HARVESTING TECHNICAL NOTE

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Acoustic Analysis of Mechanical Log Processing

Summary

Acoustic analysis techniques are used to explore the concept that efficient and productive operations sound different to unproductive and chaotic work and to determine if there is a quantitative relationship between sound and work. In addition, the analysis of sound may provide information on productivity and skill of the operator. This report describes the background to acoustic analysis of machine sounds and a first analysis of a forestry excavator-based processor. Sound analysis can discriminate between mechanised delimbing and other tasks on the landing.

Richard Parker, Brionny Hooper, Brooke O'Connor Scion; Keith Raymond, FGR

Introduction

The Human Factors programme of the Primary Growth Partnership "Forestry Work in the Modern Age" (FGR, 2018) aims to develop methods and tools to measure and understand the work of machine operators and be able to monitor changes to their work with the introduction of new innovations. This knowledge will guide engineering design of new technology to improve the operator experience, productivity and safety thereby enhancing human-machine interactions (FGR, 2019). Scion's Human Factors group leads this work and engages specialist expertise when appropriate.

Large forestry machines make considerable noise when working (Figure 1).

Figure 1: Tigercat excavator-based log processor used in the study

Some forestry experts have commented that "A harmonious operation sounds more harmonious". In other words, the sound of a cohesive, productive, and efficient forest operation is different from one that is not. This project aimed to explore the concept of using acoustic analysis techniques to and try to determine if there is a quantitative relationship between sound and work. In addition, the analysis of sound may provide information on productivity and skill of the operator. For example, a novice machine operator may use the machine throttle more aggressively than an expert and so the machine sounds differently. The novice may also drop logs or work slowly so their acoustic signature may be different than that of an expert.

Acoustic analysis is common in the condition testing of machinery to detect bearings that are wearing out or unbalanced rotating components. The military have used acoustic techniques to detect the presence and type of vehicles in terrestrial and aquatic environments (e.g., Altmann, 2004). We will draw on that knowledge and explore the feasibility of analysing the sound from forest operations.

It is often difficult to collect useful data from real work situations because the presence of the researcher can disturb the normal flow of work. Furthermore, high risk workplaces can introduce unacceptable hazards to participants and researchers. Unobtrusive data collection methods are required. These methods must be relatively inexpensive, simple to administer and provide data in a form that is easily analysed.

Forest Growers Research Ltd., P.O. Box 1127, Rotorua. Ph: 07 921 1883 Email: forestgrowersresearch@fgr.nz Web: www.fgr.nz

Kirwan & Ainsworth (1992) identify three levels of intrusion by researchers on a participant. The lowest intrusion level, 'observer unobserved', is using video or other sensors to collect data without the researcher being present. The researcher is completely removed from the workplace.

The study aimed to record log processing activities without the need to observe in person or view recorded video of the activities. This work is the early stages of determining if the smoothness of machine operation can be determined from an audio record. Does smooth harmonious work sound smooth and harmonious? In contrast harried and inexpert work may sound less harmonious and more of a cacophony.

Microphones have been used to monitor work in other sectors. For example, acoustic measurement has been used to detect the presence of military vehicles (Blumrich, 1998; Altmann, 2004) from the sound of the engine and tracks. The vehicle tracks transfer energy through the ground which is picked up by a geophone. This seismic detection might also be of value monitoring forestry machines.

Blumrich (1998) reported heavy-vehicle acoustic spectra consist mainly of lines which form series at a fundamental frequency (lowest frequency) and its harmonics. The engine acoustic series exists with all vehicles; the fundamental frequency—not always present as a line—is equal to the engine rotation rate (for two-stroke engines) or its half (for four-stroke engines). For tracked vehicles, the track produces an additional series with a fundamental frequency approximately equal to the vehicle speed divided by the track-element length. In the acoustic channel, it is mainly produced by the drive sprocket gripping into the gaps between the track elements; in the seismic channel, it is primarily caused by the road wheels rolling over the track elements.

Method

The forestry machine under observation was a Tigercat excavator-based machine which was processing stems on the landing (Figure 1). A microphone was directed at the operating machine from approximately 30m away. This study technique corresponds to 'observer observed' using wearable technology.

A video camera (Garmin) and a Zoom F1 sound recorder (Figure 2) were set up on a tripod 30 m from the operating machine. The video was recorded at a resolution of 1080p (high definition), a rate of 60 frames/second.

The Zoom F1 field recorder and Lavalier microphone collected data on the recommendation of the acoustics consultant at a 24-bit sampling rate and a 48 kHz sampling frequency. The signal was record in mono rather than stereo which reduced the recorded file size and noise. To ensure the sound was not clipped by the recorder the inbuild LCD screen was monitored to ensure sound level did not exceed -12bB.

