What Makes Loader Handling So Difficult?

A contribution dealing with the motor sensory and information processing problems of loader handling.

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INTRODUCTION

The most productive forest machines are feller bunchers for felling, harvesters for felling and processing forest trees and forwarders for transporting the logs out of the stands to the roads. Most of the mentioned machines have loaders to grip trees or logs and move them. Anybody who has had the opportunity to try to operate these machines knows that it is rather difficult to handle the loader successfully. Therefore, it is no wonder that much time is required for practise until operators reach the point of mastery. This paper tries to answer the question why this is the case. A comparison between the motor sensory events of the manual grasping process and the loader grasping process is made in the attempt to find a sufficient solution for this problem. An analysis of both processes also makes it possible to give some recommendations to the forest machine industry for the development of new systems for loader controlling for higher productivity.

MANUAL GRASPING PROCESS

Grasping an object is one of the most common tasks that human beings are able to perform. Even a newborn baby tightly closes its fingers around objects that have touched its palm. This happens in a reflexive manner and for this reason this process is called the grasping reflex [1]. With the increase of neuronal structures the reflex regresses, i.e., with increasing development the reflex diminishes. Meanwhile, the visual system is being developed and the baby thus learns to distinguish different objects from one another and to estimate distances by trying to reach them with its hands [6]. In this way, the baby combines the visual information with the proprioceptive information from the muscles and arm joints. The result of the grasping trial is given back to the baby in two different ways: by visual and by haptical feedback.

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Over the years the child becomes very skilled in this motor ensory process. It practices grasping tasks several times each day, gradually taking less concentration to do them successfully. Adults cope with grasping tasks so easily that they are no longer aware of the process. In some situations they do not even control their arm movements with their eyes. The sensory receptors in their fingers tell them whether they have been successful and also what is held in their hands. The result of this natural motor sensory development is an elementary internal model for grasping tasks. It contains precise information about the muscles that have to be activated at a special time and the typical proprioceptive and haptical feedback. The model is built by the motion pattern that is adapted to a special situation by the expended force and velocity [4]. Such elementary internal models also exist for other common skills such as walking, running and jumping. They are firmly embedded and regarded as extremely stable against stress [2]. Figure 1 tries to characterize the manual grasping process in a scheme from an information processing point of view.

LOADER SUPPORTED GRASPING

There are three main reasons for using loaders. The first is the possibility of enlarging the space of grasping by using a tool. This newly opened up space is called an instrumentally expanded grasping space [7]. The second reason for using loaders is to be able to cope with heavier and larger objects by using the power of machines. Finally, there is the possibility of moving objects that cannot be grasped by human beings due to the risk of exposure to radiation or heat.

Loaders used in the forestry sector are needed to support or replace man's power and to thus enable the handling of heavy trees and logs. The construction of forest machine loaders is very similar to the hand-arm system of human beings. We can distinguish, for example, two parts of the loader that are connected by a hinge just as the upper arm and the forearm are linked by the elbow joint. We can also find analogous shoulder and wrist joints. Last but not least, the grapple functions as our hands and fingers do. Since the anatomy and movement characteristics are similar, it is sometimes difficult to understand that human beings have problems handling the loader. For a better understanding of the causes of the difficulties, deeper analysis is called for.

