HARVESTING TECHNICAL NOTE

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Human Factors of Teleoperation in Harvesting

Summary

Using teleoperation means that the operator can be removed from the cab of a purpose-built feller buncher or excavator-based felling machine operating on steep terrain and control the machine from a safe location. In the future, forest harvesting machines will be unmanned and remotely operated. The move to teleoperation has already occurred in the mining industry and in military operations. This transition occurred because of increases in safety and productivity that teleoperated systems provided. The forest industry can learn from the experiences of the mining industry and the military. Teleoperation is difficult and demanding and requires specialist skills which have been the subject of previous human factors studies, particularly in military settings. The human operator of teleoperation systems is critical to the system's success. The operator must learn new skills and operate with limited sensory input. This report summarises the principal human factors issues which will have to be addressed in the development of a teleoperated forest harvesting machine.

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Introduction

The method for felling trees on steep terrain has changed little since Andreas Stihl patented the first portable gasoline-powered chainsaw in 1929. This was the first successful patent for a hand-held chainsaw designed for tree felling. Previously trees were felled by skilled fallers wielding axes, which was a dangerous and demanding job. Today, professional tree fallers on steep terrain use a chainsaw but are still exposed to numerous hazards and have limited control of the fall of the tree. On less steep terrain trees can be felled by purpose-built feller bunchers or excavator-based felling machines, but on steeper terrain the risk to the machine operator in the cab increases.

Future Forests' Primary Growth Partnership Programme is focusing on reducing the cost and improving the safety of steep terrain harvesting primarily through increased mechanisation. In very steep environments, it is desirable to have the operator situated in a safe location away from the machine and the falling tree, and to reduce the physical and mental workload on the operator. This requires a remote control system for the operator of the machine, and the use of video cameras or other sensors to enable better vision of the terrain and the task. Other advantages with such a solution are potentially higher productivity and machine utilisation and lower ground disturbance, fuel consumption and emissions due to the lower weight of the machine.

In the development of forest machine automation it is unlikely that in the near future machine functions will be fully autonomous, because of the complexities of the tasks and the dynamic forest environment. Automation systems incorporated in forest machines will likely have some level of human control [1]. Therefore to advance mechanised harvesting on steep terrain remote control or teleoperation is required.

Figure 1: Teleoperation station for a remote-controlled underground mine loader. Video monitors display camera views from the machine and maps showing the location and orientation of the machine in the mine (www.mining-technology.com/features/feature95923).

Teleoperation requires remote perception and remote manipulation. Both of these skills are difficult because the performance of operators is limited by

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their motor skills and their ability to maintain situational awareness. Also it is difficult for operators to build mental models of remote environments and estimate distances and detect obstacles [2] [3].

The operator is decoupled from the machine's environment so cannot hear the engine and feel the movement of the machine across the ground. In addition, the operator relies on video cameras for vision. If the cameras are positioned in places that do not match normal eye height, operators are confronted by a viewpoint which does not match their experience.

Vision is the predominant sense that the operator relies on to control the machine. There are numerous reports of the effects of poor vision systems on the performance of the operator of remote machines. Bomb disposal robot operators report that it is very difficult to perform tasks with a monochrome and monoscopic video system [4]. Of particular relevance to forest operations is the difficulty posed by bright sunshine and shadow conditions. Not only does poor design of the video system reduce operator effectiveness, but system failures also degrade effectiveness. The video feed from the device and control feed to the device rely on uninterrupted communications. Unmanned ground vehicle (UGV) systems have had relatively few communications failures in real life operations [5].

Harvesting Tasks

The operator of a harvesting machine must perform the following tasks by remote control:

- drive across the hillside to the stand of trees;
- position the harvester at the base of the first tree to be felled;
- safely fell the tree and place it in the desired position on the hillside. The harvester must be in a position where it will not be hit by the falling tree or where the machine will not topple over; and
- move to the next tree.

In practice, there are always exceptional circumstances that require a high level of operational skill. These include the harvester getting caught on stumps or in holes in the ground or being constrained by the close proximity of other standing trees. To perform these tasks, the operator must be able to see, and vision is the primary sense used to teleoperate a machine (Figure 1).

Factors Affecting Vision Systems

The factors that affect the operator's ability to perform tasks in a teleoperation system include:

- limited field of view;
- orientation and attitude of the machine;
- camera viewpoint;
- depth perception;
- degraded video image; and
- time delay [2].

Limited field of view reduces the operators' situational awareness because they only have the view provided by a camera. This can result in a "keyhole" view of the world [6]. A normal camera lens which provides a view similar to our vision is called a "unity vision display". In the teleoperation of vehicles that move rapidly over the terrain (e.g. driving a car), a wider field of view is created by using wide angle camera lenses. Motion sickness can occur with distortion of the moving scene. A system which allowed the selection of wide angle view for situational awareness and unity vision for control could be the best solution for teleoperation of a vehicle [7].

Orientation refers to the operator knowing where the machine is physically located and in what direction the machine is moving. This can be achieved using GPS tracking and placing the machine on an electronic map.

Two general types of electronic map are used. 'Track-up' maps always depict the machine at the centre of the map pointing towards the top of the display. The terrain appears to move around the machine (Figure 2).

Figure 2: Track-up display – map moves and machine remains in centre (from www.lxavionics.co.uk).

'North-up' maps show the machine moving as if it were on a conventional map. The terrain does not move and the icon denoting the machine moves and changes direction (Figure 3).

