

Chainsaw Vibrations, a Useful Parameter for the Automatic Tree Volume Estimations and Production Assessment of Felling Operations

Raimondo Gallo^{*a}, Filippo Nalli^a, Luca Cortese^b, David Knollseisen^c, Werner Noggler^c, Fabrizio Mazzetto^a

^aFaculty of Science and Technology, Free University of Bozen (FUB), Piazza Università 5, 39100 Bolzano (Italy)

^bMechanical and Aerospace Engineering Department, Sapienza University of Rome, Via Eudossiana 18, 00184 Rome (Italy)

^cAzienda Provinciale Foreste e Demanio, Via Michael-Pacher 13, 39100 Bolzano (Italy)

raimondo.gallo@unibz.it

An innovative approach for the automatic operational monitoring of motor-manual felling activities with chainsaw is here described and discussed. This new system of assessment can be considered as a solution for Precision Forestry (PF) applications and can be employed as a ICT tool for the management of the forest companies. Aim of the proposed system is to manage operational information such as: a) positioning of each felling operation inside the forest, b) measurement of the time spent to carry out the felling, c) estimation of the size of every felled tree, and in the end, d) the analysis of the productivity of the felling operations. This experience is based on the operative principle which considers that the lumberjack, during the actual cutting, drives the chainsaw with the engine at the highest number of rpm. During this action, the generated vibrations reach the maximum amplitude. Some preliminary experiments were conducted during thinning operations in a spruce stand (*Picea abies*), where a dedicated device composed by a triaxle accelerometer (sampling frequency of 10Hz) and a GNSS module were installed on the filter cover of a professional chainsaw (Husqvarna 560 XP). During the test, for each cut, the duration of the vibration with the maximum amplitude and the section cut area were measured and collected, with the assumption that a strong positive correlation exists between these two parameters. The test objectives were to validate such a correlation and to provide a methodology to estimate the volume of each cut plant. To this aim, once entered the diameter of each plant (derived from the estimated section), the volume for each felled tree was estimated through a specific single entry table commonly used by forestry manager. During two consecutive days of thinning operations, 30 trees were felled and monitored and all the operative parameters through the proposed automatic system were recorded. Simultaneously, a manual time study and diameter measurement using respectively watch and calliper, were performed. 20 of these records were used to create a mathematical model for the volume estimation, while the other 10 were used for its validation. Comparing the results obtained by the automatic time study with those from the manual survey, and with the identification of the felling location, very good correlation values were obtained ($R^2 > 0.75$). Beside this, a difference lower than 5% resulted by the comparison between the estimation volume carried out through the new approach and the classic one.

1. Introduction

Productivity is the most important operative parameter analyzed by the forest engineering community in order to assess the amount of work performed by the forest crews and equipment (Cavalli, 2012). Productivity is considered as the product rate output per unit of time (Björheden et al., 1995). Therefore, to obtain this operative information it is necessary to have information of the amount of time spent to do the task as well as the amount of timber harvested. This operative parameter is usually expressed in tons per hour or cubic meter per hour. Thanks to productivity the entrepreneur can assess both capability and efficiency of his own forest company to operate in forest. In other words, by knowing the productivity it is possible to assess if the

performed operations were done in the right ways or were affected by some troubles (i.e. delays, breakdowns, etc.). By identifying the reasons that cause the productivity loss, the entrepreneur can act with corrective actions in order to maximize the production. Beside this, knowing the productivity and the unitary machine cost, the entrepreneur may calculate the support costs during the harvesting operations. Then, thanks to this information, it can decide the most proper selling price for the harvested timber.

Nowadays, the combination among the forest machinery fleet, the environmental and logistics constraints as well as the kind of felling intervention planned, influences the forest company's decisions about the most suitable mechanized chain to use. The forest operations can be divided in two main mechanization processes: low and high mechanized chain. While in the first one the equipment used are generally a chainsaw, a tractor and small yarder, in the other chain are mostly employed harvester, forwarder or heavy yarder.

The machines used in high mechanized supply chain are usually equipped with dedicated on-board computers (OBC). These ICT supports have the task to store and elaborate all the operational parameters collected by the large number of sensors installed on the machines, in order to edit operative reports of the activities. On the contrary, in low mechanized chain, as consequence of the absence of ICT supports, usually, if done, each operator manually fills out the register of the activities.

