PO Box 1127
Rotorua 3040
Ph: + 64 7 921 1883
Fax: + 64 7 921 1020
Email: info@ffr.co.nz
Web: www.ffr.co.nz

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Falcon Forestry Claw Motorised Grapple Carriage: Solving Performance Limitations

Author:
Stuart Milne

Research Provider:
University of Canterbury School of Forestry

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EXECUTIVE SUMMARY

The primary goal of the FFR Harvesting Theme is to reduce the cost of harvesting on steep country by introducing new technology that is more productive and cost effective than existing equipment. The secondary goal is to remove workers from the hazardous tasks of manual tree felling, breaking out and unhooking. The specific aim of project Task 2.2 in the FFR programme is to develop improved grapple carriage control systems in order to reduce cable hauler element times by at least 20%, resulting in improved productivity by 25% over current practice. These aims will be achieved by developing an improved grapple carriage for use in a swing yarder operation.

Within the next ten years the New Zealand forestry sector will be faced with the task of harvesting a significant area of first rotation *Pinus radiata* that has been planted on steep and marginal terrain. Because of the location and the difficult terrain on which the forests are planted, there will be increased infrastructure and harvest costs which will limit profitability of harvest operations. If efforts are not made to reduce harvesting costs, harvesting could become non-viable economically, and the valuable forest resource will be left un-harvested.

It has been identified that using cable harvesting systems with a gravity return ("shot gun") system and motorised grapple carriages could reduce logging costs and increase worker safety. Moutere Logging Limited, a harvesting contracting firm in Nelson, and its subsidiary DC Repairs Ltd have developed a motorised grapple carriage suitable for use in a shot gun cable system. However, the process of grappling can result in the grapple colliding with the ground, and the shock of this collision is transferred through the carriage and its internal components. This shock loading can cause damage to components which results in downtime and lost profits. By providing the operator with real time range data that relays the carriage's position in relation to the ground back to the operator, the risk of collisions will be reduced and the profitability of the system improved.

An investigation into the working environment of the system, the operating principles of the carriage and distance or range finding methods was conducted. From this investigation it was determined that an ultrasonic range finding system could fulfil the required design specifications for the carriage. A field test was carried out with an ultrasonic sensor to determine if it could accurately determine the range from the ground. Ultrasonic sensors were shown in experimental results to be effective in determining range from forest residues on the cutover and have strong potential to be installed into carriages to provide real time range data to the hauler operator.

INTRODUCTION

During the 1980s and 1990s the New Zealand plantation forest industry grew significantly. From analysis of the 2011 National Exotic Forest Description statistics (MAF, 2011), there is an estimated area of 500,000 ha of small, steep terrain forest that is due for harvest in the next ten years. This presents a challenge, considering that the combination of steep topography, poor soils and environmental constraints associated with the oncoming harvest means that cable harvest systems will be used extensively to harvest the timber. Although it is safer to harvest steep terrain with cable harvesting systems than lower cost ground-based systems (Jarmer *et al*., 1992), it is still a hazardous procedure. Between 2005 and 2010, the industry-wide injury database run by the Forest Owners' Association recorded 18 fatalities in New Zealand. Tree felling and breaking out contributed to 39% of these fatalities (MBIE, 2012).

Compared to cable harvest systems, mechanised ground-based harvest systems are more cost effective (Visser, 2011). It is clear that the higher harvest costs that are associated with steep terrain harvesting will have a negative impact on the profitability of the forestry sector. One of the best opportunities for reducing harvest costs whilst improving worker safety is through developing improved cable extraction systems. Reducing the cost and improving the safety of steep country harvesting has been identified as a priority by the New Zealand forest industry. The primary purpose of the FFR Primary Growth Partnership (PGP) programme "Innovative Harvesting Solutions" is to reduce the cost of harvesting on steep country by introducing new technology that is more productive and cost effective than existing equipment. The secondary goal is to remove workers from the hazardous tasks of manual tree felling, breaking out and unhooking.

The purpose of Objective Two of the programme is to increase productivity of cable extraction to reduce the cost of cable harvesting in three ways: better vision for hauler operators (Task 2.1); improving grapple systems (Task 2.2); and developing an innovative yarding system (Task 2.3). The specific aim of project Task 2.2 is to develop improved grapple carriage control systems in order to reduce cable hauler element times by at least 20%, resulting in improved productivity by 25% over current practice. These aims will be achieved by developing an improved grapple carriage for use in a swing yarder operation.

The main contributing factor influencing the productivity of cable harvest systems is the terrain, which in turn dictates what type of rigging configuration and equipment can be utilised (Visser, 1998). One rigging configuration which is regarded as being highly productive when used in areas that allow high deflection is the gravity return (or "shot gun") system. The shot gun rigging configuration consists of a simple two-rope system used for uphill yarding utilising a skyline and mainline (Studier and Binkley, 1974). From a recent survey of experienced cable yarder operators and planners from within the New Zealand industry, it was found that less than 20% actively used this configuration despite it being simple to configure while maximising deflection and payloads (Harrill and Visser, 2011). The shot gun is a preferred configuration when deflection increases from medium to high; such instances occur during the transition from rolling to steep terrain. A typical shot gun system in displayed in Figure 1.

Advanced yarding equipment such as motorised carriages are commonly viewed as productive, versatile devices, and are the most preferred in high to extreme deflection scenarios. Despite this perception, only 25% of survey participants had used any motorised carriages, mechanical slack pulling carriages or grapples within the last five years (Harrill & Visser, 2011). This may be attributed to contractors not being willing to make the capital investment required for a motorised carriage because of the risk of damage during operations and additional maintenance requirements.

