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Data analysis and inference model for automating operational monitoring activities in Precision Farming and Precision Forestry applications

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Abstract. Each application of Precision Agriculture or Forestry should be supported by a technological platform able to perform, in an integrated way, the following data-information cycle functions: 1) data collection; 2) data processing; 3) data analysis and evaluation; 4) use of information. In accordance to this view, information are data that are usefully used in a decision making process or within a reporting protocol destined to users external to the enterprise (certification tasks). In order to manage the platform in a complete and efficient manner an adequate information system is needed. Firstly, the paper shows a classification of the possible monitoring solutions based on the different enterprise typologies, highlighting the main technological and interpretative requirements. Secondly, some case studies related to the application of operational monitoring in orchards and forestry are introduced, mainly focusing on some peculiar aspects of the algorithms developed for the implementation of the inference engines.

1. Introduction

The evolution of ICT in production processes in industry sector is well known and leads to the industry 4.0 concept. By analogy we hear about agriculture 4.0, smart agriculture or similar definitions, but despite them the fundamental concepts that connect Industry 4.0 and Precision Agriculture are: 1) automation; 2) hyper-connectivity among production components and devices (cybernetic approaches); 3) treatment of huge amount of data (Big Data); 4) quick interpretation of data achieved for targeted and quality decision making processes.

Each application of Precision Agriculture or Forestry should be supported by a technological platform able to perform, in an integrated way, the following data-information cycle functions: 1) data collection; 2) data processing; 3) data analysis and evaluation; 4) use of information. In accordance to this view, information are data that are usefully used in a decision making process or within a reporting protocol destined to users external to the enterprise (certification tasks). In order to manage the platform in a complete and efficient manner an adequate information system is needed, capable of satisfying the specific organizational needs of agro-environmental enterprises [1, 2].

Such an information system has to be designed following an info-logical approach, with the following characteristics: 1) considering the entire data-decision cycle from the design of the



individual phases (e.g. data acquisition targeted to the decision-making objectives); 2) using hardware and software technology to solve technical and cultural aspects (e.g. attention to the presentation of information); 3) break down the objectives into simple and modular task to provide solutions that are adaptable to different contexts (e.g. environment, production goal, dimension); 4) break down the objectives according to the different decision levels (strategical, tactical, operational).

Data collection function requires relevant technological and organizational efforts, for the multiplicity of aspects to be kept under constant monitoring, and its whole management system must be designed based upon a decision-related view, rather than a data-related view. In particular, operational monitoring is the most complex from an organizational standpoint, especially when it is expected to be carried out in an automated way, because it involves all the functions of the whole data-information cycle. By definition, operational monitoring includes tasks performed to survey, record and report the information necessary to get an overview of the execution details applied in a given process activity [3]. To this standpoint, it must be distinguished from other monitoring functions such as environmental and crop monitoring.

Figure 1 shows a possible classification key of monitoring solutions based on the different enterprise typologies, highlighting the main technological and interpretative requirements. In fact, the object of operational monitoring varies according to the farming system (arable farms, orchards, livestock, forestry enterprises, etc.) and the main decision-making processes that must be there undertaken. In general, the automation of operational monitoring requires: a) different data acquisition systems, with characteristics conditioned by the dynamic modalities with which the operation at hand is carried out; b) an inference engine, as an integral part of the processing procedures, to synthetically interpret the relevant aspects of the work carried out; c) an access system to information, to allow an interactive evaluation, as well as a correct use of information depending on whether the decision-making processes concern aspects internal to the enterprise (control and organization of activities) or external to it (certification, traceability). With reference to Figure 1, for example, the geographical monitoring referred to the "site of work" characteristic is less important for livestock farms (intensive livestock farming) than the others. However, the use of information must be quick to adapt to the stable management processes.

