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Design of the Robotic Tree Felling Machine

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EXECUTIVE SUMMARY

The goal of the FFR harvesting research programme is to realise substantial gains in productivity and cost reductions through developing improved harvesting technologies for mechanised harvesting in New Zealand's steep terrain forests.

Most mechanised harvesting in New Zealand is performed using modified excavators fitted with specialised tree harvesting heads. These harvesters are controlled by the operator in the cab of the machine. Due to the hazards of operating machinery on steep slopes, the current Health and Safety code of practice prohibits the use of tracked machines on slopes greater than 23^{O}. Teleoperation provides a possible solution that combines the proven productivity gains of mechanised harvesting and the safety improvements from isolating workers from machinery on steep terrain.

The challenge is to develop a machine that can move over steep, difficult and sensitive terrain without causing damage to the terrain and can fell trees cost-effectively.

As part of the FFR harvesting programme, teleoperation of tree felling machinery for steep country harvesting is under development. Part of this project is to design a novel forest locomotion machine for tree felling. This concept machine should be able to use standing trees as a means of locomotion.

This report details the design of a Robotic Tree Felling Machine, and reports on progress to date on the development. Currently a working scale model has been designed and constructed at the University of Canterbury. Once completed, the scale model will be trialled later in 2013. The scale model will be used to guide the development of a full sized machine.

CONCEPT DESIGN

Scion conceived of a concept machine which should be able to use standing trees as a means of locomotion. Because of this novel means of locomotion, this tree-to-tree mobility device was dubbed the “Stick Insect” (Figure 1).

Figure 1: Conceptual image of the “Stick Insect” moving through pruned radiata pine

The robot is able to move from tree to tree without contacting the ground. Figure 1 depicts the device moving through a forest on flat land, but it has been designed to be able to traverse forests planted on sloping terrain. By eliminating contact with the ground the device will reduce soil disturbance.

CONSTRUCTION OF ALPHA PROTOTYPE

After the initial concept was developed, a working scale model was built to demonstrate the concept.

A larger scale working prototype (dubbed "alpha prototype") is being designed and constructed at the University of Canterbury. Once constructed, the alpha prototype model will be trialled later in 2013 and will be used to guide the development of a full sized machine.

To date, post-graduate Research Assistant Andre Geldenhuis has constructed a working arm. Subsequent work by University of Canterbury Summer Scholarship students George Buchanan and Scott Paulin has refined the control of the arm and trialled haptic feedback. Haptic feedback enables the operator to feel, through a joystick, if the arm touches an object.

Figure 2 shows the device in the form that it is currently being built.

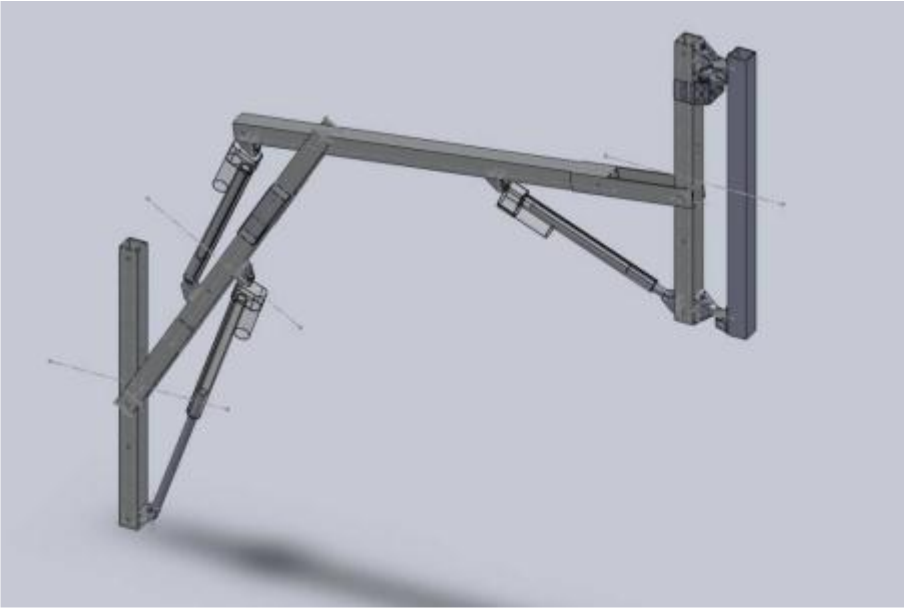


Figure 2: Diagram of the robot in its current "as built" configuration reaching up slope.

