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Review paper

Concept to Practices of Geospatial Information Tools to Assist Forest Management and Planning under Precision Forestry Framework: a review

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Abstract - Precision forestry is a new direction for better forest management. Precision forestry employs information technology and analytical tools to support economic, environmental and sustainable decision; the use of geospatial information tools enables highly repeatable measurements, actions and processes to manage and harvest forest stands, simultaneously allowing information linkages between production and wood supply chain, including resource managers and environmental community. In this contribution, we reviewed the most recent advances in the use of geospatial information technologies in forestry, and discussed their potential opportunities and challenges towards forest management and planning in the framework of precision forestry.

Keywords - Precision agriculture, Information and Communication Technologies, Decision Support Systems, Site-specific management, Forest planning

Introduction

The concept of precision has emerged in farming since the 1990s and it is based on the recognition that spatial and temporal variability in crop production need to be addressed by means of variable management practices, according to site or soil conditions (Tran and Nguyen 2006). Accordingly, "precision agriculture" means the integration of technology in the collection, interpretation, and analysis of data to support the decision-making system, in order to improve the agricultural processes by precisely managing each step to ensure maximum agricultural production while maintaining the sustainability of natural resources (Martinićet al. 2001).

The idea of precision was translated also into the forest sector since the early 2000s in the US (Becker 2001), where the First International Symposium on Precision Forestry attempted to provide the state of the art in the use of information technologies and analytical tools to support site-specific, economic, environmental, and sustainable decision-making for the forest sector (Dyck 2003). Subsequently, precision forestry has rapidly gained ground in various application like forest inventory, management, engineering, and operations community applications (IUFRO 2015), especially in Europe and North America.

Precision forestry is based on similar principles than those of "precision agriculture" (Kovácsová and Antalová 2010). The substantial difference with precision agriculture is the broader spatio-temporal domain covered by precision forestry, ranging from a single tree to global scale, over different temporal frequencies of observations. However, despite its wider potential domain of application, it is remarkable that the term "precision forestry" has received less consideration than the more comprehensive precision agriculture terminology (Corona et al. 2017). This implies the need of a better understanding of precision forestry peculiarities with respect to the agricultural production system.

The precision forestry discipline exploits information technology and analytical tools to support economic, environmental and sustainable decisions (Gallo and Mazzetto 2013, Gallo et al. 2013). The use of such technologies enables highly repeatable measurements, actions, and processes to manage and harvest forest stands, simultaneously allowing information linkages between production and wood supply chain, including resource managers and environmental community (Dyck 2003).

The need for precision forestry is no longer a choice in managing forest and providing forest products. The demand for high-quality geospatial information about forests is supporting technologies

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to converge with the field of applications to provide the measurements, storage, analysis, and decision-making needs of the forest sector. At the same time, multifunctional forest management requires that multiple forest ecosystems services (ES) are simultaneously sustained. This pushes decision-makers towards GIS-based decision support systems to explore trade-offs between forest ES (Bottalico et al. 2016), thereby increasing the interest on reliable spatial estimation approaches to map the supply of ES across multiple spatio-temporal scales (Corona et al. 2014, Ferrara et al. 2017).

Notwithstanding cultural and technological advances, there are currently some difficulties in introducing precision technologies in forestry. In relatively few cases forestry applications have driven research efforts related to precision technologies (Schmoldt and Thomson 2003). More often, once precision technologies have been developed and made available, they often find ready application to research and management of environmental and ecological systems. Recent technologies like biosensing, micro-electromechanical systems (MEMs) and sensor networks are undergoing a rapid expansion, which is continuing modifying the framework of technologies, tools, processes, and materials available for precision forestry. This implies that many precision forestry applications are still at an initial stage of implementation. At another level, the push in technology use in the forestry sector often contrasts with its slow adoption from the end-user community, which is often poorly trained about how technology potential can improve and optimize their work.

In this paper, we discuss the most recent advances in precision forestry technologies and applications with specific reference to geospatial-information tools to assist forest management and planning. Firstly, we provide a definition of precision forestry; then we show the main categories of tools and applications available for precision technologies. Finally, we discuss current challenges and opportunities of precision forestry.