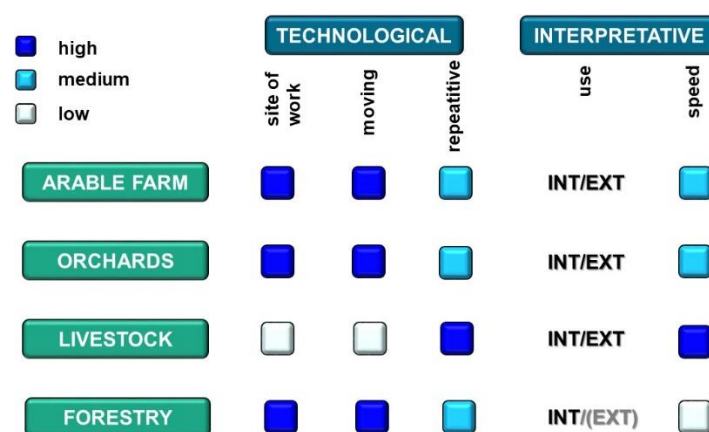


Figure 1. Monitoring solutions based on the different enterprise typologies and the main use of the information in decision making processes.

2. Farm and forestry information systems application

In this section, some case studies related to the application of operational monitoring in orchards and forestry are introduced, focusing on some peculiar aspects of the data acquisition devices there applied and the algorithms developed for the implementation of the inference engines.

2.1. Operational monitoring in orchards

In the case of orchards, the objective is to automatically reconstruct the sequence of work events in the field by identifying: a) type of operation performed; b) machines involved; c) workplaces (crop and/or varieties treated). The project focused on mechanized field activities and the automatic fill of the field activities performed [3]. This is done providing both a summary of the way the operation at hand was carried out - with details on each work phase (actual and auxiliary times, including stops, supplies and intra- and extra-farm transfers) - and an estimate of fuel consumption.

The transition from data to information is transparent to the end user. Everything is charged to the analysis algorithms that deal with processing the new data as they arrive and prepare the summary information ready to be evaluated and used (Figure 2).

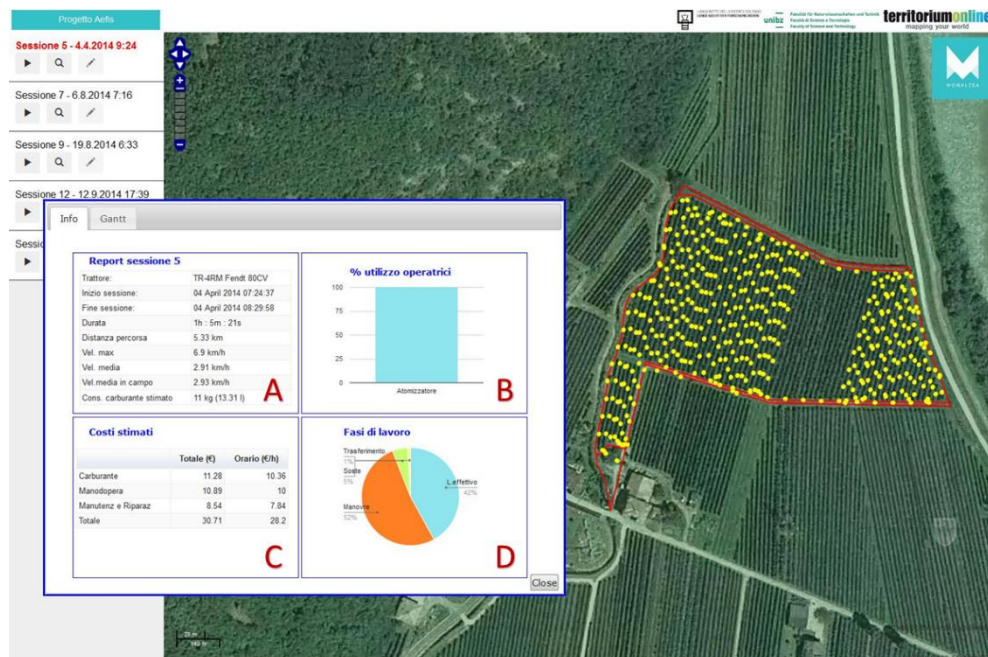


Figure 2. Example of user interface showing details of a single farm activity, as output of an operational monitoring system. A: detail of the selected working session; B: use of implements in percentage of total time; C: estimated costs; D: details of elementary working phases (effective work, stop, manoeuvres, and transfers).

