Robotics in forestry

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Abstract

New technologies are increasingly being integrated into everyday tasks to assist users and could radically change the nature of how industries operate. Forest harvesting operations have been traditionally considered physically demanding and potentially dangerous, with forest workers on foot exposed to heavy and fast-moving trees, logs and machinery. Many tasks in forestry have already been mechanised to reduce hazards to the worker and increase productivity. For example, the axe was replaced by the chainsaw, which was replaced by the harvester. Workers on log landings have been displaced by delimbing machines and breakers-out by grapple carriages. A recent survey of New Zealand forestry staff found an acceptance of the introduction of robotic devices in forestry, but a caution to manage carefully their impact on employment in small rural communities (Bayne and Parker, 2012). This paper provides a broad background to robotics and then focuses on aspects of robotics relevant to forestry.

Forest mechanisation

Mechanisation has primarily been driven by the need for greater productivity and safer work, but it has also changed the nature of forestry work. It is now possible to achieve greater intensity of work. The faster pace of forest harvesting is now measured in cycle times of seconds rather than minutes. Researchers from Sweden observed that as work becomes faster, operators become the bottleneck because they cannot work as fast as the machine (Ringdahl, 2011). A human can only move joysticks so fast and needs regular breaks, whereas a machine may only be limited by the size of its fuel tank and maintenance requirements.

Also, as more forest workers are confined to a machine cab fewer are getting to experience the natural environment of the forest which could, for many, result in lower work satisfaction. Harvesting tasks such as tree felling and extraction are becoming more of a sedentary task than an active outdoor job. While this allows older workers to stay longer in the workforce, they are now exposed to occupational injuries such as musculoskeletal overuse, thereby presenting other health issues, although this is not as immediately dangerous as manual felling and breaking-out.

Types of machine control

Most forestry machines today are under manual control, i.e. controlled directly by an operator. But in other industries manual control has been superseded by remote control, teleoperation and automation (Table 1).

Table 1: Types of machine control

Manual control
Operator sits in the machine and operates controls through a direct mechanical, hydraulic or electrical link to the machine
Remote control
Operator is not on machine but is within visual sight. A radio signal links the operator's controls with the machine's controls
Teleoperation
Operator is viewing the work scene via a transmitted video image (or some other sensory system such as radar, LiDAR, sonar). Control is the same as radio control
Automation
There is no human machine operator. The machine is making all the decisions about work and is doing the work. There may be human supervision of the machine

Remote-controlled machines are controlled by an operator who is not physically on the machine but is within line-of-sight. Small remote-controlled machines are relatively common now in New Zealand. For example, a radio-controlled roller can be hired to compact soil while the operator stands a safe distance away. A radio-controlled full-sized excavator has been used for dangerous house demolitions in Christchurch (3 News, 2014).

Teleoperated machines are less common because they are considerably more complex. The operator can be very distant from the machine – in some cases thousands of kilometres away. The operator can see and (with some systems) hear and feel the machine at the work site through the use of video cameras and other sensors mounted on the machine. Examples of teleoperated machines are unmanned aerial vehicles (UAVs or drones) used by the military and some mining machines, such as load-haul-dump (LHD) trucks. Underground mines in New Zealand have had teleoperated LHDs for some years (see first photo).

Teleoperation of a LHD machine in a New Zealand underground mine. The operator is viewing a video monitor showing the scene in front of the machine

Automation is not common in large mobile machines. There are machines with some semi-automated functions, such as mining trucks that travel automatically to the next work site, where they then wait for a human operator to initiate the next work task such as load or unload. Smaller machines such as UAVs have auto-pilot functions which can automatically control the whole flight from take-off to landing, or 'return to base' at the push of a button.