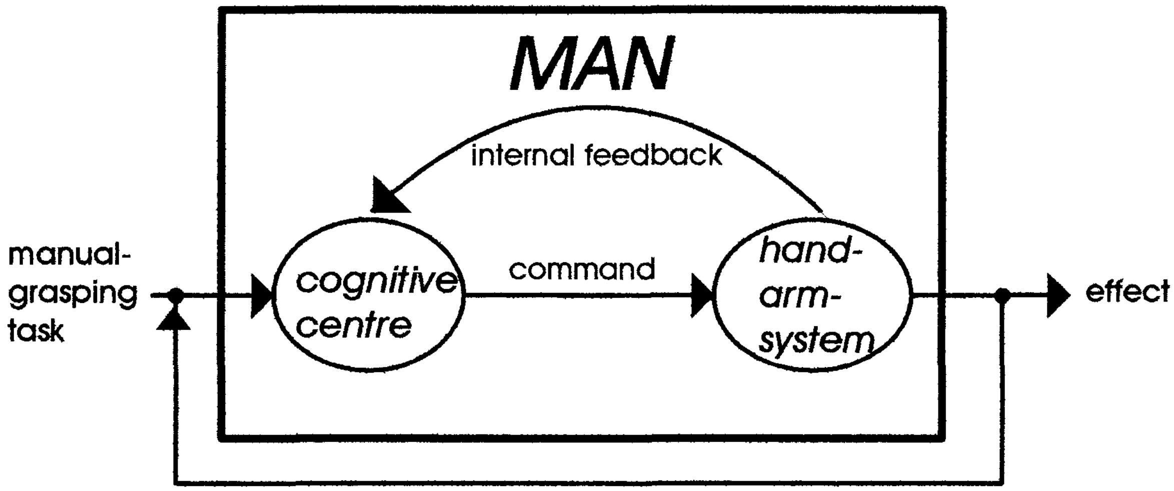

Figure 1. Scheme of the information flow of the elementary internal model of manual grasping. The internal feedback consists of proprioceptive, haptical and optical signals.

INFORMATION FLOW AT THE MAN-MACHINE-INTERFACE

The man-machine system can be distinguished into two subsystems; one is the operator and the other the machine. Both subsystems are equipped with sensors for perception, processors for cognition and effectors for executing the reactions. This is a prerequisite for bilateral dialogue, i.e., the so-called man-machine dialogue. This dialogue is required for the combination of both subsystems in a superordinate system. If we want to understand what happens during the loader grasping processes, we have to analyze this dialogue or information flow that connects both subsystems at the man-machine interface and compare it to the information flow of the manual grasping process.

What kind of information does the operator have while handling the loader of a feller buncher, harvester or forwarder? The primary information source is his visual supervision of loader motion. There is information regarding the loader position and the direction and speed of the movement [3]. Another kind of information is given to him by his hands and muscles. The sensors of the palms tell him about the state of the controls. The information he receives from his palms and proprioceptive sensors, however, cannot be used for obtaining a picture of what is happening with the loader in the same way as in the manual grasping process. There the internal information enabled a precise evaluation of the momentary position of the hand, its direction and the speed of movement, and the weight and shape of the grasped object. In the case of loader handling, the operator only gets directly relevant information from his visual sense. A lack of internal proprioceptive information exists about the weight of the grasped object, the force the machine needs to handle it and the position of the loader [5]. Experienced operators are able to derive some of this information indirectly by interpreting the changing sound of the machine or the tilting of the cabin during the lifting of heavy trees or logs. However, this kind of indirect information cannot replace the missing relevant information of the loader status. It can only be estimated by visual information.

LIKE TALKING IN A FOREIGN LANGUAGE

The operator of the forest machines uses the controls to cause a hand movement to become a loader movement. Thus, the hand movement of the machine operator results in a type of command. This command is received by the sensors in the machine and is passed on to the "brain of the machine." The command is processed there and is turned into a reaction by addressing the corresponding electronic or hydraulic circuits. The reactions are manifested in the movement of the loader, the effector organ of the machine. The movement is a visual signal for the machine operator, who will compare it to his plans for manoeuvering the loader. If there are deviations from the plans, the machine operator communicates this to the machine by changed hand movement on the controls resulting in new commands.

Problems which arise with the steering of the machine result from the necessary transmission of the steering plans into a language the machine can understand. This language comes from the steering movement of the hands at the controls. This transmission is necessary since the manual steering motion of the controls do not have an obvious relationship with respect to the desired direction of movement of the loader. In some circumstances the movement of the hand results in an opposite movement of the loader which almost implies mistakes in the steering. The fact that both the left and right hands are required to perform the movement patterns of the loader also shows how little in common the steering the machine operator has with the loader's pattern of movement.

