Information Coding by Means of Adaptive Controlling Torques

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Abstract. The investigated approach shows that the currently rarely used haptic perception channel can systematically be applied for information transfer. The encoding of information by variable controlling torques and the haptic transmission of information to the user via a central control element can lead to a reduction of visual distraction and cognitive stress in difficult tasks. Furthermore, this approach allows innovative interfaces so that the usability of products can be improved and the operational safety can be increased.

Keywords: haptic, information coding, adaptive control element, adaptive controlling torque, haptic display, human-machine interaction.

1 Introduction

Due to the technical progress, an increase of functions and associated to this, a growth of control elements and audiovisual displays can be noticed [1]. This leads on the one hand to an increased complexity of usability and on the other hand to an overload of the human perception channel. Especially the visual perception channel is overloaded which might lead to operating errors.

An adaptive control element is an approach to substitute single control elements. According to Petrov an adaptive control element is characterized by its ability to vary and adapt its gestalt (structure, shape) depending on the context of the human-machine interaction [2, 3]. Combined with a haptic feedback, such a control element can be adapted to different situations, users or tasks. It can be especially used to transfer information by the haptic perception channel so that the visual channel of the user is being relieved in situations of complex information input. The aim of this research is to investigate how this haptic feedback should be designed.

2 Basics

To understand the subject the definition of some basic terms like human-machine interaction, haptic display or controlling torque is necessary.

According to standard [4] a human-machine interaction is a closed control system. In this system the user gets information from the machine by perceiving and

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recognizing the information. After the user has processed the information he interacts with the machine. This interaction which is called behaviour [5] can be a statement (verbal behaviour) or a direct operation and use (visual or kinesthetic behaviour).

But how does the user perceive the information? One way is to get the information through a visual display. But there are also other ways to perceive the information, e.g., through an auditory or a haptic display [6]. While visual and auditory displays are already well studied and well known in the practice, there are hardly any concrete findings regarding haptic displays.

According to [7] a haptic display is an element that transfers information by active touching and moving and that requires the use of muscular strength. Such an element can be a control element which adapts and varies its gestalt (structure and shape) or operating force depending on the context of the human-machine interaction. Scientific findings regarding control elements which adapt and vary its gestalt can be found in the thesis of Petrov who describes design recommendations for such control elements [2]. In contrast Hampel researched the operating forces of rotary control elements [7] with the aim to use these results for control elements which adapt and vary its operating force. For example, he researched the control torque of rotary control elements regarding to the comfort range, the positioning accuracy and the perception of differences [7].

Operating forces of rotary control elements can be classified into the type of entry. For example there are a mono-stable, a continuous and a discrete value input. The difference between them is the number of detents. In this paper the focus is on the discrete value input. As figure 1 shows this type of entry can be also classified, e.g., into a rising and falling saw tooth shape as well into a sinusoidal shape. The main parameters which can be varied are the amplitude and the rotary angle in each case.

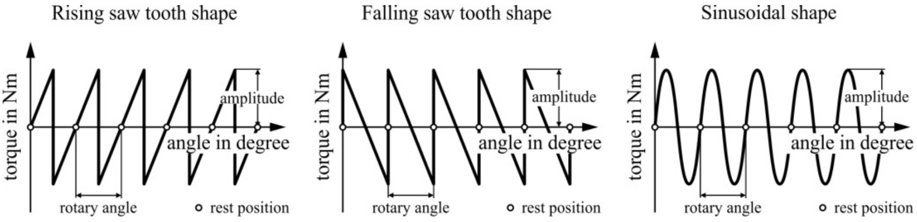

Fig. 1. Torque functions and parameters of discrete value input according to [7]

As investigations [7] and practice show [8], the falling saw tooth shape is preferred due to best comfort and precision impression which can be explained by the special characteristic of this function. The steep rising angle of the rest position ensures a high stability. In turn, this causes a high impression of comfort and operating quality. This is the reason why the following investigations were done with the falling saw tooth shape.

