7 Controls in Future Earth Moving Machines

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The last 25 years the application of joysticks has increased. The use of the joystick in computer gaming is nothing special anymore. Nowadays, joysticks are also applied for professional use. For example, in the latest earth moving machines these joystick controls are almost standard. They are used for instance to steer the boom or the buckle. In other vehicles the application of joysticks is increasing as well. Even experiments are done with joystick steering in passenger cars. In this chapter we explore whether a new way of steering has positive effects. We also compare controlling the speed of a movement versus the position of a movement.

7.1 Introduction

Whether designed for fingers or palms, or combined with buttons for extra functions, there are many different forms of joysticks (see Figure 7.1). There are also different ways for their movements to influence functions; for example, forward-backward movement could influence the position or the speed of the shovel. No empirical scientific studies provide criteria for choosing the best joystick for a specific task.

Figure 7.1 Some examples of joysticks

In this study it is explored what the disadvantages and advantages are of the use of different joysticks. Three main themes are addressed:

1. orthogonal steering

   In 'orthogonal steering' movements along straight horizontal and vertical

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lines are controlled. In this theme the issue is whether this is favourable compared to the traditional way of steering the machine cylindrically;
2. form of the joystick
   This theme questions what the advantages are of a new developed joystick;
3. speed or position
   This theme regards the advantages and disadvantages of controlling the speed of a movement versus the position of a movement.

7.2 Current design

As is seen in Figure 7.1 the current joysticks used in earth moving machines look like joysticks used in computer gaming. Some ten years ago large lever controls were replaced by these joysticks in earth moving machines. As a consequence large forceful movements are replaced by small localized movements (Krause, 2003). Another type of joystick is the finger joystick, which is controlled by one or two fingers. This finger joystick localises the muscle efforts even more. In discussions with drivers of earth moving machines they mention that for precision tasks the finger joystick works better. The selection of a joystick is now mostly made by the manufacturer and it is based on common sense and experience. There is no firm knowledge base to support the decisions concerned.

7.3 Current problems

As is mentioned above a major problem in designing a new earth moving machine control system is that criteria are missing based on empirical data. One criterion has some empirical support: joysticks could lead to end-user complaints. At least 20% of the operators of earth moving machines indicate that joysticks need to be improved (Kuijt-Evers et al., 2003). Also, in the wood industry problems with joysticks are mentioned. In a cross-sectional study among 1,174 wood-industry operators, half of the operators reported neck/shoulder complaints (Pontén, 1988). One third of the operators ascribed this to the joystick.
Research among 300 operators of earth moving machines showed that the change from the large lever controls to joysticks is seen as an improvement (Kuijt-Evers et al., 2003). So, the joystick will probably be introduced on a large scale the coming years. However, the same study shows that 20% of the opera-

tors are still not satisfied with the applied joysticks. Sometimes the joysticks are fixed to the console and have little or no adjustability. Sometimes the armrests cannot be adjusted to give the lower arm support while the hand is on the joystick. Often if the operator adjusts his seat to get a proper seat height, the joystick does not follow. In general, solutions for these problems are available. In fact, the solution is to make the joystick position adjustable. However, it is also important to reduce the static load. So, freedom in body movement is also needed.

Apart from the health problems it is important that joysticks facilitate high quality of work and speed of the job with limited time requested for learning how to use the joystick. However, an ideal design is still unknown. This study explores the three themes to stimulate a better performance.

7.4 Possible solutions

In the future drive by wire will be introduced in earth moving machines. According to some manufacturers this will be available in 5 years from now. This makes it possible to introduce new control techniques based on the possibility to manipulate the electronic signal with microcomputers and software. Hereby the freedom for choosing the steering system increases and knowledge for making the right choices is needed.