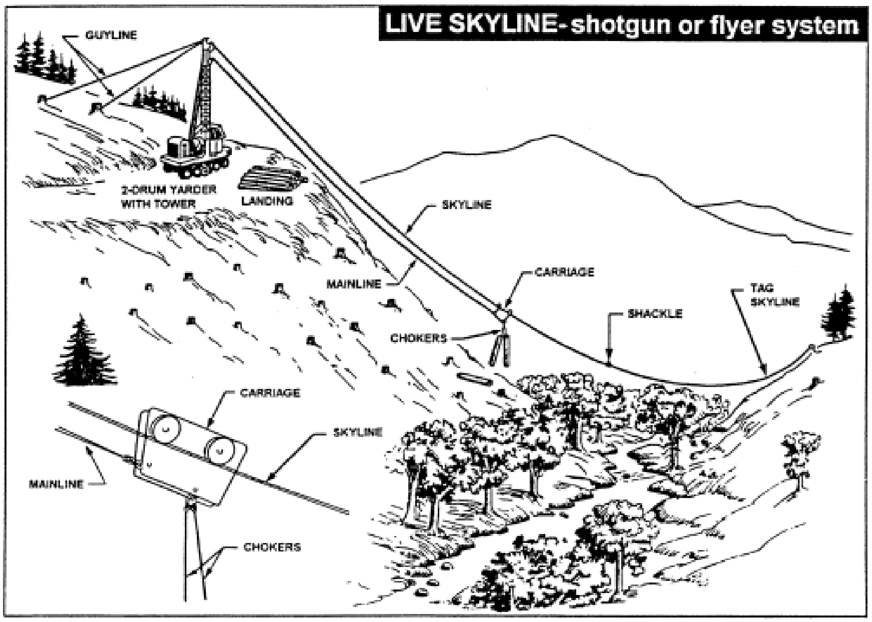

Figure 1: Live Skyline-Shotgun system (WAC, Department of Labor and Industries)

An alternative that is favoured over the motorised carriage is the mechanical grapple. Favoured for its simplicity and robustness, mechanical grapples are perceived to be very productive and good for short hauling distances (Harrill and Visser, 2012). The primary advantage associated with mechanical grapples is that workers are removed from the cutover during stem extraction. Removing workers from the cutover improves worker safety and reduces crew size, which also reduces operational costs. Mechanical grapples are commonly used on running skyline configurations requiring an additional line to open and close the grapple.

Advances in grapple technology have resulted in grapples which do not require mechanical control from an additional line, but rather they use an integrated power supply that enables them to be radio controlled. This advancement is known as the motorised grapple carriage and can be used on simple rigging configurations such as shot gun. The motorised grapple carriage and shot gun configuration is a very attractive option when considering the possibility of increased production and fuel savings. However, the process of shot gunning exposes the motorised grapple carriage to the risk of damage from collision with the ground and or felled stems in the cutover.

Moutere Logging Limited and its subsidiary DC Repairs have been developing a motorised grapple carriage called the Falcon Forestry Claw (“Falcon”). This report was commissioned by Future Forests Research Limited (FFR) to investigate and explore opportunities to improve the control system on the Falcon. In order for the Falcon to be successfully accepted by industry, owners must feel that their investment is going to return a profit and not be damaged during stem extraction. It was proposed that providing the operator with real time range data that related the Falcon’s proximity to the ground (“cutover”) could reduce the frequency of collisions with the ground as well as improve operator carriage control. From a literature review it is understood that there are no grapple systems in existence that utilise range finding systems. The report covers an investigation into current range finding technology, operating function and environment of the Falcon, and a field trial of a range finding sensor. Conclusions are drawn on the applicability of range finding technology to the Falcon for the purpose of warning the operator of an imminent collision.

RANGE FINDING TECHNOLOGY

Range finder technology, developed primarily for range determination in industrial applications such as surveying or examination of objects, now is a widespread mature technology (Herbet, 2000). A range finder, as the name suggests, is an instrument that provides a non-contact measurement distance between the instrument and an object. Range finders are classed broadly as passive or active, and on the other hand into monocular and binocular methods (Jarvis, 1983a).

Passive Range Finding

The passive monocular approach includes such techniques as shape from texture, shape from shading, shape from contours, and other shape principles. Electronic methods gather three-dimensional (3-D) information about the scene from the brightness and intensity of the captured image. Passive binocular ranging methods, known as stereo vision, work on the same principle as human vision. A target 3-D location is found by viewing the object from two different positions. Stereo vision is constrained by the correspondence problem, the matching of scene features in the two images. The process of matching is computationally expensive (Jarvis, 1983b), and cannot be justified for real time applications.

Passive ranging techniques suffer from environment factors, such as scene illumination, surface reflectance and camera hardware characteristics (Moring 1989). Because environmental factors have a large influence over passive ranging performance, such techniques are poorly suited to outdoor environments (Wagner *et. al*., 2004) .

Active Range Finding

Active ranging techniques involve some form of controlled energy, where a beam is directed at the target and the reflected energy is detected. Active binocular techniques are based on triangulation, which differs from stereo as one of the cameras is replaced with a controlled light source (Moring, 1989), see Figure 2.