This insight causes us to realize the unsatisfying fact that the steering motion of the machine's controls neither matches the manual grasping motion nor the motion of the loader. Despite the above-mentioned extensive similarities between the loader and the hand-arm system, we also learn that there is no possibility to use the known manual grasping strategies for steering the loader.

Since the machine is a lifeless object and therefore is forced to react in a quasi-reflexive manner, the total responsibility for transmitting the desired grasping task into a language that is understood by the machine falls on the machine operator. He is forced to keep the cause-and-effect relationship between the lever position and the resulting loader movement in mind. The following is a summary of the information balance required by the machine operator for the steering of a forwarder or harvester:

1) Design an imaginary course upon which the grapple or the processing head will be guided toward its goal.

2) Analyze the necessary movements of the loader's elements with respect to their direction of motion and speed relative both to the loader's surroundings and to one another.

3) Assign manual movements of the controls that produce the desired effects mentioned under 2).

4) Command the hand-arm system to execute movements which will bring about the supposedly correct position of the controls.

5) Control visually the loader movement and compare it with the planned course of motion using simultaneous the proprioceptive control of hand-arm movement.

Therefore a transformation from the actual steering task in the space-time framework of the *instrumentally expanded grasping space* to the differently designed movement task of the hand-arm system is inevitable. It can be compared to the task of having a dialogue in a foreign language. However, in contrast to the machine, the conversational partner may be able to interpret and correct possible grammatical or vocabulary errors. This necessary translation can be considered the most important cause for difficulties in the operation of a loader. Figure 2 attempts to illustrate this complicated process schematically.

DIFFERENT PRINCIPLE OF MOTION INITIATION

A further difference between the steering of the hand-arm system and the loaders of forest machines exists. In order to trigger movement of the loader, the machine operator must command his hand-arm system to move. When the triggered loader movement has reached an appropriate speed, a second command to the hand-arm system is necessary which stops momentary movement of the lever. The paradox situation arises when the loader moves at a constant speed, but the machine operator's hand rests on the lever in the extended position. Two commands are necessary for the hand-arm movement in order to stop the loader in the target area. The first is to move the lever back to the neutral position and the second is to terminate this movement when the position is reached.

The commands for a manual grasping task only require half the effort of the four necessary hand-arm system movements for a target-oriented loader movement. For the manual reconciliation between hand position and target position, it is sufficient to decide to move the arm to execute an action and then to stop it when it arrives at its target. In contrast, the origin and speed of the manual grasping movement are controlled, although the area which was crossed is indirectly a product of speed and time. In the manual movement, however, the span of area which is covered is directly controlled and only requires half as many decisions.

The following is a summary of reasons for the complexity of the loader steering tasks of harvesters, feller bunchers and forwarders:

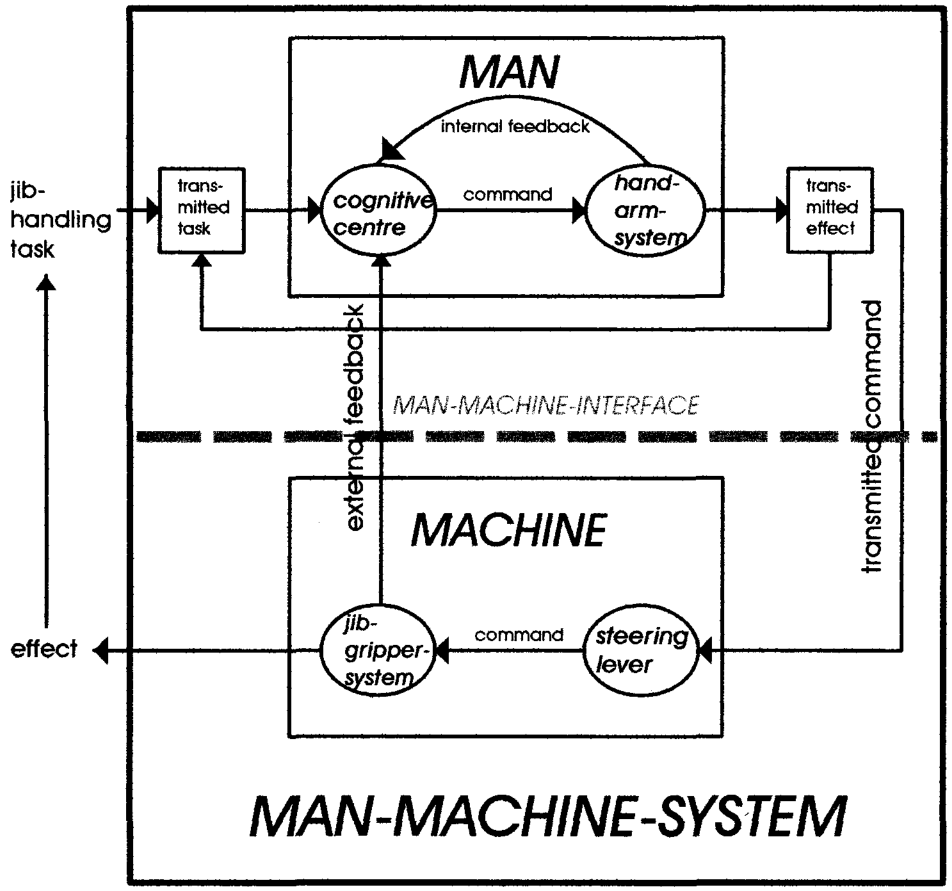

Figure 2. Scheme of the information flow of a man-machine system. The external feedback only consists of optical signals, unlike the internal feedback.

1) There is a proprioceptive information deficit due to lack of stimulation as would be the case with the manual grasping task which is used by humans for control.

2) The transformation of the desired loader movements into the physically different orientation of the controls is required in order to successfully steer a loader.

3) The steering system of the machines uses a different principle than that of humans. An arm movement of a human is a change in distance, but when the arm moves a lever in a logging machine the speed controls the distance covered indirectly by the time required for the loader movement.

These three reasons result in complicating the sensomotor steering process in contrast to the manual grasping process. This complication is due to an increased stress to the information balance of the machine operator while working with a loader.

SOLUTIONS

The problem of an information deficit with respect to the stress on the loader can be relieved by so-called "active steering elements" [2]. Active steering elements differ from regular ones in that the necessary moving force is proportional to the strength of the loader. The effort required by the machine is directly felt by the machine operator via the controls. It is suspected that the operator will attempt to work in the convenient ergonomic range. Therefore, he will try to keep the forces at the controls as low as possible. Unfavourable and strenuous movement sequences of the machines would also be avoided as the result of the proportionality between the forces on the controls and the hydraulic effort on the loader. It is therefore suspected that the wear and tear on the machine will be minimized, and necessary repairs and the servicing of the vehicles will become less due to the high percentage of productive time and reduced servicing and repair costs.

The way in which the steering parts function should be redesigned such that the direction in which the loader moves is also the direction in which one steers. Clark [5] conducted a study in which comparable steering parts (coordinated motion control) were integrated into a feller buncher. His study showed that productivity increased due to the fact that the operators learned faster and operational time was reduced. Since it is only necessary to point the lever in the direction of the tree to be logged with the help of this steering system, the steering processes have become more similar to manual grasping. Therefore, some portions of the elementary model for the use of manual grasping tasks can be used. The increased security for the machine has the result of reducing the number of accidents and also increasing the productivity of the machine.

Since equipment such as feller bunchers or harvesters (apart from windfall areas) generally work with their harvesting heads quite parallel to the ground, the harvesting head movement is primarily two dimensional. Therefore, the controls which Clark developed are very appropriate for these machines. The differences in the height of the working area which may arise can, for example, be balanced by using a rocker switch on the upper end of the lever which is operated by the thumb.

