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Using VR for Efficient Training of Forestry Machine Operators

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This paper presents the results of two years of field trials of a 3D graphical simulator of forestry machines called processing harvesters, for the training of students in wood harvesting. It is a comparative study of the results between the traditional training where students go directly from the classroom to real machine operation in the woods and a new VR augmented training. The results indicate that the addition of 25 hours of hands-on VR training increases by 23% the volume of wood harvested and reduces by 26% the repair and maintenance costs during the first month of operation in forest. The use of VR also allowed precise recording and monitoring of the evolution of trainees' performance during their training sessions, showing learning curves that decrease with time for all the defined performance criteria (execution time, error rate and precision). The field trials were held in a training center with four classes of eleven students in wood harvesting and are the first known experiments concerning the use of virtual reality technologies for the training of students in forestry.

Keywords: virtual reality; training; forestry; processing harvester; human performance.

Introduction

Since the mechanization of forestry operations in the 1960's, all operators of forestry machines are learning their job mainly by doing 'hands-on' training on the real machine in the forest. In the same time, forestry machines became more complex, evolving from single task machines such as feller bunchers, skidders and delimbers to multitask machines such as processing harvesters, which can fell, delimb and cut to length a tree in about 30 s (see Figure 1).

All that complexity, however, comes at a cost and that cost is learning time. Currently, it takes from four to six months of operations for a new operator of processing harvester to reach a profitable level of productivity (around 80 stems per hour) and up to two years before reaching maximum efficiency, i.e. $\geq$100 stems per hour (Richardson and Makkonen, 1994).

Given the high operation cost of these machines, there is an obvious need for a reduction of the hands-on learning time on the real machine. In the same way as flight simulators are used in the aerospace industry to train pilots, we believe that virtual reality

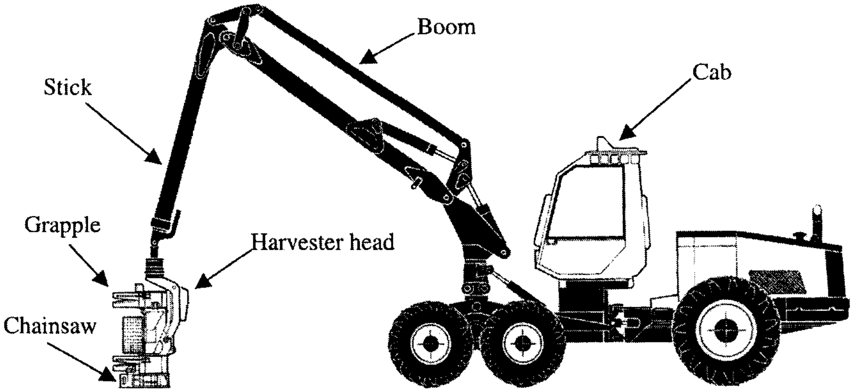

Figure 1. Typical processing harvester.

[VR] can be used to train forestry machine operators. Moreover, we think it can do that in a cost effective way.

This paper presents the results of two years of field trials where apprentice operators learned how to operate a processing harvester on simulator before going into the real machine in the forest. We show the evolution of their performance on a simulator and compare their performance in the woods with that of previous classes of apprentices who had no prior training on simulator before going into the woods. The objective is to test and measure the effectiveness of virtual reality as a training tool for forestry machine operators.

Previous work

Since the advent of the processing harvesters during the 1990's, the longer learning time required to operate these complex machines called for the development of specialized training courses for future operators of these machines.

Currently, the Department of Education of Quebec appointed five professional training centers to give a course for operators of wood harvesting and processing machines. This training course lasts six months during which the students become familiar with the basic notions needed to operate, maintain and repair cut-to-length forestry machines such as processing harvesters. The first four months are passed in school, where apprentice operators learn basic skills in security, mechanics, hydraulics, electricity and wood harvesting and processing. The last two months are passed in forest, where the students learn how to operate, repair and maintain machines in real working conditions. Each student thus operates a processing harvester during the equivalent of four full-time weeks (40 h/week), alternating day and night shifts.

Experiment

The main objective of this experiment is to assess the efficiency of VR as a training tool to improve the performance, security and satisfaction of new operators of processing harvesters. We also wanted to verify that the number and duration of the training sessions are appropriate for knowledge transfer.

