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Research Article

Solutions for the automation of operational monitoring activities for agricultural and forestry tasks

Lösung zur Automatisierung der betrieblichen Überwachungsaktivitäten bei agrarischen und forstlichen Arbeiten

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Summary

An innovative approach for the automation of operational monitoring activities in agricultural and forestry tasks is described and discussed in this article. This approach can be considered as a solution for Precision Agriculture and Precision Forestry applications and can be used as an information and communication technology (ICT) tool for the management aims by a variety of agricultural and forestry companies. The aim of the proposed concept is to develop a system, composed of both hardware and software units, with the ability to collect and manage operative raw data and then to translate them into operational information that will be used in decision-making processes. All the procedures will be carried out automatically, in order to ensure an objective compilation of the field activity register. Thus, the entrepreneur will have all the operative information automatically updated in a dedicated database system. All the obtained documents can then be used for certification and traceability processes, if required by the procedural guideline, as well as to satisfy any other management tasks, including the estimation of the actual operative costs of the farm.

Keywords: Operational monitoring, precision agriculture, precision forestry, ICT, sensors

Zusammenfassung

Die Studie beschreibt einen innovativen Ansatz für die Automatisierung von Betriebsüberwachungsaktivitäten bei agrarischen und forstlichen Aufgaben. Dieser Ansatz kann als eine Lösung für Anwendungen der Präzisionslandwirtschaft und Präzisionsforstwirtschaft betrachtet werden und kann als ein Tool der Informations- und Kommunikationstechnik (ICT) für die Managementziele einer Vielzahl von Agrarumweltunternehmen eingesetzt werden. Ziel des vorgeschlagenen Konzepts ist es, ein aus Hardware- und Softwareeinheiten bestehendes System zu entwickeln, das in der Lage ist, operative Rohdaten zu sammeln und zu verwalten und diese dann in operative Informationen zu übersetzen, die bei Entscheidungsprozessen verwendet werden. Alle Verfahren werden automatisch durchgeführt, um eine objektive Zusammenstellung des Feldaktivitätenregisters zu gewährleisten. Der Unternehmer bekommt somit automatisch alle operativen Informationen in einem eigenen Datenbanksystem aktualisiert. Alle erhaltenen Dokumente können dann für Zertifizierungs- und Rückverfolgbarkeitsprozesse verwendet werden, sollte dies in der Verfahrensrichtlinie gefordert werden, sowie zur Erfüllung anderer Managementaufgaben, einschließlich der Schätzung der tatsächlichen operativen Kosten des Betriebs.

Schlagworte: Betriebsüberwachung, Präzisionslandwirtschaft, Präzisionsforstwirtschaft, ICT, Sensoren

1. Introduction

Operational monitoring refers to all those tasks that are necessary to monitor a survey and report all those information required to get an overview of the working processes performed to accomplish a specific activity. The operational monitoring is carried out to ensure a continuous traceability of the input of a system. In the agro-forestry sector, the assessment of the abovementioned information is a strategic point to be monitored in order to optimize all the resources and maximize the profits.

Through the operational monitoring, a large amount of useful information about the management and the logistic of each activity performed by a farmer or lumberjack were collected. With this procedure, the information on the productivity, the efficiency, and the estimation of input and output can be provided. Owing to the strategic importance of the collection and elaboration of this information, combined to the growing up of dedicated information and communication technology (ICT) systems, new solutions of Farm Management Information System (FMIS) were developed and used. Fountas (2015a) considers the FMIS as an electronic and ICT tool suitable to generate operative information acceptable to be used by a farmer, in order to carry out decisional tasks through well-established procedures for collecting, processing, and elaborating data. Nowadays, all the operational data necessary for a system to perform all the processes is based on manual entry (Nikkilä et al., 2010). In theory, operators should collect and enter all the operative data at the end of each activity or, at least, at the end of each working day. Therefore, during the job, all input and output should be noted by an operator and then entered inserted into the FMIS. Farmers consider these tasks as highly time consuming, and they do not always accomplish it for lack of time. Hence, the FMIS is filled up during the weekend or at the end of the entire operation, which leads to uncertainties and missing information because of forgetfulness.

