Technologies for Silviculture Activities: Understanding of the practicality of GIS and Remote Sensing, Smartphone, and UAV Lidar

by

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Technologies for Silviculture Activities, Past, Present, and Future

by

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ABSTRACT

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Key Words: silviculture, silviculture practices, GIS, remote sensing, smartphone, UAV Lidar, 5G, clound technology.

This thesis explores the technologies apply in silviculture activities. Silvicultural activities are an essential process in forest management. To meet management objectives, the forester requires to collect any data, information on the site and do silviculture practices like thinning, tending, and harvesting. Back at the beginning of 20 century, manpower was the primary tool in doing silviculture activities. With the development of science and technology, more handy tools appeared, helping us do silviculture activities. The leading technologies that we use today are geographic information systems (GIS) and remote sensing. They can gather a large amount of information with a few operators. With GIS, we can update the site's information in a short period to monitor the site and change management strategy. A smartphone is also an excellent tool to improve site data collection. Smartphone has many valuable applications like a map, a global positioning system (GPS), and digital camera. It is a useful technology for the student with a limit budget. However, limit by its saved data and running speed, the smartphone is more suitable for small-scale forest management than large-scale forest management. More and more foresters use UAV LiDAR to get 3D information to get precise details of trees. The 5G era is coming. With the faster computer running speed, what will silviculture activities be like in the future? Just imagine a drone can do every silviculture practice on the site. People do not need to take a risk to do some dangerous silviculture practices. This thesis mainly discusses the technologies that apply in silviculture activities to analyze the pros and cons of those technologies.

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1.0 INTRODUCTION

Data collection and maintain electronic records of forest resources are essential for forest activities. In Ontario, Canada, forestry companies are required to conduct their data collection (Kennedy et al. 2013). These data include density, tree species, age, size, and distribution. Those are the basic information about the forest. Silviculture activities are an essential process in forest management planning. To meet management objectives, foresters also are required to collect information on site and do silviculture practices like thinning, tending, and harvesting. Back at the beginning of 20 century, manpower was the primary tool in doing silviculture activities. It is inefficient and sometimes dangerous to the worker. With the development of science and technology, more handy tools appeared, helping us do silviculture activities.

Silviculture activities mainly serve under wood production and other socio-economic and conservation purposes (Rosset. C, Sehutz. J. P, 2003). It requires a large amount of data to help with decision making. The leading technologies that we use today are geographic information systems (GIS) and remote sensing. They can gather a large amount of information with a few operators. Remote sensing and GIS are complementary technologies. We can improve the monitoring, mapping, and managing forest resources by combining these two applications (Franklin, 2001). Back in the 1980s, GIS has been widely used by the U.S. Forest Service in forest management. Canada has applied GIS in forest fire monitoring in the 1990s.

With GIS and remote sensing, we can update the site's information in a short period and change management strategy. However, with smartphone technology development and more phone applications appeared, a smartphone can also be a tool for data collection in forestry. Smartphone has many valuable applications like a map, a global positioning system (GPS), and digital camera. It is a helpful technology for students with a limited budget. However, limited by its saved data and running speed, the smartphone is more suitable for small-scale forest management than large-scale forest management.

In recent years, LiDAR (Light detection and ranging) is increasingly being applied in silviculture activities to support decision making (Vepakomma and Cormier, 2017). More and more foresters use UAV LiDAR using 3D information to get precise details of trees. UAV LiDAR can go back and forth in the site to get 3D elements and morphological properties of several biophysical parameters across broad spatial scales (Vepakomma and Cormier, 2017).

Technologies have changed the act of forest management. The 5G era is coming. With the faster computer running speed, what will silviculture activities be like in the future? Just imagine a drone can do every silviculture practice on the site. People do not need to take a risk to do some dangerous silviculture practices. Heavy machines do not need to go into the site to do damages.

1.1 Objective

This thesis mainly discusses the technologies that apply in silviculture activities to analyze the pros and cons of those technologies. We will focus on GIS, remote sensing, smartphone, and UAV LiDAR. To discuss how and when they can be applied in silviculture practices. The main objective of this thesis is to compare and analyze those mainstream applications that use in silviculture practice; to advice on how these technologies can help us in silviculture practice and how they change the act of forest management.