Method

We compared the performance of operation in the forest of four classes of operators who had VR training sessions prior to their operation in forest (classes of summer and fall 1997 and 1998) to the four previous classes who had no prior VR training before operating in the woods (classes of summer and fall 1995 and 1996).

It should be noted that the trainers and the forestry machines used here were the same in all the classes, since all the results come from the same training center.

Subjects

Four classes of 11 students each have been trained on the simulator just before being sent into the forest (i.e. at the end of the four month period in the classroom). Each student had 25 one-hour sessions of training on the simulator before going on the real machine in the forest. Their results in forest have been compared with those of the four previous classes, also with 11 students each, who had only the regular training, without simulator sessions. All the students were men aged between 17 and 49 y old, with no prior experience concerning the operation of a processing harvester. They were also selected with the same criteria and all had a similar level of education (between three and five years of high school).

System

The VR system used for training consists of a desktop simulator made of a chair equipped with two standard two-axis joysticks located at the end of the armrests (see Figure 2). The chair replicates the control interface used to operate the manipulator arm and the processing head of the harvester. This control interface is linked to a graphical workstation via a microcontroller-based hardware interface that reads the control signals coming from the joysticks. Finally, the workstation runs the simulation program and displays the image on a color monitor with a 50 cm (diagonal) viewable area and a resolution of 1280×1024 pixels.

Each joystick is equipped with six buttons, one for each finger and two for the thumb. Those buttons control the different functions of the felling head (e.g., opening/closing the grapple, cutting, delimbing, etc.).

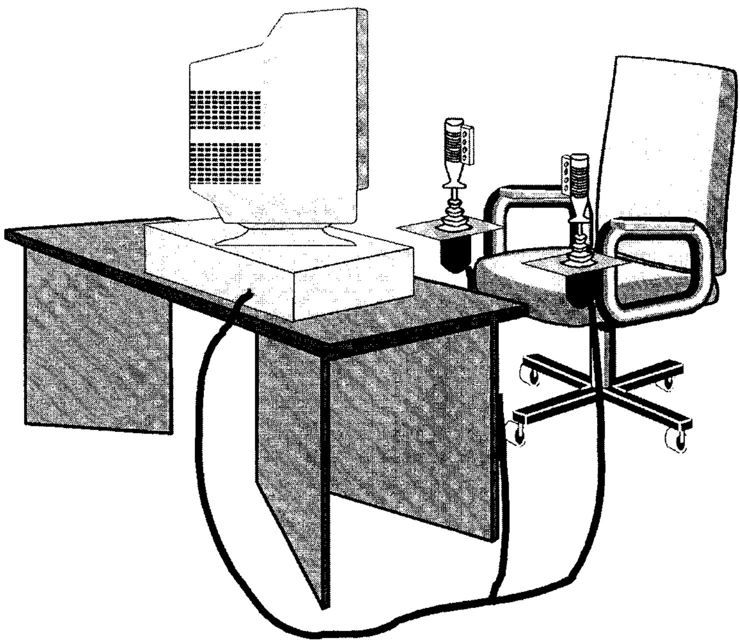

Figure 2. Illustration of the simulator.

There is also an audio interface that reproduces the different sounds used during the simulation (countdowns, collision sounds, cutting sounds, etc.).

Many cues are used in order to improve the depth perception of the operators (perspective projection, shadows, textures, grid on the ground, etc.). Also the system runs at an update rate of 20 frames/s.

The VR system has been designed from the start in collaboration with trainers in the field, with frequent meetings at different stages of development of the VR system, in order to get feedback from them. In fact, the first design step has been to visit the operators' work site and carry out a task analysis of the processing harvester's operators (Lapointe et al., 1995). The objective here was to design a training tool that was useful and cost effective.

Tasks

Training sessions were separated into six modules of growing complexity, ranging from simple grabbing tasks to complete planning and harvesting of trees. The division of training into six modules is based on the pedagogical principles of part-task training and adaptive training (Wickens, 1992), where a task is divided into its various subtasks, which are then learned individually, before being gradually combined together. The Table 1

Table 1. Training modules, tasks and number of sessions

Module	Tasks	Number of sessions
1	Grabbing	6
2	Felling	3
3	Functions buttons	3
4	Processing	3
5	Piling	3
6	Planning	7
Total		25

shows the different modules used during the training along with the tasks and the number of one-hour sessions associated with each of them. This is the final compromise that we found after trying different combinations of duration and number of sessions for each module.