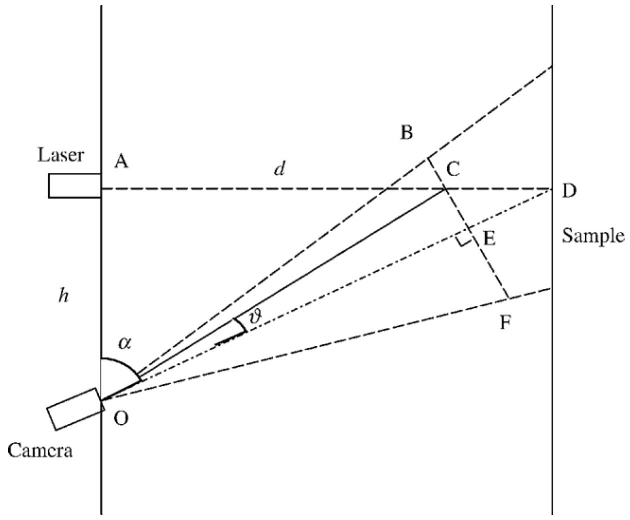

Figure 2: Simple active triangulation instrument (from http://www.emaerldinsight.com)

The controlled light source illuminates a light pattern on the target; the pattern is then detected by a camera which is positioned parallel at a certain lateral distance (baseline) from the source. The image is processed by using the principle of triangulation to determine the location of the target.

Compared to passive techniques, active triangulation methods greatly simplify the signal processing to be done to recover distance information (Rioux, 1984). The simplicity of active range finding is an attractive feature; however the technique has several critical drawbacks when used in a dynamic outdoor environment.

The first problem relates to the depth of field over which the system can effectively range. The length of the baseline directly affects the resolution relative to depth ratio of the system. To determine the range of distant targets, the system is required to have a large baseline. Increasing the baseline increases the occurrence of occlusions and missing data, which limits the system to short range applications (Herbet, 2000). There are a limited number of commercially available active triangulation rage finders; available systems are primarily used for ranging targets less than 10 m away (Beraldin *et al*., 2003).

The second problem is detecting the illuminated light pattern on the target in the camera image. External sources of energy can add a non-negligible contribution to the irradiance introduced by the controlled light source on the target (Ilstrup and Manduchi, 2010). A simple way to combat this problem is to increase the power of the light energy source. This however causes eye safety concerns; established regulations such as the American National Standards Institute (ANSI) pose limits on the amount of energy that is allowed to be emitted in a laser pulse.

Active monocular methods determine the range of an object by measuring the time taken for the emitted energy to travel from the transmitter to the target and reflected back (Gokturk *et al*., 2004), refer to Figure 3. These sensors are typically referred to as Time of Flight (TOF) sensors. TOF sensors directly produce range information that does not require any further computation (Moring 1989). Two common TOF ranging sensors are commercially available, laser and ultrasonic or sonar. They differ in the form of energy that they emit to establish the range of targets.

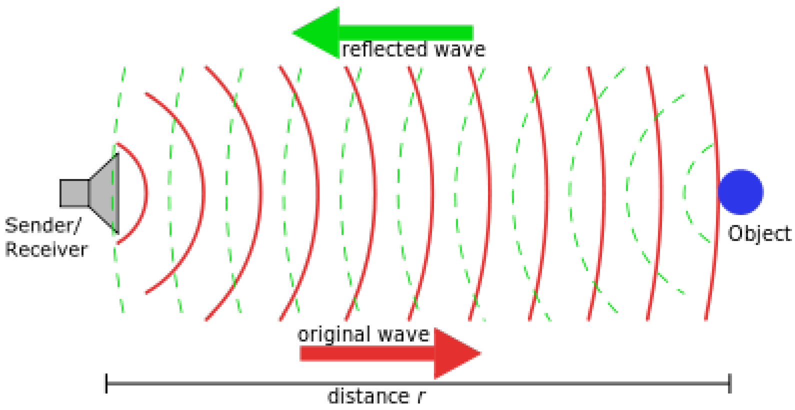

Figure 3: Ultrasonic Time of Flight Principle (Source: http://en.wikipedia.org/wiki/Ultrasound)

Ultrasonic sensors transmit a short burst of ultrasonic sound waves toward the target. Ultrasonic sensors are not affected by ambient light or the colour of the target. There is a wide range of available sensors on the market; they vary from one another in their features, protective housings and mounting configurations. More importantly, they operate at different frequencies and produce different wave radiation patterns. The ranging environment combined with the sensor's acoustic characteristics can have a great effect on how the sensor operates and the measurement generated (Massa, 2011). The sensor's operating range and spatial resolution is directly influenced by its operating frequency and power, impedance of the propagation medium, the sensitivity of the receiver and target reflectivity. Therefore, it is essential to stipulate the desired performance of the sensor and tailor the system to work within the environmental parameters (Canali *et al*., 1982). Ultrasonic sensors have been successfully used in outdoor environments since the late 1980s, where they have been used to measure the height of tree canopies so that biomass could be estimated (Lee *et al*., 2010). More recently, Fricke (2011) attached an ultrasonic range finder to a mobile tractor and successfully determined the height of legume grass over a paddock. Thomas's work demonstrated that an ultrasonic sensor can be used effectively in a dynamic outdoor environment. Ultrasonic sensors are well suited to use in industrial environments as they are robust and unaffected by dirt and grease (Sains, 1964). In addition, ultrasonic sensors are inexpensive, compact, have simple circuitry and are easy to interface with computers (Tanzawa *et al*., 1995). A concern with ultrasonic sensors is that the majority of commercially available sensors have an operating range of less than 10 metres. From investigation into product lists, it was found that there are cost effective ultrasonic sensors that can range out to 25 m.