2.0 Literature Review

In this section, I will focus on the technologies that apply in silviculture activities to learn how these technologies use in actual practice. These technologies are served under our decision-making, and we also need to understand how the technologies can affect and help with our decision-making.

2.1 GIS and Remoting Sensing

GIS has been widely used in all aspects of forestry. The characteristics of GIS can be divided into two categories. The first category is forest resource inventory and monitoring (McKendry and Eastman, 2014). It is essential to obtain primary inventory data in forest management to protect specific forest ecosystems. The fundamental inventory data includes tree species type, plantation size, stand structure, soil type, crown closure, and density. GIS can display the information after we enter the data, then we can understand the general distribution of tree species and other information. GIS monitoring has been applied in forest fire monitoring since the 1990s in Canada. The satellite can go around the Earth and return to the same place every time (depends on the type of satellite) and update the ground information. Some applications can achieve real-time monitoring, which is widely used in forest fire monitoring. The second category is analyzing, modeling, and forecasting to support decision-making (McKendry and Eastman, 2014). The primary purpose of gathering forest information is to support decision-making and fulfill management objectives. As one of the primary sources of forest management information, these databases support a wide range of management decisions, from logging plans to formulating long-term strategies (Wulder et al., 2005). These are the most frequent use of GIS and remote sensing.

Knowing that GIS and remote sensing are complementary technologies. GIS is a computer-based tool for mapping and analyzing characteristic events on the Earth, while remote sensing is the art and science of earth surveying using sensors on airplanes or satellites. These two technologies can be linked together to form a synergistic system, particularly suitable for examining landscape conditions through the interrelationship between scale, style, and process. This paradigm is well known in biogeography and landscape ecology (Walsh et al., 1997). Generally, GIS provides an analysis framework for data synthesis, which combines a system capable of data capture, storage, management, retrieval, analysis, and display (Walsh et al., 1997). Forester can analyze the relationship between spatial and non-spatial of the site to visualization the information with GIS. Remote sensing, on the other hand, provides a way to evaluate the landscape of spatial, spectral, temporal, and radiometric resolution results. As a result of the integration, when remote sensing data is combined with other landscape variables organized in a GIS environment, the system's analysis capabilities are expanded.

2.1.1 Integration of GIS and remote sensing

When we talk about GIS and remote sensing or GIS technologies, we often associate with mapping. In forestry, even a tiny map may be a product by GIS and remote sensing. Typical remote sensing derivatives used for GIS analysis include baseline forest cover maps, life form maps, and forest cover change maps for map updates. The relationship between remote sensing and GIS practice is traditionally the relationship between suppliers (remote sensing) and consumers (GIS). As a result, there are four forms of integration of remote sensing data and GIS data (Rogan and Miller, 2007):

1. GISs can be used to store multiple data types.

2. GIS analysis and processing methods can be used for raster data manipulation and analysis (such as buffer/distance manipulation).
3. Operating on remote sensing data to obtain geographic information system data.
4. Using GIS data can guide image analysis and extract more complete and accurate information from spectral data.

GIS and remote sensing are excellent tools for mapping and forest change detection. There are few steps for mapping and forest change detection (Rogan and Miller, 2007):

1. Multi-date image acquisition and co-matching.
2. Radiometric processing.
3. Image transformation and change mapping.
4. Verification and change analysis.

GIS and remote sensing are combined systems. With the development of GIS and remote sensing computer applications and more GIS and remote sensing data open to the public, operator can quickly get access to the ground information in any part of the world at any time. Assisting with computer applications, like ArcGIS or QGIS, opperator can analyze the spatial data or simulate road construction in a high-resolution image.