Human factors

Humans are going to be in the forest workplace for a long time yet, because forests are very complex environments compared with mining or even flying where there are few obstacles. In time there will be a greater number of remote-controlled and teleoperated machines in our forests. While teleoperation may remove people from very dangerous environments, it is not a magic bullet. There are considerable human factors issues to overcome with teleoperation systems and the more complex the environment becomes the more expensive the solutions (Parker, 2009; Parker and Milliken, 2011). Some of the issues are:

- Limited field of view of the operator – they can only see what the camera can see and too many cameras can be confusing. There is nothing like experiencing a working environment first hand to understand the conditions, especially scanning for the dangers present.
- Difficulty knowing if the machine is on a slope and how steep that slope is. This can be overcome with an artificial horizon, like those in aircraft, for the operator.
- Poor depth perception with video cameras, making it difficult to see hollows and rises in the terrain in the path of the machine.
- Time delays between the operator moving a control and the machine moving.
- Motion sickness of the operator because their eyes see movement but their body is motionless.

All of these issues are currently being examined by numerous research groups around the world to improve the user experience of the teleoperator.

Industrialised robots

The term 'robot' is being used broadly in this article to refer to machines that are not under the direct manual control of an operator. They may be remote-controlled, teleoperated or autonomous. The mining industry and the military are leaders in automation and robotics, primarily because they are trying to remove people from dangerous tasks and they have invested heavily in technology. They have also gained productivity increases as machines can go into environments where people cannot, due to the environment being unsafe, too small, or lacking in visibility or outside a human's physical operating environment. For example, underground mines using teleoperated machines can be operated at greater temperatures than conventional mines because the machines can work at higher temperatures than people. Huge savings are made through lower air cooling costs.

In Western Australia, machine operators are based in a control centre in Perth and by teleoperation control machines at mines hundreds of kilometres away. In military applications, bomb disposal robots can disrupt the triggering mechanism of a bomb while the human bomb disposal specialist is at a safe distance. Similarly, teleoperated drone aircraft can deploy weapons under the command of an operator on another continent.

Robotics is a fast-developing field with remote-controlled, teleoperated and autonomous machines now employed in agriculture, construction, medicine and manufacturing. Enabling technologies such as sensor networks, haptic controls, augmented reality, 3D graphics and cloud computing are also assisting in the uptake of robotic technologies.

International perspective

In April 2015, FFR sponsored Richard Parker's attendance at the 'Robotics in the Forest Workshop' organised by FPInnovations in Canada. At the workshop he presented the robotics work in the FFR programme and got to mix with technology innovators from the forestry, mining and space industries (Parker, 2015).

Robert Hall from the University of British Colombia spoke at the workshop. He is an international expert on mining machine automation and explained how advances in technology have revolutionised thinking in the mining industry. Automation of huge haul

Large mining machines can be controlled remotely

trucks has resulted in mines being planned differently (see second photo). The trucks have no on-board driver (they are supervised remotely by a human) and are guided by GPS, which is so accurate that the haul roads can be much narrower resulting in lower road construction costs.

Automation and robotics in forestry will have a similar effect – forest management will have more options. For example, harvesting may be achieved with multiple smaller cheaper machines, which can work in swarms to fell and extract pre-selected trees rather than clear felling.

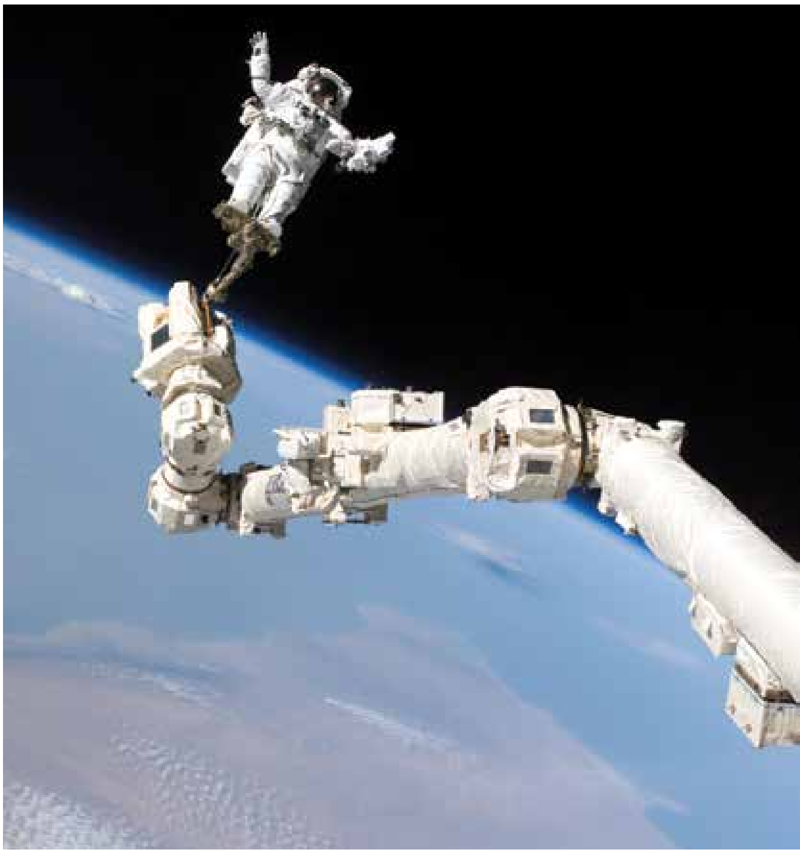
Robert Hall gave some advice from the mining industry's experience with automation:

- Automation and advanced technology is only 'really important' when times are good.
- There is a trend for enthusiasts to oversell the benefits of automation.
- The industry in collaboration with robot providers needs a plan to develop and implement automation and advanced technology.
- We need to ensure human resources are available for the new equipment and the mine (forest). People are needed to repair and recalibrate the machines.
- We need to look at step change technologies vs incremental change. Step changes can have the biggest gains.
- We need to convince companies to continue to invest through the highs and lows of commodity cycles.

Greg Baiden also spoke at the workshop. He is Chairman and Chief Technology Officer of Penguin Automated Systems Inc, a private company whose mission is to formulate existing and new technologies that create teleoperation systems to allow people to go where they should not or cannot go. Penguin ASI build specialist teleoperated machines, primarily for the mining industry, and also develop software to give remote operators greater situational awareness.

One example of a specialist mining machine the company developed was for the removal of 'draw bell blockages', where explosives have to be placed precisely on hung up rocks balanced precariously in an underground mine. Before robots, a worker 'volunteered' to go under the precarious rock blockage and place explosives (with a bamboo pole!) against the rock blockage. Penguin ASI developed a teleoperated electrically-powered six tonne machine, which can place the explosives precisely while controlled remotely. Many of the machine control and machine design problems that have been confronted by the mining industry will be found in forestry. We will learn from the solutions already developed in mining.

Robots developed for space have relevance for the forest industry. MDA's second generation robotic arm is Canadarm2, a robotic arm that can do useful tasks on the outside of the International Space Station (see third photo). A more recent development is the 'Dextre', which has its own arms and can operate independently or from the end of the Canadarm2. Cameron Ower, CTO at MDA, described how they do considerable prototyping and simulation before they finalise a robot design. Getting reliable robotic systems to work in hazardous or extreme environments is a real challenge, but very important because maintenance can be impossible.



Canadarm on the International Space Station. (Photo: Cameron Ower, MDA)