The loader of the forwarder, however, has a range of motion which is as much vertical as horizontal. Since the log cradle is bordered by stakes, the grapple must lift the wood over them. Since vertical movement plays such an important role, steering with controls which are typically only to be shifted in one plane is suboptimal. In contrast, therefore, it seems that it would be appropriate to substitute data gloves for the controls.

The data glove is worn on the hand of the machine operator. It gives information to a computer regarding the position, direction of motion and speed of the hand in the natural grasping space. The computer evaluates the information, calculates the analogue position of the grasping equipment in the instrumentally expanded grasping range, and converts these data into steering impulses for the grasping loader. Through this it is possible to anticipate the desired loader movement with the hand-arm system of the machine operator. That is, the loader movement in the instrumentally expanded grasping space is an exact representation of the guiding and positioning of the hand in the cabin.

The benefits of this steering technology are obvious:

1) The proprioceptive information of the hand-arm system approximates the stress situation of the machine.[1]

2) Since the position of the grapple in the instrumentally expanded space corresponds exactly to the hand positioning in the cabin, models which have been learned in early childhood using a manual grasping function can be used. This promises maximal security while having a minimal learning time.

3) The machine's functioning principle is similar to that of a human's, i.e., by moving the hand, a corresponding movement of the grapple occurs. The speed of motion of the loader depends upon the speed of motion of the hand-arm system. Therefore, the machine operator has reduced stress for processing information.

4) Since existing machines require operation of the controls with both the left and right hands, it is impossible to steer the machine in the direction of the motion simultaneously. This is possible in most machines only when the left lever is switched into drive. While using the data gloves which are analogous to the manual grasping motion of one hand, the other is free to drive the machine in the direction of motion even during a loading procedure. It is therefore theoretically possible that an experienced forwarder driver would not have to stop in order to load. He would be able to grasp objects while he is rolling by, just as humans can pick up something in passing. It is suspected that the productivity of the machine would thus be increased.

It is necessary to examine objections that the active arm of the machine operator will fatigue quickly. However, since loading with a forwarder also requires a large amount of manoeuvering, fatigue of

[1] *Since the machine operator in the cabin performs the grasping motion, but in doing so does not lift any load, the stress of the loader is relatively higher than the information given by the body's hand-arm system.*

quires a large amount of manoeuvering, fatigue of the hand-arm system is more unlikely than if the loading is primarily static, i.e., holding tasks. Moreover, working with a forwarder loader is characterized through many short breaks while driving.

CONCLUSION

If one considers the cognitive processes necessary for working on a loader, it becomes obvious that the difficulties involved in the task are primarily cause-and-effect relationships between the position of the controls and the resulting loader movement. Since the steering motion of the controls only seldom resemble that of the direction and motion of the loader, the machine operator not only has to choose the best way for the grasping equipment to get to the object, but must send commands to his hand-arm system which do not have an obvious relationship to the desired loader movement. This transformation of loader grasping from the movement of the hand-arm system is a superfluous mental stress for the machine operator. The use of modern technology offers the possibility to do without this transformational process.

Equipping feller bunchers and harvesters with a one-lever steering mechanism seems to be promising if the cooperation with the hydraulic system enables parallel movements to be performed.

The substitution of a data glove for the conventional steering in forwarders which require vertical as well as horizontal motion seems to be appropriate.

In this way it becomes possible to reduce the information-processing effort of the machine operator considerably, thereby enabling the work to be designed better ergonomically. That is, the operator should be less fatigued and be able to work faster while at the same time enjoying more security and productivity.

SUMMARY

It is difficult for the beginner to work with forest harvesting machinery. This contribution attempts to analyze the necessary information and decision processes of the human brain used in the guiding of a loader. These processes are compared with the manual grasping processes which, in contrast to loader grasping tasks, are performed virtually subconsciously having a high degree of precision and security. This comparison makes clear that on the one hand there is an information deficit, and on the other hand the necessity of the operation of the controls by the hands to be transformed to the loader's grasping task stresses the information processing center. In order to reduce the stress on the cognitive processes, innovative technological changes in the steering parts should be considered.

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