The aim of this work is to describe the approach and the technologies developed to carry out automatic operational monitoring for three common operations in the agro-forestry sector: apple harvesting, timber yarding, and motor-manual felling with chainsaw. The devices that are described will be an active support for Precision Farming and Precision Forestry approaches. The provided system will be able to automatically collect and interpret all the operative parameters for achieving management and logistic information. This automatic system will permit not only to improve the efficiency of human work but also to reduce it by speeding up the processes of operational parameters acquisition, improving the production, and motivating skilled work (Lopes and Steidle Neto, 2011). At the end, this new concept of intelligent system is capable of translating ex-post or actual operative parameters into information, in order to automatically perform an objectivity compilation of the field activity register. Thus, the entrepreneur will have automatically updated all the operative information in a dedicated database system. All the obtained documents can then be used for certification and traceability processes, if required by the procedural guideline, as well as to satisfy any other management tasks, including the estimation of the actual operative costs of the farm.

2. Materials and methods

2.1 The approach

The aim of this research is to develop an integrated system capable of performing an automatic operational monitoring of field activities in order to carry out an automatic compilation of the field activity registers. Hence, the final target is to develop a management tool that has the ability to reduce the stress of a farmer or a lumberjack, allowing them to concentrate only on the planned operations and forgetting all the documents compiling procedures. To achieve the research goal, different innovative hardware and software solutions were developed according to the monitored operation. Generally, the proposed solution is composed of a prototype Field-Data Logger (FDL) coupled with other sensors.

The FDL is the core of the system. It is an embedded unit with its own identification code to identify the machine on which it is installed. According to the operation and the machines' constructive layout and power supply possibilities, different units were developed. Anyway, all the units are characterized by having an accelerometer module and a Global Navigation Satellite System (GNSS) unit that has the ability to acquire double constellations: the Global Position System and GLObal NAvigation Satellite System (GPS and GLONASS). The system is provided with a multiprocessor that drives all these components, collects the data from the connected sensors, and carries out the first data processing. All those embedded components are contained in a commercial or customized IP67 plastic box.

The space availability and the possibility of connection to the electric system of the machine determine the dimension and the presence of external batteries. The different solutions developed to conduct the experiment are shown in Figure 1.

The embedded accelerometer has the aim to turn on the datalogger automatically when a vibration overpasses a well-determined threshold. The set threshold refers to the switching on of the machine's engine or its displacement. When the FDL is on, a maximum of 30 s of warm-up period is required for the GNSS acquisition and for the connection to the phone network (where present), via General Packet Radio Service module (GPRS). The data recording starts when the GNSS unit receives the satellite signals. Different fixing sampling frequencies were set according to the operation to monitor (0.2 Hz for field operational monitoring, 1 Hz for chainsaw monitoring, and 0.5 Hz for yarding monitoring). At the same time, when the recording procedure starts, the multiprocessor synchronizes the raw data collected by the GNSS and by the other sensors.

The three FDL were connected to different sensors according to the operation to monitor and the goal to achieve.

1. Tractor-FDL: The datalogger was mounted on the tractor's cab and it was equipped with a radio-frequency identification (RFID) antenna in order to read the code transmitted by an active RFID transmitter installed on an implement. Thanks to the double code (datalogger + transmitter), it is possible to identify the power unit and the implement coupling, allowing the identification of *who* did *what* during a determined working session.
2. Yarding-FDL: The datalogger was mounted on the carriage and connected with a load cell and an inclinometer. Thanks to the embedded GNSS module, the system is able to carry out an automatic time study by recognizing all the elemental phases (outhaul, hook, inhaul, and unhook) as well. Meanwhile, the load cell and the inclinometer were placed between the hook and the chokers and on the choker, respectively. These sensors were used to measure the pulling force applied by the carriage and the consequent inclination of the steel wire in case of dragging during the inhaul phase. The aim of this application is to have an automatic and fast estimation about the hauled weights without the need of any manual measurement for the operator during the hooking phases. For this computation, two assumptions were necessary. The first refers to the weight of the load above the tying point, which was considered negligible because it is much smaller than the rest. The second was the friction coefficient during high skidding operations, which was set to 1.25 (Samset, 1985) in order to calculate the resistance because of the component of log's weight discharged to the ground in case of dragging. For validating the first assumption, four points of application of the choker (at 2%, 5%, 10%, and 20% of the total log's length from its upper top) were evaluated, in order to investigate if this variable could influence the weight assessment. The estimations obtained by the system can then be evaluated by comparing the results obtained by other applications (e.g., Chainsaw-FDL and sawmill scaling).