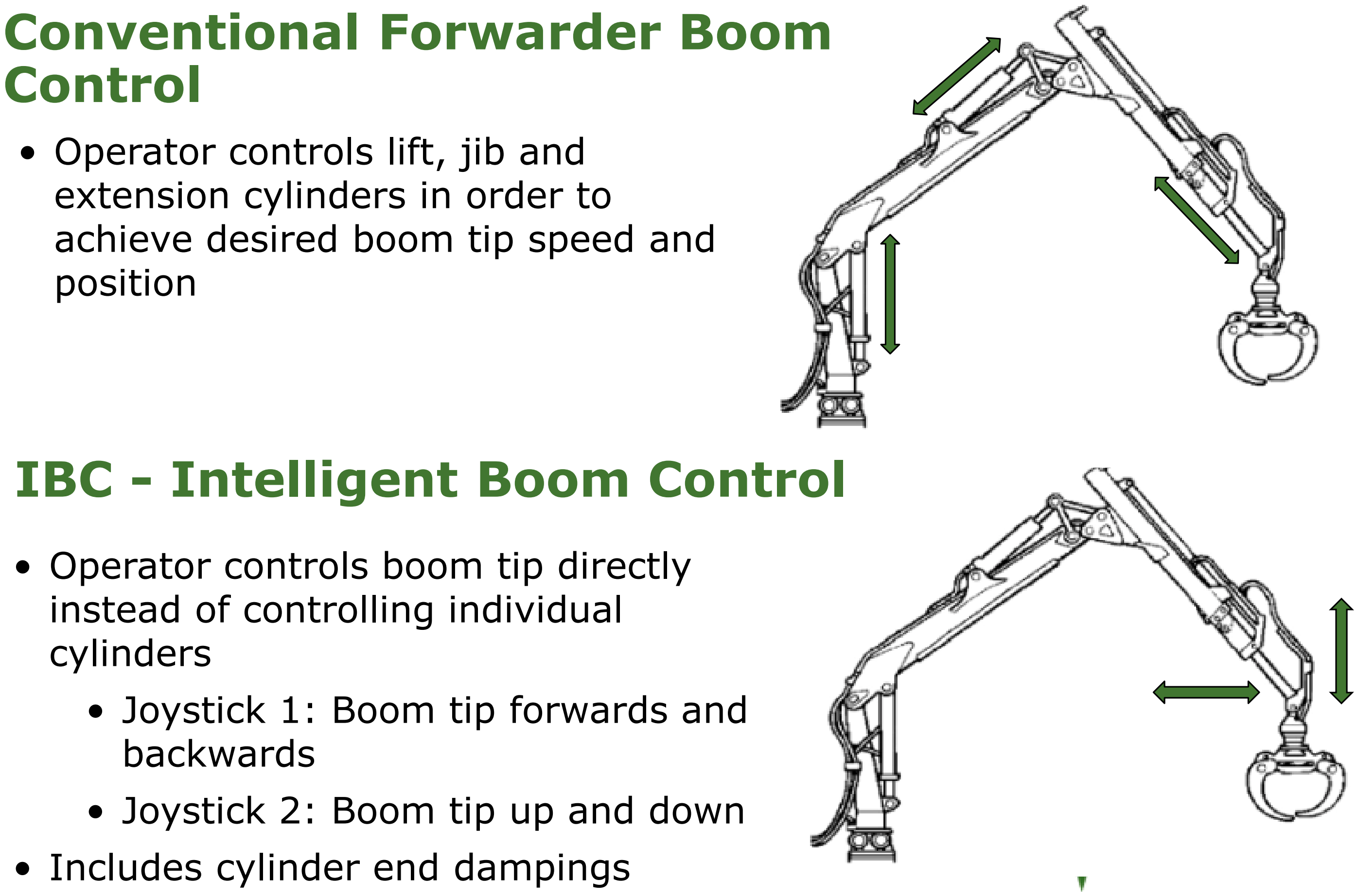


Figure 1: John Deere intelligent boom control. (Source: Marko Paakunainen and Timo Kappi, John Deere Forestry Oy)

Autonomous harvester concept machine developed by design students in Sweden. (Photo: Ludwig Östman, Skogstekniska klustret)

Tree-to-tree locomotion robot – Stick Insect conceived by Scion and built by Department of Mechanical Engineering, University of Canterbury

Their robots have been used to build and maintain the International Space Station and have been on the last four missions to Mars. They are so famous they are featured on the Canadian five dollar note.

Recent robotic forest machine developments

John Deere Forestry Oy in Finland has developed a boom control system, which automatically adjusts hydraulic rams to move the boom tip to wherever the operator wants it (see Figure 1). Therefore the operator is not controlling individual rams, which reduces their workload. The system is called 'intelligent boom tip control' and has shortened the learning curve of operators, resulting in faster cycle times and improved fuel economy. With automatic boom control the life of the boom structure and cylinders is extended because motion is smoother than if under human control.

New Zealand can learn from the innovative research collaborations of other countries. In Sweden, there is a collaborative forestry machine concept development group called the Cluster of Forest Technology (Skogstekniska klustret), which consists of 11 companies collaborating with research organisations within Northern Sweden. One example is that students from the Umeå Institute of Design at Umeå University, in consultation with the forest industry, have developed innovative new concepts for forestry machines. A concept for an autonomous harvester machine is shown in the fourth photo. Only a few of the designs will end up as working machines, but the cluster encourages innovation and links students with future employers.