Figure 3: North-up display – map is fixed and machine moves (from www.lxavionics.co.uk).

Both track-up and north-up displays should be made available to operators according to human factors design guidelines from the US Department of Transportation [8].

Attitude of a machine is its pitch (nose up/nose down) and roll (side-to-side movement in the horizontal axis). Operators find it very hard to assess the pitch and roll of their machines because there are few visual references, and because they are not physically on the machine to 'feel' pitch and roll. In one study the teleoperator of a mining loader was observed using a temporary marker on the video screen as a known horizontal reference to determine the pitch of the loader. In another study a 'gravity referenced view' of the terrain was used to provide the operator with attitude information which could be particularly useful for a forest machine on steep terrain [9].

The operator will be viewing the immediate environment of the machine from the viewpoint of a video camera. For example on a harvester, a camera can be placed on the body of the machine providing an 'exocentric' view of the harvesting head. Alternatively, the camera can be placed on the boom providing an 'egocentric' view of the harvesting head. Either (or both) views may be useful to the harvester operator, but the use of both simultaneously may cause difficulty in understanding views from two different viewpoints [10].

Depth of field is difficult to determine from a video image because the 3D environment is being compressed into a 2D display. Considerable research has investigated the usefulness of stereo video camera displays to provide depth perception and increase operator performance. The distance between the video cameras was found to influence distance estimation performance, with the best results achieved when cameras were 2 to 3 cm apart rather than the normal distance between human eyes (interocular distance) of 6 cm [11].

Other studies have used 'hyperstereo' displays where the interocular distance is increased to accentuate depth cues [12]. Improved detection of depressions in the terrain was reported but such displays were difficult to use because objects appear smaller and closer, which provided conflicting clues to the brain. The use of stereo displays needs to be trialled with forest harvesting tasks to determine if they provide a productivity and perceptual advantage. In the forest environment, trees may provide a constant visual clue allowing the use of monocular cameras.

The video image transmitted from the machine to the operator can be degraded by distance, obstacles or electronic interference. The frame rate (images per second) can be reduced to 10 Hz before operator performance will be degraded [13]. For forestry operations we should design systems with sufficient bandwidth to ensure that a video signal of at least 10 Hz is delivered to the operator.

All radio control systems suffer from some time delay or lag because the input action of the operator has to be transmitted to the machine before an output response will be performed by the machine. The results of numerous studies of teleoperation performance under various time delays were summarised by Chen *et al.* [2]. Their results indicated that the effect of time delay is very task-specific, but a delay of as little as 170 milliseconds can affect car driving performance. Most forest harvesting tasks will not be as fast moving as driving, but the lower limit of time delay will have to be determined for effective operation.

Potential Display and Control Systems

In the previous section it was shown that there are many potential human factors which can limit the efficiency of the teleoperation of a remote machine. The most simple teleoperation control system provides only visual feedback to the operator. More sophisticated displays using combinations of visual, auditory and haptic feedback (touch or tactile feedback) are being trialled and used in modern teleoperation systems. Haptic systems have been used in micro-surgery where the surgeon needs to 'feel' what is happening, such as in tying knots or manipulating sutures [14].

Audio signals give machine operators greater awareness of their surroundings and have been trialled [15]. Audio signals in conjunction with visual feedback give the operator more 'intuitive robotic control' [2] meaning that it feels easier to control the machine. The use of visual, audio and haptic feedback to the operator is known as 'multimodal' feedback and has been used to improve operator performance by providing more information about the work environment.

Virtual Fixture

A development which will also improve the performance of the operator of a teleoperated forestry machine is the 'virtual fixture'. The concept of virtual fixtures as an overlay of abstract sensory information on a workspace was first introduced by Rosenberg [16] in order to improve the telepresence in a telemanipulation task. For example the location of a nerve in the body which must not be cut could be defined as a virtual fixture and if the surgeon was cutting nearby he would be alerted to the close presence of the nerve.

In forest harvesting situations, hazards in the workspace could be identified as virtual fixtures. For example the edges of a forest track or standing trees in the swing zone of the machine could be marked as virtual fixtures. Multimodal feedback has been used to signal the presence of virtual fixtures to the operator [2].

Recommendations for Future Work

This study has reported some alternatives for the improved control of teleoperated machines. Specific options for forest harvesting machines need to be examined under New Zealand forest operational conditions. These include:

- a system which allows the selection of a wide angle view for situational awareness and unity view for control;
- a comparison of Track-up vs North-up map displays;
- the use of temporary markers on the screen to provide the operator with known visual references or a gravity referenced view;
- trials of camera position ('exocentric' and 'egocentric) for efficient operation;
- the use stereo video displays compared with monocular imagery;
- determining the bandwidth required for video and other data transmission;
- determining an acceptable time delay for control and feedback signals;
- testing video, audio and possibly haptic feedback signals to determine the most useful combination; and
- measuring the utility of virtual fixtures in forest harvesting.

Conclusions

The most difficult forest tasks, such as tree felling, will not be automated for a long time because human skill and judgment are needed for task performance. The human operator provides the brain and the teleoperated robot provides the muscle. Many of the human factors challenges inherent in remote control of a harvesting machine are similar to those confronted by other industries and military developers.

This study has shown that teleoperation is a complex task with considerable human factors issues. However, these issues have already been identified in other industries, and the solutions will be incorporated in New Zealand developments of teleoperated forestry machines. This work has identified the major human factors issues that we will need to address in the development of a teleoperated system for forest harvesting on steep terrain.

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