3 Methods

Based on the scientific findings by Hampel [7] several investigations were done to check how variable control torques must be designed for information transfer. The investigations were divided into two research studies whereby the second study was built on the first study. The number, age, and body size of the test person during the two studies are shown in Table 1.

Table 1. Number, age and body size of test person

	number [-]		age [years]		body size [cm]	
	total	relation m / f	average	standard deviation	average	standard deviation
1st study	20	10 / 10	25,7	7,0	178,1	9,2
2nd study	22	11 / 11	24,0	2,4	175,9	9,2

3.1 First Research Study

First Experiment. The first experiment of the first research study investigated the perception of linear changes of the torque amplitude and whether they can be used for haptic information transfer. Based on the falling saw tooth shape and its parameters (figure 1) different torque functions were created (figure 2).

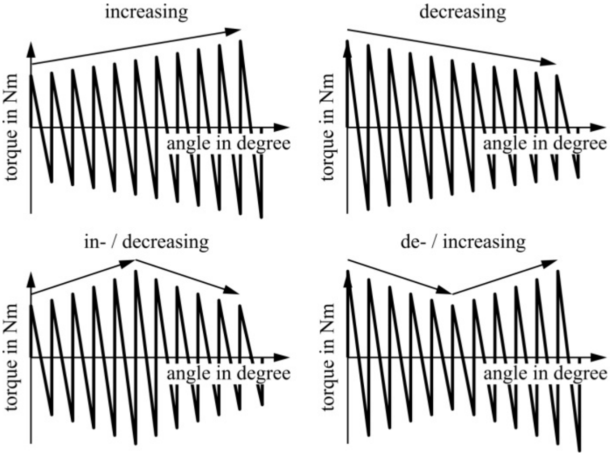

Fig. 2. Torque functions with linear increasing, decreasing and combined amplitude changes

Starting from a rotatory angle of 24 degree linear amplitude changes were installed. This resulted in functions which had an only increasing respectively decreasing or a combined (in-/decreasing respectively de-/increasing) operating character (figure 2). Related to practice these torque functions can be transferred to a passage of a menu list. A gradually increasing or decreasing torque function could be associated with the end or beginning of a list. A combined increasing and decreasing torque function might show the middle of a list through the haptic channel. Thereby, a visual control can be relieved or even omitted completely.

Second Experiment. The next experiment researched whether a single amplitude change at a defined point at the torque function can be recognized (figure 3). Such a function can be used, e.g., to display the middle of a list or a special value through the haptic perception channel. Further, it can be used during a long list to get an approximate orientation without the need of a visual control. Starting from a rotary angle of 24 degree and a torque of 0.08 Nm the torque was increased at the defined point to 0.10 Nm, 0.12 Nm and 0.15 Nm.

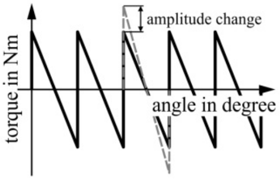

Fig. 3. Torque function with amplitude change at a defined point

Third Experiment. The last experiment investigated whether a change at the rotary angle (figure 4) can be recognized and used for information transfer through the haptic perception channel. Such a function might show the change of a menu or of grouped zones. Starting from a torque of 0.08 Nm and a falling saw tooth shape the rotary angle was changed from 24 degree to 28, 32, 36, 40, 44 and 48 degree.

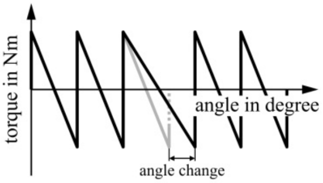

Fig. 4. Torque function with angle change at a defined point

3.2 Second Research Study

Based on the results and experiences of the first study (see chapter 4.1) the individual experiments were adjusted and detailed.

First Experiment. As the results show (see results of first experiment of the first research study) the recognition of combined amplitude changes are insufficient (figure 7). Especially the recognition of combined decreasing and increasing amplitude changes is improvable. In order to increase the recognition of such functions the gradient of the combined torque functions was adjusted and researched again.

