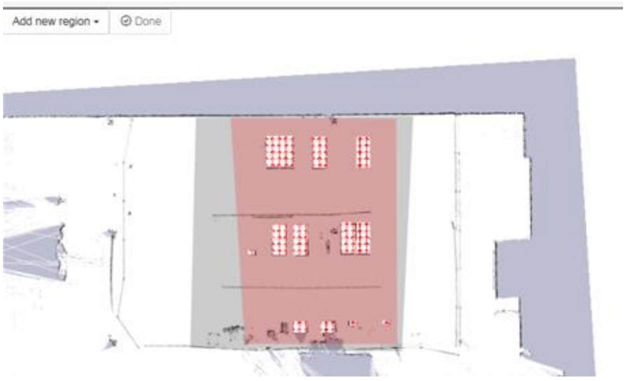

Figure 11 shows the screen after placing the racks and pallets. The directions of the arrows mark the direction of the racks, i.e., from which direction the robot would have to approach the rack. One can also see that large boxes/pallets (at the bottom of the area) are shown much smaller than the racks (top).

displayed in the center of the screen, and from there it should be moved to its designated location. However, it may be hidden behind a container already placed. The volunteers suggested to display the newly created container in the top right of the screen.

- The required precision to place the created container in the image is not provided to the user,

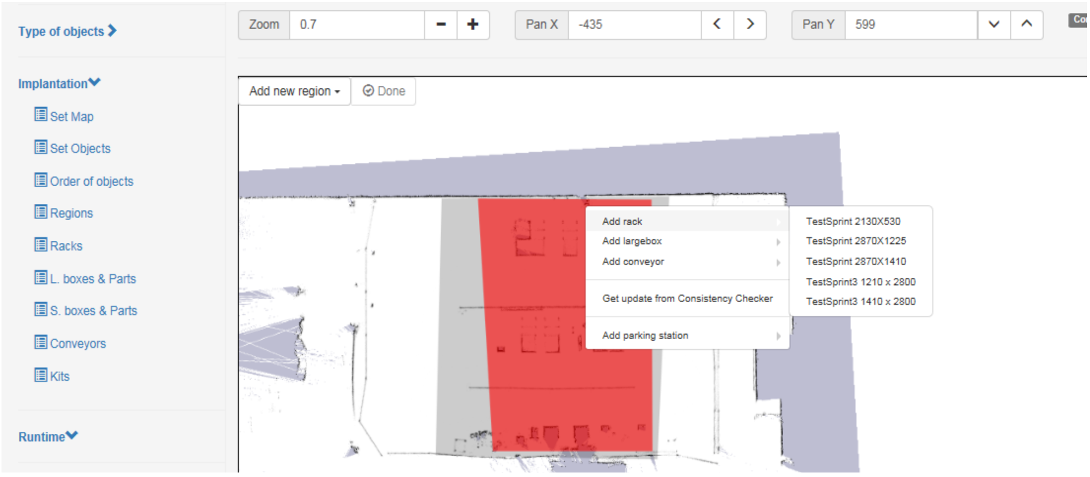

Figure 12 shows how racks and pallets can be added with different sizes.

and this can potentially reduce the precision of the virtual map. Therefore, the user should get a feed-back to user actions to reach the requested precision, to prevent errors.

The expected screen after setting the container is presented in Figure 11.

4.3 Associate the parts to containers

This task is concerned with associating the various parts with the containers, i.e., the inform the logistic planner which part is located in which container. The desired correspondence is specified in Table 2.

All the participants easily went to the menu “L. boxes & parts”, where five lines are displayed showing that five large boxes have been created previously, see Figure 13.

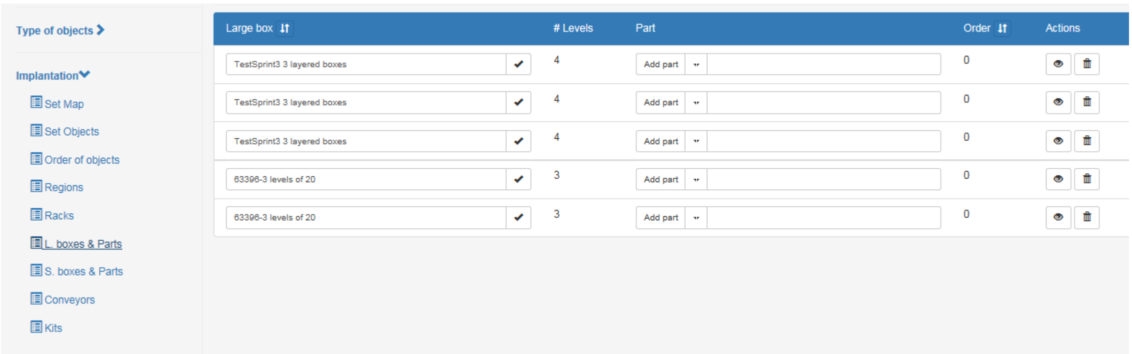

Figure 13 shows the screen for associating parts and large box

However, it turns out that several of the 5 large boxes have the same reference even though they are not supposed to contain the same parts. This is because the identifiers chosen by the participants in the previous step only reflected physical properties of the containers but they were otherwise not unique. In addition, there is no strict correspondence between one line and one particular large box

so that it is not possible for the users to deduce which box is which, which makes adding the right part to the right box impossible.
Therefore, the volunteers propose to remind the user at the time the container is created to give each one a distinct name or number.

4.4 Check the 3D world model generated for the robot

The last task is to compare and verify the 3D model with the real kitting area. This function is part of the "runtime" menu, as displaying the 3D world model is primarily intended to allow the kitting technician to monitor the robot locations and movement trajectories during the execution of the kitting tasks. As a nice side effect, it allows to check the implantation of the new area.

During the final interview, some of the participants revealed that monitoring the robot in real time during kitting activity is neither realistic nor needed, and that they only need to get alerts if the robot faces problems. In that sense, the main goal of this 3D world model visualization function turns out to be best used for check the new implantation. Therefore, the "3D model" should be moved from the "runtime" menu to the "implantation" menu.

5 Conclusion

In the present study, we have evaluated the acceptability of a new tool, the logistic planner, developed for the future Kitting Technician, who will be in charge of the management of robots that will take in charge the kitting of heavy parts in automotive logistic areas.
Using the logistic planner will require training of the future users because

a) information system pre-requisites are necessary as some user are not so familiar with using computer,
b) as the technician needs to walk in the kitting area, we need to propose to use a tablet computer as a supporting device for some of the operations,
c) to facilitate the configuration of a new kitting implantation, incl. the association of parts with one corresponding container, it might be useful to use the geo-localization of each container to prevent errors as in Sect. 4.3, which is especially important in real kitting areas that contain a very large number of containers.

As an additional feedback to the system engineers, to design an interactive system, ergonomics rules proposed by Bastien, J. C., & Scapin, D. L. [2], can be used which can prevent errors as described in the experiments, incl. "give an immediate feed-back to the user after each action", and "let the user cancel any action (user control)".

Finally, the user testing should be extended to the other phases of the kitting, that have not been tested in this present study, incl. training of the picking and the placing of objects.

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