Implication of haptic interface for complex interaction in specialized vehicles

Amid Moradganjeh
Umea Institute of Design, Sweden

Abstract
It is likely that the sense of touch will be playing an important role in the evolution of the art of computing [1]. To the date, haptic interface has been considered to have limited applications for complex environments. In this paper, I use the screen based interface of a harvester machine as an example of a complex specialized interaction and explore the implication of a haptic interface in that environment. I design and propose a haptic control system which delivers the same functions in the absence of visual information and without using input buttons. Also, I argue how this system solves some of the problems associated with sole visual interfaces and provides new beneficial characteristics to the interaction between man and the machine.

Introduction
The approaches in using the information technology in industrial machinery operations remains a design task of adding graphical displays and digital buttons to the existing mechanism. The limitations and disadvantages are revealed within complex interaction environments, where repetitive decision makings are based on the visually presented data and the inputs are still in the form of manual.

I use an example of a harvester machinery operation, where the whole process is being assisted with a computerized system and the operator is constantly monitoring, evaluating, confirming and changing the outputs shown on the screen by using the buttons on two separated joysticks.

To evaluate the possibilities of improving the interface, a series of qualitative research was done by interviewing expert users, observations, and also reviewing the related literature and the technical data related to the machine. The problems identified were categorized into two categories; issues related to the usability of the interface and the ones around the processing of the visual information by the operator.

In the following sections, after analyzing the identified problems, I develop the idea of having a special haptic interface that suits specialized machinery like the harvester. In the end, I argue the benefits of having this haptic control when it comes to learnability, flexibility, adaptation and some other related areas.

In order to validate the concept and to be able to conduct user tests, I made a prototype which includes the main functions of the proposed concept. I also use the observations results to validate the arguments I make on the characteristics of such haptic interface.

Problem identification – complex visual interfaces
In the early stages of research, it became clear that some of the problems are exacerbated with information technology. Because of the fact that the input interface is in the form of discrete buttons, it is less likely that the operator can form a useful mental model for the whole system.

On the other hand, processing relatively comprehensive graphical information on the screen in a very short period of time demands a heavy mental work from the operator. The heavy mental work demand is due to the fact that the operator is to make frequent decisions based on the observations from the changing surrounding as well as the visual data constantly presented on the screen. This leads to overloaded visual information channels and most of the mistakes made by operators occur when they are not able to handle the heavy load of visual input. By utilizing additional sensory channels of the user, such as haptic, it is possible to lower the amount of visual information and allow the visual attention to be concentrated on the details of the environment.

Figure 1. Operator in the cabin using the screen-based interface.

Feedback level
As the operation situations constantly change, the level of control, also the type and the amount of feedback an intermediate operator needs is different from an expert one. An expert operator is not only more skillful in using the interface, but also there is a parallel skill development for work strategies. In operating a specialized vehicle, these two expertise do not develop at the same rate and the users normally become more proficient in using the interface while they might be in the middle of learning curve of the operational skills. A complex interface like the one of the harvester machine does not meet the needs of both the

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intermediate and the expert user at the same time. Moreover, the control interface is passive and its response contains little information pertinent to the state of the environment.

In addition, the screen and button based interface influences the strategy of the operation. This inflexibility is partly the result of the computer and control buttons that have been added into an originally mechanically controlled interface and without addressing the nature of the operation and the environment in which the user is using it.

Haptic feedback

Within possible alternative forms of exposing the information to physically driven type of interfaces, I find haptic an important new opportunity. Haptic interface has shown to be advantageous as an interaction modality for specific tasks [2]. The results of utilizing haptic steering wheel have shown a significant reduction in visual demand [3].

With the computerization of interactions which historically we carried out manually, the future will be to bring back the original feelings associated with mechanical age presentation. Besides, the haptic modality is the only modality that can be employed as a simultaneous input and output channel, to allow a more exact modulation of input to be achieved [4]. Haptic feedback is also capable of providing the users with salient information when visual information channels are overloaded [5]. On the other hand, by combining haptic feedback and visualization, it is possible to increase the intuitive understanding of the operation [6] and reduce the energy in the action and response time [7].

One of the most important characteristics of haptic feedback is the possibility to have output in the form of input [8]. Considering the fact that the visual attention has originally been supposed to be used to acquire information from the surroundings, being exposed to a constantly changing screen can involve a big portion of the short term memory of the user with the visual feedback which is not necessarily useful.

Device architecture

The choice of mechanism for a haptic interface is influenced by both the nature of the application and the part of the body interfaced with. Considering the number of degrees of freedom of each hand, the challenge is to develop a control architecture which includes a range of input gestures and meets the perception requirements of human being. In complex machinery, the operation involves both the spatial control and digital-analog input of commands. The big number of actions, the range of combinations, sequences and time dependency of tasks in operating a specialized vehicle, makes it less practical to have an input-output control with the existing joysticks and necessitate a new configuration of a hand control device for the interface.

Concept structure

My solution to create a wider range of distinctive input gestures is to combine the two separated hand-controlled joysticks into one device with up to 24 degrees of freedom, allowing both translation and rotation in 3D for each component. This way the control device suits the control of the crane as well as accommodating a bigger number of actions. By using hand gestures instead of buttons, there is a more possibility to implement haptic feedback in the configuration.