The approach was to design the amplitude changes steplike instead of linear (compare figure 2 and figure 5).

The initial parameters were the same as in the first experiment of the first study. That means, starting from a torque of 0.08 Nm, a rotatory angle of 24 degree and a falling saw tooth shape steplike amplitude changes with a factor of 1.25 were installed. As in the first experiment of the first study functions were created which had an only increasing respectively decreasing or a combined (in-/decreasing respectively de-/increasing) operating character (figure 5).

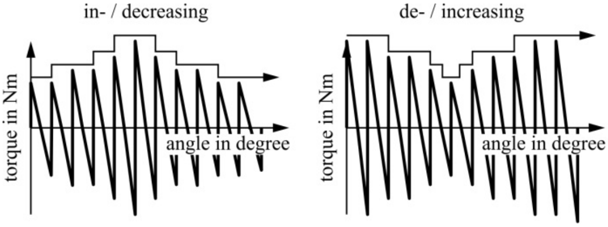

Fig. 5. Torque functions with steplike increasing, decreasing and combined amplitude changes

Second Experiment. The results of the second experiment of the first study show that users recognize – depending on the parameters – a change of the amplitude at a defined point very well (figure 8). To increase the recognition even more a detailed investigation was necessary. Therefore, based on the findings of the second experiment of the first study, further torque functions were created. The difference between them was the character of the amplitude change at the defined point (figure 6).

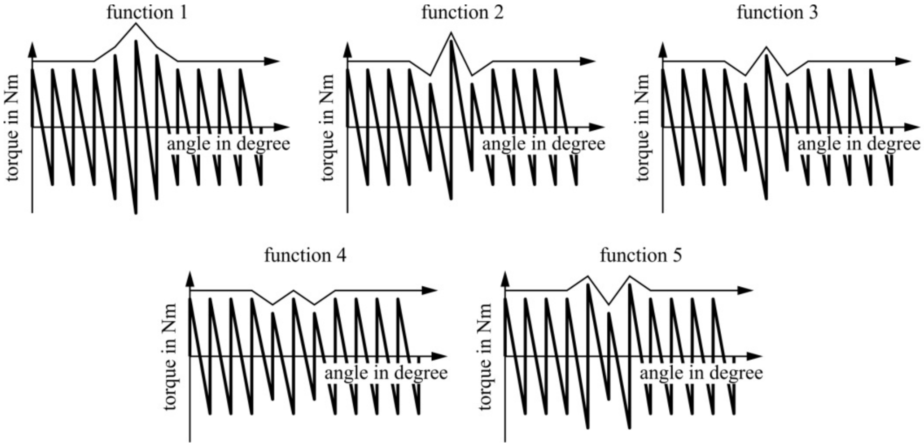

Fig. 6. Torque function with special amplitude change at a defined point

For example torque functions were installed which had at the defined point an increasing or an in-/decreasing respectively de-/increasing character. The hypothesis was that torque functions with such a special character lead to better results regarding the recognition. Starting from a rotary angle of 24 degree and a torque of 0.08 Nm the torque was increased or decreased with a factor of at most 1.5.

Third Experiment. The results of the third experiment of the first study show that changes at the rotary angle can be recognized – depending on the parameters – very well. As the results show changes from 24 degree to 36 degree or higher lead to significant recognition. Smaller changes were hardly or rarely detected. The question is whether a change of 12 degree or a change at the factor of 1.5 is deciding. Starting from a torque of 0.08 Nm and a falling saw tooth shape different initial rotary angles (12, 16, 20, 24, 28, 32 and 36 degree) and their related changes (plus 12 degree or with factor 1.5) were defined.

