Robots in Weight Carrying Scenarios: From Transportation to Co-navigation

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Abstract
Nowadays, robots are introduced in many scenarios for their physical capabilities, and the clear objective is to relieve workers from physical strain. However, even in scenarios where the task allocation between robots and humans seems simple, it often becomes more complicated than expected as questions related to worker autonomy, task responsibility, and accountability come to the surface. In order to design for better acceptance and to avoid unforeseen side-effects, it is important first to understand the existing workflows. This also allows to consider and prepare for future robot usage involving more ambitious task allocations or higher levels of human-robot collaboration. In this paper, we examine and describe our observations of two typical scenarios involving heavy weight carrying, a data center, and a hypermarket. We then elaborate on our design steps towards introducing robots. We extend the simple role of "weight carrying" by the robot to provide situational awareness for better human-robot collaboration during co-navigation. In the future, we also aim to design for more fine-grained attribution of tasks between humans and robots.

Keywords
introducing automation, human-robot collaboration, co-navigation, user observations

1. Introduction

One frequent motivation for introducing robots in workplaces is their physical capabilities. In this paper, we will examine one typical example, the case of stocking and re-stocking scenarios where robots are introduced primarily for their physical weight carrying and transportation capabilities. In such scenarios, the clear ambition is to facilitate the work of the human collaborators by removing the physical strain of transporting heavy objects and enabling humans to concentrate on other tasks. In this context, the attribution of tasks among robots and humans seems simple and straightforward.

However, even in seemingly simple scenarios, such as this one, introducing robots may be less simple and more complicated than initially envisioned. Indeed, prior studies [1, 2, 3] have shown that the introduction of robots often has unforeseen side-effects on the workflows they are supposed to support, such as loss of worker autonomy. Also, when robots are introduced for one reason in a work context, it may make sense to think about which other tasks they could

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also support (later on) in addition to the initially considered ones. Exploring those additional tasks in advance will later facilitate their (potentially partial) re-allocation to robots, limiting disruption.

When human workers interact with robots in their workflows, human-robot touchpoints and human-robot collaboration (HRC) are introduced. Different levels of HRC [4] exist, and the impact of introducing robots in a workflow depends on the targeted level of HRC. In the scenarios we consider, the initial target is a low level of HRC, where the robots simply fulfill physically difficult weight carrying tasks. However, as stated above, once robots are introduced in a workplace, more tasks and more intelligence can be assigned to them in the future, increasing the level of HRC. To understand the current workflows, the possibility of introducing robots and the additional tasks that could be assigned to them (beyond weight carrying), and the possible impact of introducing robots, we conducted observations at two sites, a data center, and a hypermarket.

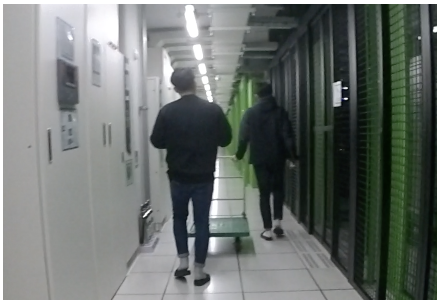
We found that, in both settings, the workers use similar tools like carts to carry heavyweight from one place to another and perform similar actions like stocking-restocking, with differences that stem due to organizational structure and task autonomy. In this context, the immediate value of introducing robots is to help carry the weight and relieve the workers of their repetitive and physical transportation-related work. However, this introduces human-robot touchpoints and human-robot interaction and enables collaboration like co-navigation requiring situational awareness. The importance of situational awareness in human-robot teams is well documented in prior literature [5, 6], especially in the area of autonomous driving, which is safety-critical [7, 8]. It is also crucial for human-machine teams in the scenario of co-navigation to keep the human-in-the-loop and in control for better acceptance of technology. In the remainder of this paper, we discuss our observations and findings at the sites, their implications on robot introduction, and some initial ideas for a better HRC in the identified collaborative tasks.

2. Observations

We conducted three-days ethnographic studies at two sites, a data center in Korea and a hypermarket in France. The work involves frequent transportation of heavyweight and where introducing robots to take over this physical task seemed a promising approach. Our aim was to understand similarities and differences in the workflows followed on both sites and their impact on the possible introduction of robots. We collected audio and video recordings of the observations. Below, we first summarize our analysis. Then we highlight the similarities between the sites, namely in terms of tools used and tasks performed. These similarities hint towards a possible very similar first phase of introducing robots in the workflows on both sites. However, we also observed some important differences between the sites that will certainly impact the longer-term acceptance and attribution of additional tasks to the robots in a second phase.