In the Alpine region, the terrestrial felling machines cannot operate because of the steepness and the terrain roughness of the hillsides. Therefore, in those extreme conditions, chainsaw is the only equipment that can be used to carry out the felling operations (Rottensteiner et al., 2012). Hence, at the end of every working day, the operator should signs the volume of trees felled in order to monitor the work process. Actually, the operators do not fill the register of activities every day, but at the end of the working week or when the harvesting operations are concluded, entering mistakes in the production assessment, as well as the computation of costs. The aim of this work was to develop a Precision Forestry tool driven by a dedicated Operational Inference Engine (OIE): The OIE is a set of mathematics and statistics algorithms usable to translate raw data into operative information suitable to perform an automatic operational monitoring of the motor-manual felling operations (Gallo et al., 2013). In the present work, the first approaches followed to find a solution for the automatic assessment of the operative parameters for the computation of the productivity of the cutting operations, as well as the time spent for the felling, the size of each processed tree and the localization of the felling are described. Goal of the research was to study and developed a tool able to perform, automatically, the assessment of those operative parameters necessary to compile the reports of activity and to monitor input and output of motor-manual felling operations.

2. Material and Methods

The parameters necessary to be assessed are the time to perform the tree processing, the size of the tree, its placement into the forest and the working productivity. In literature is reported that there is a relationship between the diameter measured at the stump (DST) and the diameter at breast height (DBH) (Pond and Froese, 2014). Several studies report that there is also a clear correlation among the effective cutting time and DBH, as well as the engine running time and DBH (Ciubotaru and Maria, 2012; Vusic et al., 2012). Therefore, measuring the effective time spent by the operator to perform the cut, it should be possible to obtain the measure of the stump diameter, the DBH, the volume and also the productivity.

The motor-manual felling operations are characterized by unsteady operation conditions, because of the continuously adjustments made on gas throttle. Indeed, when the lumberjack performs an effective cutting operation, he drives the chainsaw with wide-open throttle, otherwise he maintains the device at the minimum rpm or he switches off the chainsaw in order to evaluate or conclude the cut using the lever or the wedge. Hence, only when the chainsaw runs with the throttle completed opened the engine reaches the highest rpm, generating vibrations with large amplitude. Therefore, by measuring the duration of the vibrations with the maximum amplitude it will be possible to calculate the time spent to carry out the felling.

A preliminary test was carried out in the Latemar Forest, Bolzano (Italy) in a pure Norway spruce forest (*Picea abies* L.), where a Husqvarna 560 XP® chainsaw, driven always by the same operator, was monitored. For the automatic parameter assessment of vibrations, it was used a BeanDevice® AX-3D tri-axle accelerometer (± 2 G), with a WI-FI communication with an external data logger, whereas to assess the localization of each felled tree as well as the movements of the operator was employed an Ashtech® GPS MobileMapper 6, with 12-channel singular frequency. While the accelerometer was set with 10Hz frequency of sampling, the GPS was set at 1 Hz. These devices work independently each other, so in post-processing a manual data synchronization was performed. The accelerometer was installed on the cylinder cover top with screws. Considering the guide bar as reference, the x-axis was pointing leftward, the y-axis backward, while the z-axis upward. As consequence to the rounded profile of the cover, a rubber sheet of 5×10^{-3} m height was placed in between to ensure a good adherence of the device. The external antenna of the GPS was directly fixed at the operator's shoulder (Figure 1).



Figure 1: The left figure shows the chainsaw equipped with accelerometer, while the right shows the operator during the felling procedure. In the white box, fixed at the belt, is placed the GPS.

Before the beginning of the test, DBH and DST (at the level of the performed cut) of each selected tree were measured, as well as their coordinates.

During the test, the GPS was run in continuous, while the accelerometer was remotely turned on and off, at the beginning and at the end of each felling. At the same time, elemental time study was performed through a stopwatch. Beside this, all the felling operations were recorded with a camera. During the test, three repetitions for each diameter class (CL) from 1 to 10 were done. In total, 30 felling operations were monitored. The first step of the OIE was the recognition of the felling session (FS). The FS starts when the chainsaw is turned on, and it finishes when the felling operation is concluded, hence when the operator processes the entire tree and turn off the equipment. During the FS two distinct phases were performed: the felling cut and the bucking and delimiting phase. Through the felling cut, the lumberjack performs the separation between the trunk and the stump, while during the bucking and delimiting he cuts the branches and he carries out the cut of the stem into logs. During the preliminary test, this recognition was manually performed, but in subsequent studies it will be performed automatically through the analysis of the spectrum of the vibrations. The entire recorded dataset corresponded at the processing time (PT), as well as the amount of time spent to process a tree into logs suitable to be harvested.