Internationally a number of other concept forestry robotic machines have been developed to prototype form. A few of these include:

- A walking forest harvesting machine was developed in Finland in the 1990s (Plustech Oy, 1996), but has not been put into production.
- Woody – a forestry assisting robot from Japan that can climb trees and prune branches (Sugano Lab, 2003).
- Tree rover – a prototype tree planting robot from two Canadian students at the University of Victoria (CBC News, 2015).

Tree-to-tree locomotion robot

Example robots today

Machines that seemed fanciful a few years ago are now reality. For example, the concept of the exoskeleton, a wearable frame with motors which amplifies human strength as seen in the movie *Aliens*, was mentioned as science fiction at a Logging Industry Research Organisation conference in the late 1990s. Exoskeletons are now a real technology used to assist disabled people to walk and soldiers to carry more weight for longer, although they have not yet been used in forestry.

Walking robots have a much lighter footprint because they can lift their feet for locomotion, making them more suitable on forest soils. Although not developed for forestry, Boston Dynamics (now owned by Google X) developed the 'BigDog', a four-legged robot which can walk unassisted over rough terrain while carrying loads. It has also developed a military version called 'AlphaDog', which carries heavy loads and walks alongside soldiers. The machine bristles with sensors and high technology and has been trialled in war zones, although not in New Zealand forests which contain blackberry, a serious tripping hazard to a walking machine.

New Zealand's forestry robots

Huge advances in remote control, and eventually teleoperation, for forestry have been made in New Zealand through the Forest Growers Levy Trust (FGLT) and the Ministry for Primary Industries (MPI) supported Future Forests Research programme. As part of the research programme, a John Deere 909 excavator-based felling machine has been fitted with a control system developed by robotics engineer Paul Milliken (3 News, 2015). This is the first remote-controlled forest harvesting machine in the world capable of working on steep terrain. Paul is currently working on a teleoperated control system for the machine, where the operator is viewing the environment on television screens and controlling the felling of trees remotely.

Animals have lived in the trees for millions of years and have developed behavioural, structural and physiological adaptations to the arboreal environment. Some animals move slowly from branch-to-branch like the stick insect. Others can move rapidly using brachiation, engaging in the arboreal equivalent of running through the forest moving from branch-to-branch (Windy54m, 2006). In 2002, Richard Parker at Scion saw the ability to use this form of locomotion, although more slowly than gibbons, for the movement of forestry machinery. The proposed machine could always stay above ground moving from tree-to-tree using the trees for support. The machine would eliminate the problem of soil disturbance and would not be limited by terrain steepness. Coincidently Kimmo (2010, p. 2) stated that what should be invented in the way of a future semi-automated harvester is 'operated with a remote control, moves like a spider, leaving no traces in the forests, or produces a map of all Finland's trees with co-ordinates and measurements for each tree.'

With funding from Scion, MPI and the FGLT, the concept of a tree-to-tree forestry machine became real (Rural Delivery, 2015). In 2013, four University of Canterbury Mechanical Engineering and Mechatronics students built a working radio controlled tree-to-tree locomotion machine (see fifth photo). Their efforts won them the New Zealand Institute of Professional Engineers Ray Meyer Medal for Excellence in Student Design for 2014.

Development of a real machine demonstrated that being independent of the ground makes operator control of the machine easier because the ground conditions (holes, rocks, loose soil) do not have to be adjusted for. We envisage that eventually there will be a range of forestry machines that use the trees of the forest for support and always operate independently of the ground. They will perform economically valuable tasks such as measuring trees, pruning, thinning young trees and felling mature trees. The machines may work in swarms so that they do not have to be large to perform a task. For example, a small lightweight machine could control a chainsaw and fell a tree, while another machine is working four metres above, pushing the tree in the required direction.

Conclusions

Forestry, like many other industries, will use robotic and automated machines in the future. But forests offer particular physical challenges with steep terrain, sensitive soils, remote locations and a crop that is large and heavy to handle. Machines will be designed to work in harmony with the forest environment in a similar way to forest animals.

Acknowledgements

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