7.4.1 Orthogonal steering

Traditionally, a joystick controls a cylinder that rotates a part of a machine. This means that movements in circles are directly steered (see Figure 7.2, at the left). Wallersteiner et al. (1993) described another steering principle for log loaders in the wood industry: the orthogonal principle. We applied this to an excavator. This means that a forward-backward movement of a joystick controls a horizontal forward-backward movement of the shovel and the forward-backward movement of the other joystick controls a vertical movement (see Figure 7.2, at the right).

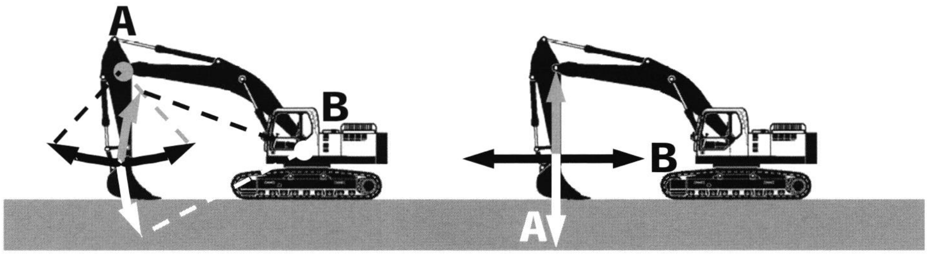

Figure 7.2 Left side: the traditional way of steering. The joystick movements control the rotation of different parts of the shovel
Right side: the orthogonal steering principle. The joystick movements control a horizontal or vertical movement of the shovel

To test orthogonal versus traditional steering a scale model was made of an earth moving machine (1:10) and tested by seven subjects. This machine was controlled by joysticks attached in the front of the armrest of a seat. Four subjects started working with the orthogonal technique, which means that a forward movement of the joystick resulted in a forward movement of the shovel. After a break they worked with the traditional method, where cylinders were steered. The other three subjects first worked traditionally and then orthogonally. Four tasks had to be completed:

- moving along horizontal lines (simulating levelling);
- moving along slope lines (simulating talus work);
- touching several points (simulating earth moving);
- touching points close to each other (simulating digging between cables).

The number of movements (indication for efficiency and musculoskeletal load) was significantly lower in all tasks for orthogonal steering. In general the orthogonal steering principle was preferred by all seven subjects. For specific tasks some differences are shown. In moving orthogonal steering was preferred by all subjects. For the lasts two tasks (touching) three subjects mentioned no difference and three preferred orthogonal steering. One subject saw no difference in touching several points, but preferred the traditional way with points close to each other.

We conclude that there is an indication that orthogonal steering is preferable.

7.4.2 *Form of the joystick*

To study the effect of the form of the joystick a new design was developed as a more logical connection to the task. The new design was compared with a traditional joystick to learn more about the effect of the form.

The design process

Based on the new possibility of 'drive by wire' and on the preference for orthogonal steering the designing of the new control started with ideas. Some of these ideas were materialized and tested by subjects. Based on discussions with experts in the field of ergonomics (to prevent health problems and increase the job quality and speed) and by tests of preliminary controls with subjects, three concepts were further developed. The three concepts were presented and discussed with experts in the field of ergonomics. This gave input for the final designs for the new controls to be referred to as: 'ball', 'unfixed' and 'wheel'.

In the concept 'ball' (see Figure 7.3) two functions are separated and controlled by two different muscle groups. Positioning the handle forward and backward generates the front-backward movement. Rotating the ball clockwise and counter-clockwise controls the sideward movements. The theoretical advantage should be that the two movements can be steered separately.

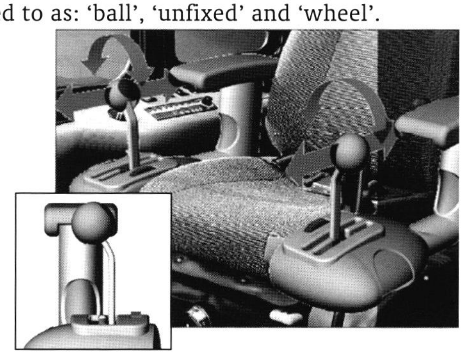

Figure 7.3 Concept 'Ball': this joystick can rotate left-right and translate forward-backward. An extra function for talus is the knob in the console

The concept 'unfixed' (Figure 7.4) is in fact a bar with two balls approximately the size of a tennis ball. Changing the distance between the balls steers the left-right motion of the shovel. Hand pads can support the hands.