2.1.2 A case study for GIS application in silvicultural thinning

The objective of thinning in silviculture is to influence the growth and structure of a forest stand. Generally, thinning objectives are including but are not limited to maximize economic returns and maintain continuous canopy cover to reduce soil erosion on a steep slope, and produce quality timber (Kerr and Haufe, 2011). When foresters plan to carry out a thinning project, foresters need a large amount of ground data to formulate a thinning plan. The accuracy of traditional ground measurement methods is reasonable but labor-intensive. To improve the working efficiency, foresters can use realistic 3-D thinning technology to simulate and evaluate the real-world thinning treatments. This type of forest management is also called recreational forest management. A study summarizes a six-step protocol for 3-D thinning simulation. First, it is necessary to conduct a comprehensive survey of the actual forest. Next, build a three-dimensional model for each tree species in the forest stand. Third, use the stand structure parameters to establish a digital forest model. Fourth, generate a series of different scene images according to varying combinations of refinement factors. Fifth, a scenic beauty estimation (SBE) questionnaire survey was conducted among the public who watched scene images simultaneously. Finally, analyze the SBE questionnaire data to determine the most suitable scenario (Lin et al., 2012). SBE is a perception-based method for evaluating the visual impact of landscape changes. SBE is a value that indicates the aesthetic impact of thinning intensity, thinning types, and spatial pattern of retention woods.

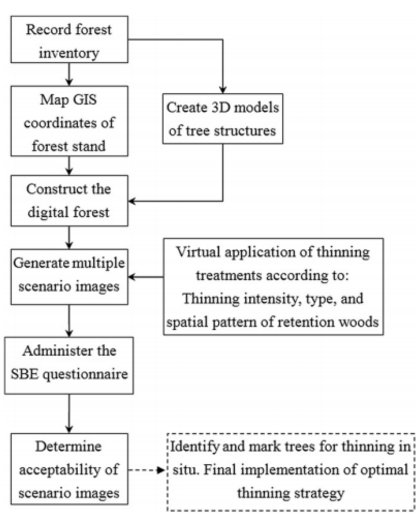

Figure 1. A six-step protocol for 3-D thinning simulation.

Source: Lin et al., 2012.

To create a digital forest, Lin needs to carry out a forest inventory by using a handheld GPS and a base map to precisely locate the boundary of the research site. Lin records a few critical data, include location coordinates (*x, y,* and *z*), DBH, total height, trunk tilting azimuth, crown depth, crown width measured in four directions, and tree species. Lin also needs to record the trunk, branches and foliar frame, and bark color with a video camera. All these data will be input to commercial software, 3ds Max. These data and the completed GIS database can create a 3-D digital forest (However, it is not an easy step since we need to have some knowledge about 3ds Max). With proper coding, we can change the thinning intensity level to generate alternative scenario images for various forest thinning treatments.

Figure 2 shows the digital simulations of three forest scenarios in different thinning treatments. With other thinning treatments, the forest structure can display various. Group (a) was the most disliked scenario. The SBE value was relatively low due to the high thinning intensive. The tree density was high, but the clown closure was soft in group (a). Group (b) was the original stand with no thinning method. The density and clown closure were intensive in group (b), which was not good for regeneration and tree growth (height and DBH). Group (c) was the most preferred scenario among them. With low thinning intensity, the upper forest canopy leaving a dispersed retention pattern.

Figure 2. Three forest scenarios in different thinning treatments: (a) the most disliked scenario, (b) the original stand, and (c) the most preferred scenario.

Source: Lin et al., 2012.

In this case study, the recreational forest management is combined with GIS, GPS, and 3ds Max. GIS plays an important role. To create a realistic 3-D forest landscape simulation, we need to locate every tree on the site by collecting GIS coordinate. The model is highly adaptable. Each tree in the digital forest model can be deleted or replaced arbitrarily or according to a set of rules (Lin, C. et al., 2012). When operator simulates a thinning plan, he can remove specific trees in the stand according to GIS coordinate. The realistic 3-D forest landscape simulation can provide a direct perspective result in a thinning plan. Operator can complete the thinning plan by changing the removal trees over and over again.

2.1.3 A case study for Remote Sensing application in silvicultural

Remote sensing and GIS are complementary technologies. In most of the relevant studies, remote sensing or GIS will not appear alone. However, there are priorities between them in different studies. In the study "*Using multi-source remote sensing data to classify larch plantations in Northeast China and support the development of multi-purpose silviculture*', researchers mainly used remote sensing to determine temporal and spatial distribution patterns and topographical features of larch plantations in northeastern China. According to the main ecosystem service functions (production function and ecological function) of the larch plantation, the larch plantation is divided under the site conditions to explain the measures which change the larch plantation into a larch broad-leaved mixed forest.