Concerning data acquisition, there are several possible constructive architectures of data acquisition systems for the automation of operational monitoring (Figure 3). The main difference is between the position of the data logger that could be tractor-on board or implement-on board. The solutions A, B and C are of the tractor-oriented type, with the acquisition devices installed on the tractor. The solution D is implement-oriented, having the devices installed directly on the implement. Solution C is equipped with an identification system installed on implements for the autonomous recognition of the operations performed [4]. The implement-on board solution gives more details of the operation but is able to follow one operation at a time. The tractor-on board solution is more flexible, but requires the capability of identifying the implement.

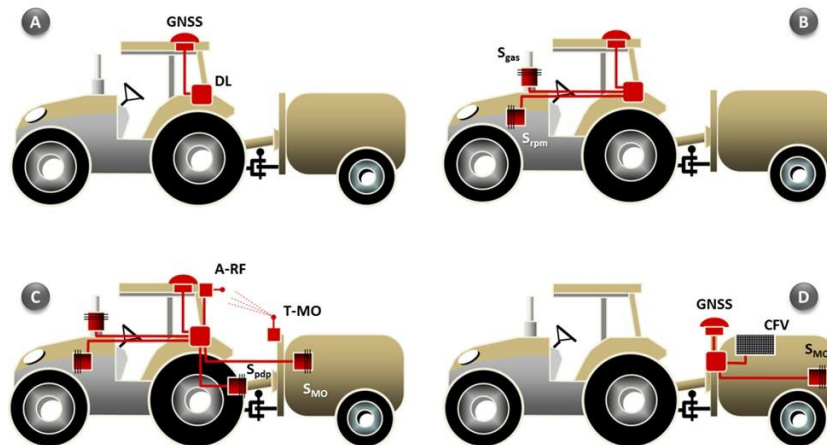


Figure 3. Data acquisition systems for the automation of operational monitoring [4]. DL = data logger; GNSS = receiver for satellite positioning system; SX = sensors for aspects of tractor operation or the operator; T-MO = transmitter of identification code of the operating machine (in RF); A-RF = receiver that identifies the transmitted codes; CFV = photovoltaic cells.

Our tests in orchard were performed implementing architectures mainly referred to solutions of type B (forest monitoring) and C (monitoring in vineyards and orchards). More in detail (Figure 4), field data logger identify the power unit (tractor), and are equipped with: accelerometer, positioning system (GPS+GLONASS receiver), transmission system (GPRS-UMTS modem unit, real time), RF receiver (to log data from coupled implement) and internal memory buffer. Implements are equipped with active tag to identify the implement it self, accelerometer to automatic turn on of the tag (active only when the implement is coupled and moving), RF transmitter (low power signal emitter, 433 MHz - UHF, broadcasting distance < 10 m), long life battery (approx. 500 hrs).



Figure 4. Data acquisition systems details. From the left the first two images show the data logger on the tractor, the third image shows one of the code transmitter on an implement [3].

Once data are acquired, the inference engine extracts the maximum information from all available data and combines it in order to obtain the final information on the activities carried out with the highest degree of reliability possible. Monitoring tractor's activity two different behaviour could be considered: kinematic and functional. Kinematic behaviour identifies the tractor's activity from position data; it comes to identifying the working pattern, but it is difficult to infer the operation performed. Functional behaviour identifies the tractor activity from additional information related to specific properties of the operation in progress (e.g., functional site map, implement code transmitters). The degree of reliability of the inference depends on the data availability. The minimum

equipment is the farm monitoring system (data logger on tractor). Kinematic is always good inferred, but activity inference reliability depends on other information availability to refine the kinematic model.