Figure 1. Three developed FDLs: On the left side the Tractor-FDL, in the center the Yarder-FDL, and on the right side the Chainsaw-FDL. The Tractor-FDL is the energy supplied by the electric circuit of the tractor, while the others foreseen the use of external batteries.
Abbildung 1. Die Abbildungen zeigen die drei FDL: links der Traktor-FDL, in der Mitte der Kippmastgerät-FDL und rechts der Kettensägen--FDL. Der Traktor-FDL wird durch den Stromkreis des Traktors mit Energie versorgt, während die anderen die Verwendung von externen Batterien vorsehen.

3. Chainsaw-FDL: The datalogger was mounted on the top of the air-filter cover. It is composed of a tri-axles accelerometer in order to monitor all the acceleration generated by the engine as well as the displacement of the equipment in the space. Then, by measuring the amount of time spent at high revolutions per minute (rpm) (when the chainsaw does an effective cut), it was possible to measure the time spent for the cutting, which was suitable to estimate the diameter at the stump level, the diameter at breast height, and, finally, the volume of the entire tree.

All the synchronized data are stored in a buffer memory or in a mini-SD. They can be downloaded manually through Universal Serial Bus (USB) connection or via radio modem if the GPRS module is present. All the collected data are then uploaded in a server. Here, a Relational Database Management System (RDBMS) is implemented in order to store and elaborate the raw data. Here, all the stored data are organized in tables in order to be analyzed by the so-called Operational Inference Engine (OIE). Authors considered the OIE as a set of mathematical and statistical procedures that have the ability to elaborate and translate raw data into useful information. Therefore, thanks to specifically developed algorithms, which are driven by the OIE, it is possible to interpret the raw data in order to obtain an operative monitoring of the field activities (Mazzetto et al., 2012). In chronological order, generally, the OIE analysis

- Identifies the Working Sections (WS) (which is considered as a sequence of activities between two switching on/off subsequent events);
- Eliminates possible fixings classified as outliers (all the records at a distance (d) higher of $d > d_{avg.} \pm 2\delta$ from the centroid of collected data set);
- Classifies the different working phases (effective work (EW), stops, auxiliary activities, maneuvers, breaks, transports, and displacements according to the monitored operation) by applying specific algorithms according to the type of operation to be analyzed.
  In case of orchards, the most common operation involves activities that must process a field surface following parallel and contiguous paths determined by the direction of the crop rows. In such a case, fixings that can be classified as EW are the ones that (i) have a coupled implement, (ii) are inside a field, (iii) are performed following a parallel pattern, and (iv) are associated with values of speed and direction that must be included into an expected range.
  In case of forestry sector, the aerial logging operations are those activities carried out to transport felled trees from the felling area to the landing area, where they are processed and stored. The related EW is thus determined by grouping the fixings featured by having a given speed range and a given direction (the same along which the skyline is tensioned). The mass of the transported load is here estimated, measuring the applied pulling force and the inclination of the choker.
  Concerning the chainsaw monitoring, the felling is an activity performed to cut and process trees. The related EW is thus determined by measuring the time ranges linked to high vibration levels generated by the chainsaw, here a threshold of an acceleration higher than 1.4 m/s^2 was considered to identify the effective cutting operation.
- All the fixings that are classified as EW are then clustered into common spaces on a map in order to identify common areas, centroids, or segments on a direction in case of field work in orchards, felling, or yarding activities, respectively. The approach is described in detail in literature (Mazzetto et al., 2017, Gallo et al., 2017, Gallo et al., 2013).
- The synchronization of GNSS data with the data collected from the sensors to compute, according to the activities, the working coverage rate on each crop unit, the productivity (hence, also the tree volume), the worktimes occurred during the current WS, as well as a summary of all the consumed inputs.

As the also OIE manages algorithms based on spatial analysis, it is necessary to map the entire farm as well as the forest parcels boundaries.

All the computations performed by the OIE are then summarized and displayed on a Web-Geographical Information System (GIS) platform for an easy and a quick consultation for the entrepreneur. Thus, a final user can access, through his/her domain and own credentials, his/her personal page, in order to monitor and check all the supervised operational parameters (Figure 2).

2.2 System validation

All the proposed systems were validated by comparing the time duration assessed by the OIE's elaborations and the manual survey for the same operations.