Module 1 – Grabbing: The goal of this first module is to grab a tree at a given height and orientation with the grapple of the harvester head. This task requires the manipulation of the four degree-of-freedom (dof) manipulator arm of the harvester (swing, boom, stick and head), through the use of the two joysticks, each dof being associated with one of the joysticks' axis.

Figure 3 shows a scene displayed during this module, where the operator has to displace correctly the harvester head from its initial pose to its final (target) pose. To achieve that, the operator has to position (with swing, boom and stick movements) and orient the head correctly (by rotating it in the horizontal plane). To grab the tree at the correct height, the operator has to match the position of the chainsaw so that it is at the same height as the height target (the pink band in Figure 4). In a similar way, the operator has to orient the grapple, so that it faces the orientation target (the blue band in Figure 5). Finally, once the grapple of the head is in position of grabbing the tree in the required manner (i.e. at the required height and orientation), the operator closes the grapple by pushing the corresponding button on the joystick. The Figures 4 and 5 illustrate in a schematic way the initial and final (target) poses of the manipulator arm during the execution of the task.

Module 2 – Felling: In this module, the trainee must grab the tree as in the module 1 and then activate the cutting by pushing the cut button on the joystick. Once again, it has to orient the tree correctly, in order to fell the tree in the correct direction (indicated by a red band on the ground).

Module 3 – Functions buttons: Here, the trainee has to learn correctly the correspondence between each of the 12 buttons of the joysticks and the functions of the harvester head. To achieve that, we display in a random order the different functions of the head and the trainee must push the corresponding joystick button.

Module 4 – Processing: In this module, the trainee must grab and fell the tree, as in the first two modules, but also delimb and cut it to length by activating in sequence the feed rollers and the cutting saw until all the tree is cut in logs of the desired length.

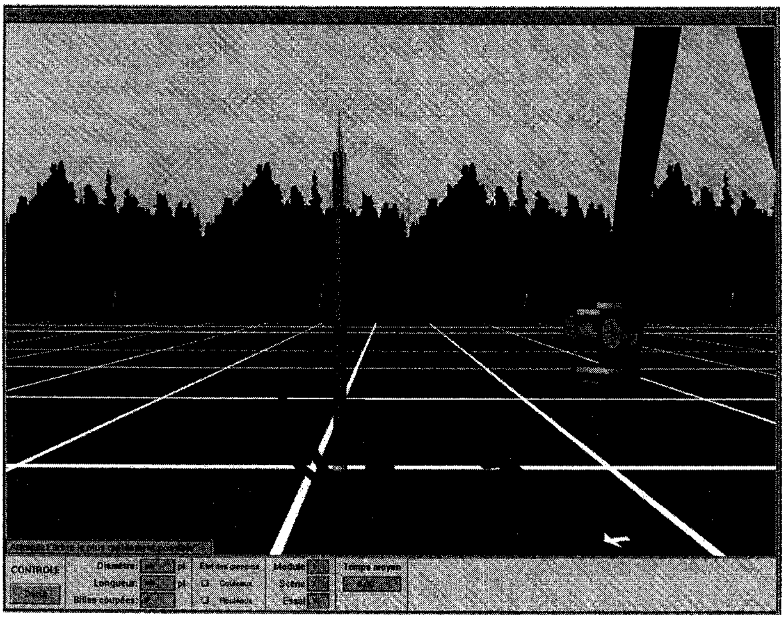

Figure 3. A scene from the first training module.