The whole computational process (Figure 5) includes a mixed of fuzzy logic, statistic and spatial analysis algorithms, and generally works on the assumption that the farm map is a priori known. This map includes both elementary shape areas (say a cultivation unit, CU, set as polygon assigned to a specific crop or variety; one or more CUs form a field) and specific functional points of interest (downloading/uploading sites, refilling points, workshops, shelters etc.). Anyhow, if a map is not a priori available (e.g. in case of contractors), additional sets of spatial algorithms permit to identify areas where works were carried out following special patterns (e.g., works with parallel adjacent rows or alternating rows, transport cycles to the farm centre).

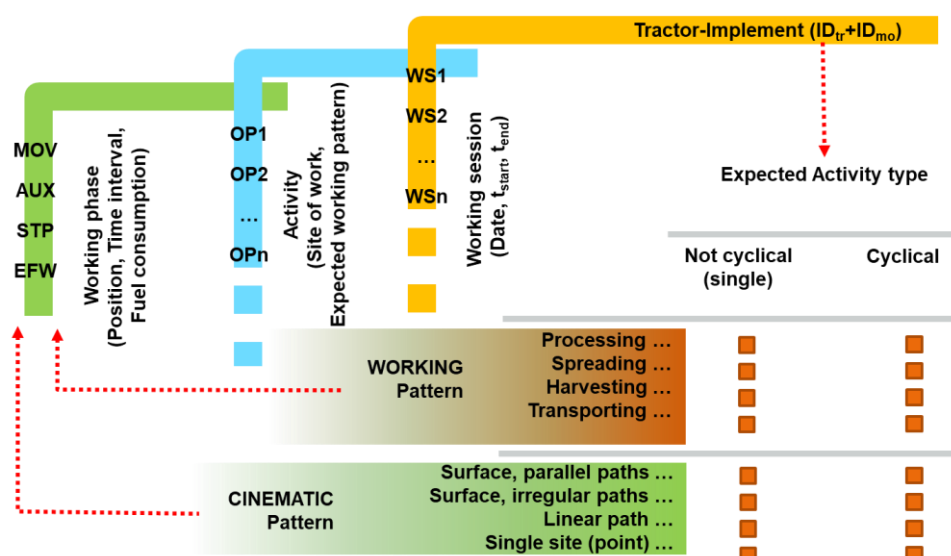


Figure 5. Inference model for detecting mechanized field activity on farm [3].

Figure 6 shows an example of application of the inference engine for the operational monitoring of anticryptogamic treatments in apple orchards. The objective is to interpret the types of activities carried out in a work session (SL) together with the related execution methods (work phases, times and fuel consumption). Every single fixing represents the minimum elementary state (SE) of the activity and the sequence of the SEs on the map shows the entire route taken. Each SE is first classified as actual work, stop or transit based on parameters that evaluate the instantaneous values of speed and direction. A further analysis based on spatial contiguity with other SEs fixes the portions of space in which parallel contiguous passages have been made. A subsequent clustering then identifies the related areas involved, which are then superimposed (intersected) with the pre-registered areas of the crop units. Finally, a last procedure calculates the degree of coverage of the work in the SL on the surface of the individual crop units identified in the previous point.