The Tractor-FDL was tested during harvesting operations in apple orchards. Here the operator had the task to bring empty fruit bins to the harvesting machines placed inside the interrow of the same or different parcels, to pick up full bins and to bring them to the trailer. During this test, the effective harvesting operations, stops, and displacements were analyzed.

The Yarding-FDL was tested during logging operations using cable cranes. Here two different tests were performed: one on the capability of the system to carry out an automatic time study, while the other on the capability to assess the weight of the transported load during the inhaul. For the first test, the validation consisted in the automatic identification of the four typical working phases (outhaul, hooking, inhaul, and unhooking), the assessment of each duration, and the total number of cycles done, comparing the results with a manual time study. Meanwhile, for safety reasons, the weight assessment was performed in an in-scale yarding system. Here, the results obtained by the inference engine are compared with a reference value of the weight manually measured through a scale.

The Chainsaw-FDL was tested during motor-manual felling operations. The validation procedures consisted in the comparison of the volume calculated by the developed system with the same parameter estimated using specific single entry tables.

3. Results and discussions

3.1 Tractor-FDL

In literature, only documents that describe the ontology, the data flows, and the functioning of the FMIS were found (Sørensen et al., 2011; Fountas et al., 2015a; 2015b); nevertheless, no quantitative results as presented in this study were reported.

Testing of the Tractor-FDL was carried out by monitoring and evaluating 23 working sessions. During the validation, the total duration of the working session, the work in field, the stops, and displacement were assessed. In Table 1, a summary of the surveys was reported.

Very small differences were found by comparing the two methods. Indeed, considering the duration of each work session, the work in field, and the stops, the differences were lesser than 2%, in absolute terms, while they were equal to 11% for the displacements. In terms of minutes, these differences are equal to 0.09, 0.69, 0.40, and 0.98 for working session, work in field, stops, and displacements, respectively. Very good correlation values were recorded, and no statistical differences were recorded between the two methods ($p > 0.05$). The higher differences in the displacement phases can be due to a non-proper identification of the beginning and ending of the phase by the

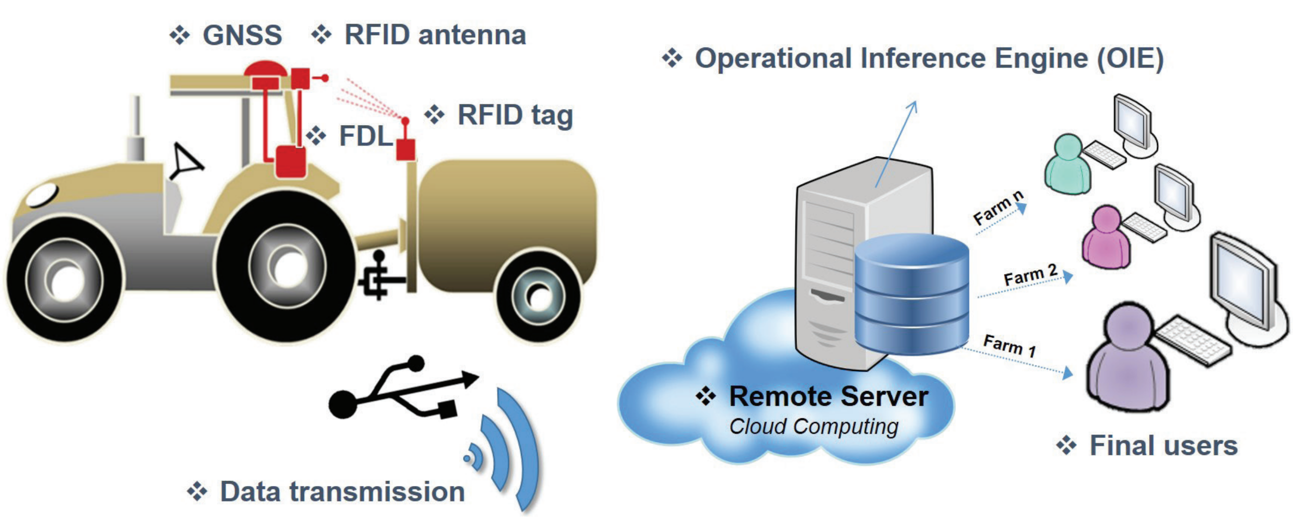

Figure 2. The conceptual model followed is reported. On the left side the collection and transmission of the raw data and on the right side their elaboration and consulting through a Web-GIS platform.
Abbildung 2. Das angewandte Konzeptmodell: Links die Sammlung und Übertragung der Rohdaten, rechts ihre Ausarbeitung und Beratung durch eine Web-GIS-Plattform.

