MyLYL: Towards Flexible Interaction Design for Operator Assistance Systems

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Abstract. Assistive systems in industrial assembly, such as cranes, hoists, and robotic arms are installed to reduce the ergonomic stress operators are exposed to. Whether such a system is suitable for a certain assembly step is currently evaluated based on ergonomic criteria. This does not seem sufficient as operators often choose not to use the assistive system. It is therefore important to ask why this is the case and what can be done to minimize the chances that support tools are not used.

To address the why-question, we ran contextual inquiries at three large production companies and used the results to design a simple scoring sheet to evaluate and compare the usability aspects of assistive systems in industrial assembly. This scoring sheet represents a design space: it provides an overview of different attention points relevant to the operators. As a first evaluation, we retroactively compared the (then) current to the desired situations in the visited companies. Further research is necessary to evaluate the design space and its representation.

1 Introduction

The manufacturing industry has long sought to automate and where that was not possible, provide tools that assist users in their tasks. One major driver for the latter are the negative health effects of physical stress on the worker due to handling of heavy loads or repetitive handling of (slightly) less heavy loads in the production process [6,9,10].

While such efforts frequently led to hoists and robots that assist workers in handling loads, such tools are regularly underused. Several usability factors lead potential users, in the remainder called *operators*, to not use these tools, even when knowing their use is beneficial to their health. One of the contributing factors is the sometimes large number of additional non-value added actions that are associated with hoist systems, as noted by a.o. Papetti et al. [8]. They propose a human-centered process for the design of human-centered manufacturing equipment. Within this process quantification of, among others, the number of tasks and ergonomics plays an important role. Virtual environments provide a

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means to test potential technology before its actually made. El Makrini et al. [5] also demonstrated the benefits of a human-centered process for the introduction of assistive technology – a cobot for a gluing application – in manufacturing while they put more emphasis on qualitative research. In both these cases a large and diverse cooperative team led to success.

However, such a large team with deep knowledge on a large set of domains is not always available. For example, updating existing installations due to changing requirements, or transferring knowledge to work cells with similar tasks for different products may be such cases where it may be useful to have a view on what is possible and what are important points of attention. In this paper we want to address the questions of how to find out why current situations should be adapted and how this can be done; which design options are desirable in the specific situation.

Contextual inquiry [1] is a method to gain qualitative insight in the work experiences related to a specific goal. We used this method to investigate the operator's needs related to the repetitive handling of loads in their work environment at specific work cells in three large production companies. We then tried to generalize the outcome using a design space. Design spaces have been used for a long time to characterize possible design options. Buxton [2] and Card et al. [4] were among those that provided characterizations for input devices for computing systems decades ago. Card and Mackinlay [3] proposed a design space for information visualization. These design spaces use a set of variables (and associated values) to define the range of design options that are possible. These focus on the technical aspects of both input and output of computing systems. In contrast, our focus is on how the user, the operator, experiences the usage of the interactive system, the (smart) hoist.

In an effort to generalize the knowledge gained from the contextual inquiry, we identified six variables with three potential values each that characterize the interaction with an assistive system for industrial assembly. These characteristics can be used to assess the current situation in which operators work and to identify potential solutions in terms of desired qualitative values for these variables. We noticed that these variables can be applied to actions that relate to manipulating the load. These characteristics are the base of a simple sheet to assess the current situation and determine characteristics of the desired situation in terms of user needs, without prescribing specific solutions. The sheet contains spider diagrams that visualize the values for the different variable-action combinations in two situations. In this paper we discuss the contextual inquiry, the resulting design space, and its application.

2 Contextual Inquiries

In the context of a research project aimed at introducing smart hoists (or collaborative robots) to assist operators in the manipulation of heavy or large objects, we performed contextual inquiries in three companies. We obtained ethical approval for the approach before the start of the observations. We did one contextual inquiry in each of the companies. All inquiries were done by the same researcher, who used a camera to make movie clips and pen and paper to write down the operators' comments. The people involved in the inquiry and the timing were determined by the involved companies. During each visit, we observed and talked with two to three operators working in the same environment. Table 1 provides more details on characteristics of the sites, including the number of hoists available in the observed work cells. The questions were focused on understanding their current working environment. Each of the environments already had at least one hoist installed. The approach was approved by the relevant ethical committee of Hasselt University.