2.1. Data center

At the data center, the work is organized around a service desk paradigm with tasks originating from another organization. The tasks performed by the workers can be characterized as reactive



(a) Datacenter

(b) Hypermarket

Figure 1: The carts of the two settings

maintenance of servers. The aim is to keep the data center operating and prevent any errors that might deteriorate its service. The work is organized in different shifts throughout the day. Tasks are performed in teams of two workers, and each task is carried out according to a well-defined and structured workflow. Tasks are time-bound, and if a task is not finished within a shift, it is transferred to another team in the next shift through a shared task list that is updated by the teams after each intervention, precisely recording what has already been done and what not.

The tasks mainly consist of server installation and un-installation on the one hand and fault monitoring and repair on the other hand. Workers use carts to transport heavy servers between the warehouse and the server rooms. During the transportation of the servers to the server rooms, the pair of workers separate to facilitate the navigation: one walks in front, providing information of the floor, guiding the other who pushes the cart towards the site of intervention, and helping at the same time to avoid any obstacles on the way. Workers' main difficulty in the data center is the heavy physical strain linked to moving the servers between their storage and their installation locations and lifting the heavy servers. This is why introducing robots for weight carrying in this context seems particularly suitable. During our observations, another interesting finding came to the surface: error prevention is key in the data center context and goes beyond preventing and fixing technical failures. Indeed, for the workers, avoiding any accidental *human* error *during the interventions* is a permanent secondary concern. Such possible human errors are, for instance, accidentally bumping into surrounding (and correctly running) servers during an intervention or unplugging/shutting down a wrong server instead of the correct one due to insufficient verification or improper communication within the team. Consequently, the two workers within each team do not only collaborate to accomplish their tasks, but they also share the responsibility of accomplishing them properly, i.e., avoiding any error.

2.2. Hypermarket

At the hypermarket, the work is organized around the different types of products sold and the way they are organized into aisles. The aim is to keep the aisles always full and appealing to the customers. Most of the corresponding work happens during the morning shift, i.e., before opening hours. Each worker is responsible for a specific aisle or part of an aisle. During the morning shift, they have to replenish the products in this aisle, either with goods arriving in the morning directly from external suppliers or with goods already locally available, which they retrieve from their respective local storage area. Similar to the data center context, workers use carts for transporting these goods. All workers simultaneously and continuously go back and forth between the storage area and their respective aisles. Thus, while under time pressure, workers have to pay attention to avoid bumping into each other or any obstacle on the way.

In the hypermarket context, workers are autonomous and organize their work themselves as they deem efficient to finish in time with a good-looking, clean, and re-stocked aisle. Through their work experience, they have tacit knowledge enabling them, at a glance, to understand where to focus and how to optimally proceed. There is some collaboration between the individual workers, mainly to transfer goods that arrived at the wrong aisle to the correct one or at the end of the shift during cleaning. The physical work consists on the one hand of moving the goods between the reception area or the local warehouse and the aisles using carts. On the other hand, it consists of physically placing the goods on the corresponding locations on the shelves within the aisles. Especially the first type of work seems suitable to be supported by robots. Indeed, for the second task, the support from robots is more difficult to envision as the task is not standardized. For instance, the products have very different weights, shapes and each worker executes the work differently.

2.3. Similarities and differences

A common characteristic of the work in both sites is that it involves heavyweight carrying using carts and the repetitive and physical strain for the workers. In both cases, either servers or goods have to be moved between a warehouse and a target location, requiring situational awareness and careful navigation along the way as multiple teams work in parallel. In both cases, this weight carrying and transportation can be termed as the first phase of the workflows. One interesting aspect is the way they navigate with the carts. In the data center, one worker pushes the cart around, following instructions of another team member on where to go. In contrast, in the hypermarket, the workers pull these carts behind them to see the immediate environment.

The second phase is also different at each site, with precise and standardized fine-grained procedures in the data center and more flexible and individualized procedures in the hypermarket for stocking of goods. In the data center, the work is done following strict protocols. The focus is on correcting, preventing, and avoiding errors, and success can be precisely measured in terms of zero breakdowns or errors. Work is carried out in teams of two workers who collaborate and share the responsibility of error avoidance and accountability for their tasks. In contrast, hypermarket workers have an overall less precise and more vague objective, namely keeping the aisle nice and full. They have more individual agency and responsibility to achieve this objective and can organize their work mostly themselves.

3. Introducing automation

Introducing robots to help with the main problem of weight carrying is justified in both scenarios, and the benefit of this automation is obvious. Our organization aims to introduce robotic technology in such settings to decrease the worker strain from repetitive physical tasks. Hence, the current plan for technology introduction in both the settings entails introducing cart-like robots that help with weight carrying. However, as mentioned earlier, robots could do more than just weight carrying when considering human-robot teams. Indeed, we identified two general phases of the current workflow, (1) weight carrying of heavy objects to the desired aisle and (2) stocking and re-stocking objects in the aisle. The robots in this workflow have the opportunity to benefit workers in both these phases, possibly with two different levels of HRC, one in the first phase of weight carrying and one in the second phase of fine-grained execution of the tasks, i.e., stocking and re-stocking products or installing, uninstalling and repairing servers.