2. Context

As outlined in the 'First international conference on Precision Forestry' in Seattle, USA (Sarre 2014), there are several definitions of precision forestry for instance: "*Precision Forestry uses high technology sensing and analytical tools to support site-specific, economic, environmental, and sustainable decision-making for the forestry sector supporting the forestry value chain from bare land to the customer buying a sheet of paper or board*" (IUFRO 2014, IUFRO 2015). Taylor et al. (2002) proposed to define precision forestry as "*planning and conducting site-specific forest management activities and operations to improve wood product quality and utilization, reduce waste, and increase profits, and maintain the quality of the environment*".

However, the term precision should be understood as a new priority focus of land cultivation, including forestry, where the central concern is to deal with the environment, its variability and heterogeneity (Auernhammer 2001). In this view, precision forestry can be regarded as an "*environment friendly system solution that optimizes product quality and quantity while minimizing cost, human impact and intervention, and the variation caused by unpredictable nature*" (Joint Research Centre of the European Commission 2014). Indeed, other definitions of precision forestry include terms related to risk, environmental effects, and degradation, as key concerns.

Albeit precision forestry has received relatively limited consideration by the European Parliament's Committee on Agricultural and Rural Development, its document "Precision Agriculture: an opportunity for EU farmers potential support with the CAP2014-2020" has outlined the importance of exploiting available and advanced technologies for the smart and sustainable management of natural resources. Further, the Horizon 2020 (block Industrial Leadership) aims to achieve industrial leadership via key enabling technologies such as information and communications technology, nanotechnology, advanced materials, biotechnology, advanced manufacturing and processing, and space technology. On this basis, the "Strategic Research and Innovation Agenda for 2020" of the European Forest Institute and Forest-based Technology Platform intended to address the Societal challenges and improve industrial competitiveness in accordance with the European Strategy. Although not directly mentioned in these documents, precision forestry represents a cornerstone of the technologic development in the forestry sector.

3. Precision forestry applications

Measurements of forest variables are taken at spatial scales from millimeters range (e.g. nitrogen fixation in the soil) to the kilometer range (e.g. stand volume) up to global scale. Such multi-spatial scales also imply that different temporal scales can occur, where application can range from short time periods to much longer-period phenomena.

In this contribution, we focus our analysis on geospatial-information tools and techniques for forest data collection, which can be subdivided into three activity fields:

i) Remote sensing technologies
ii) Field survey technologies
iii) Decision Support Systems

In the following sections, we first briefly describe the tools and techniques available, mainly to outline their strength and weakness. Next, we move to more general considerations about the main challenges and recommendation to make these tools operational in forest management and planning.

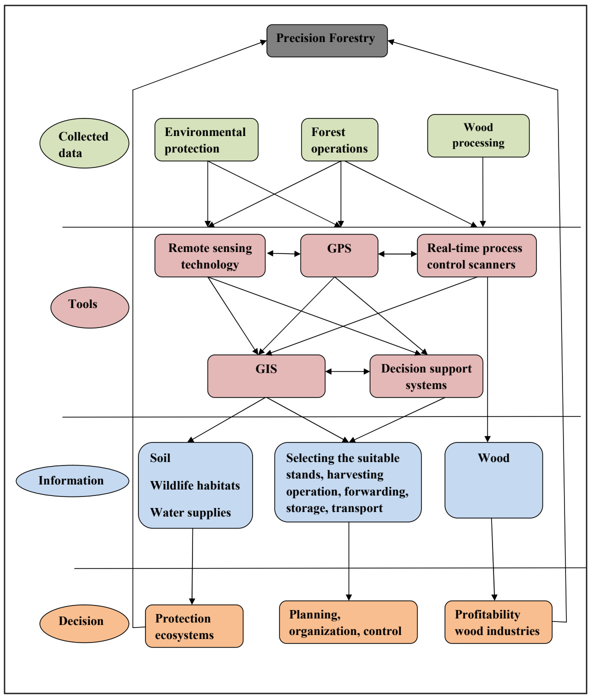

Figure 1 - Diagram of precision forestry (modified from Kovácsová 2016).