For each FS, raw data elaboration starts with the polynomial summing of the acceleration values recorded on each axis, in order to consider all the vibration components. Then, at this point, it was applied a dedicated algorithm able to recognize if a single record corresponds to a vibration at high or low rpm. This algorithm, core of the OIE, investigated the standard deviation among the previous and the next one record. If the computed value is higher than the set threshold, the analysed record is classified as high rpm, so effective cutting. The sum of all these events determines the effective felling time (EFT).

The felling operational parameters of 20 trees, randomly selected, were used to develop a prediction model for the estimation of DST and DBH. The EFT parameter was used as the independent variable to obtain this model. The operative parameters of the other 10 trees were used for the validation of the models.

In forestry science, the DBH is the parameter used to estimate the volume of the selected plant. Thus, using the DBH calculated with this model, through a specific single entry table commonly used by forestry manager, was estimated the volume for each felled tree.

All the collected GPS data were manually post-processed in order to split the entire dataset and to synchronize it with each felling operation. Therefore, the first GPS point of the dataset corresponded at the beginning of the felling procedure. The felling operation starts in proximity of the selected tree, so all the points recorded by the GPS are considered as felling operations if they are far from the first record at a maximum distance of 1.5 m. Hence, a cloud points was isolated, and it corresponds to the movements carried out by the lumberjack during the cutting. The coordinates of the stumps were obtained by calculating the average coordinates of the selected cloud. These results were then compared with the GPS points collected during the selection procedures of tree felling. In order to evaluate the accuracy in the stump geolocation, the distance among the points and the centroid of the collected dataset was calculated. The coordinates of the centroid were computed by averaging the coordinates of the entire dataset.

3. Results and discussion

Usually, during the cutting operation, the lumberjack does not perform a single cut, but he performs several cuts according to the felling technique adopted and the necessary corrections to fell the tree in the right way. For these reasons, during the manual time study, the surveyor encountered several problems to properly manage the recording, in order to identify the time referred at the effective cut. Therefore, the time study was realized using the recorded videos, attempting to obtain a more precise evaluation. This is explained by the gap between the two coefficients of correlations ($r=0.85$ instead of $r=0.78$) when a comparison between manual and automatic time study was done. As consequence, the Authors decided to use the materials collected by video analysis as reference for the elaborations, instead that one obtained by stopwatch. This result highlighted the difficulty to perform a good and a reliable manual time study with a stopwatch for those operations characterized by fast movements.

3.1 Model validation

Due to recording issues, one of the sample of the validation dataset was not usable. The EFT, computed from the vibrations analysis carried out by the OIE, was the independent variable used to calculate DST and DBH, Eq(1) and Eq(2).

$$DST = 6.1861 \sqrt{EFT}; \quad R^2=0.71 \quad (1)$$

$$DBH = -0.00177 DST^2 + 0.88638 DST - 1.90016; \quad R^2=0.95 \quad (2)$$

In Table 1 the comparison between the estimated parameter and those recorded manually is reported.

Table 1: Summary of the validation results. The measurements collected by manual survey and time study are reported on the left, while the results obtained by the application of the proposed methodology are shown on the right.

Tree ID	Manual measurements					Automatic measurements				
	MTS video (s)	DST (cm)	DBH (cm)	CL	Volume (m ³)	ATS vibrations (s)	DST (cm)	DBH (cm)	CL	Volume (m ³)
3	50.2	49	36	4	1.29	71.8	52.4	39.7	5	1.69
5	63.0	55	38	5	1.69	60.9	48.3	36.8	4	1.29
6	77.2	59.5	43	6	2.15	90.8	58.9	44.2	6	2.15
7	76.1	63	48	7	2.66	120.1	67.8	50.1	7	2.66
8	27.9	27	20	1	0,32	26.8	32.0	24.7	2	0.57
16	50.2	46.5	30	3	0,90	51.2	44.3	33.9	4	1.29
18	24.5	32.5	25	2	0.57	27.9	32.7	25.2	2	0.57
21	95.5	77.5	55	8	3.21	107.1	64.0	47.6	7	2.66
29	174.4	81.0	58.0	9	3.70	178.8	82.7	59.3	9	3.70
<i>sum</i>	<i>638.9</i>	<i>491</i>	<i>353</i>	-	<i>16.49</i>	<i>735.4</i>	<i>483.1</i>	<i>361.4</i>	-	<i>16.58</i>
<i>mean</i>	<i>71.0</i>	<i>54.6</i>	<i>39.2</i>	-	<i>1.8</i>	<i>81.7</i>	<i>53.7</i>	<i>40.2</i>	-	<i>1.8</i>