The primary frame of the robot is constructed of 50 mm x 50 mm aluminium extrusion. This was selected due to its rigidity and to simplify construction. In its current configuration the machine can extend to approximately 2.0 m and reach up or down at a 30-degree angle. The angle of reach up/down is currently limited by the force the actuators can exert. The design would be capable of reaching greater angles with more powerful actuators, enabling operation on steeper slopes.

Figure 3: Photograph of the robot resting on the floor with a prototype gripper.

It is envisaged that a “heel” will be used in combination with grippers to help support the robot when it is attached to a tree. The heel will work in the same way as the heel on a “heel-boom” log loader.

DETAILED DESIGN OF ALPHA PROTOTYPE

In March 2013 the design and construction of a tree-to-tree locomotion device was offered as a final year project for University of Canterbury Engineering students. Four students took up the challenge. The students are: Scott Paulin and George Wareing (Mechatronics Engineering) and Sean Bayley and Tom Gilbert (Mechanical Engineering). These students are supervised by Dr Stephanie Gutschmidt of the Mechanical Engineering Department, University of Canterbury. The students have studied the preliminary design of the Prototype robot arm (Figures 2 & 3) and have improved its mechanical and electrical design.

Design Process Developed by the Students

Initial Geometry and Component Selection (completed)

- Create the layout of arms and actuators using a Solidworks layout sketch.
- Analyse the range of movement in 2D and estimate the actuator forces.
- Select potential linear actuators.
- Check requirements and proceed to next stage of development or revise the layout/actuator selection.

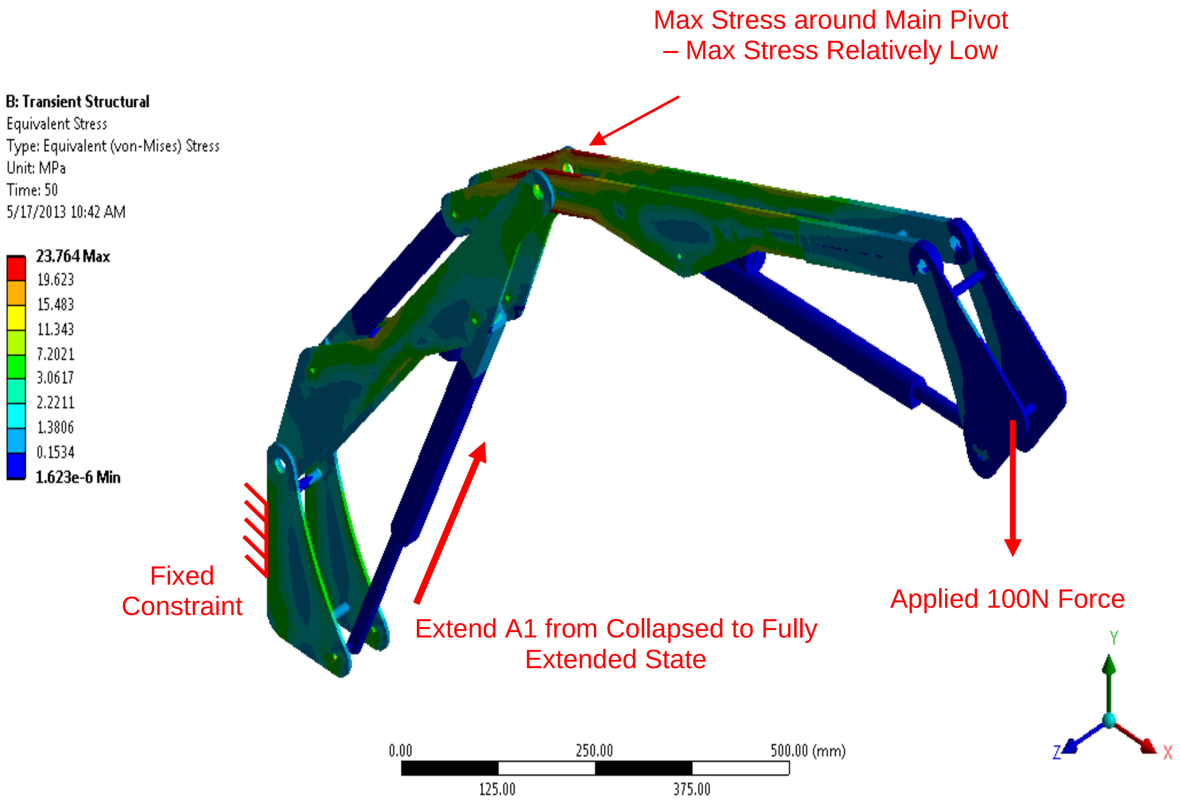
Provisional Model and Analysis (completed)