Table 1. Observed operators and how they work

Company	Operators	Team	Hoists
A	2	separate work cells	1, 2
B	2	team along conveyor belt	1
C	3	team in one work cell	1

In company A, operators pick a gear from a bin (Fig. 1, lower left), put it in a machine (Fig. 1, right), get it out, do a check, and put it in a sink. Operators work in teams across work cells and switch work cells during the day to increase diversity in tasks. One hoist is available to move the gear in and out of the machine (Fig. 1, center inset and right) and, in one work cell where the heaviest gears are manipulated, one for the other movements (Fig. 1, left). The hoists have different characteristics and, therefore, cannot be interchanged for all tasks. One hoist is used for movements from/to the machine, the other for the remaining movements. Operators experienced issues with ergonomics regarding the inertia of the hoists, specifically when rotating, or starting/stopping hoist movement. There was no clear labeling/instructions on one essential hoist control which reportedly had an effect on the memorability of when to use the control. This in turn led to harmful incidents. Picking products from a relatively low box involved several additional non-value-added actions because it was impossible to pick the products in the position they were delivered.

The operators in company B, have to do an assembly in which a pressure vessel is a central component and the heaviest one to manipulate. A hoist is available for transporting the heaviest pressure vessels over a relatively long distance to a turntable for a smaller sub-assembly and a short distance to the main assembly on the conveyor belt (Fig. 2, left). Operators in this case work in a team along a conveyor. The team decides on task distribution. One person in a team is responsible for transport using the hoist. It was this person that took part in the contextual inquiry for two different teams. In case of incidents, tasks are dynamically redistributed. Difficulties mentioned by the operators were the slowness of using the hoist, hindrance of the hoist during other actions and difficulty with coupling and decoupling of the pressure vessels.

Fig. 1. Hoists in company A: chain hoist (left) and second hoist center and right.

Fig. 2. Hoist in company B (left) and company C (right).

In company C, the operators primarily build an enclosure consisting of poles, doors, and panels, around an existing sub assembly. A hoist (Fig. 2, right) is available to transport the top panels. There is no hoist[1] available to manipulate

[1] A new hoist has been installed since the visit that supports almost all panels and doors.

the other panels and doors. These can be handled without a hoist, although it is not ideal. The operators mentioned no issues with using the hoist. The researchers observed that the overall process of using the hoist was completely manual, relatively slow, it was not easy to correctly balance the top panel, and the process required the presence of two operators to guide the hoist to the top of the assembly. The height of the assembly necessitates operators to use stairs for mounting and fixing the top panel. Other panels need to be rotated and some sides consist of two panels, which were assembled before integration in the full assembly.

Despite significant differences in the settings, some common themes emerged: The observed operators were aware of the importance of ergonomic behavior for their self interest. Meeting or beating expected production goals was at least as important. Implicit social pressure heavily influences decisions on among others using the hoist. Task allocation was dynamic to meet a shared goal. Dragging and turning induce physical stress.

More specifically for hoists the following requirements were observed or explicitly mentioned by the operators:

- It should be easy to attach and detach loads, and to start and precisely stop movement.
- Hoists should not impact other actions and not make meeting production goals more difficult.
- Operators would appreciate if hoists would also support other actions (e.g. assembly or inspection) but should minimize additional actions.

These conclusions, together with video's of actual operator use of the hoists was presented to stakeholders. This type of qualitative information was appreciated and a reduced version, video recordings by the companies themselves were adopted to document operator practices.

3 Usability of Hoists in Changing Contexts of Use

ISO 9241-110:2020 [7] defines usability as the

> extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use

The context of use in this definition includes the user, goals and tasks, environment and resources. In the situations discussed before, the goals and tasks can be considered mostly static, changes in the physical environment are also limited. Users, in this case operators, can change quickly (and thus also the social environment); at one of the companies none of the operators participating in the contextual inquiry still work there. Resources change the most as there is a significant variety in products being treated.

This means that in order to be usable, it should be easy to learn using the hoist system and to remember how to use the hoist system with specific resources. It is thus essential that the system provides good affordances and a clear feedforward [11], it is clear what *function* will be performed when activating a control. One option to do that is to provide clear labels. The hoist in the middle of Fig. 1 has clear labels for the two top-most controls. The lower control was however missing a clear label and operators provided a fix. Such a fix is temporary and ideally a signal to provide a more permanent solution and not a reason to mark the issue as resolved. Sometimes control usage might be more complex and instructions may be needed.