4 Results

4.1 Results of First Research Study

First Experiment. Figure 7 shows that an only increasing respectively decreasing amplitude change was recognized of 90 or more percent of the test persons. The recognition of combined amplitude changes is worse especially with the combined decreasing and increasing function. One reason could be the small distances during which the changes (in-/decrease) happen. That means that a haptic display for the middle of a list has to be designed by another function, e.g., by a higher torque amplitude at a defined point at the torque function.

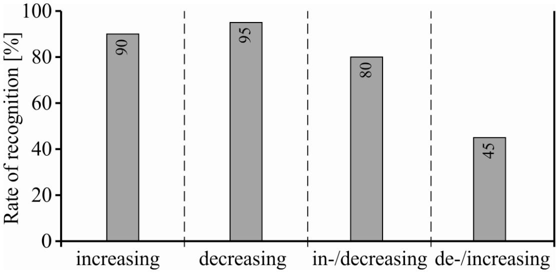

Fig. 7. Results of experiment with linear increasing, decreasing and combined amplitude changes

Second Experiment. Actually, the results show that users recognize – depending on the parameters – a change of the amplitude at a defined point (figure 8). The best results are achieved by a change from 0.08 Nm to 0.12 Nm which means an increase by a factor of 1.5. A higher increase (from 0.08 Nm to 0.15 Nm) is also recognized very well. However, such a change of the amplitude is not necessary due to the very good results of the middle change (from 0.08 Nm to 0.12 Nm). In addition, a large increase constitutes the danger that the subsequent detent will be jumped over due to the very large factor of increase.

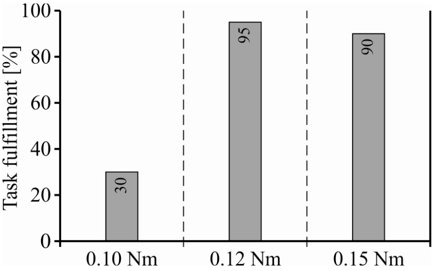

Fig. 8. Results of experiment with amplitude change at a defined point

Third Experiment. The results of the experiment with angle changes also show that such functions can be used as a haptic display (figure 9) and that they help to fulfill a task without visual control. Convincing results are achieved by changes from 24 to 36 or higher degree. The task fulfillment is 90 to 95 percent and confirmed that such functions can be used to show the change of a menu or of grouped zones. Smaller changes were hardly or rarely detected. This means that further investigations should be done with a change from 24 to 36 degree because higher changes do not achieve significant better results. The question is again whether a change of 12 degree or a change at the factor of 1.5 is deciding.

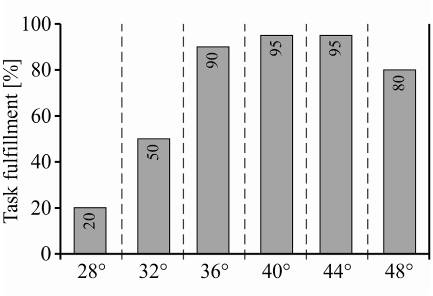

Fig. 9. Results of experiment with angle change at a defined point

Interesting is a decrease of task fulfillment at the change from 24 to 48 degree. A reason for this could be the limited slewing range of the human wrist so that the test person has to change one's grip which may lead to the lower task fulfillment.

4.2 Results of Second Research Study

First Experiment. As the results show, steplike amplitude changes do not increase the recognition of amplitude changes (compare figure 7 and figure 10). On the contrary, the results are even worse. The recognition of both, the pure increasing respectively decreasing and of the combined (in-/decreasing respectively de-/increasing) steplike functions is worse than of the linear functions.