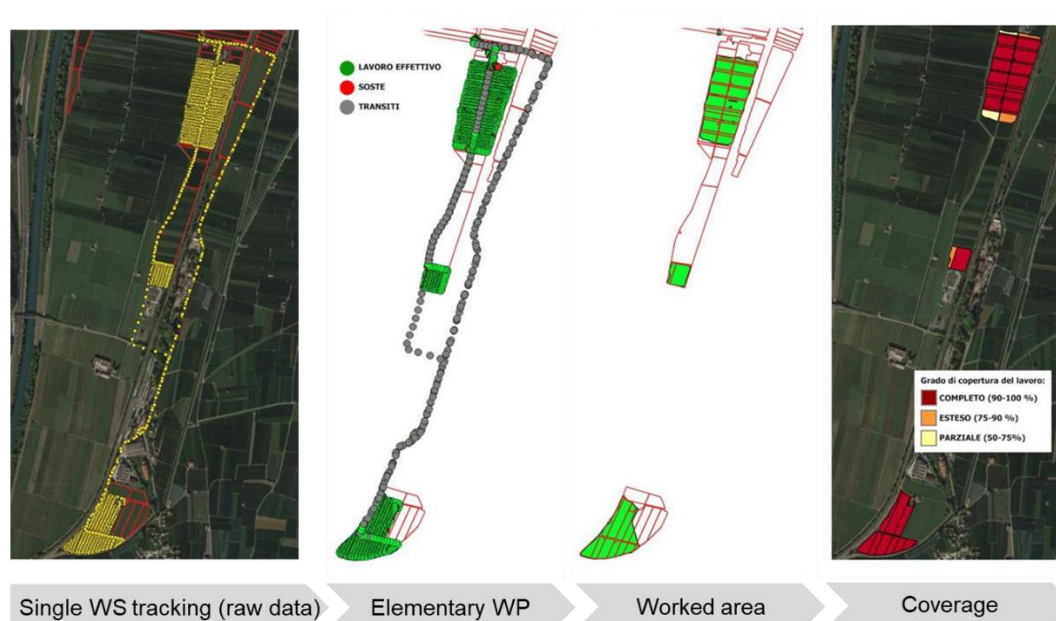


Figure 6. Example of automatic detection of the worked areas, based on tractor's positioning data.

The behavior of the automation system (following the scheme shown in Figure 7) of operational monitoring was tested comparing elementary time recorded by the system and by hand. No statistically significant difference between manual and automatic measures are observed, with a strong correlation for all the elementary times with the exception of maneuvers. This can be due to a not proper working phase assessment done by the algorithm and a stronger work on field speed and pattern complexity have to be done, taking into account also GNSS drift.

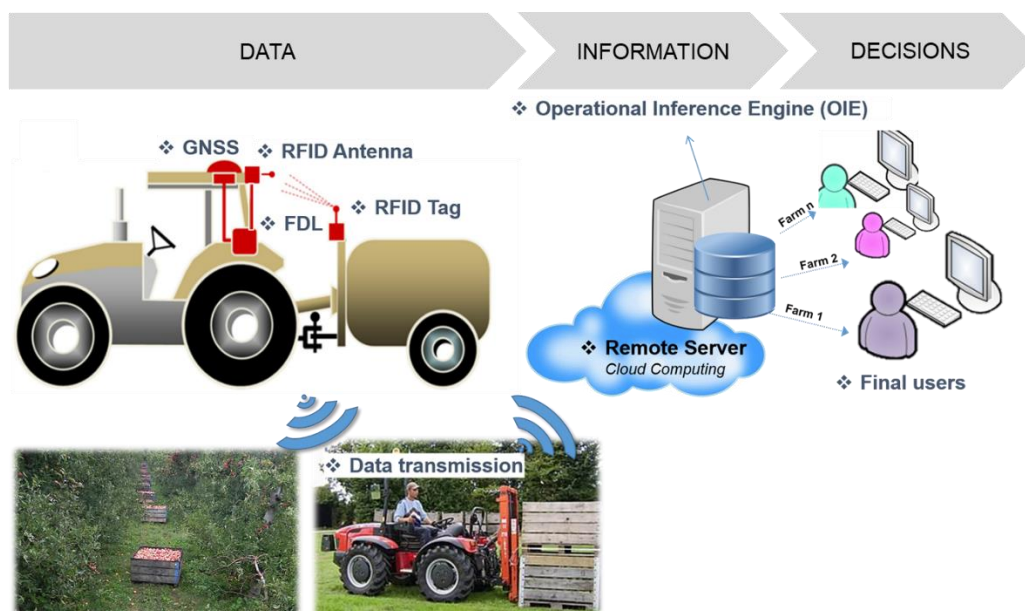


Figure 7. Schema of the operational monitoring system in orchards.