The concept control device is based on a main part with 6 degrees of freedom. There are two arms connected to the main part which could be rotated in three different directions. Each arm is connected to a grip which has 3 degrees of freedom. All of these joints and arms can have force and position sensing feedback. Also, by adding passive touch cues which are presented to the observer's skin [9] the grip can be used for notification of events and to create relatively nonintrusive, ambient background awareness [10].

Figure 2. A basic model of the concept showing the main part, arms and grips.

As the number of degrees of freedom goes up, the number of possibilities explodes. However, this can result in a device that could be harder to build or be used. Further expanding the design space, each joint can be controlled to be passive or active at different stages of operation. [11]. For example a joint could be fixed during one part of the operation to make it possible for the mechanism to function in a specific direction assigned to that stage of the operation. The structure of this interface makes it possible to implement kinesthetic feedback to the most linkages as the main type of haptic feedback.

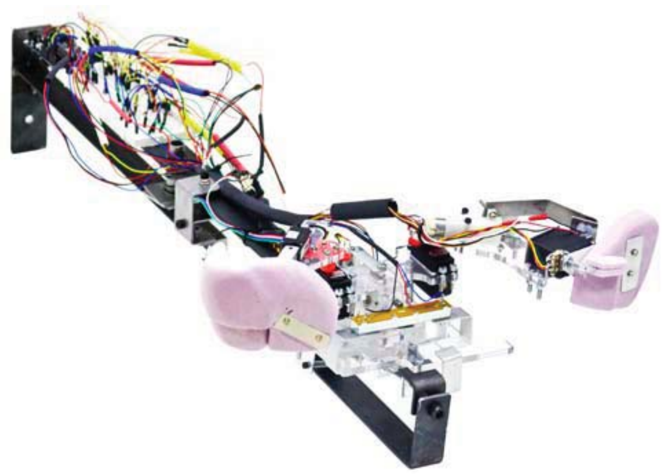

Figure 3. The prototype consists of more than 80 parts, 6 actuators and 8 sensors which are all being controlled by an Arduino microcontroller.

Movements and mental models

The way operators are interacting with this interface structure can be categorized into three different mental model groups: One is when both hands apply forces in line with each other, for example pushing both hands to move the arms in the same direction. This allows the operator to use either hand to accomplish the same task. This brings the freedom to select either of hands depending on how the user prefers to divide the tasks between them. For instant in the test prototype, it was seen that the users tend to control the cutting length by their right hand while the left hand is used for positioning the crane; they learn to automatically use their right hand for positioning the crane once they need to perceive a specific haptic feedback on the other hand.

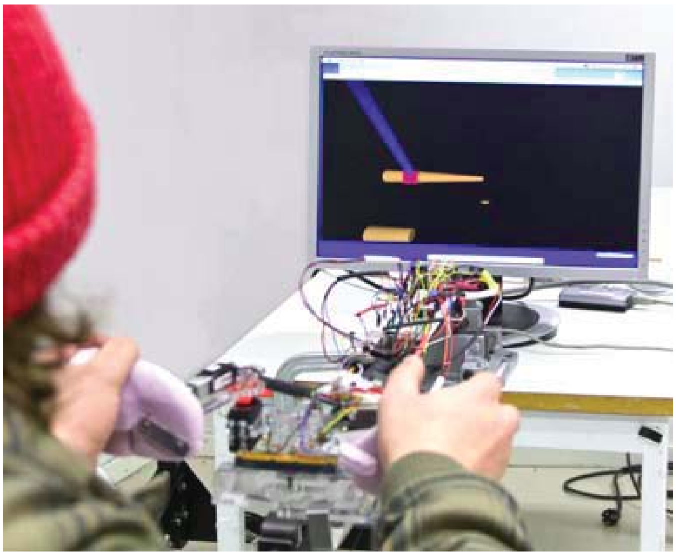

Figure 4. Simulation of the operation in Processing environment.

The other group are the type of hand movements that are supposed to apply opposite forces. This requires that both hands be involved at the same time. This is essential for the actions that need to be done as one task at the time and therefore it is essential that hands be involved together.

The other group of hand movements are the ones associated with a single arm and therefore are assigned to only the left or the right hand. This way, it is possible to have a specified number of parallel tasks. As an example from the prototype I made, while activating the automatic cut button, it is barely possible, to activate the quality change on the right arm of the control device.

In this haptic system, tasks can be assigned to the interface components depending on their relations, possibility of being parallel to each other, sequences, timelines, frequency of usage and the possibility of error occurrence.

From the cognitive point of view, a complex task involves a mixture of controlled and automatic processes. Automatic processes are not limited by working memory capacity and can coexist with other tasks as opposed to controlled processes which are slow, serial, effortful, and capacity limited. A skill component becomes automated when it's triggering conditions and associated actions can be compiled into procedural form in the long term memory [12]. Therefore, an initial design consideration for such haptic interfaces is to identify those components of the user's task which would benefit from becoming an automated cognitive process and those components that should remain controlled. Here, the architecture of the proposed interface makes is possible to assign the tasks accordingly and in order to make it more relevant to the mental process. In addition, harvester operators can benefit from continues input of haptic control as continuous tasks become more natural when controlled with continuous input [13].