Laser Range Finders (LRFs) differ from ultrasonic in that they emit energy in the form of light. LRFs are used in a large range of industrial applications, ranging from sub-meter to kilometre distances in some applications. Although TOF LRFs are thought to be well suited for long range applications in outdoor settings (Herbet, 2000), they operate poorly in low visibility conditions (Xiujuan and Hong, 2004). Atmospheric conditions such as fog, smoke or rain can cause the emitted light to scatter, resulting in invalid range data. In addition to atmospheric conditions, an LRF's performance is limited by a target's reflective property (Sabatini, 2010). The reflectivity of a target can be expressed by two components, the specular and diffuse component, displayed in Figure 4 below. The energy that reflects away from the target at the opposite angle of incidence is referred to as the specular component. The diffuse component refers to the energy which is reflected off in all directions. Natural broken terrain, such as soil, has low reflectance and is highly diffuse. SICK Sensors, a leading producer of sensors and sensor systems for industrial applications (Bennetto, *pers. com.,* 2012) reported that bare soil in some cases can be comparable to coal in terms of reflectance. Acuity, a laser sensor supplier, state that when ranging off coal, the maximum range and depth of field of a LRF could possibly be limited to 1/5 of what is possible from light-coloured targets (Schmitt Industries, 2012).

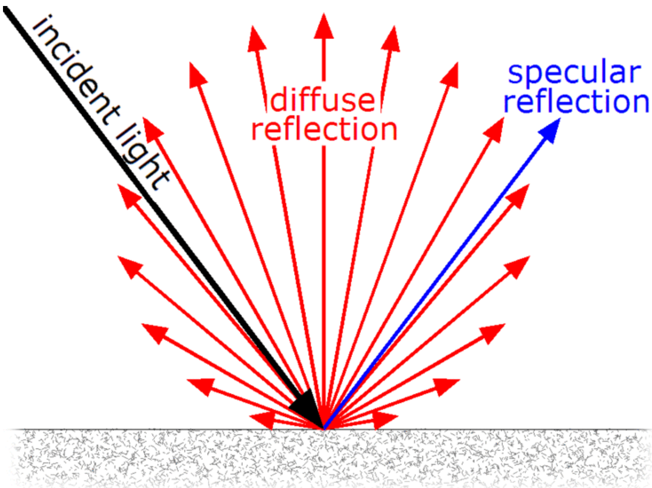

Figure 4: Different modes of reflection depend on surface characteristics (retrieved from http://en.wikipedia.org/wiki/Diffuse_reflection)

Many turnkey systems are now available and have been demonstrated in robotics research (Herbet, 2000), but they are costly when compared to other solutions such as ultrasonic. Unlike ultrasonic systems, LRF systems are viewed as a less durable option and are not recommended to be exposed to shock loading (Bennetto, *pers. com.,* 2012).

FUNCTIONS AND PRINCIPLES OF OPERATION OF THE FALCON FORESTRY CLAW

The Falcon Forestry Claw carriage is equipped with an internal combustion engine which powers a hydraulic grapple and rotator unit through a hydraulic pump. The Falcon provides flexibility during extraction operations over traditional mechanical grapple systems through utilisation of a hydraulic power supply to open and close and rotate the grapple. Unlike mechanical grapples which are fixed on a single axis and use a cable and gravity to operate the grapple, the remotely operated hydraulic grapple and rotator unit allows the operator to have full control over grapple functions. As a result, stems that would have been previously inaccessible to a mechanical grapple can be extracted with the Falcon.

Recently, mechanical grapples have been fitted with camera vision systems to eliminate the need for manual spotters to guide the hauler operator through radio communications. The Falcon has also been fitted with a video camera so the carriage can be operated if the operator doesn't have good vision of the stems. The video camera is mounted on the carriage in the downward position to capture the grapple and cutover. The video data are transmitted via a wireless radio frequency data link to the operator who views the live data stream on a LCD monitor. From the live video stream, the operator is able to locate stems on the cutover and determine where the grapple is relative to the stems.

Through using wireless radio frequency links to transmit data, the Falcon can be operated in a shotgun configuration out to distances in excess of 600 m from the hauler. The operating principles behind the Falcon allow the carriage to be utilised in scenarios where breaker outs and strops would previously have been favoured over a mechanical grapple. This is the primary advantage of the Falcon, as it is vastly improves worker safety because workers are removed from the cutover. This eliminates the risk that is associated with performing the inherently dangerous task of breaking out.

WORKING ENVIRONMENT OF THE CARRIAGE AND SENSOR

Environment of the Carriage

The Falcon Forestry Claw operates exposed in the outdoor environment of the forest cutover. This introduces non controllable factors into the system. Conditions include varied ambient illumination, changeable atmospheric conditions and temperature fluctuations. The range finding technology must operate effectively in the environment in which the carriage operates.

The above factors can have a profound effect on the performance of range finding systems. To perform to an acceptable standard, the range finder must be able to range effectively over a variety of light and weather conditions.

Another factor that has a large effect on the performance of a range finder is the surface that it ranges from. In this application, the cutover (comprising bare ground, tree stumps and forest residues such as branches and foliage) is the surface from which range measurements are taken. The surface is irregular, highly diffuse, has low reflectivity and has multiple objects arranged in various orientations (tree stems, branches, foliage and undergrowth etc). The range finder system must be able to range off the highly variable terrain that is the forest cutover.