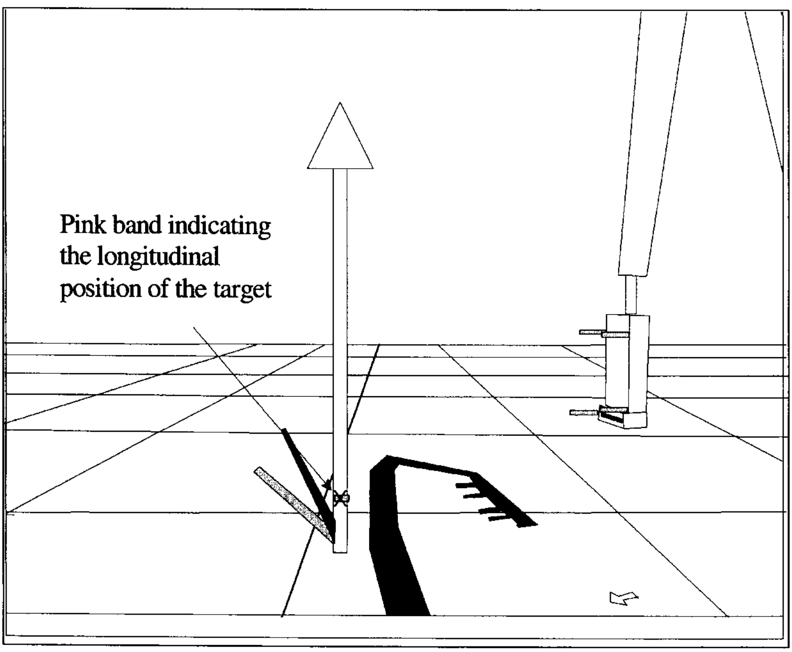

Figure 4. Initial pose of the manipulator.

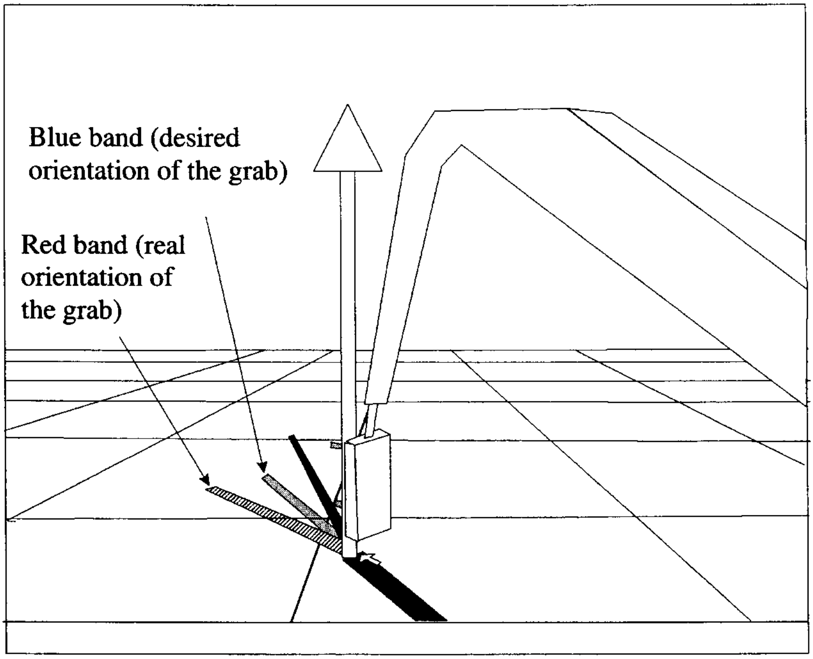

Figure 5. Final pose of the manipulator.

Module 5 – Piling: The goal here is to learn how to pile correctly the logs that are produced after felling and processing a tree. They have to be aligned and grouped in a rectangular pile whose length is about equal to that of the logs.

Module 6 – Planning: This final module aims to help trainees to plan their operations when there is more than one tree to cut. The planning here is important since cutting the trees in a wrong sequence can block or make more difficult the subsequent tasks of processing and piling them.

Experimental design and procedure

We analyzed the students' performance on the simulator and compared their performance in the forest with that of the trainees who had no prior training on the simulator.

Performance on simulator

In order to measure the evolution of the students' performance on the simulator, we used the grabbing task (module 1) as a performance indicator. This task was chosen because it is the basic one and is the only one repeated in each training module (except for module 3), from the beginning to the end of the VR training. The four criteria used to measure the performance for the grabbing task are the execution time, the error rate, the longitudinal gap, and the orientation gap.

Those criteria have been found to be the best indicator of performance for the task of grabbing a tree with a harvester head (Lapointe, 1999).

The execution time is the total time elapsed between the end of an audio countdown preceding each trial and the grabbing of the stem (which is indicated by the operator when it pushes the button that closes the grapple of the harvester head). Only the execution times of successful grabs are taken into account in the results.

The error rate is the ratio between the number of failed grabs and the total number of trials for the grabbing task. As indicated in Figure 6, a grab is considered as a failure when the grapple does not completely encircle a stem when the operator pushes the 'close' button.