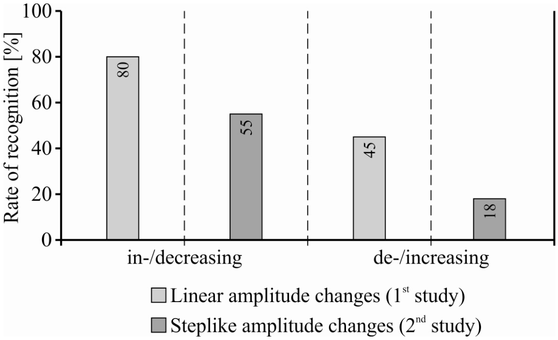

Fig. 10. Results of experiment with steplike in-/decreasing and de-/increasing amplitude changes

Second Experiment. Similar results are achieved in the second experiment of the second research study. As figure 11 shows, there are functions, e.g., number 1, 2 and 3 which the users recognize very well. But there are also functions, e.g., number 4 and 5 which can be hardly perceived by the subjects. In comparison the perception of all these functions is worse (highest value 77 percent) than the perception of the investigated function of the first study (95 percent). Interesting is the bad perception of function 4 and 5. One reason could be that the amplitude at the defined point of these functions is not higher than the initial amplitude value. And this could be the reason why the functions 1, 2 and 3 are perceived better. The amplitude at the defined point of all the three functions is higher than the initial amplitude value. This finding is very remarkable and should be researched in further investigations.

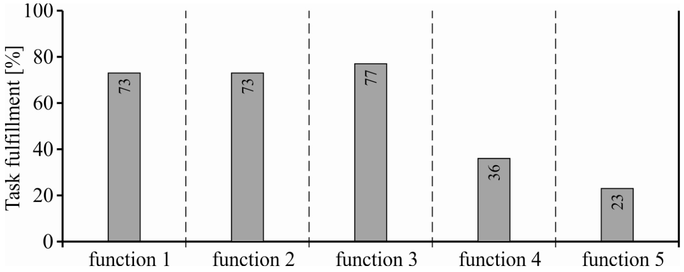

Fig. 11. Results of experiment with special amplitude change at a defined point

Third Experiment. The results of the last experiment of the second study are very interesting. The question was whether a change of 12 degree or a change at the factor of 1.5 is deciding to perceive a change in the rotary angle. As figure 12 shows, the answer depends on the initial rotary angle. For initial angles less than 24 degree the change should be 12 degree and not the factor 1.5. For initial angles bigger than 24 degree it doesn't matter whether the angle changes happen by adding 12 degree or by multiplying with the factor 1.5. The perception in both cases is nearly equal (figure 12).

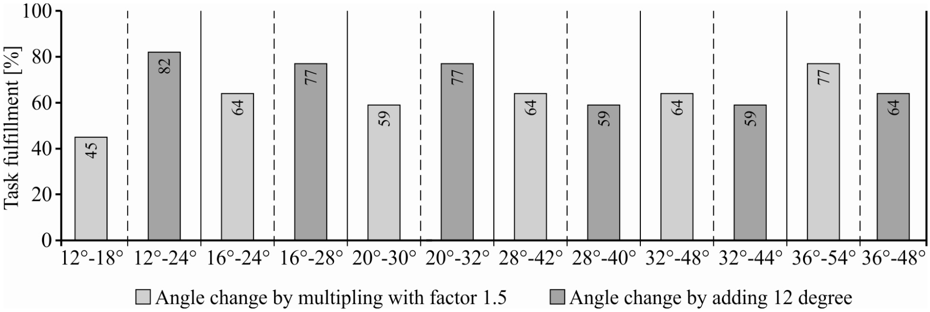

Fig. 12. Results of experiment with adjusted angle change at a defined point

5 Conclusion and Discussion

The investigated approach shows that the currently rarely used haptic perception channel [9] can systematically be applied for information transfer. For example the results show that the middle of a list or a special value can be displayed by an amplitude change at a defined point. But also other functions like linear increasing or decreasing amplitude changes or functions with angle changes at a defined point are suitable for information transfer through the haptic perception channel. The question which will be investigated next is how the functions must be in detail in order to get 100 percent recognition all the time.

Besides investigations are planned to show that the encoding of information by variable controlling torques and the haptic transmission of information to the user via a central control element lead to a reduction of visual distraction and cognitive stress in difficult tasks.

All in all, this approach allows innovative interfaces so that the usability of products can be improved and the operational safety can be increased.

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