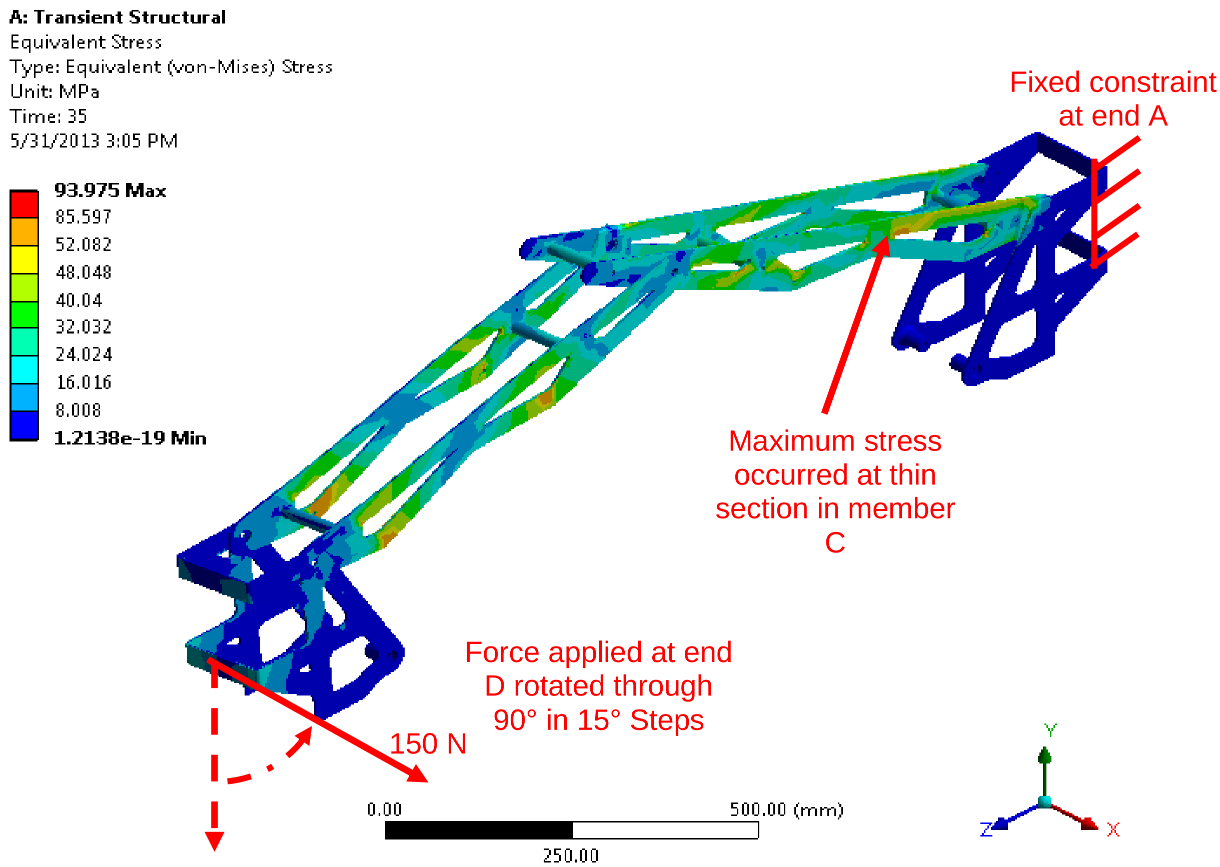
- Model the arm in more detail (3D) based on the layout sketch.
- Analyse the design based on the 3D geometry. Check the design's range of movement and clearances.
- Determine the weight of the frame/arms.
- Calculate joint and actuator forces and check the design for stress and deflection.
- Optimise the design by removing weight from the arm profiles and repeat the stress and deflection analysis.
- Check requirements and proceed to next stage of development or revise the layout/actuator selection.