3.1 Remote sensing technologies

Airborne and satellite data provides a unique way for mapping forest attributes on spatially extensive areas, from regional to global scale. For this reason, remote sensing products have long been widely used for many forestry application including forest inventory (Corona et al. 2012), biodiversity assessment and monitoring, global change (Trumbore et al. 2015), as well as to support decision-making sustainable forest management (Franklin 2001). Traditionally used remotely sensed products include satellite and/or air-borne passive (multispectral, hyperspectral) and active (radio detection and ranging - RADAR, light detection and ranging - LIDAR) sensors. More recent advancements are bringing unmanned aerial vehicles (UAV) as a promising platform for meeting local objectives (Tang and Shao 2015).

The literature trends showed a constant increase of remote sensing application in forestry over the last few decades. Such trend is mainly supported by the increased availability of airborne hyperspectral and (particularly for the forestry sector) LIDAR data. Both data sources have been frequently applied in forest inventory and forest tree species classification (for a review, see Fassnacht et al. 2016). The significant progress that has been achieved in remote sensing of forests in recent years is related to the four linked drivers: i) technological sophistication in sensor design and deployment; ii) growth in data processing techniques and user-driven tools for image analysis; iii) increasing computational capabilities; iv) development of open source code; v) remote sensing imager archives opened free of charge online; vi) increased understanding of how and why remotely sensed information are important in forestry for information synthesis (Wulder and Franklin 2012) and vii) continuing advance of IMU sensors, particularly low-cost MEMS solutions, which are becoming the primary georeferencing components. In addition, new platforms such as unmanned aerial vehicles are opening an unprecedented opportunity for scale-appropriate measurements of ecological phenomena (Anderson and Gaston 2013), with large potential in precision forestry applications (Tang and Shao 2015).

For a more comprehensive overview of the available platforms and sensors, the reader is referred to review by Toth and Józków (2016). In the next section, we focus mainly on the most consolidated and promising technologies in precision forestry, related to multispectral/hyperspectral satellite sensors, airborne laser scanning, synthetic aperture RADAR, and unmanned aerial vehicles.

3.1.1 Multispectral and Hyperspectral satellite sensors

Spaceborne sensors have been operational for more than 40 years. First Landsat mission started in 1972, followed by SPOT-1 in 1986 and Ikonos in 1999. Based on the number of bands and their spectral resolution, satellite optical sensors can be divided into multispectral and hyperspectral (also called imaging spectroscopy) systems. Whereas most of the multispectral sensor systems typically have 4–8 bands, hyperspectral imagery is acquired in narrow, contiguous bands that can cover the visible (VIS), near-infrared (NIR) and shortwave-infrared (SWIR) portions of the electromagnetic spectrum (0.4–2.5 µm). Both multispectral and hyperspectral sensors have been widely used in forestry application including forest inventory (Corona et al. 2012, Babcock et al. 2016, Ferreira et al. 2016) and tree species classification (Ke et al. 2010, Dalponte et al. 2012, Fassnacht et al. 2016). These systems allow retrieving ecosystem information by measuring the spectral response of vegetation in sensor-specific wavelength regions. The advantage of hyperspectral sensors, compared with multispectral ones, is that the narrow bandwidths characteristic of hyperspectral data permit an in-depth examination of earth surface features which would otherwise be 'lost' within the relatively coarse bandwidths acquired with multispectral data. In this line, the use of narrowband vegetation indices from hyperspectral sensors allows a variety of ecophysiological processes (e.g. photosynthesis, light use efficiency, chlorophyll content) to be monitored (Marshall et al. 2016, Zarco-Tejada et al. 2016) than is possible with multispectral sensors. However, as some studies (e.g. Galvao et al. 2005, Koch et al. 2005, Govender et al. 2007, Govender et al. 2008) pointed out, the selection of important vegetation wavelength region is more important than the number of available bands from these passive sensors. For example, Govender et al. (2008) concluded that "for describe diverse vegetation classes optimal hyperspectral bands is the best option to use. Optimal hyperspectral bands ought to be fused into multispectral system through sensor adjustments or spectral filters. A definitive objective is to move from unrealistic expansive information volumes and costly sensor advancement towards useful operational low information volumes, high temporal resolution and less expensive sensor improvement". The recent launch of Sentinel-2 mission from the European Science Agency fits well with this strategy; although it is not a hyperspectral sensor, Sentinel-2 is specifically designed for vegetation sensing, due to a combination of fine-tuned spectral capabilities (e.g., three narrow-bands in red edge wavelength), high spatial resolution (10 m), wide swath and quick turnaround (up to 5 days). Because of its relatively recent release (23 June 2015), its capability in forest remote sensing needs to be further verified, but early experience and simulations already indicate a clear potential in a wide range of forest applications at medium to large scale (e.g. Laurin et al. 2016, Immitzer et al. 2016), including forest management and planning.