Figure 2: Zoom F1 digital sound recorder

The purpose of the study was explained to the operator, and he was then free to commence his normal activities. The researcher then left the immediate vicinity of the operator and retreated to a safe area approximately 30 m from the machine (Figure 3). Recording continued for 20 minutes of normal operational activity.

Figure 3: Zoom sound recorder and Garmin video camera monitoring processing machine on the landing. Sound recorder was not held in hand during use but attached to tripod

Coding Analysis

In the laboratory, a coding scheme was set up in the behaviour observation package Boris using the elements described in Table 1 (Friard & Gamba, 2016). The elements were derived from observation of log processing operations and experience.

Table 1 Elements used to describe log fleeting activities

Element	Event Type*
Slew	State
Pick up stem	Point
Delimb stem	State
Cut log	Point

**A state event exists for a period and a point event is instantaneous.*

Coding of the video file into an event log file was performed using the Boris observation window. The play speed and direction of the video file could be controlled with the Boris interface enabling repeated views of an event. The playback controls of Boris observation window were used to start, stop, rewind, and play video multiple times to ensure coding of tasks was accurate. The whole video file was coded, and the codes saved in a synchronous event log.

The acoustic file was downloaded from the Zoom recorder and sent to Marshall Day Acoustics Ltd for analysis. The analysis consisted of a simple plotting of sound pressure level (SPL) in dB and a spectrogram of sound frequency plotted against time with a colour indication of loudness. The task analysis was used as a guide to mark activities of interest on the spectrogram.

Results

Task Element Analysis

Manoeuvring logs requires numerous individual movements to be performed by the operator. The task elements from the video file were presented in a timeline demonstrating the order of activities (Table 2).

Table 2 Example of task elements performed in 75 seconds of analysis

Time mm:ss	Task	Event type
6:00	Pick up stem	Point
6:10	Delimb	State
6:13	Slew	State
6:25	Delimb	State
6:28	Cut log	Point
6:36	Slew	State
6:37	Pick up stem	Point
6:42	Delimb	State
6:48	Slew	State
6:53	Slew back	State
6:54	Pick up stem	Point
7:04	Delimb	State
7:06	Slew	State
7:12	Delimb	State

Only 75 seconds of data are presented in this analysis because graphical representation of more would be difficult to display in this report and would not add any additional information. The purpose is to show that useful information can be identified by this simple acoustic analysis.