Detail Design (under way)

- Design the joints, actuator brackets and fastenings.
- Model in more detail, including the integration of rotary encoders and preliminary electronics placement.
- Create preliminary gripper design.
- Analyse the design in more detail based on the estimated weight of the additional components and grippers.
- Refine the gripper design and analyse their range of movement and grip force.
- Optimise the gripper design for weight and repeat the detail design and analysis.
- Proceed to manufacture.

Stress Analysis of the Most Likely Design

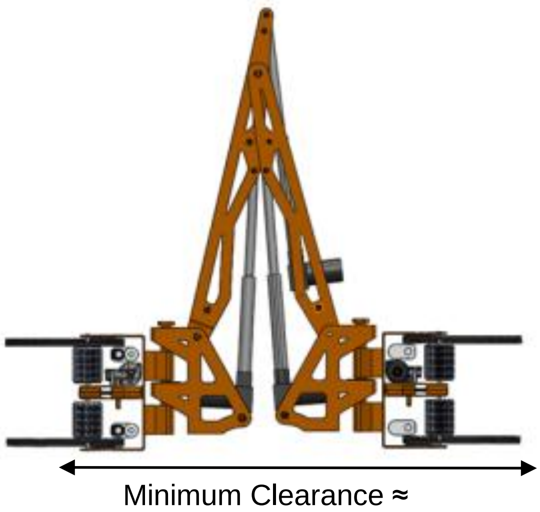




Detailed Design of Alpha Prototype

Chassis

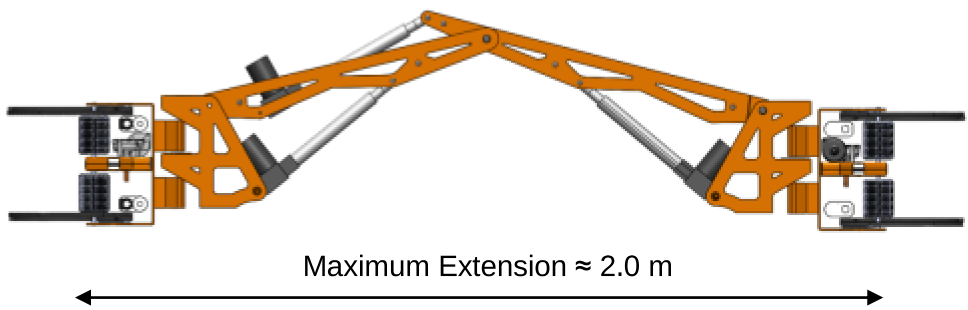
The prototype design has been developed so that its appearance is similar to what a large scale version might look like. Individual components have been selected based on their size, weight and load carrying capabilities. The geometry of the mechanism has been refined to provide a large range of movement. The chassis will be made from aluminium, and it will be assembled from water-jet cut profiles.