3.1.2 Airborne Laser Scanning

The height of individual trees or canopy density of the stand can be measured accurately with this active remote sensing technology. Airborne Laser Scanning (ALS) has significant advantages over optical passive remote sensing because it can collect highly detailed 3D data quickly from a large area with varying conditions at repeated time intervals. For example, from airborne LIDAR data, the upper canopy height is correctly measured from the canopy height model (CHM), making this methodology particularly suited to estimate timber volume and biomass in forest stands (Naesset 1997, Barbati et al. 2009, Corona et al. 2012).

From ALS, different data products can be derived, such as digital elevation model grid, contours, raw point data and intensity clouds. Recent advancements in this technology in forestry is related to the increasing sophistication in sensor design and deployment, which currently allows very dense point clouds to be generated at decreasing costs, becoming operational in many regional and national forest inventories (Næsset 2007, Wulder et al. 2012). Currently, ALS represents one of the most promising and effective technology for a wide range of forestry applications, like e.g. above ground biomass estimation (Laurin et al. 2016, Nie et al. 2017), automatic forest area delineation (Alivernini et al. 2016), forest harvesting planning (Heinimann and Breschan 2012). However, the standardization of the point cloud processing, the comparability between different products generated by different resolution ALS data, and the influence of LIDAR accuracy's on topography, land cover categories, canopy density, represent still critical issues for the operational use of ALS data (Scrinzi et al. 2014).

3.1.3 Synthetic Aperture RADAR

Synthetic Aperture RADAR (SAR) is an active remote sensing technology which demonstrated relationships with biomass, and the all-weather data collection capacity (Tsui et al. 2013). According to Wulder et al. (2012), it provides complementary sets of information for estimating forest biomass. Orthorectified Radar Imagery (ORRI) has a wide variety of applications. These products are used in hydrology modelling (Bates et al. 2006), flood risk assessment (Mason et al. 2016), land use and land cover mapping (Yang et al. 2016), earth crust deformation monitoring (Vilardo et al. 2009), riparian studies (Makkeasorn et al. 2009) and forestry mapping (Kovácsová and Antalová 2010, Naidoo et al. 2015). However, SAR is height sensitive, and multiple baseline DEM generation has the potential to resolve phase ambiguities in an area with high vegetation and to solve the problems from foreshortening and layover. In addition, SAR tomography has the potential to resolve image distortion due to layover and foreshortening (Krieger et al. 2010). Compared with other active remote sensing technologies like satellite LIDAR, airborne radar systems are quite expensive and this has limited the number of commercial operators. Spaceborne radar systems have seen major advancement recently, and provided progressively informative data worldwide. In general, the application of RADAR technology has been less frequent in forestry than LIDAR and optical remote sensing. However, the recent Sentinel-1 radar system can represent a potential mission to support improvements in the remote sensing of forest vegetation via SAR sensors.