In this paper, we elaborate on the first phase of the workflow, where robots are primarily introduced for transportation and weight carrying. As observed, the tasks performed in these settings are time-bound, and multiple teams of workers perform their work in parallel. It is a fast-paced work with multiple static and dynamic obstacles in the same space. The workers have to navigate carefully towards their destination while avoiding any collision or accident. Given also the layout of the space in many narrow aisles, in these settings, the transportation of goods cannot be fully automated, and semi-autonomous navigation seems more practical, with the human navigating the robot at least through the *riskier* floor paths. In terms of the artifact, the flexibility of the current (manual) carts allows workers to make last-minute positional adjustments necessary to avoid obstacles and accidents very quickly. No robot can provide the same level of quick and easy flexibility. However, robots can provide additional sensing capabilities that can strengthen the situational awareness of the human workers and support them beyond weight carrying through human-robot co-navigation. Below we discuss our corresponding design.

4. Designing for Co-navigation

The robot to be introduced in this service is autonomous in *not risky* floor paths and semi-autonomous in the *riskier* paths. During semi-autonomous navigation, it moves forward with force applied by the human worker on its protruding handle, like a typical cart. However, the force required to pull, push, move, or stop this robot is very low compared to normal carts and is used as a guiding input. The worker pushes the robot, and the robot supports the worker during navigation with situational awareness. Indeed, to successfully co-navigate to the intervention site means proactively avoiding errors like accidental bumping into aisles or interfering with other teams on the ground. This can be achieved by designing for efficient robot control and sharing the task responsibility, i.e., navigating, between humans and robots. The robot can inform the worker of obstacles ahead and the path and location of other teams to make necessary adjustments. This information can be given as haptic feedback, which presents a good alternative from other modalities such as visual (too many sources of information) or audio (noisy environments) to provide situational awareness [9, 10, 11, 12].

We draw inspiration from the haptic shared control model by Abbink and the level of haptic authority (LoHA) [7, 13] for human-automation interaction to define the shared control during co-navigation. The LoHA constitutes how forcefully the human-automation interface connects human inputs to automation inputs and mainly addresses the provided support on a skill-based level through a single control interface (to control vehicles or robots). In our solution, the human inputs are the navigation nudges and directional orientation given to the robot. The robot inputs consist of information about obstacles and corresponding tactile cues given through counterforces that help avoid accidents. The control interface is the handle used to navigate the robot.

Our goal is to explore the following questions: a) What information (in addition to obstacles ahead) is important for humans for a better spatial awareness? b) Is haptic feedback an understandable and useful solution, and are complementary modes of information like visual screens required? c) What are the different ways to give haptic feedback and display information? d) How does the human respond to the information given by the robot? How does the human adapt to the actions of the robot? e) Is the proposed solution of shared control seen as beneficial by the workers?

To answer our questions, we will first design and collect responses through an online survey with workers. This will allow us to understand which information people would like to get for better spatial awareness when navigating with a robot and how they would like to get it. We will also probe the situations in which humans accept robots to control and apply counterforces. The questions will include a top view of a typical hypermarket floor with products aisles and a path to follow. An example question is, "What is the point during co-navigation where you would like to get information of upcoming obstacles?"

Second, we will define the tactile cues that convey the information identified in the survey. For example, the length and duration of vibrations can be adjusted to communicate urgency and distance to obstacles. Third, we will conduct user experiments in a VR environment with differing levels of tactile feedback ranging from none to feedback on immediate and extended surroundings. The aim is to validate the designed tactile cues and the defined level of haptic authority between humans and robots. We will collect measures such as the cognitive load of the worker, success rate of the task, time taken for completion, and misunderstandings of the cues. The results of this experiment will help improve the shared and cooperative guidance of the robot. During this experiment, we will also collect data regarding the force applied by participants to push the robot (through a physical cart handle connected to the VR environment) and make directional changes and the adjustments they make in response to counterforces by robots (felt through the handle). The collected data will help model intuitive counterforces and robot navigation paths.

5. Conclusion and Future Work

Our position paper gives an overview of the characteristics of the two sites we observed and the different phases of the workflows followed, which can benefit from the robot introduction. We focus on the first phase of co-navigation and describe the proposed plan to improve situational awareness, contributing to shared control and responsibility of the task. After conducting the user experiments for the first phase of co-navigation, we will design and test the human-robot collaborative interaction for the second phase of fine-grained execution of tasks. Through our participation in this workshop, we hope to have meaningful exchanges around these topics.

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