The longitudinal gap is the vertical distance between the chainsaw of the harvester head and the longitudinal grabbing position indicated for the grabbing (Figures 4 and 7). It is a measure of the precision of positioning along the longitudinal axis of the stem, hence the name of this criterion.

The orientation gap is the angular distance between the real orientation of the grapple when the operator closes the grapple and the desired orientation that should allow felling the tree in direction of the blue band on the ground (Figure 5). This criterion is important because the operator must learn to position the harvester head correctly in order to orient

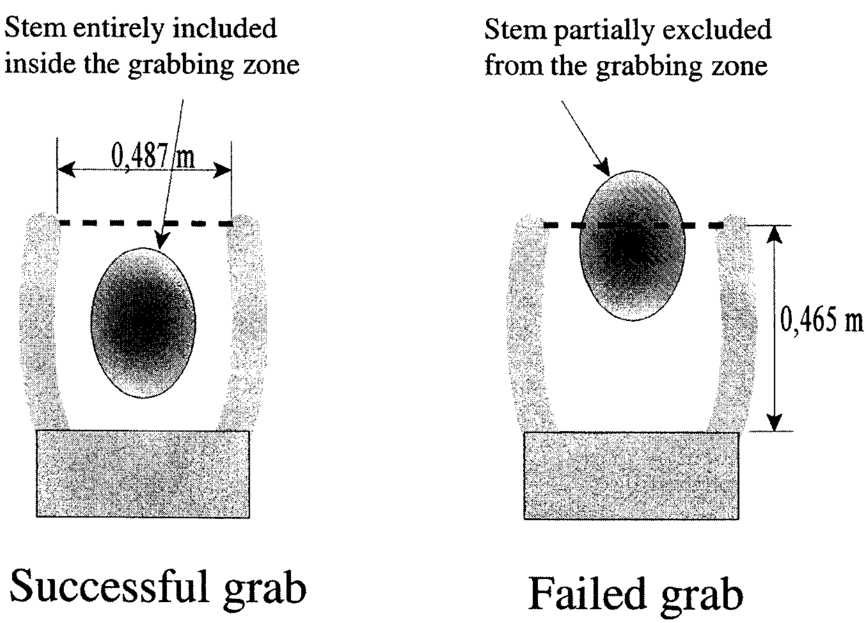

Figure 6. Error criteria for the grabbing task.

the fall of the tree during its felling. For this reason, a red band appears on the ground when a grab is successful, to provide a visual feedback that gives the real orientation at the moment of the grab, comparatively to the desired orientation (Figures 5 and 7).

We asked all trainees to execute a series of grabbing tasks after 13, 181, 349, 517, 685, 917, 1149 and 2452 trials of this task since the beginning of their VR training sessions, for a total of eight levels of experience. Two distances of the trees were used and six replicas were realized, for a total of 12 trials per student at each level of experience. The trials were realized at the beginning of training sessions and were preceded by one practice.