3.1.4 Unmanned aerial vehicles (UAV)

Also referred to as drones, unmanned aerial vehicles systems have emerged over the past few years as remote sensing platforms. The benefits of UAV include low material and operational costs, flexible control of spatial and temporal resolution, high-intensity data collection, and the absence of risk to crews. The current forestry applications of drone remote sensing are still at an experimental stage, but they are expected to expand very rapidly (Tang and Shao 2015). Recent forest application tested drone remote sensing to measure forest canopy height (Lisein et al. 2013, Tulldahl and Larsson 2014, Wallace et al. 2014, Zarco-Tejada et al. 2014), mapping canopy gap (Getzin et al. 2012), canopy cover and leaf area index (Chianucci et al. 2016), to detect fallen trees (Inoue et al. 2014) or pest infestation (Lehmann et al. 2015) and tracking forest wildfires (Ambrosia et al. 2011, Hinkley and Zajkowski 2011). The sensors currently used on remote sensing UAV are predominantly optical cameras, as they are widely available in lightweight and inexpensive versions. Dense point cloud generation from non-metric cameras (Ostrowski et al. 2014) has matured in recent years, and, as an emerging technology, it is a promising alternative to LIDAR sensors for small-scale inventory of forest structural variables (e.g. Puliti et al. 2015, Wallace et al. 2016). The relatively recent upsurge and the exponential growth in this technology system are rapidly changing the benchmark of UAV applications. Currently, the main challenge in UAV technology is related to the development of sensor technologies, particularly regarding the radiometric and geometric resolution of payloaded cameras. Also, portable LIDAR and hyperspectral sensors are introduced recently, but their accuracy and reliability still need to be verified. Developments are also still required in the navigational capabilities, in the miniaturization of measurement technologies (i.e. smaller, lighter payloads, GPS, and inertial units) and in the navigation accuracy, as particularly laser and Hyperspectral imaging HSI sensor requires accurate georeferencing. However, the convergence process is strongly accelerated by the customer market, as the demand for anywhere and anytime navigation with full visualization of the environment is quickly increasing, supporting a rapid increase in autonomous system and vehicle navigation (Toth and Jóźków 2016).

3.2 Field survey technologies

Field survey technologies can support forest management and planning by reducing the time and cost of ground sampling. Among the available techniques, the most promising and effective ones are related to terrestrial laser scanning and Field Map, which are described in detail in the following sections. Other instruments are also briefly considered.

3.2.1 Terrestrial laser scanning systems (TLS)

TLS has been demonstrated to be a promising mobile-system tool for plot-level advanced field inventories (Liang et al. 2011, Seidel et al. 2011). The main advantages of using TLS to support forest planning and management lie in its capability to document the forest details automatically and at very fine (millimeter) spatial scales. TLS data can theoretically improve the accuracy and efficiency of field measurements, and the capability of locating trees on the plot. In addition, TLS data document the entire plot at a particular time, which enables accurate subsequent measurements and time-series analyses. In the last few years, TLS has been widely used in different forestry applications, such as tree mapping (Pueschel et al. 2013), callipering (Srinivasan et al. 2015), tree height estimation (Olofsson et al. 2014, Srinivasan et al. 2015) and forest biomass calculation (Yao et al. 2011, Seidel et al. 2012, Srinivasan et al. 2014, Greaves et al. 2015). The use of TLS has also been intensively studied, e.g., for the estimation of canopy structural parameters (Huang and Pretzsch 2010, Béland et al. 2011, Van der Zande et al. 2011, Moorthy et al. 2011, Seidel et al. 2012, Zhao et al. 2012, Zheng et al. 2013, Bayer et al. 2013, Hopkinson et al. 2013, van Leeuwen et al. 2013, Cifuentes et al. 2014). Notwithstanding these improvements, the current main limitation of TLS is the cost of the instrument and the complexity of data processing which requires well-trained operators. In addition, TLS data accuracy is still heavily dependent on operator, resolution scan and instrument accuracy, all factors that affect the replicability of TLS products depending on the acquisition setup (point cloud density, scan-time, the field of view) and stand structure (canopy cover, tree density, phenological period). In theory, several scans and high scanning resolution can provide complete information about forest structure. But multiple scans increase measurement times, as well as high scanning resolution, boosts data loading and processing times. In future, best data processing solutions should be found to easily deal with such a huge amount of data, especially in the case of standardized forest inventories. The development of freeware for automated extraction of stand attributes from TLS could improve the exploitation of the method in the nearly future. Another major problem when using TLS in the forest environment is occlusions caused by lower branches, surrounding trees, and understory. This phenomenon leads to lower point density and, therefore, to poor descriptions in the upper part of crowns and partially or totally hidden trees (Van Der Zande et al. 2006).