An example of a typical working environment for the Falcon is shown in Figure 5.

Figure 5: Typical working environment for the Falcon Forestry Claw grapple

Location of the Sensor

The range finder system must be able to withstand conditions within the carriage and function properly. It is vital that the sensor is mounted within the carriage housing; this is to shield it from direct impact from objects such as branches or the ground. Modern electronic range finding equipment, which is widely used in industrial applications, must be able to survive the harsh environmental conditions within the carriage for the life cycle of approximately 15 years. The hostile environment within the carriage can be mainly attributed to the internal combustion engine. The ignition pulses from internal combustion engines contribute negatively to the mounting environment of electrical components in two ways.

Firstly, the pulses cause the engine to vibrate in response, and then engine force is transmitted to the chassis by vibration isolators. Traditionally designed vibration isolators often do not maintain a fail/safe vibration environment for electronic equipment (Veprik, 2003). Insufficient isolation can result in severe vibration which can critically affect the endurance of mounted components, soldered joints, connectors etc.

Secondly, internal combustion engines produce waste energy in the form of heat from the conversion of fuel to mechanical energy. Compression engines, such as diesel engines, typically lose 38-70% of the fuel heating value through cooling of the engine and spent exhaust gases (Haidar and Ghojel, 2001). While the exhaust is directed outside of the carriage, the other radiant energy from the engine is dissipated into the carriage. This leads to high temperatures within the carriage, which can induce temperature-related failure modes for electrical components. Research conducted by Mattila and Simecek, 2006, in the field of failure modes of solder interconnections, found that the average number of drops and vibrations that component boards could withstand decreased by 40% when the temperature was elevated up to 70°C from room temperature.

Additional to the vibratory forces that are transferred through the carriage, shock loads are also prominent. The process of grappling stems often results with the grapple colliding with the ground. The shock of this collision is transferred through the carriage and all its internal components. Therefore it is vital that the range finding technology that is chosen is of quality construction, well isolated and with strong vibration and shock resistance. As well as the issues with vibration and high temperatures, the carriage is not water tight. Therefore the range finder system must be sealed to avoid water damage. Figure 6 displays the internal environment within the Falcon Forestry Claw.

Figure 6: Falcon Forestry Claw grapple carriage

RANGE FINDER PERFORMANCE REQUIREMENTS

A set of performance requirements was established for the range finding system; the system must meet these requirements during all operating conditions of the Falcon. It is believed that these are the base line requirements that must be satisfied, so that the operator is supplied with enough information to avoid collisions.

Depth of field

The minimum depth of field of the system, defined by the distance over which the sensor will be able to measure displacement reliably, is specified as 1.5 to 15 m. This range was chosen for two reasons. Firstly, there is no perceived advantage in having a smaller minimum range as the grapple extends down past the carriage. Therefore the grapple is the first part of the Falcon that will collide with the cutover; any range data below this point is redundant. A maximum range of at least 15 m is required. With this span, if the carriage is falling at a very rapid rate of 3 m/s, the operator has 4.5 seconds to react from when the ground is first ranged to the point of collision.

Resolution

Resolution is defined as the smallest increment of change in distance that the range finder system can detect. It is directly affected by the vertical speed of the Falcon. Because the target is moving rapidly, the sampling frequency needs to be increased to reduce error. For the falling rate of 3 m/s, the minimum allowed resolution is 3.7% or 0.5 m.

Accuracy

The measurement of the difference that can be expected between a sensor's reading and the actual distance measured is defined as the accuracy of the sensor. The lowest acceptable accuracy for the system is specified at 0.5 m.

SENSOR SYSTEM SUITABILITY

A weighted decision matrix was used to determine which range finding system was best suited for the Falcon Forestry Claw. Three active range finding methods were chosen for analysis: active triangulation, ultrasonic, and laser range finding. Passive range finding techniques were omitted on the basis that according to the literature they do not perform strongly in outdoor environments. The weighted decision matrix was built on the attributes that were identified as key components which will ultimately define the performance of the range finding system.

By using information from the literature and relating it the operating environment of the Falcon, the performance of each individual ranging system was rated from 1-5 in each category. An ascending scale from 1-5 was used, 1 representing very poor performance and 5 representing excellent performance within the category (Table 1). The scores were then weighted on how important the attribute is to the function of the system. Many of the attributes were ranked with the maximum weight of 5 because they were seen as critical to the system's performance. The weighted decision matrix is shown in Table 2.

Table 1: Attribute rating scale for decision matrix

Rating				
Excellent (5)	Good (4)	OK (3)	Poor (2)	Very Poor (1)

Table 2: Range finder decision matrix

		Active triangulation		Ultrasonic		Laser range Finder	
Selection criteria	Importance	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Operational Range	1	1	1	3	3	5	5
Low Light Performance	1	5	5	5	5	5	5
Bright Light Performance	1	1	1	5	5	5	5
Diffuse Target performance	1	3	3	5	5	3	3
Durability	1	1	1	5	5	2	2
Accuracy	1	5	5	5	5	5	5
Cost	0.5	1	0.5	5	2.5	2	1
Resolution	0.5	5	2.5	4	2	5	2.5
Ease to mount	0.4	2	0.8	5	2	5	2
All Weather Performance	1	2	2	4	4	2	2
Total		21.8		38.5		32.5	

From the weighted decision matrix, it was concluded that ultrasonic sensors were the best candidate for further investigation. Although literature indicates that ultrasonic sensors perform well when ranging off natural continuous surfaces such as legume grass, there was no research found on range performance over forest residues. The clear felled landscape consists of a variety of reflective surfaces such as rocks, bare earth, grass, and tree residues. Measured ranges could vary between the changeable surfaces; it was necessary to establish a field trial to determine how an ultrasonic sensor performs over the cutover.