The third concept 'wheel' (Figure 7.5) is close to the current joystick. However, two joysticks are connected together to form a kind of a large steering wheel. Pushing the left side downwards results in an upward movement of the right handle. The two hands support each other. With the steering movement of the complete steering wheel an extra function is created for an additional function.

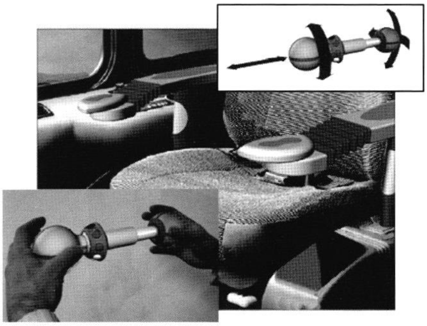

Figure 7.4 Concept 'Unfixed': two hands can be positioned in various ways to control the machine. Pads support the hands

Figure 7.5 Concept 'Wheel': two traditional joysticks are coupled and can be moved as a steering wheel. This creates extra steering functions wit a good support

The final design

For all three concepts end-users and experts mentioned disadvantages and advantages. These were listed and gave the input for the final design of the new control. In fact it was an optimisation of concept 'ball'. The anatomically natural position of the hand is with the palm downwards, but more with the palm facing laterally. This means that the stick under the ball had to be bended. In levelling ground this control is easy to handle. A forward movement of the control results in a horizontal forward movement of the shovel. A sideward rotation results in a horizontal left-right movement (orthogonal). In case of a talus, the knob next to the control can adjust the slope.

An experiment

To test whether the new design has effects experienced by end-users, an experiment was set up. It was tested whether the new control would be more simple and would lead to less mistakes and a more efficient task performance. The effect is studied by the indicators: the number of mistakes (errors), the efficiency of the task (speed) and the experience of subjects.

The difference between the new designed control and a traditional joystick was measured in four conditions:

- task 1: speed-controlled, drawing of a square (10 times);
- task 2: speed-controlled, drawing of a 45 degrees rotated square (10 times);
- task 3: position controlled, drawing of a square (10 times);

- task 4: position controlled, drawing of a 45 degrees rotated square (10 times).

Subjects and experimental set-up

Eight students with no experience in joystick control participated in the test. These participants where right-handed. The experimental setting consisted of a seat with a joystick (changeable between current or new) situated at the right side. The joystick was linked to two electronic servos, each for one direction, capable of switching between speed and position control. In the speed control mode the servo speed is analogous with the deflection of the joystick (when there is no deflection the servos will not move, when there is full deflection the servo will move at top speed). In the position control mode the position of the servo is analogous to the position of the joystick (the servo returns to the origin when the joystick returns to its origin). The servos are orthogonally aligned, thus enabling a controllable X-Y axis system.

The servo powered, mechanical construction moves a Wacom tablet pen over a tablet. The movements are input for the mouse pointer of a personal computer. On the computer, software was installed that shows two squares (or rhombus when the table and monitor are rotated 45 degrees). The software recorded the track of the mouse pointer, the time a task takes and the amount of errors during a task. An error is counted by the software when the mouse pointer is moved outside the path between the squares (see Figure 7.6).

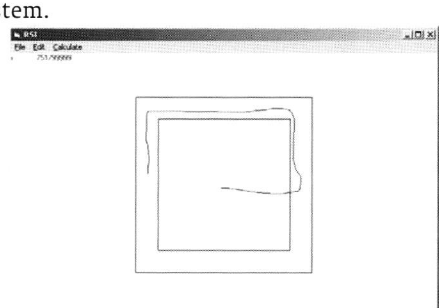

Figure 7.6 Screen dump of the interface. A line has to be drawn between the two squares. Outside the squares is defined as an error

Protocol

The experiment was performed in two different series of tasks, each with one of the two joysticks. Each series consisted of four tasks that have been repeated once in the same order. After the second series subjects were interviewed with regard to the experience with joystick controls and they had to rank the tasks in difficulty from 1 (easy) to 4 (hard).