Recently, handheld TLS has been made available; reducing the cost of instrumentation, but their reliability in forestry remains to be verified. In short, use of TLS is strongly promising, but still far from an operational phase, because the greater 3D characterization available from this system currently does not balance the higher cost, training, processing required by TLS.

3.2.2 Global Navigation Satellite System (GNSS)

Historically, except for space platforms, such as the International Space Station, GPS is the core component of any georeferencing system, providing highly accurate absolute positioning in open areas worldwide (Toth and Jóźków 2016). The GPS/GIS on the GNSS is effective in data collection for predicting important attributes of forest plots including mean tree height, mean diameter at breast height, basal area, stem volume and tree biomass (Liu et al. 2016) and detailed object location in thematic mapping which increase the accuracy and availability of GNSS technology in forest. The application of GNSS on harvesting operations has already permitted to evaluate efficiency of the forest operations (Gallo et al. 2013). But the signal shading from the foliage is one of the main problems of GNSS. When the device follows a path that travels under tree canopy direct signals between receivers and satellites are blocked and weaker reflected signals that are affected by higher noise and multipath are used. Most direct georeferencing solutions are based on integrating GPS and IMU sensor data (Toth and Grejner-Brzezinska 1998, Toth 2002), supplying positioning and attitude data as well as providing better continuity and limited protection against GPS signal anomalies. High-end solutions, typical for airborne remote sensing, use dual-frequency carrier phase GPS data and tactical grade IMU sensors that can provide sub cm level accuracy in post-processing mode. At the other end of the spectrum, a simple code based GPS solution is usually integrated with MEMS IMU data, typically in real-time, providing sufficiently accurate georeferencing for UAV flight control and approximate imaging sensor orientation (Toth and Jóźków, 2016).

3.2.3 FieldMap

Field map is a very useful tool for forest inventorying, which computes field data collected during fieldworks (Figure 2). FieldMap is used for forest mapping and field measurements (tree height, crown projection, and profile, stem profile, estimation of timber volume), assessment of biomass and growth (Kovácsová and Antalová 2010). The disadvantage of the tool is that it is quite expensive, which might limit its application in practical forest inventory.

Figure 2 - FieldMap data collector (Source: http://www.fieldmap.cz/)

3.2.4 Other field instruments

Other commonly employed advanced field instruments in forestry include SilvaScan, and ultrasound decays detectors (UDD), which are used to carry out *in situ* wood quality measurements like density, stiffness (modulus of elasticity), microfibril angle, dimensional stability, and so on (Figure 3). These wood quality measurements can be incorporated into operational inventories to allow the improved characterization of the resources that will allow for raw material be allocated to the most appropriate manufacturing plant (Ritland et al. 2011) (Figure 4). This provides strategic information that can help make economic and environmental management de-

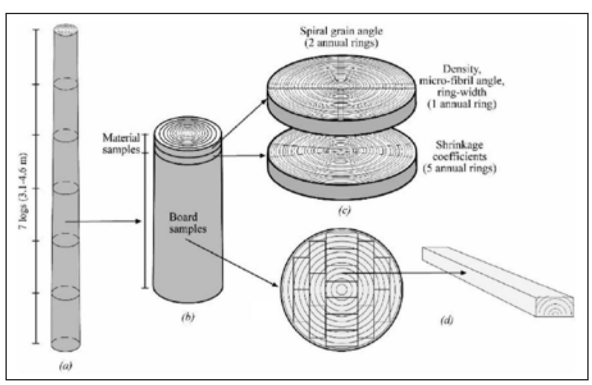

Figure 3 - Wood density and microfibril angle measurement from wood disc by SilvaScan (Source: Ormarsson and Cown, 2005).

cisions on treatments for individual trees and forest stands, improve thinning and harvesting operations, and more efficiently allocate timber resources for optimal utilization. Using acoustic non-destructive evaluation can help to operationalize the collection of wood properties that can support the primary log supply chain. Today, the precision of such technologies has been improved to the point where tree quality and intrinsic wood properties can be predicted and correlated to the performance and economic values of the final products. With continuous advancements and refinements, this technology could assist in managing wood quality, assessing forest value, and improving the timber quality of future plantations (Wang 2012). However, more research is needed to connect wood fibre properties with the performance of huge and growing number of products and processes which will help the forest product industry decision making.