Linear Actuators

Progressive Automations
PA-02-#-400 Linear Actuators

- Load: 180 kg Push/Pull Force
- Voltage: 12v DC
- Speed: 15 mm/s (@180 kg)
- Mass: 2 kg
- Stroke: 250 mm (lower actuators) and 300 mm (upper actuator)



CONTROL OF THE ALPHA PROTOTYPE ROBOT

Teleoperation and Haptic Feedback

The forest robot will be controlled by teleoperation so the operator is sited remotely from the machine and out of harm's way. To aid the control of the machine, haptic feedback will be used, which provides an enhanced operator experience. Haptic feedback enables the operator to feel, through the joystick controller, the action of the machine, for example if the arm touches an object. In this application haptic feedback is used to provide additional information about the physical actions the operator is performing.

Combining teleoperation and haptic feedback is a challenging task. Haptic feedback is sensitive to communication system delays. It is also sensitive to the movement of the robot. Delays are a common cause of control system instability. Stability and controllability in the design of the machine is of particular concern, especially with large machinery. After the construction of the prototype arm by post-graduate Research Assistant Andre Geldenhuis, subsequent work by University of Canterbury Summer Scholarship students George Buchanan and Scott Paulin has refined the control of the arm and trialled haptic feedback. These students have collaborated with PhD student Bart Milne to investigate control of the robot arm.

This involves working with the Phantom Omni device, a commercially available six degree-of-freedom haptic device for positional sensing which makes it possible for users to touch and manipulate virtual objects. The summer student project investigated the effect of communication delays on the stability of haptic feedback devices. Sending signals over the internet results in unpredictable delays which affect the control of the robot (stability and transparency).

Their work has developed a novel method combining internet based teleoperation with haptic feedback. The solution has been validated by the prototype haptic teleoperation system built around a pair of Phantom Omni arms. This work has been summarised in a paper submitted to the ninth IEEE International Conference on Automation Science and Engineering (Milne, Buchanan, Paulin *et al*., 2013).

Path Planning and Robot Dimensions

University of Canterbury Master of Engineering (ME) student Chris Meaclem analysed data from a Scion forest survey where each tree's location had been precisely plotted and each tree's diameter measured at breast height. Figure 4 indicates that the grippers of the robot would have to be able to open to at least 600 mm to be able to grasp all the trees in the forest. They would also have to be capable of grasping trees as small as 200 mm diameter. This information will be used to help design a suitable gripper.