automatic survey. Indeed, owing to a non-correct data interpretation by the OIE, more fixings than the actual ones are identified as displacements instead of effective work, with the consequence of errors in the automatic assessment. This happens because a part of the EW on the parcel border is considered displacement by the OIE. This happens because the fixings jump outside the parcel as a consequence of GNSS drift, because of multipath or cycle slip phenomena. The multipath consists in the bouncing of the satellite signals because of the metal frame of the machine or the implement and the consequent missing or double acquisition of the same signal. The cycle slip happens when one or more satellite signals are lost or acquired, determining a recalculation of the position with the consequent temporary reduction of the GNSS signal accuracy. In this case, these points are considered as displacements by OIE's elaboration. To solve this problem, a buffer zone should be applied around the field boundary to enlarge the parcel surface.

3.2 Yarding-FDL

During the studies, because of safety reasons, the testing of the Yarding-FDL was split into two different tests: the first consisted in an automatic time study, while the second consisted in an automatic weight assessment in an in-scale system. The automatic time study trials were set in four harvesting sites of the Alpine region (North-East of Italy). During this study, a total of about 41 h (2,450 min) of effective manual time study was performed and an amount of 228 working cycles have been detected. Of the total working cycles detected by the automatic procedure, 220 cycles were successfully recognized. Hence, for gross time study, Yarding-FDL recognized the 96.5% of the working cycles, as reported in Table 2.

Some working cycles were missed because of a low number and a bad displacement of satellites. If the missed cycles were not considered, the differences recorded between manual and automatic time study would be below 1%. For the analysis of the elemental time study, the missed cycles have not been considered in the discussion of the result (Table 3).

High correlation values ($R^2 > 0.8$) have been obtained for both the gross and the hook and unhook elemental phases. Lower correlations were recorded for the outhaul and inhaul, probably due to the dynamic characteristic of these operations. However, in terms of time, the recorded difference was always lesser than 10%. This means that the system is able to automatically carry out a time study analysis with an error of less than 10 s.

Regarding the weight assessment, the value of the load's weight transported during 120 inhaul operations have been registered and collected. For each evaluation, the parameters collected were the weight and the inclination of the choker during the dragging. Indeed, the friction generated by the contact between the soil and the log generates a resistance proportional to the weight of the load. During the test, two repetitions with four different distances of choker application (CK-nn%) were carried out, and the estimated weight was compared with the reference weight (Table 4). A coefficient of friction for high skidding operation of 1.25 was used to calculate the weight discharged to the ground during the pulling operation. Also in this test, a high R^2 (> 0.9) was obtained by comparing the estimated and the manually measured data set, for both the repetitions as well as for all the different considered choker application points. The difference in terms of weight is less than 6%, corresponding to 2 kg. The results here obtained underline the capability and reliability of the proposed system to carry out an automatic weight

Table 1. Tractor-FDL: Summary of the results obtained for the manual and automatic operational monitoring. A_S: automatic survey, M_S: manual survey.
Tabelle 1. Traktor-FDL: Zusammenfassung der Ergebnisse für die manuelle und automatische Betriebsüberwachung. A_S: automatische Vermessung, M_S: manuelle Vermessung.

	Total time		Mean time		Standard Deviation		Difference		R^2
	A_S	M_S	A_S	M_S	A_S	M_S	–	%	
Working session (s)	1519.2	1517.2	66.1	66.0	49.0	49.0	–0.09	–0.1%	0.998
Effective work (s)	847.5	831.7	36.8	36.2	26.5	21.3	–0.69	–1.9%	0.827
Stops (s)	490.3	481.1	21.3	20.9	18.7	23.0	–0.40	–1.9%	0.907
Displacements (s)	181.9	204.4	7.9	8.9	4.7	8.3	0.98	11.0%	0.641

Table 2. Yarding-FDL: Summary of the gross time of working cycle for each data set. Data include data set with missed cycles. A_S: automatic survey, M_S: manual survey.
Tabelle 2. Kippmastgerät-FDL: Zusammenfassung der Bruttozeit des Arbeitszyklus für jeden Datensatz. Daten beinhalten Datensätze mit verpassten Zyklen. A_S: automatische Vermessung, M_S: manuelle Vermessung.