ULTRASONIC RANGE FINDER FIELD TRIAL

Technical description of the ultrasonic sensor

Measurements were recorded using a model UM30-15113 ultrasonic range finder, manufactured by SICK Sensors. The sensor used in this study was single headed, having one sonic transducer (frequency 80kHz) that acts both as a transmitter and receiver (Figure 7). The operating scanning distance was specified as 6 m. The sensing range was checked against a concrete wall. The sensor was supplied with power from a 12V from an automotive battery and the ultrasonic echo was converted into an output voltage that increased linearly with distance. A volt meter was used to display the voltage, and results were manually recorded.

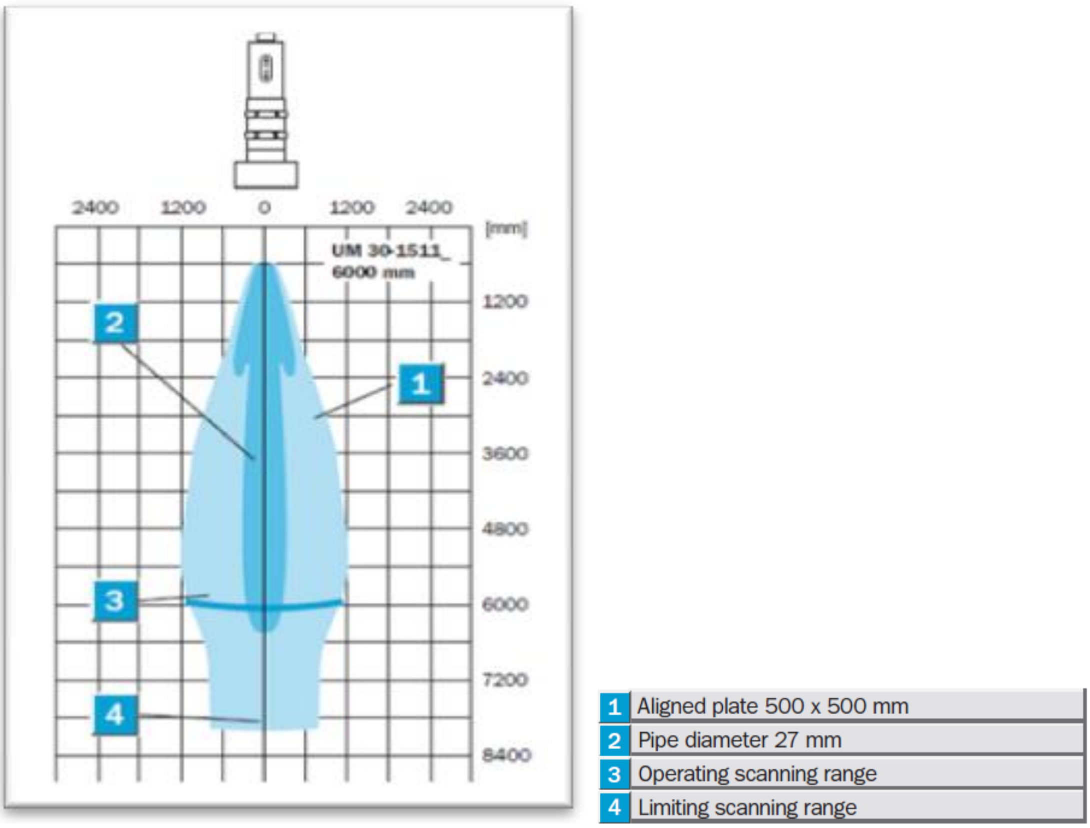

Figure 7: Radiation pattern of the ultrasonic range finder used for the field test.

Field experiment for static measurements

The experiment was conducted on 20th August, 2012 on a clearfell site in Moutere Valley, Nelson New Zealand. Tests were conducted over bare ground, surface wet undulating clay, and over dense forest residues. Residues consisted of *Pinus radiata* branches and needles. The sensor was mounted to a rope which was strung over the harvest site. The use of a rope assured that the sensor was not taking obstructed readings from a mounting frame, instead taking readings only from the cutover surface. The rope was raised and lowered in intervals; a survey staff was used to measure the height from the surface residues to the sensor.

In terms of results, the specified operating scanning distance was not realised during any of the tests. The maximum range over which the sensor generated outputs was 4.0m. This value was obtained for the concrete wall as well as the clay residue. Due to limitations in rope length, it was not possible to extend the sensor out to find a maximum range while testing over the residues.