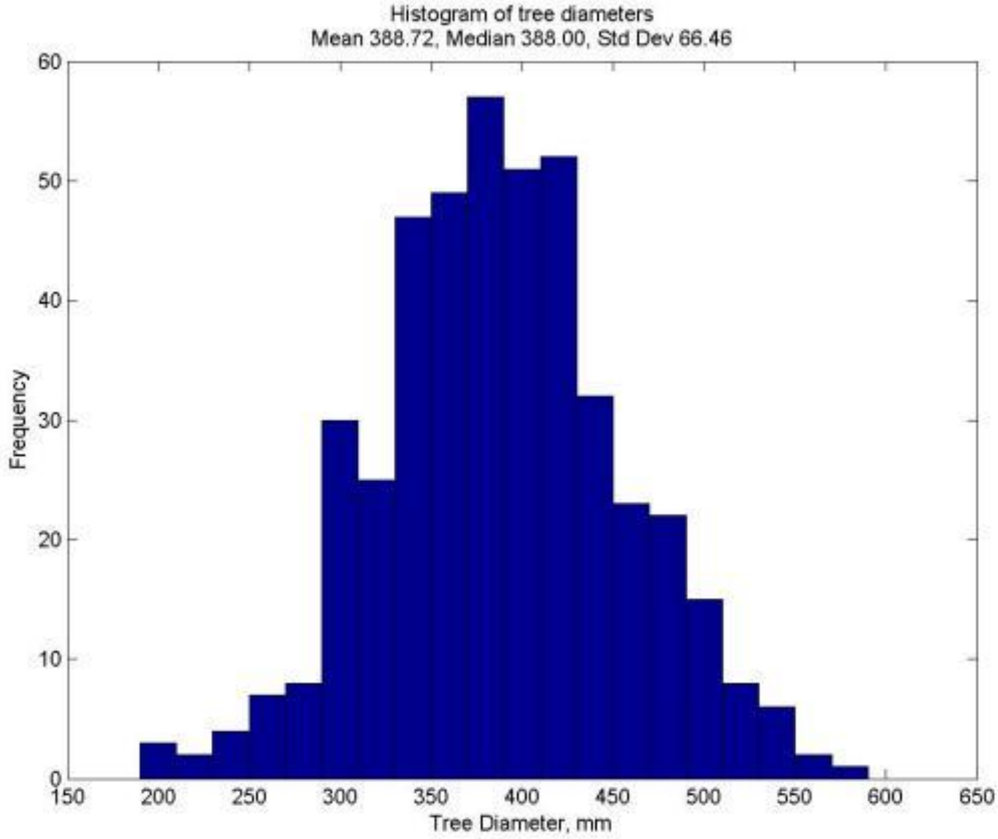


Figure 4: Histogram of tree diameters for 500 trees in the forest survey indicating the size of gripper (grapple) required to grasp trees

GPS tree location has been used to model possible paths and reach requirements for the robot (Figure 5).

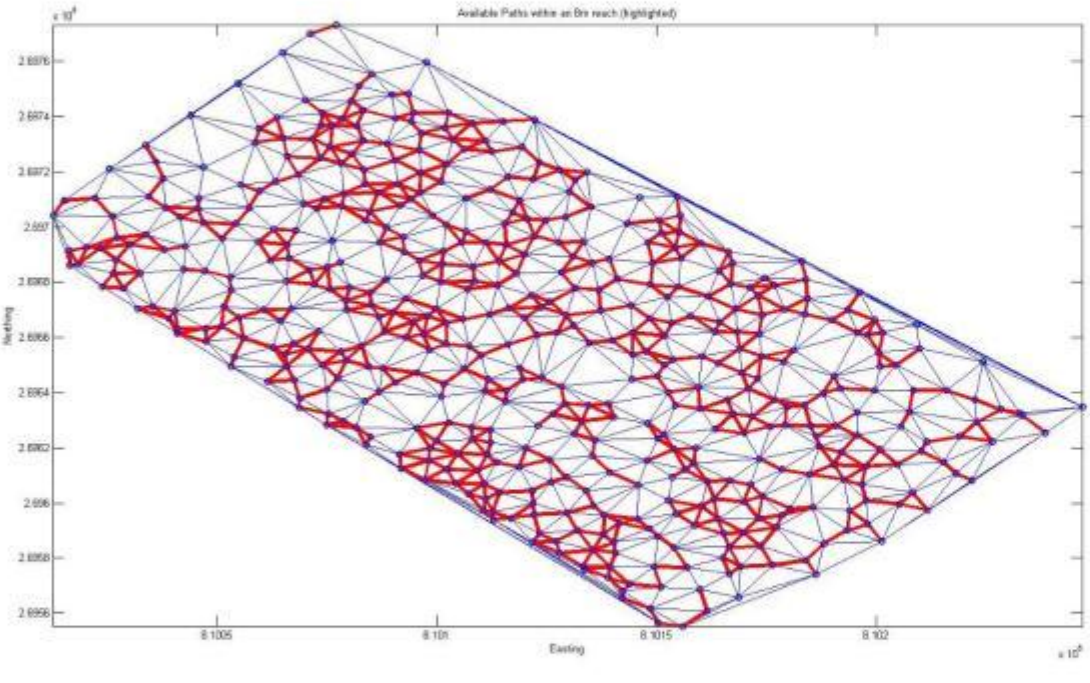


Figure 5: Traversable paths of the robot with an 8-m reach. Islands of isolation can be seen where an 8-m machine could not traverse the whole block.

In Figure 5 each tree is represented by a blue dot. The thin blue lines indicate a possible path between trees. The thicker red lines indicate paths that are less than 8 m distance. Therefore a robot with an 8.0-m reach could move around the forest following the route indicated by the thicker red lines.

In this example forest there are still some trees that cannot be reached by the robot. These example data were the only viable data set of tree locations available for analysis and may not be representative of a mature radiata pine forest stand that is ready for harvest. Additional data sets are being investigated to get more representative samples of tree diameters and spacing (locations).