2.2. Forestry operational monitoring

On its turn, the forestry operational monitoring has mainly focused on manual tree felling operations with chainsaw [5, 6], with the objectives of: 1) identifying the points of felling; 2) providing an estimate of the volumes of the cut plants (through algorithms that estimate the effective cutting times, which are proportional to the cutting section of the trees themselves); 3) estimating the worktimes, including the successive stages for completing the work on the felled trees (declaiming and bucking).

For the vibration assessment a chainsaw was equipped with a tri-axes Wi-Fi accelerometer (10 Hz). The device was fixed thanks to screws at the cover of the air filter (Figure 8). Vibrations and position were measured. During the trial 30 trees were felled, 3 for each diametrical class, for each one the felling time, the stump diameter and the DBH (diameter at 1.30 m from the ground) were manually surveyed and measured. 20 of these parameters were used to develop two mathematical models to calculate the stump diameter and DBH respectively. The amplitude that detect the felling threshold is acceleration $> 1.4 \text{ ms}^{-2}$, identified empirically. Through visual assessment each vibration sample was divided into two components the felling and the stem processing (Figure 9). For the research aim only the vibration recorded during felling was taken into account. The effective cut is characterized by having the highest in amplitude (acceleration $> 1.4 \text{ ms}^{-2}$). The sum of all these events determine the amount of time spent for the felling.



Figure 8. Measurement equipment on chainsaw.

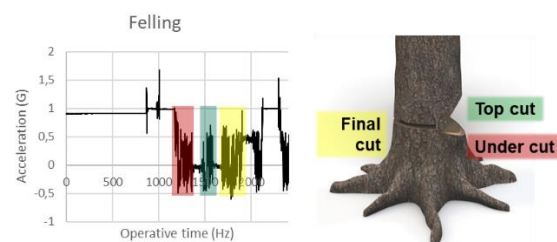


Figure 9. Vibration analysis for productivity evaluation from felling operations.

During the post processing, for each tree the collected dataset was manually split and synchronized with the vibrations dataset. The first GPS and vibration record collected at the same time corresponds at the beginning of the felling operation. Since during the felling the operator is very close to the tree, the points collected inside a radius of 1.5 m, far from the first point, were considered as felling. After that the coordinate of the stamp was calculated averaging the coordinated of the point cloud considered as felling. For both models a satisfactory correlation value was achieved confirming the strong relationship between the variables considered. A very good correlation was obtained also for the volume estimation.

3. Conclusions

The paper presents some applications of farm and forestry operational monitoring based on information systems, considering the whole cycle from data to information ready to use in decision processes. The proposed solution has the goal to summarize useful information in a fully autonomous way. The purpose is achieved through: 1) providing the equipment and the machines in the field of instruments that collects data autonomously without the intervention of the operators and 2) extracting the desired information from the data through suitable algorithms, also in this case without take charge of the end users of data processing tasks.

The first tests carried out to check the reliability of the inference engines highlighting the reliability of the proposed systems to monitor and interpret the operations in an automatic way. Operational Monitoring is fundamental for future information systems supporting Precision Agriculture and Forestry applications and its development must be further enhanced according to a fully automated

approach. These solutions will facilitate and enable new generations of farm information systems to be specifically developed for applications on agro-environmental enterprises.

Operational monitoring generates the so called big data, that should be approached in the correct way, then throughout the given cycle data-information-decision. To do this very specific and very different skills are needed: application context to set goals and contextualize information, analytical to extract information from data, management of collection and storage of data, and so on. Furthermore, these are always highly contextualized and personalized processes. It is difficult for a single farm or forestry enterprise to deal with all these necessary skills, and those could represent a barrier to operational monitoring adoption. Probably the best way to proceed is through the creation of centres of expertise, in which all technical and technological parts are entrusted to experts of the individual disciplines and are transparent to end users, who will use them in the form of services.

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