On average, the results obtained by the preliminary OIE elaboration show that the automatic system has a tendency to underestimate in both cases the diameter (DST = 2.5%, DBH = -1.6%). This difference can be due to the delays in stopping the chronometer that may happen during the manual time study, considering both methods of assessment (video and field). Comparing the results obtained for both diameters, applying a t-test, no statistical differences were found (DST, p-value=0.674; DBH, p-value=0.464). The highest differences of DBH was equal to 7.4 cm (in absolute value) and recorded for the tree ID 21. Indeed, before starting the felling process, the operator accelerated the chainsaw for several seconds in order to revving the engine. Therefore, the effective time of felling was overestimated due to the higher amount of recorded vibrations causing an underestimation of both diameters. The differences in the CL identification are due to the estimation system used. Indeed the CL ranges every 5 cm, so it is highly possible that errors will be found

mainly when the diameter values are on the boundary between two consecutive CLs. Therefore, when the FS starts with uncontrollable situations such as revving the engine or removal of the lower obstacles (branches), the estimations EFT, DST and DBH can be strongly influenced. As reported in a specific study (Fisher, 2010), by using the data collected by the accelerator it is possible to establish the chainsaw position in the space. So, in an easy way, it is possible to know if the chainsaw is working in horizontal (typical position during the cutting) or vertical (position during obstacle removing).

3.2 Tree geolocation

The geolocation of the stumps was performed for the entire dataset. Aim of this part was to evaluate if the geo-localization of the tree, during felling and selection processes through GPS, gave back results with enough accuracy, also under coverage. Due to energy supply issues with the GPS, the data of five trees were not recorded. In average, the difference recorded between two points identifying the same tree was 3.7 m, ranging between 1.4 m and 7.8 m. While, considering the distance from the centroid, very strong correlation value was obtained ($r=0.98$).

Besides, overlying the identified points on the forest parcel maps, it is also possible to identify with good precision the forest plot on which the felling operations are performed (Figure 2).

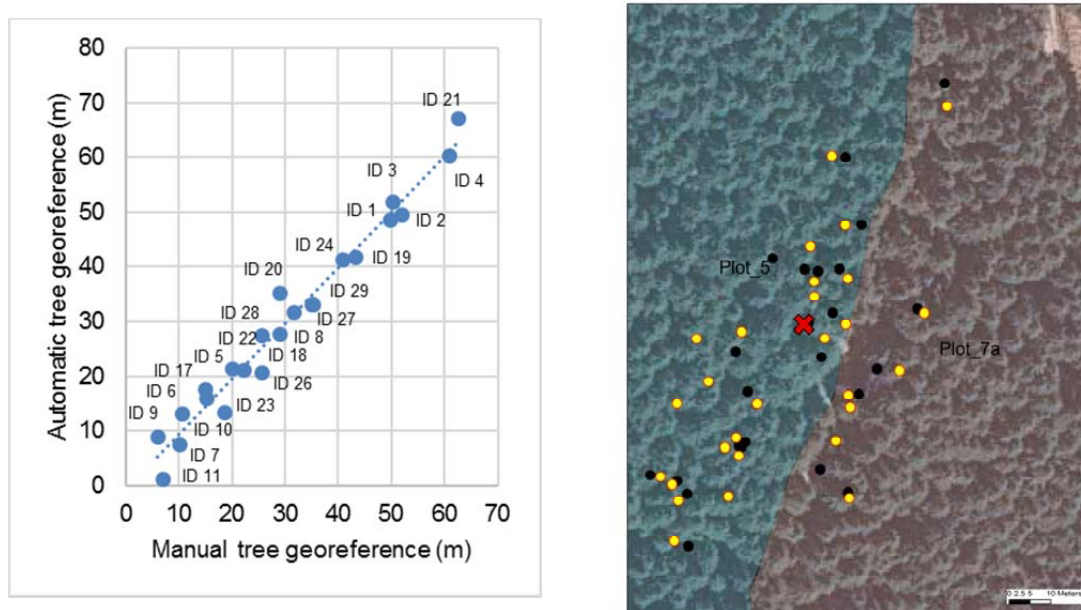


Figure 2: In the left figure, was reported the comparison of the distances from the centroid, computed from the automatic and manual assessment, while on the right one is shown the graphical identification on map of the felled tree. This accurate identification permit an easily identification of the plot where operations are performed.