Another ground instrument employed in precision forestry includes Ground Penetrating Radar (GPR), which can be used for estimating soil moisture, root architecture, and wood properties (Ferrara et al. 2013).

3.3 Decision Support System (DSS)

Decision Support Systems refer to an approach that integrates decision maker's own insights with computer's information processing capabilities for improving the quality of decision making. Decision support systems for forest management (FMDSS) have been developed world-wide to account for a broad range of forest ecosystems, management goals, and organizational frameworks. The main features of FMDSS include definition of sustainability of forest management which embraces the ecological, economic and social targets; measures of sustainability regarding the spatial and temporal dimensions; operationalising sustainability in terms of defining strategies to improve forest management. The decision support role of a geographic information system is particularly notable. Geographic information systems (GIS) assist the evaluation of a greater number of alternatives. Examples include the INVEST model for assessing ecosystem services (Tallis et al. 2013), which has been developed in North America and it has been also adopted in Europe (e.g. Bottalico et al. 2016). Many DSS applications are focused on wildfire risk reduction and management (e.g. Bonazountas et al. 2007, Kaloudis et al. 2008) and disaster risks in general (Iliadis et al. 2005). Other application includes planning of forest road (Karlsson et al. 2007), transportation planning (Forsberg et al. 2013), selecting timber harvesting system (Kühmaier and Stampfer 2010) participatory planning (Pastorella et al. 2016) and harvesting plan (Scrinzi and Clementel 2014).

The main current challenge is that there is an increasing number of DSS, which significantly vary in scope and underlined approaches, and which not often allow determining what DSS is more suited to the applied forest reality. To this end, a general conceptual and operational framework is needed, at least as concerns FMDSS. Theoretical developments have moved faster than empirical applications in forest management and planning; FMDSS are less compared to e.g. applications in water resources management. Expanding empirical applications need innovations in several areas; there is need to refine decision criteria to reduce their vagueness, add clarity and limit analysis to a manageable set of attributes. Furthermore, forest management is dynamic and the objectives are evolving towards sustainable/adaptive management. Finally, more efforts are required to develop FMDSS innovatively to capture the changing dynamics of forest management (Ananda and Herath 2009).

4. General challenges and recommendations

Introducing precision tools and technologies into forest management and planning is still challenging. General needs and issues are outlined here below.

4.1 Tools integration

Remote sensing, computing science, and in-

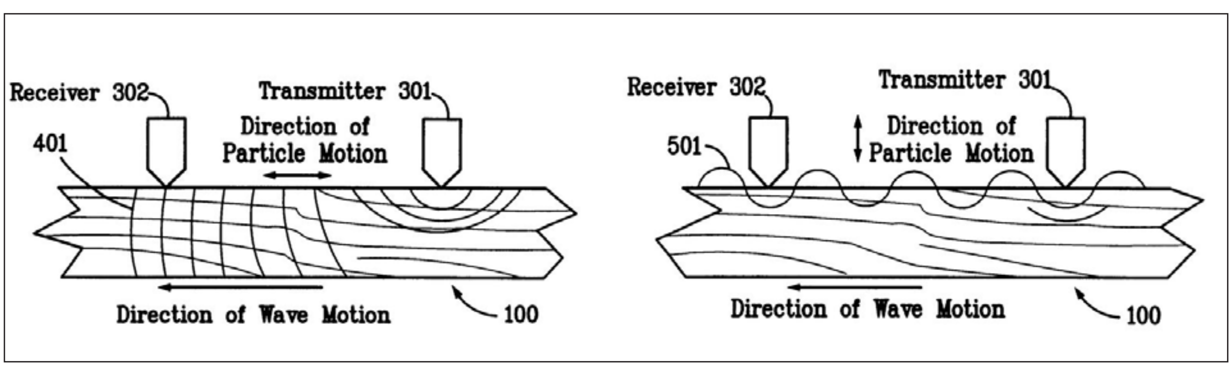

Figure 4 - Schematic diagram of the ultrasonic propagation time tests on the thick wood (Source: https://www.google.si/patents/US6276209).

formation technologies are greatly affected by universal development trends (Toth and Jóźków 2016), which are mainly driven by the fast pace of technological advances in material sciences, optical physics, nanotechnologies, and so on. Consequently, algorithmic research and software are generally lagging the potential offered by emerging hardware. Hence, there is an increasing need for integrating the existing tools, techniques, and sensors in a way that allow the coupling of all the different information available in a multi-scale and multi-source system.