So, there are eight possibilities in task-joystick order of the experiment (four tasks and two joysticks). Each participant had a different order.

Participants where asked to start from the centre point and follow the path of the squares. They where asked to draw the figure ten times. Whenever they would get outside the borders of the figure they should correct themselves, but they didn't need to go back to the point where they crossed the border. There was no indication given whether they should focus on speed or precision. The four tasks were repeated once and only the second series were analysed.

Results of the experiment

It appeared that all subjects preferred the traditional joystick. The main reason the subjects mentioned, was that the new joystick didn't function good enough. The force needed to steer the control was experienced as high compared with the traditional joystick.

Figure 7.7 and Figure 7.8 show that for task 4 the performance indicated by errors and speed is significantly ($p<0.05$, t-test for paired comparison) better with the current joystick. These results resemble the preferences of the subjects (see Figure 7.9).

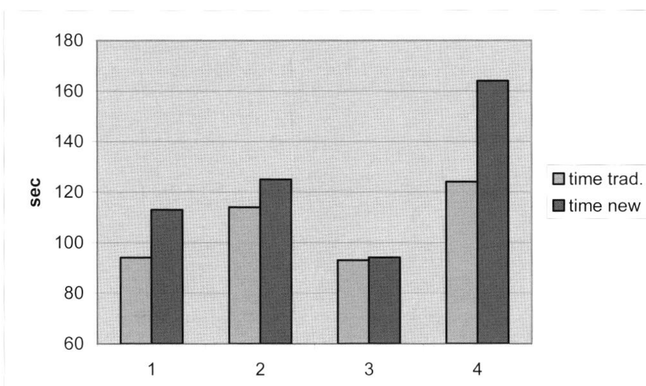

Figure 7.7 The time the different tasks (1-4) consume for the traditional joystick (time trad.) and the new control (time new) in seconds averaged over 10 trials and 8 subjects

Most errors were found in task 4; consequently task 4 consumed most time. This task was experienced as most difficult. Task 2 was experienced as the second most difficult, which again corresponds with the time needed and the errors made. These observations were highly correlated (r (Pearson)= 0.90 and 0.92 between experienced difficulty and time for the new control and the traditional joystick respectively; 0.95 and 0.99 between experienced difficulty and number of errors for the new control and the traditional joystick respectively).

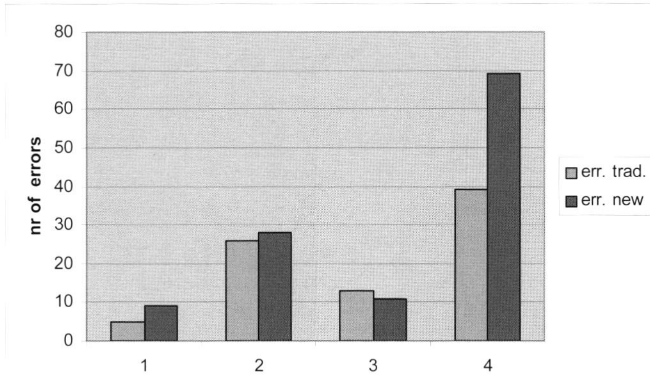

Figure 7.8 The number of errors (number of crossing the lines of the squares) for the different tasks (1-4) using the traditional joystick (err. trad.) and the new time control (err. new) over 10 trials and 8 subjects