It is obvious that mastering this haptic interface demands more training. However, since the system is going to be used for a long time, the ease of use after a specific time period is more important. In fact, I consider this as a benefit, as becoming skillful in using the interface will be happening at a speed closer to the operational skills development. Expert users constantly seek to learn more and to see more connections between their actions and the interface behavior. Their mastery of the product prevents them from becoming disturbed by the added complexity [14]. In the proposed flexible haptic interface, for example, it is possible for the expert users to develop new ways of manipulating the interface while the intermediate users are still able to perform the same task but in a different way suitable for their experience level.

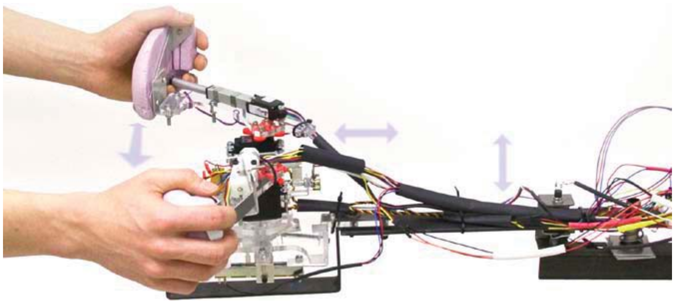

Figure 5: The haptic control being used by two hands.

Characteristics

Adaptation

One of the dilemmas of interaction and interface design is how to address the needs of both beginning users and expert users with a single, coherent interface [14]. While an intelligent interface can be a solution for some of the adaptation problems, the desired degree of adaptation remains a factor of the operator's need [12]. For this haptic control architecture the adaptation of the interface can be controlled directly by the operator. For example, as observed in the prototype test sessions, the participants learn to alter the orientation and adjust the compensating force on the left hand grip to control the amount of feedback they need to perceive for the next suggested cutting line. Users learn feedback compensation for the extrinsic dynamics and forces, with the potential for lower control effort [15]. As the level of operational skills increases, the role of feedback diminishes and there is a shift in attentional control from low level processes to more conceptual high level processes [16]. This means that too much of feedback for an expert user can have reverse effects on the performance. Depending on the experience of the user and also the task, I observed that users become aware that they are able to filter the type and control the amount of feedback they need to receive. At the beginner's level, the haptic feedback can also offer clues as to what an operator's options are, through constraints and gentle guidance.
Figure 6: The user trying to position the hand to feel the force feedback generated by the linear motor.

Flexibility

In the control of complex machines, the operation consists of a series of sequences of smaller tasks and their relations depend on the personal work strategy and the skills of the operator. For example in a semi-computerized process of cross cutting a tree, at the same time of felling a tree, operator is planning ahead the strategy of cross cutting the logs. In button based interface the operator can only activate the buttons at a certain time and order; this affects the flow of the operator's mental process, while in the proposed flexible haptic control, the operator is able to orient and position his hands at anytime when he makes a decision and is waiting to perform it. As an example, the operator needs to change the suggested quality type of the tree, should he encounter a curve in the tree. In this case the operator has to push the assigned buttons at a certain time simply to avoid the interference with the other action buttons and sometims because it is not ergonomically possible. In my observation of user tests on the prototype, I realized that the users are changing the quality of the tree as soon as they notice the need to do so by orienting the right hand at a different angle. Rotating the grip, in this case, is not going to affect the other parts of the operation. This results in a smooth flow of the process.

Replacing buttons with the hand gestures also give the flexibility of performing a combination of tasks at the same time. From the user tests, I observed that the methods used to accomplish the same goal change by practice, whereas in the button based joystick, the order of actions remain the same for the users at different proficiency levels and only the performance time decreases. As another benefit, using hand movements has a positive influence in regard to the Fitts' law.

Figure7. A scene of a prototype user test session.

Conclusion

Although the touch sense is generally used in conjunction with other sensory to have the best possible results [10], by using this prototype I show that the operation's goal can be accomplished without the existence of any visual clue and without using buttons as means of input.

Reconfigurability is an important advantage of the haptic interfaces as they can change their feedback in response to the environment they control [13]. I observed this to some degrees in using the prototype with the available functions.

Haptic feedback can reduce motor or visual strain when the manipulation is exacting or prolonged. It can also offer selective, suggestive guidance with a cue that the user can smoothly and variably over-ride [13]. For long term operations like harvesting, continuous control of haptic has benefits over discrete input of buttons.

Human adaptation to dynamic interaction forces and the ability to learn the control of extrinsic states has previously been shown in visuo-motor tasks. In a feedback task, the adaptation can be probed by altering the dynamics of the object or the sensory information regarding the object's motion [15]. Muscle memory is a great source of manual skill and the frequent and patterned nature of the tasks of this haptic architecture helps to structure stylized gestures, reducing cognitive load and long extra steps.

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