4.2 Open access data

Appropriate access to data and software has both technical and intellectual components. The real question is more about to accessing the sensory data, which directly connects to communication and the general Information Technology infrastructure. In 2012, about 2.5 quintillions bytes of data were acquired worldwide per day (IBM 2012). Exploiting the potential of crowd sensing data leads to new methods, including Data Analytics and Big Data (Najafabadi et al. 2015). Accessibility is also challenging if results are presented inappropriately. For example, data may be aggregated at a fixed scale that may have limited value for many users. In other cases, language and concepts beyond the end user's understanding or vernacular might render a decision support system useless for a large audience segment. The continuous, transparent, and "user-friendly" information access makes interoperability a required attribute of databases, systems, and vocabularies. Because end-users of data are not necessarily local or regional, and because large-scale forest assessments are becoming more important, standards and protocols for forest data are looming on the horizon.

4.3 Skilled operators

Precision forestry technology implementation requires human resources and institutions with the appropriate proneness and knowledge to use the technologies. For example, the technology transfer issue is very worth to be solved to implement REDD+ or other programs in developing countries. Technology transfer must be a prominent consideration in helping solve the challenges we face in managing forests, locally, nationally, and globally.

4.4 Cost-effectiveness

Despite the potential, precision forestry tools have only just begun to be used in forestry communities (especially in the research environment) and are still not considered as standard tools. The main reason lies in the cost of instruments and peripherals (reference targets, software suites, graphic workstations). However, the price of devices has decreased by half during few last years. This trend should continue for some time. When prices become affordable for foresters, precision forestry instruments should become essential tools to provide extensive information about forests with a smaller investment in time and labor than current operations.

5. Conclusion

Managing forests in an increasingly environmental- and profit- concerned market have become a complex challenge for forest planning. Precision forestry could generate future forestry operations at a macro and micro level in a more economically and ecologically sustainable way to satisfy public and environmental demands. Modern Information and Communication Technologies can contribute to higher precision in forest management and decision making process.

Wood and food security are now central concepts in most parts of Europe, but there is evidence that increased production has led to significant harmful environmental consequences in terms of water pollution, greenhouse gas emissions and damage to natural ecosystems (Geiger et al. 2010, Kleijn et al. 2011). Confronted with, apparently antagonistic, pressures to conserve the environment and be careful with natural resources (Tilman et al. 2011), the forestry sector must face this main challenge and produce more with less environmental impact. The way to address this is to look at science and technology for possible answers.

Current precision and information technologies portend a future filled with improved capabilities to manage natural resources with greater skills and understanding (Schmodlt and Thomson 2003). The application of information and communication technologies into precision forestry has clear benefits to optimize production efficiency and to increase quality, but also to minimize environmental impact and risk, which include undesirable variability caused by the human operator (Gebbers and Adamchuck 2010). Precision forestry becomes a management practice of increasing interest because it links to key drivers directly related to worldwide issues such as Sustainable Forestry and Wood Security (Joint Research Centre 2014).

Precision forestry presents also some benefits for social and working conditions. The evaluation of precision technologies holds great potential to develop automated monitoring and management applications and thus reduce labor requirements.

A customer oriented production, an integrated forestry wood chain and the global vision of precision forestry are concepts that researchers and people involved in the forest and wood industry must deal with. Fulfilling, the specific requirements for the site, length, biological features and proof of origin that customers demand to wood products entails the existence of advanced methods and tools for understanding and thus controlling the production process along the forestry-wood chain value.

However, precision forestry could generate future forestry operations at macro and micro level more economically possible way to satisfy public and environment demands. Modern technologies i.e. LIDAR, UAV, TLS, hyper spectral remote sensing etc. may contribute for higher precision in forest management and decision making process and. Also it can be applied to increase the efficiency and information basis of existing national forest inventories and operational forest management planning.

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