	No. of cycles		Gross time		Average		Standard Deviation		R2
	A_S	M_S	A_S	M_S	A_S	M_S	A_S	M_S	
Working session (s)	220	228	138536	138157	638.4	636.7	323.6	324.3	0.886
Difference (s)	8		–379		–1.75		–		

assessment, although some assumptions were needed. Beside this, it was possible to establish that the different choker application points do not have influence on the assessment. Given the good results obtained with the application of the two separate systems of the Yarding-FDL, further steps foresee the synchronization and testing of both systems.

3.3 Chainsaw-FDL

In literature, data on the correlation among felling time, diameter, and volume assessment are available. Nevertheless, data on the automatic collection procedure of the raw data as well as their elaboration are missing (Ciubotaru and Maria, 2012; Vusic et al., 2012).
The measurement of the time in which the chainsaw was operated at high rpm during the working session allows the implemented OIE with dedicated mathematical models (Gallo et al., 2017), to calculate the diameter at the stump level (1) and at the breast height (2).

$$DSt = 6.1861 \times \sqrt{EFT} \quad (1)$$

$$DBH = -0.00177DSt^2 + 0.88638DSt - 1.90016 \quad (2)$$

where DSt is the diameter at stump level, EFT is the effective felling time, and DBH is the diameter at breast height. Thus, using the diameter at breast height, the volume for each felled tree was estimated using specific single-entry table commonly used in forestry management. The validation of this estimation was done for 9 felling operations (Table 5). A t-test was conducted to compare the results obtained for the automatic time acquisition as well as for both estimated diameters with those manually collected; no statistical differences were observed ($p > 0.05$). Often occurred that when the felling session started with auxiliary uncontrollable situations such as revving the engine or removal of the lower obstacles (branches) with the chainsaw, the estimation of effective felling time is strongly affected, with a difference of higher than 10%. Nevertheless, no sensitive differences are found in the stump diameter and in the diameter at the breast height assessment. Thanks to the very satisfactory R^2 (> 0.8), the next steps foresee the study of a solution with the capability to distinguish the felling operations from the trunk processing. In this way, the final goal will be to offer an operational monitoring device with the ability to collect information on the processing of the entire tree. Indeed, as reported in a specific study (Fisher, 2010), by using the data collected by the accelerometer, it is possible to establish the chainsaw position in the space. So it is easily possible to know if the chainsaw is working in horizontal (typical position during the cutting) or vertical position (during obstacle removing or bucking processing).

Table 3. Yarding-FDL: Statistics of the elemental time study recorded during the cable logging working cycles. Missed cycles were not considered. A_S: automatic survey, M_S: manual survey.
Tabelle 3. Kippmastgerät-FDL: Statistiken der Elementarzeitstudie, die während der Arbeitszyklen der Kabelprotokollierung aufgezeichnet wurden. Verpasste Zyklen wurden nicht berücksichtigt. A_S: automatische Vermessung, M_S: manuelle Vermessung.

	Average		Standard Deviation		Difference		R^2
	A_S	M_S	A_S	M_S	–	(%)	
Outhaul (s)	99.7	99.1	60.6	59.3	0.61	1%	0.563
Hook (s)	288.2	295.6	208.7	215.6	–7.4	–7%	0.880
Inhaul (s)	163	153.8	84.1	82.9	9.7	9%	0.663
Unhook (s)	87.4	88.1	166.2	160.8	0.6	–1%	0.930

4. Conclusions

The results obtained by innovative solutions for the operational monitoring, based on the use of a field datalogger and specific sensors, as well as a dedicated OIE for data collection and interpretation were here reported.

The developed application was tested on three operations: apple harvesting, timber logging, and motor-manual felling. For all the operations, the experience has obtained very interesting and important outcomes, achieving very satisfactory results in terms of capability and accuracy. In general, by comparison with manual surveys of the same operations, very low differences were observed. Nevertheless, except for the effective felling time assessed by Chainsaw-FDL, which was affected by accessory operations, the difference is always lower than 10% and this is considered acceptable for management tasks. In Figure 3, a final output of the operational monitoring process is shown, reporting the final result obtained by the automatic elaborations carried out by the OIE. Every single user (farmer, lumberjack, or contractor) who has his/her own access to the Web-GIS interface can consult all the operative information elaborated by the system in a simple and easy way for each working day. In this way, a user is able to monitor constantly the efficiency and the productivity of his/her company. Besides this, directly from the interface, it is also possible to get a concise input/output report that is useful to evaluate the performances of any field activity from a profitable, energetic, and organizational perspective.