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Acoustic Analysis

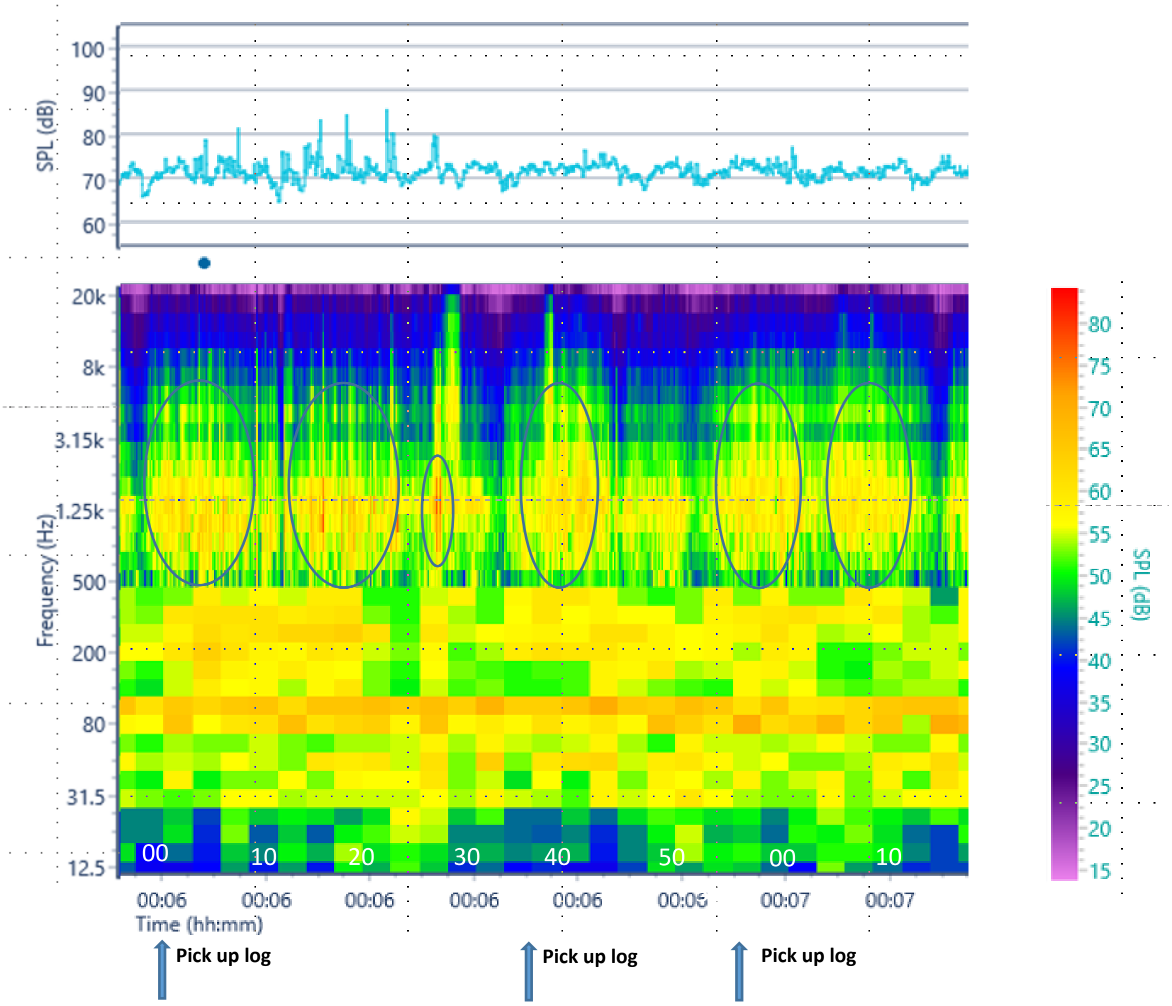

Figure 4: Overall sound level (SPL axis) and sound frequency distribution of a processing machine working on the landing. Large ovals represent periods of delimbing, and the small oval indicates a period of loud log cutting. Colours represent loudness in dB indicated on the scale on the far right.

Figure 4 is a plot (top of chart) of the overall sound level (SPL) and a frequency distribution spectrogram (bottom of chart) of the sound recording. Time slices are every 0.1 seconds and time is represented across the bottom axis.

The overall sound level is showing the very loud 'rattling' sound of the stem being moved through the processing head and being delimbed. Sounds of up to 85 dB are being recorded. The large ovals represent periods of delimbing and these periods do not appear consistently on the SPL plot indicating that overall sound level does not discriminate between delimbing sounds and other sounds from the machine and process.

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Discussion

The current study has shown that we can collect acoustic data from a working processor and identify delimbing. We initially thought that more sophisticated analysis methods such as Fast Fourier Transformation would be needed to detect delimbing. The delimbing process sounds very distinctive with a high pitch and rapid ‘rattle’ which has made detection much easier. Other movements of the machine are more difficult to detect from our simple spectrogram and will require further analysis.

To the authors knowledge this is the first acoustic analysis of a forestry machine to investigate operator work style. Pan & McDonald (2019) used acoustic analysis to estimate the diameter of trees felled with a feller-buncher equipped with a circular saw. Using acoustic analysis, they could predict tree diameter with an accuracy of 90% within plus or minus 7 cm. However, they concluded that this level of accuracy was not sufficient for practical application in forest management.

A hybrid sensor system has been trialled by Sherafat *et al*. (2019) to characterise the activity of construction equipment. Their approach may be more suitable for our forestry problem. They combined data from an acoustic sensor with data from accelerometers using a bespoke data fusion procedure and found a 20% improvement compared with using one data source. This approach complements another project in the current PGP which is using inertial measurement units to measure the motion of forestry machines (Parker *et al*., 2021).

Eventually we want to try comparing experienced operators with novices to see if there is a difference in the harsher and high-frequency sounds indicating less smooth operation. Marshall Day Acoustic consultants will assist our investigation and provide a more high-resolution frequency breakdown.

The results may also be improved with the use of a highly directional microphone which will reduce the influence of noise from other parts of the harvesting operation such as loaders and trucks.

Log processing with an excavator-based machine is a highly skilled operation. Greater experience results in greater levels of dexterity and consequently, greater productivity. This study has been successful in identifying delimbing, some cross cutting and slewing.

Conclusions

Acoustic analysis provides another possible tool to understand work in forestry operations without the need to intrude on the operator or disrupt productive work. We are in the very early stages of learning how to collect useful acoustic data and how to analyse that data. The current study has measured sound from one machine but, in theory, it should be possible to characterise the ‘harmony’ of multiple machines working together.

This study is part of a long-term programme, with much more to be done in collaboration and partnership with sector stakeholders, researchers and innovators, and technology developers and manufacturers. Such collaboration is a key element of the PGP programme and one sure to guide the effective use and adoption of new technology across the New Zealand forest industry.

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