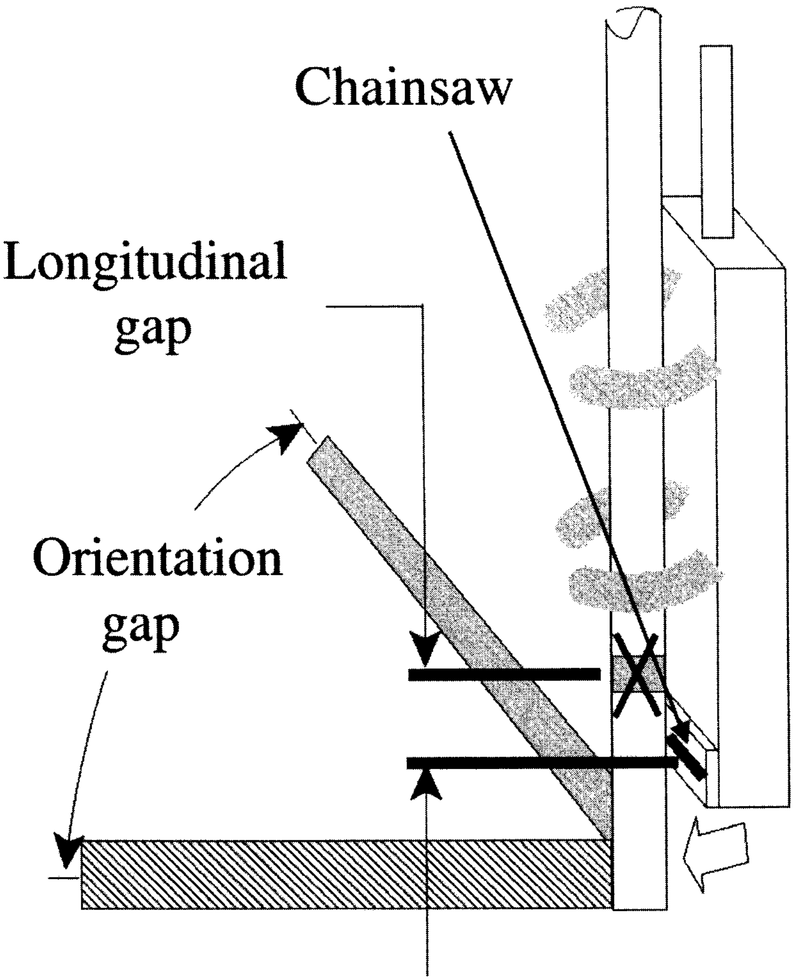

Figure 7. Longitudinal and orientation gaps for the grabbing task.

Performance in the forest

To measure performance in the forest, the only data available (apart from the trainers' comments) were the total volume of wood harvested and the repair and maintenance costs.

Students had 25 one-hour training sessions on the simulator during the three weeks preceding their operations in the forest. There was a maximum of two training sessions per day for each student, one in the morning and the other in the afternoon.

They also received instructions and a demo at the beginning of each module, to inform them of the goals and of the new tasks.

Results

Results on simulator

The Figures 8 to 11 show the evolution of the students' performance for the grabbing task, during all their training, for each of the four performance criteria defined previously for this task. Many configurations of number and duration of training sessions have been tried for the first three classes with VR training. We report here the results of the fourth class, since their training sessions follow exactly the order defined in Table 1.

Those figures illustrate that the improvement was gradual and that the learning time was appropriate since the performance tends to an asymptote at the end of the training sessions.

We present the performance in function of the number of trials instead of the number of training sessions, because the number of trials varies from one session to the other, in order to obtain one-hour training sessions (hence the strange numbers used for the eight levels of experience).

This representation is also more suitable to show that the execution time follows the power law of practice (Snoddy, 1926; Card et al. 1983). This law predicts that the execution time T_n to perform a task at the nth trial follows a power law:

$$T_n = T_1 n^{-\alpha}$$

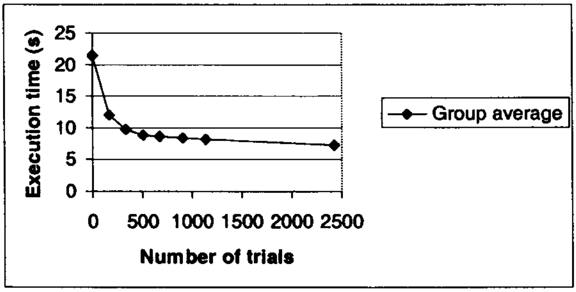

Figure 8. Execution time vs. practice.

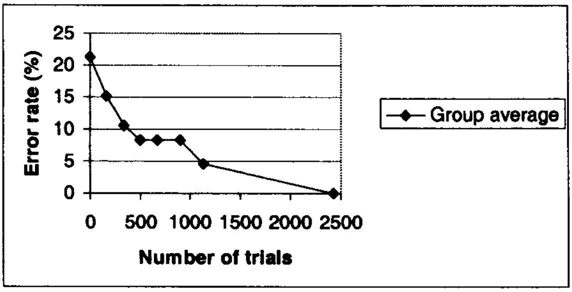

Figure 9. Error rate vs. practice.

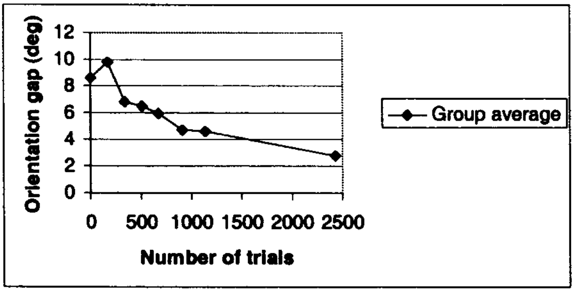

Figure 10. Orientation gap vs. practice.