However, the use of a GNSS unit with a GPS receiver in single frequency permitted to obtained satisfactory results in terms of accuracy under coverage. The use of a GNSS with double constellation can improve the measurement accuracy. The capability of the system to recognize both the tree processed and the plot on which the felling is performed, can be used to automate the tree selection process and check procedures.

4. Conclusions

Aim of the present study was to evaluate if, by analysing the vibration generated by the chainsaw, it was possible to estimated operational parameters such as effective felling time, processing time, volume estimation and productivity. Despite the small number of repetitions and samples, very interesting and important results were achieved. These good results will be considered as the basis for further improvement of the assessment methodology.

Up to now, the implemented OIE permitted to elaborate, separately, the data collected by accelerometer and GNSS module, achieving very satisfactory results in term of capability and accuracy. The small number of performed trials was a weak point for the system development, because of uncontrolled situations (such as

the chainsaw warming up, the removing of the branches or the presence of buttresses) that sensitively affect both mathematical models. In order to limit this issue, more samples will be recorded in the next months. In the present work, about the productivity no results were reported because the PT was not calculated. In order to increase the automation of the elaboration processes, must be planned a synchronization of vibrations and GNSS acquisitions. To achieve this aim, an innovative equipment was designed in accordance with the research conducted (Figure 3), and it will be test in future studies.

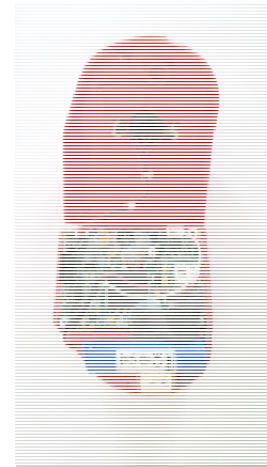


Figure 3: Those pictures represent the innovative developed device. It is a dedicated and customized device, which perform synchronized (10 Hz) acceleration and GNSS detections.

In conclusion, the positive results here obtained highlighted that the application of the proposed approach can be considered as a good and interesting tool for the volume estimation and the identification of felled tree. To sum up, the proposed methodological approach can be seen as an innovative operational procedure of PF. Indeed, this can be a useful tool to obtain operative information for the automatic compilation of the field activity registers, suitable to be used for certification and traceability processes. This tool can be also employed for the operative costs estimation, if integrated with similar devices applied on other machines involved in the logging.

Acknowledgments

Research funded by the Autonomous Province of Bozen – TN2203, MONALISA Project. The Authors would to thanks the Provincial Forest Company for the collaboration and support during the field activities.

Reference

- Björheden, R., Apel, K., Shiba, M., Thompson, M.A., 1995. IUFRO forest work study nomenclature. Swedish University of Agricultural Science, Department of Operational Efficiency, Garpenberg, 16.
- Cavalli, R., 2012. Prospects of research on cable logging in forest engineering community. *Croatian Journal of Forest Engineering*, 33(2), pp.339-356.
- Ciubotaru, A., Maria, Gh.D., 2012. Research regarding structure of working time in spruce felling with mechanical chainsaw Husqvarna 365. *Bulletin of the Transilvania University of Brasov*, Vol. 5 (54) n. 1.
- Fisher, C.J., 2010. Using an accelerometer for inclination sensing. AN-1057, Application note, Analog Devices. 1-8.
- Gallo, R., Grigolato, S., Cavalli, R., Mazzetto, F., 2013. GNSS-based operational monitoring devices for forest logging operation chains. *Journal of Agricultural Engineering*, 44 (2), 140-144.
- Rottensteiner, C., Tsioras, P., Stampfer, K., 2012. Wood density impact on hand-arm vibration. *Croatian Journal of Forest Engineering*, 33(2), pp.303-312.
- Pond, N.C., Froese, R.E., 2014. Evaluating published approaches for modelling diameter at breast height from stump dimensions. *Forestry*, 87, 683-696.
- Vusic, D., Zeljko, Z., Turk, Z., 2012. Productivity of chainsaw felling and processing in selective forest of Croatia. In *Proceedings of FORMEC Conference "Forest Engineering – Concern, knowledge and accountability in today's environment"*. Dubrovnik – Croatia (2012).