Effectiveness can only be achieved when tasks are successfully completed. In the case of hoists this means (at least) attaching, moving, and detaching loads at the correct location. A precise view of the target location is crucial to achieve this result and thus feedback is important, especially when the load or the hoist itself hinder the view on the target location. In the observed cases, viewing the target location was still possible, although the associated posture was far from ideal. Another aspect of effectiveness is the potential to recover from use errors.

User satisfaction is the aspect that might be most easily overlooked in designing hoist systems as we saw that it relates to aspects that are not always directly related to the execution of the tasks. Things like control position when not using the hoist or rotation limitations when the product is attached to the hoist during assembly tasks impact user satisfaction, but do not directly relate to hoist operation tasks.

Efficiency is very important in the manufacturing industry. The fact that hoist usage often implies additional actions or reduces operational efficiency due to inertia or safety considerations (e.g., limited speed on button-controlled movement). Computer-controlled systems can alleviate the task for the user, as they allow to implement more user-centered controls. This can be, for example, continuous speed control[2], combined movement, or automated directional mapping based on the user's orientation. Our proposed design-space and evaluation sheet allows you to compare and assess different implementations of such improvements.

4 MyLYL Design Space

We compared available industrial control solutions as well as existing human-machine design guidelines. We then looked how these could inform the design of hoist-action controls. We identified six dimensions that can be controlled for a set of actions:

speed the flexibility with which speed can be controlled. This can impact both efficiency and user satisfaction,

load physical strain on the operator directly impacts operator satisfaction (and harm),

[2] An example of continuous speed control is available at https://www.youtube.com/watch?v=GTKRwtfGzCo.

place where the action can be controlled; this may impact user satisfaction as it influences the ease with which controls can be reached and potentially whether controls hinder other actions or require additional movement and thus efficiency,

function the way functionality of controls is observable through the system,

effect feedback when controls are used,

instructions task-specific documentation on how controls should be used or combined to complete specified tasks.

To ease usage of these dimensions, we determined three qualitative levels for each of the dimensions that indicate the level of support for an operator on that dimension. A higher value indicates more support for the operator on that dimension for a specific action. Whether more or less support on a specific dimension is needed, should be determined on a case-by-case level. Table 2 gives an overview of the design space dimensions and values. The additional 0 value is shared across all dimensions and thus mentioned only once in the overview.

The stated characteristics of the dimensions and the proposed values allow to quickly get a rough idea on the level of support offered by one or more solutions for a specific set of actions. We made a first version of a supporting tool by building a spreadsheet that allows to compare the support offered to operators by current and envisioned hoists to perform certain actions. The spreadsheet provides space for in two actions with the gripper and two movement actions with two (potential) hoists (see Fig. 3).

Supporting discussion on advantages and disadvantages of potential solutions without the need for deep technical or knowledge and consideration of aspects that might otherwise be overlooked are some of the drivers behind the research.

5 Application of the Design Space

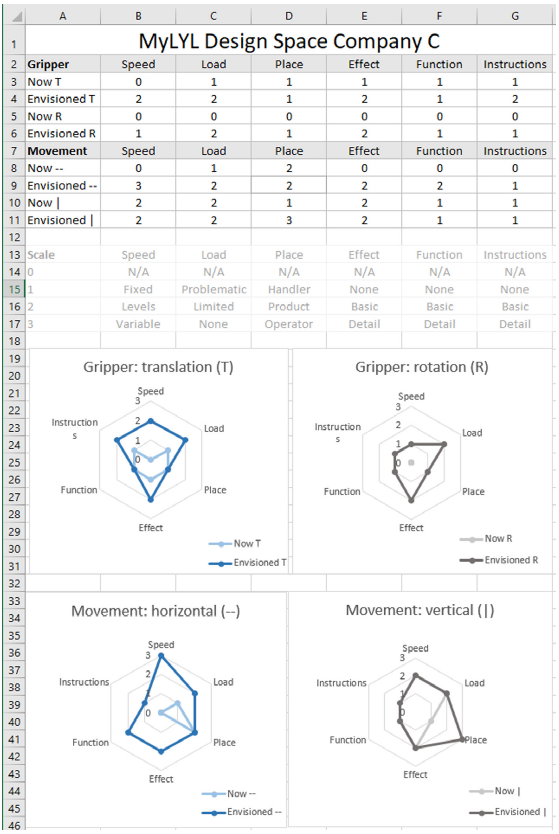
For each of the company cases, discussed in the Sect. 2, we could identify two actions related to the gripper and two actions related to hoist movement for which we identified a current and desired value.