Figure 6 shows the proportion of trees that would be traversable for a given reach of the robot. This indicates that a robot with a reach greater than 8 m would be able to reach only a few extra trees. Ideally the robot should be as small as possible to reduce weight, complexity and fuel requirements.

As an alternative to building a larger robot, innovative configurations of robots could be developed to cross 8 m spaces. Potentially two smaller robots could work together, one assisting the other to cross the space.

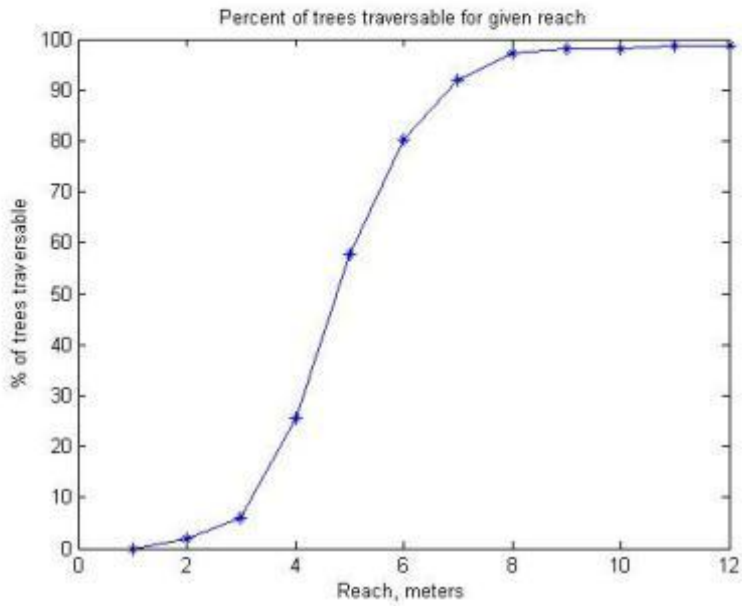


Figure 6: Proportion of trees that can be reached by robots in relation to robot reach

Kinematic Modelling

On 10 June, 2013 Chams Jied, a visiting research assistant from France, joined the project under the supervision of ME student Chris Meaclem. Chams Jied will be working on the project until September, 2013. His work will focus on developing a kinematic model of the machine. Once this model has been formed it will be applied to the forest GPS data, thereby applying further constraints on path selection leading to a better understanding of the behaviour of the machine in the forest.

The model, as applied to the forest data, will provide an illustration to parties on how the machine will operate in the real world, and show how the machine would travel through a real forest.

Intellectual Property

A provisional New Zealand patent has been filed by Scion for the tree-to-tree locomotion concept which was developed over the last eight years within Scion. The patent covers the general locomotion concept and a number of particular uses of a tree-to-tree device including silviculture and mensuration.

CONCLUSION

To date (April 2013) there are four final year B.E. students (working one day per week), one full-time M.E. student, one Research Assistant and one PhD (part-time) engaged in research on aspects of the design and development of the tree-to-tree robot.

Progress has been rapid, but significant design hurdles will have to be overcome.

These include:

- ensuring the robot has the ability to rotate enough to reach out to the next tree;
- designing an arm that is long enough to reach all trees;
- designing an arm that is large enough and strong enough to handle all trees;
- designing a system with sufficient power to drive the robot through the forest terrain; and
- capability to traverse through thick forest undergrowth.

Subsequent design challenges include developing or modifying a felling saw which will work reliably in the forest environment. Issues in relation to tree felling include:

- saw capability to double cut a large tree; and
- ability to handle shock loading during tree felling.

REFERENCE

Milne, B., Buchanan, G., Paulin, S., Chen, X., Hann, C., Geldenhuis, A., Parker, R., (2013): *Robotic Arm Kinematics and Bilateral Haptic Feedback over an Ethernet Communications Link*.A paper submitted to the ninth IEEE International Conference on Automation Science and Engineering (CASE 2013), to be held in Madison, Wisconsin, USA, August 17-21, 2013.