The solutions here proposed are capable to perform an automatic operational data collection also in complex production systems, where different subjects (workers and machines) spread across the territory operate. This task is often ignored because of the complexity of its implementation, with the result that, normally, in the agroforestry sector, the management evaluations are often incomplete and not reliable for a chronic lack of operational data. Our agricultural experiences were carried out in medium–large

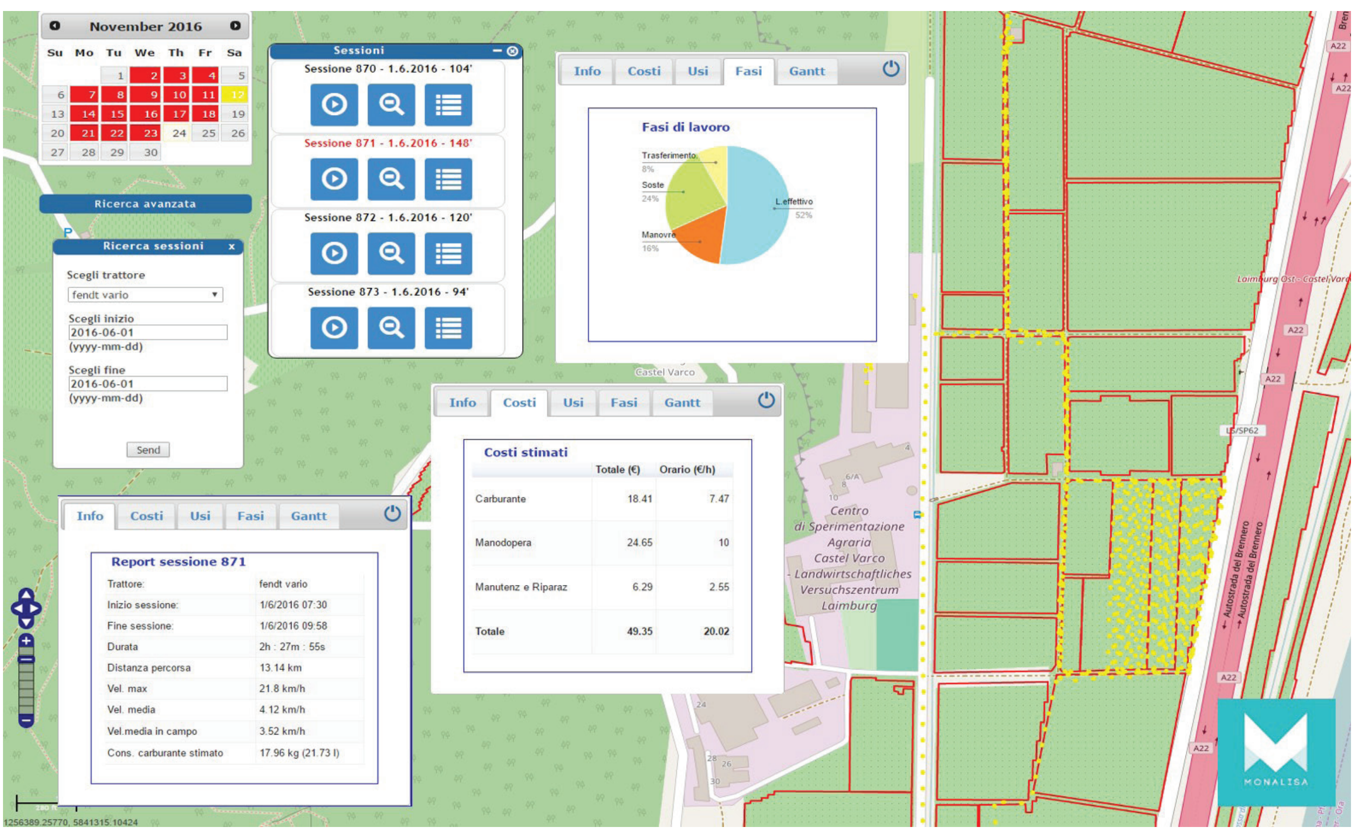

Figure 3. Example of graphical output. All the elaborations are displayed on Web-GIS tool.
Abbildung 3. Beispiel für ein grafisches Output. Alle Ausarbeitungen werden auf einem Web-GIS-Tool angezeigt.