For Company A, the actions that needed a change in support were *horizontal* and *vertical* movement, as well as *rotation* and *taking products* with the available gripper(s). More specifically, the operator load was problematic for horizontal movement due to inertia of the hoists. The effect of hoist movements was hard to see during precise positioning. This led to ergonomically straining postures during this action. The lack of information on the load compensation control on the primary hoist was a problem for vertical movement; there was no information on control function and effect, nor instructions on the hoist. This hoist did not support gripper rotation (around horizontal axis) leading to the need for a second hoist and several additional actions for some of the heaviest objects. Taking objects with this primary hoist was also difficult because the hoist limited the visibility and thus hampered the required precision. This could be solved by more explicit information on how the controls function and their effect.

Table 2. Dimensions and values of the proposed hoist control design space. *Speed*, *Load* and *Place* document the functional aspect of the provided hoist control. *Function*, *effect*, and *instruction* specify the level information provided by the hoist

Dimension	Value	Name	Explanation
all	0	N/A	Not applicable, no support provided
Speed	1	Binary	speed of operation is determined by hoist only control: on/off
	2	Discrete	operator can choose from predefined speeds
	3	Continuous	operator determines speed of operation
Load	1	Problematic	operator perceives execution of action as problematic
	2	Limited	input of operator during entire execution of the action execution of action is not considered to be problematic
	3	None	no load on operator *during* execution of action activation of the action or function by the operator might still be needed
Place	1	Handler	controller moves with hoist
	2	Product	operator uses the product to execute an action
	3	Operator	controller moves with operator
Function	1	None	no explicit indication is present
	2	Basic	basic indicator is present
	3	Detail	detailed information is provided for this variable
Effect	1	None	no explicit indication is present
	2	Basic	basic indicator is present
	3	Detail	detailed information is provided for this variable
Instruction	1	None	no explicit indication is present
	2	Basic	basic indicator is present
	3	Detail	detailed information is provided for this variable

The actions that deserved more attention were similar for the work cell in Company B. The dimensions that needed attention differed, however. For vertical movement the place of control caused problems because it hindered the assembly actions of the operators or took too much time to put aside. For taking products it was the load that caused problems, due to the force needed to open the used hook. Rotation (around vertical axis) of the product was also hindered by the hoist, leading to unnecessary, load on the operators. It led operators to adapt the work procedure. The main issue with horizontal movement was similar to that in Company A, although additional load due to product stability issues was also mentioned.



MyLYL Design Space Company C

Gripper	Speed	Load	Place	Effect	Function	Instructions
Now T	0	1	1	1	1	1
Envisioned T	2	2	1	2	1	2
Now R	0	0	0	0	0	0
Envisioned R	1	2	1	2	1	1
Movement	Speed	Load	Place	Effect	Function	Instructions
Now --	0	1	2	0	0	0
Envisioned --	3	2	2	2	2	1
Now |	2	2	1	2	1	1
Envisioned |	2	2	3	2	1	1
Scale	Speed	Load	Place	Effect	Function	Instructions
0	N/A	N/A	N/A	N/A	N/A	N/A
1	Fixed	Problematic	Handler	None	None	None
2	Levels	Limited	Product	Basic	Basic	Basic
3	Variable	None	Operator	Detail	Detail	Detail

Fig. 3. Spreadsheet supporting usage of the design space with visualisations using spider graphs for the situation in company C

In the observed work cell in company C, the actions that needed change in support (Fig. 3) resembled those in the other companies. However, the dimensions that needed to be addressed were different. To better support horizontal movement, load reduction as well as information for precise positioning were mentioned. For vertical movement the place of control needed change as both hands were needed for product control and thus no hand was available near guardrail to safely walk up stairs near large assembly. Rotation of the gripper was requested, which made usage of the hoist more complex and thus additional information might be necessary.

6 Conclusion and Outlook

Hoist, lifts, cranes, and robotic arms help operators in handling components of various weights in order to reduce ergonomic stress. As such, their purpose is human-centered, but the interaction side is still very technology-centered. With our proposed analysis sheet, we want to promote a more user-centered approach to control that puts more emphasis on usability aspects that affect adoption other than optimal efficiency and effectiveness. The MyLYL design space and supporting sheet give insight in the possibilities for technological support using hoists based on the needs of operators in a specific contexts of use. In the specific manufacturing cells, each change in the manipulated products but also the technological choices for hoists and other aspects of the work cell has a potential impact on the needs of operators. The sheet allows to compare potential changes in order to opt for the optimal solution. We applied it for some uses cases. Further research remains warranted to validate it in more diverse settings.

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