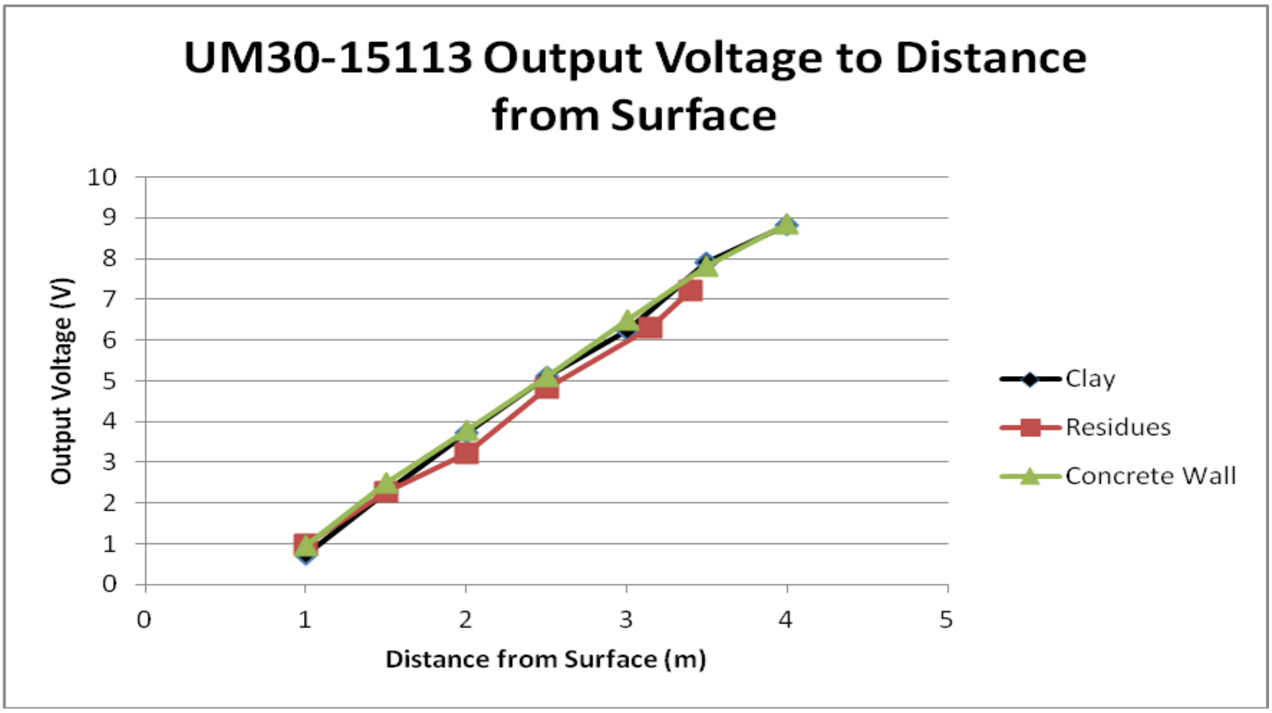

Figure 8: Field test results for the UM30-15113 ultrasonic range finder

Field results showed that the sensor provided a solid linear relationship between voltage and distance when ranging off the concrete wall (Figure 8). Testing of the clay soil produced an overlapping linear trend over the concrete wall data. The forest residues also produced a solid linear trend. When comparing the residue results to the concrete wall results, there is slight variation but it is negligible and falls well within the accuracy tolerance of 0.5 m.

There are clear limitations with this field test, primarily associated with the fact that the test was done in static conditions and only limited data points were gained during data collection. Although the test had limited data points, it clearly indicated that ultrasonic sensors can range over forest residues accurately in static conditions. With more time, further tests could have been undertaken to prove the validity of the results.

The test performed does not replicate the dynamic system in which the Falcon operates. An improvement on the test would be to simulate the operation of the Falcon by moving the sensor along a known profile over the cutover and recording the output voltage. Although a maximum distance value was not obtained over the forest residues when the sensor was attached to the rope, a maximum reading was obtained by rigging the sensor onto the survey staff. It was found that the sensor's maximum range was 4 m over residues when attached to the staff. Attaching the sensor to the staff was not consistent with the test procedure, but it indicated that the sensor's range is not limited by the residues.

One area of concern is that the sensor did not meet its maximum specified range, falling 2 m short. This is likely attributable to the fact that the sensor was second-hand and had previously been programmed for other tasks. Time was taken to re-calibrate the sensor, but this procedure was unsuccessful. If further trials were conducted to replicate the dynamic environment of the Falcon, it is suggested that a brand new sensor with an operating range of at least 15m is purchased for the trial.

CONCLUSIONS

This project investigated and explored the opportunity for providing the operator of a motorised grapple carriage, such as the Forestry Falcon Claw, with real time proximity data using range finding technologies to relate the carriage position to the cutover.

The working environment and performance requirements for a potential ranging system were clearly defined. Active and passive forms of sensing were investigated and it was determined that an ultrasonic time of flight range finding sensor had the greatest potential to provide accurate real time range measurements within the harsh working environment in which the Falcon operates.

A static condition field trial of a UM30-15113 ultrasonic sensor was conducted over clay soil and forest residues. Results showed that the ultrasonic sensor provided accurate range methods over both surfaces but the maximum specified operating range of 6 m was not achieved. The reduced operating range has been attributed to the fact that the sensor was second hand and had been previously calibrated for other uses. Further sensor trials are required to simulate the dynamic operation of the Falcon, preferably with a sensor that has a range of at least 15 m.

From this study, it was predicted that ultrasonic sensors will be fit for the purpose of ranging from the carriage to the cutover, and will endure the harsh environment with the carriage for the service period of 15 years.

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REFERENCES

Bennetto,S. (personal communication, 2012). SICK Sensors Sales Engineer. South Island, New Zealand.

Beraldin, J.B., F. Cournoyer, L. Godin, G. Rioux, M. Taylor 2003. Active 3D Sensing for Heritage Applications In: The e-Way into Four Dimensions of Cultural Heritage, Vienna, Austria, pp 340-343.