Table 4. Yarding-FDL: Summary of the automatic weight assessment: In this table the results obtained by the two repetitions are reported. The average weight measured as reference was 40.2 kg.
Tabelle 4. Kippmastgerät-FDL: Zusammenfassung der automatischen Gewichtsmessung: Die Tabelle zeigt die Ergebnisse der beiden Wiederholungen. Das Durchschnittsgewicht, gemessen als Referenz, betrug 40,2 kg.

	Repetition 1				Repetition 2			
	CK-2%	CK-5%	CK-10%	CK-20%	CK-2%	CK-5%	CK-10%	CK-20%
Average (kg)	41.4	42.2	40.2	41.7	40.8	38.4	39.5	38.6
Difference (kg)	–1.2	–2.0	0.0	–1.5	–0.6	1.8	0.7	1.6
(%)	–2.9%	–5.1%	–0,1%	–3.8%	–1.6%	4.4%	1.9%	4.0%
R^2	0.980	0.990	0.996	0.995	0.981	0.965	0.990	0.948

farms, where this task was usually assigned to the managers of the enterprise. Here, in average, managers spend around the 70% of their working time (about 5–6 h/day) in data collection activities, leaving only 30% available for evaluation, control, and coordination tasks. The data, moreover, were often incomplete and not very reliable, being for the largest part obtained from statements provided by the company workers. In family-run companies, the problem of quality management does not either arise, because the farmer-director focuses on the daily urgency of the work to be done and he/she never has time to think about collecting the data derived from it and to put them into practical management control procedures.

The main strength of the proposed systems lies, therefore, on the automation of the monitoring and the objectivity of the collected data. The main problems could concern possible default of acquisition with "holes" in the registration, which are immediately identifiable and more easily recoverable. These systems, in the future, will tend to cancel acquisition times, automatically preparing summary reports that allow management to focus mainly on its control and coordination functions.

The systems described above can be seen as a fundamental component of a future generation of information systems able to operate following Precision Agriculture and Precision Forestry approaches for agroforestry companies. Indeed, each of those applications should be supported by a technological platform that has the ability to perform the collection, the processing, the analysis, and the evaluation of the raw data, as well as the use of the obtained information, in a sequential and integrated way. To ensure the management and the processing of all these functions, the platform must be supported by adequate information system with the capability to satisfy the specific organizational need, typical of the agroforestry sector (Mazzetto et al., 2016). According to Mazzetto (2016), the operational monitoring (dealing with some aspects of the data collection) covers a relevant part of the whole information management cycle. Thus, the need to automate its functions should be quickly solved. As consequence of the good results obtained, the solutions here described can be considered as suitable devices to be used, beside for management tasks, also for performing traceability and certification tasks (of both products and processes). For all these

Table 5. Chainsaw-FDL: The data collected by manual survey and those obtained by the OIE's elaborations are reported and compared. A_S: automatic survey, M_S: manual survey.
Tabelle 5. Motorsäge-FDL: Zusammenfassung der validierten Ergebnisse. Die Tabelle zeigt die Messungen und deren Vergleich, die bei der manuellen Erhebung und den OIE-Berechnungen vorgenommen wurden. A_S: automatische Vermessung, M_S: manuelle Vermessung.

	Sum		Average		Standard Deviation		Difference		R^2
	A_S	M_S	A_S	M_S	A_S	M_S	–	%	
Time study (s)	735.4	639	81.7	71.0	45.95	42.56	–10.7	–15.1%	0.909
Stump diameter (cm)	483.1	491	53.7	54.6	15.65	17.20	0.9	1.6%	0.893
Breast height diameter (cm)	361.5	353	40.2	39.2	10.80	12.30	–0.9	–2.4%	0.928
Volume (m^3)	16.58	16.49	1.84	1.83	0.99	1.12	0.0	–0.5%	0.932

reasons, the future research developments will concern, on the one hand, the improvement of the interpretation algorithms to overcome some marginal ambiguities that still influence the recognition of the individual work phases and, on the other hand, the definition of a series of shared performance indicators through which summary reports, aimed to improving the quality of the management, can be better provided.

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