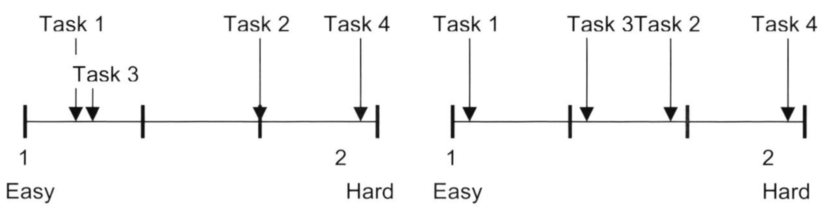

Figure 7.9 Assessment of the difficulty of the task: 1 is Easy, 2 is Hard; left scale for the traditional joystick, right scale for the new control/joystick

Considering that the new control needs more force and is less comfortable, it would seem arguable that this control is more suited for task 3: drawing a position controlled square.

The video recordings showed that subjects varied their position more with the traditional joystick. Some positioned their fingers at the top, some at the bottom of the joystick (see Figure 7.10), others had a full grip. In the new design everyone held the control in approximately the same way. From the interviews no uniform reason was found for the changing of the height. Some end-users reported that for precision tasks finger grip was more accurate.

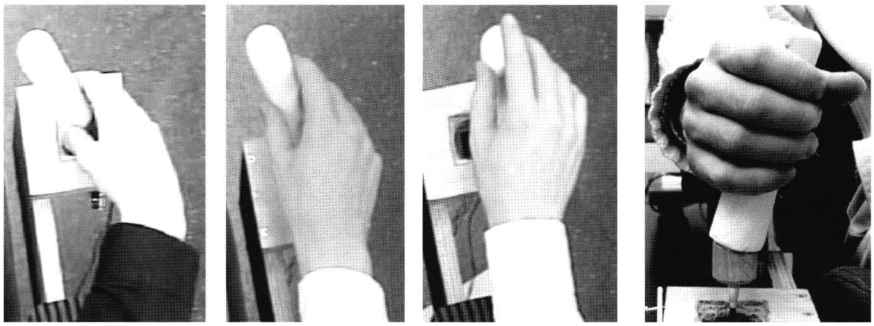

Figure 7.10 Different finger and hand positions observed in the operation of the joystick

We conclude that in this study the new control didn't have a better performance. However, this could be due to the fact that the new design didn't function well enough, which resulted in high control forces. It seems reasonable to suggest that the new control fits better to task 3 (positioning in a square). This would mean that the best form of the joystick is task-dependent. Regarding the interindividual differences the traditional joystick also has the advantage of allowing variation in posture.

7.4.3 *Speed versus position*

The experiment

In interviews with drivers of earth moving machines it appeared that most joysticks control the speed and not the position of the shovel or buckle. This means that a more forward position of the joystick in most cases results in a higher speed of the object. Since both systems (speed and position) are found in practice, it is interesting to find out which system is preferable. In the study mentioned above we also studied this issue. It is presumed (hypothesis) that the task where two directions need to be controlled simultaneously by speed (task 2) is more complex than all the other tasks. The reason for this presumption is that controlling the position is directly linked with the joystick position and the position of the shovel.

The results

Figures 7.7, 7.8 and 7.9 indicate that our presumption is false. Task 2 is not experienced as most difficult. In addition, the number of mistakes and time needed is not highest for task 2. Rather task 4 (positioning) is experienced as most difficult. This is found for both types of controls, the new one and the traditional one.

Of course this was a limited laboratory study and further research is needed to study whether the effects are also shown in working in a real earth moving machine.

We conclude that this simulation indicates that speed control is preferable over position control.

7.5 Conclusions

A machine that enables more accurate work and increases productivity is interesting for operators, management and manufacturers. Our explorative studies have generated a number of ideas that could be helpful in designing new controls. The experiments discussed in this chapter indicate that there are possibilities to improve the operator's performance by:

- applying the orthogonal principle in joysticks;
- using the principle of linking the functions in the joystick to the task performed by the machine;
- creating freedom for an operator to position the joystick in the hand;
- implementing speed control instead of position control.

This study is of explorative in nature, which means that further studies in real earth moving machines are still needed to underpin these indicative conclusions.

7.6 References

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