Canali, C. G. De Cicco, B. Morten, M. Prudenziati, A.Taroni, 1982. A Temperature Compensated Ultrasonic Sensor Operating in Air for Distance and Proximity Measurements. Industrial Electronics, IEEE Transactions on IE-29(4): 336-341.

Fricke, T. Richter, F. Wachendorf, I. 2011. "Assessment of forage mass from grassland swards by height measurement using an ultrasonic sensor." Computers and Electronics in Agriculture 79(2): 142-152.

Gokturk, S. Hakan, Y. Cyrus, C. 2004. A Time-Of-Flight Depth Sensor - System Description, Issues and Solutions. Computer Vision and Pattern Recognition Workshop, 2004. CVPRW '04. Conference on.

Haidar, J. G. and Ghojel, J. I 2001. Waste heat recovery from the exhaust of low-power diesel engine using thermoelectric generators. Thermo-electrics, 2001. Proceedings ICT 2001. XX International Conference on.

Harrill, H. and Visser, R. 2011. Rigging Configurations used in New Zealand Cable Logging. Future Forests Research Harvesting Technical Note HTN03-11. Rotorua, New Zealand: Future Forests Research Ltd.

Harrill, H. and Visser, R. 2012, June. Matching Rigging Configurations to Harvesting Conditions. Future Forests Research Harvesting Technical Note HTN04-06. Rotorua, New Zealand: Future Forests Research Ltd.

Herbet, M. 2000. Active and Passive Range Sensing for Robotics in proceedings of the 2000 IEEE International Conference on Robotics and Automation, San Fransisco, USA. pp. 102-110.

Ilstrup, D., Manduchi, R. 2010. Active Triangulation in the Outdoors: A Photometric Analysis. Proceedings of the 5th International Symposium on 3D Data Processing, Visualization, and Transmission.

Jarmer, C. B., Mann, J. W., & Atkinson, W. A. 1992. Harvesting timber to achieve reforestation objectives. In S.D. Hobbs (Ed.), Reforestation practices in southwestern Oregon and northern California (pp. 202-231). Corvallis, OR: Forest Research Laboratory. Oregon State University.

Jarvis, R. A. 1983a. A Laser Time-of-Flight Range Scanner for Robotic Vision. Pattern Analysis and Machine Intelligence, IEEE Transactions on PAMI-5(5): 505-512.

Jarvis, R. A. 1983b. A Perspective on Range Finding Techniques for Computer Vision. Pattern Analysis and Machine Intelligence, IEEE Transactions on PAMI-5(2): 122-139.

Lee, W. S. Alchanatis, V. Yang, C. Hirafuji, M. Moshou, D. Li, C. 2010. Sensing technologies for precision specialty crop production. Computers and Electronics in Agriculture 74(1): 2-33.

MAF. 2011. National Exotic Forest Description. Wellington: Ministry of Agriculture and Forestry.

Massa, D. 2011. "Choosing an Ultrasonic Sensor for Proximity or Distance Measurement Part 1: Acoustic Considerations." Retrieved 12 August, 2012, from http://www.sensorsmag.com/sensors/acoustic-ultrasound/choosing-ultrasonic-sensor-proximity-or-distance-measurement-825.

Mattila, T. T.Simecek, J. 2006. Failure Modes of Solder Interconnections under Mechanical Shock Loading at Elevated Temperatures. Electronics System Integration Technology Conference, 2006. 1st.

MBIE 2012. Forestry Sector Action Plan 2010-13. Retrieved 6 14, 2012, from Ministry of Business, Innovation and Employment: http://www.dol.govt.nz/whss/sector-plans/forestry/forestry-sector-plan_07.asp

Moring, I. 1989. Acquisition of three-dimensional image data by a scanning laser range finder. Optical Engineering 28(8): 897-901.

Rioux, M. 1984. Laser range finder based on synchronized scanners. Appl. Opt. 23(21): 3837-3844.

Sabatini, M.R 2010. Airborne Laser Systems Testing and Analysis, NATO Science and Testing Organization.

Sains, H. 1964. "Ultrasonic sensing." Ultrasonics 2(4): 179-185.

Schmitt Industries. 2012. Acuity Sensors. Retrieved 10 2012, from Performance of sensors on specular and diffuse targets: http://www.acuitylaser.com/resources/performance.html

Studier, D.D and Binkley V. W. 1974. Cable logging systems.

Tanzawa, T. Kiyohiro, N. Kotani, S. Mori, H. 1995. The ultrasonic range finder for outdoor mobile robots. Intelligent Robots and Systems 95. 'Human Robot Interaction and Cooperative Robots',

Veprik, A. M. 2003. Vibration Protection of Critical Components of Electrical Equipment In Harsh Environmental Conditions. Journal of Sound and Vibration 259(1): 161-175.

Visser, R. 1998. Tension Monitoring of Forest Cable Systems. PhD Dissertation from the Forest Engineering Department . Bodenkultur University, Vienna, Austria.

Visser, R. 2011. 2010 Benchmarking of harvesting cost and productivity. Future Forests Research Harvesting Technical Note HTN03-10. Rotorua, New Zealand: Future Forests Research Ltd.

Wagner, W. Ullrich, A. Melzer, T. Briese, C. Kraus, K. 2004. From single-pulse to full-waveform airborne laser scanners: potential and practical challenges. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 35 (2004): 201-206.

Xiujuan, L. and Z. Hong 2004. Characterization of acuity laser range finder. Control, Automation, Robotics and Vision Conference, 2004. ICARCV 2004 8th.