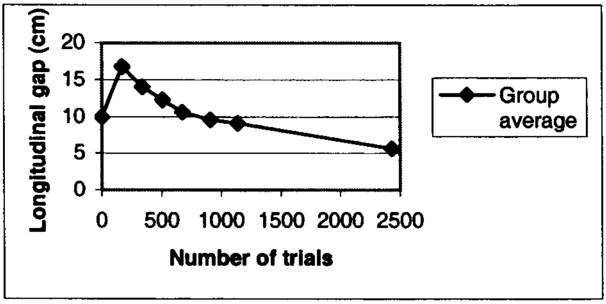

Figure 11. Longitudinal gap vs. practice.

where T_1 is the execution time on the first trial and α is the coefficient of learning. In our case, $T_1 = 37$ s, and $\alpha = 0.21$, with a $R^2 = 0.99$.

Results in forest

Table 2 shows the total volume of wood harvested each year by the two classes of students trained annually in the center. Since this volume is measured only once a year, it was

Table 2. Annual harvest results from the classes

	Volume of wood harvested (m^3)	
	Without VR training	With VR training
	9901 (summer and fall 1995)	12677 (summer and fall 1997)
	12272 (summer and fall 1996)	14500 (summer and fall 1998)
Average	11087	13589

impossible to report results for each individual class, so we present them for each group of two classes.

A one-way analysis of variance of these results reveals that the classes who had VR training improved significantly their productivity ($F_{1,2} = 2.80$; $p = 0.236$), with an average increase of 23% of the volume of harvested wood, compared to the classes without VR training.

One should notice that the volume of wood harvested not only depends on the training, but also on other factors, such as the type of forest (maturity, density and repartition of the essences), the topology and the type of terrain (flat, sloping, rocky, boggy, etc.), the desired log length (2.4 m, 3.6 m, 4.8 m, 7.2 m or tree length), the trainees' skills and the meteorological conditions.

Those factors, combined to the small amount of data available (there are only two classes each year) explain the small confidence factor obtained, due to the strong variations observed between different years. The results illustrate, however, an increase of productivity that was corroborated by the five trainers of the center.

Subjective satisfaction

Observations by the trainers indicate that the biggest increase in productivity happens during the first days of production in the forest. After that, students who had VR training improve their performance at the same rate as those who only had the conventional training, while maintaining a steady advance. The trainers evaluate that the productivity at the end of the course is 10% higher, i.e. 55 stems per hour for the VR classes, as compared to 50 stems per hour for the traditional classes.

All the trainees liked their experience on the simulator and the vast majority declared that VR training is a valuable tool for training future operators. All of them were eager to try the simulator during the first training sessions on it.

Discussion

The field trials described in this paper have shown that VR is now mature enough to be used efficiently in the classroom of forestry machine operators. The field performance of trainees without VR training has been compared to that of trainees who received 25 hours of hands-on training on a forestry machine simulator. The results show that the use of VR training increases significantly (23%) the volume of wood harvested.

To the increase in production, one should add other savings from the reduced repair costs, a non-negligible part of operation costs. A comparison of repair and maintenance costs between classes with and without VR training revealed a decrease of 26% of the costs for the former group. Those savings are mainly due to a reduction of frequent breaks to the chainsaws, blades, as well as many hydraulic components such as hoses. Finally, there was also less hydraulic oil usage, since the reduction of breaks also reduced the volume of oil spillage.

The real cost reduction that results from bad manipulations is far superior to 26% although it is hard to estimate since a good part of repair and maintenance costs comes from the periodic maintenance and normal wear of the pieces.

The results from this study allowed the startup of a new company dedicated to the production of training simulators based on VR technologies. Since then, at least six training centers have been equipped with such simulators.

Concerning the duration of training sessions, the results indicate that 25 one-hour sessions optimize knowledge transfer for the training modules developed so far. This conclusion not only comes from the fact that performance results are leveling, but also from the drop of the trainees' interest and engagement after this time. Moreover, training sessions of one hour maximum seems acceptable, since a lack of concentration and eye dryness and redness were observed with training sessions that lasted longer.

This study is a major milestone for VR-based training, since the development of the system described here was done in a context where security, i.e. risks related to human life, were not a major concern, as opposed to other domains such as aeronautics. The adoption of VR in training only depends on its efficiency and return on investment. This is the best guarantee of success for VR in education.

Acknowledgements

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