In this study, multiple remote sensing data were used included Landsat and SPOT-5 data. With these data, the study mapped the spatial and temporal distribution of larch plantations in the 1980s, 1990s, 2000s, and 2010s. The study area focus on Northeast China includes Liaoning, Jilin, and Heilongjiang Provinces, and the east of Inner Mongolia Autonomous Region (Figure 3). Combined with GIS application and technology, the study produced a spatial distribution of larch plantations in Northeast China (Figure 4) and the age-classes of larch plantations in Northeast China in 2010 (Figure 5).

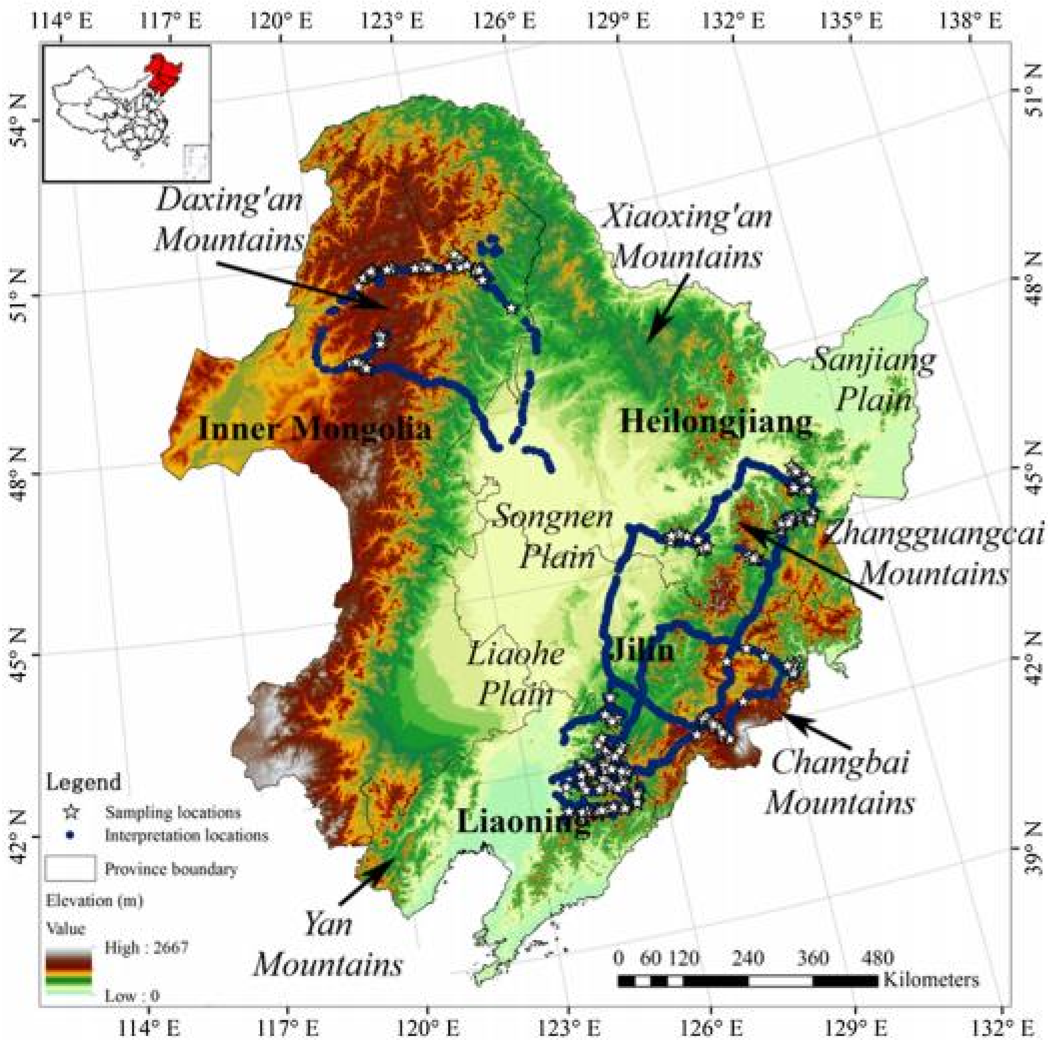

Figure 3. Study area: northeast China includes Liaoning, Jilin, Heilongjiang Provinces, and the east of Inner Mongolia Autonomous Region.

Source: Shang et al., 2018.

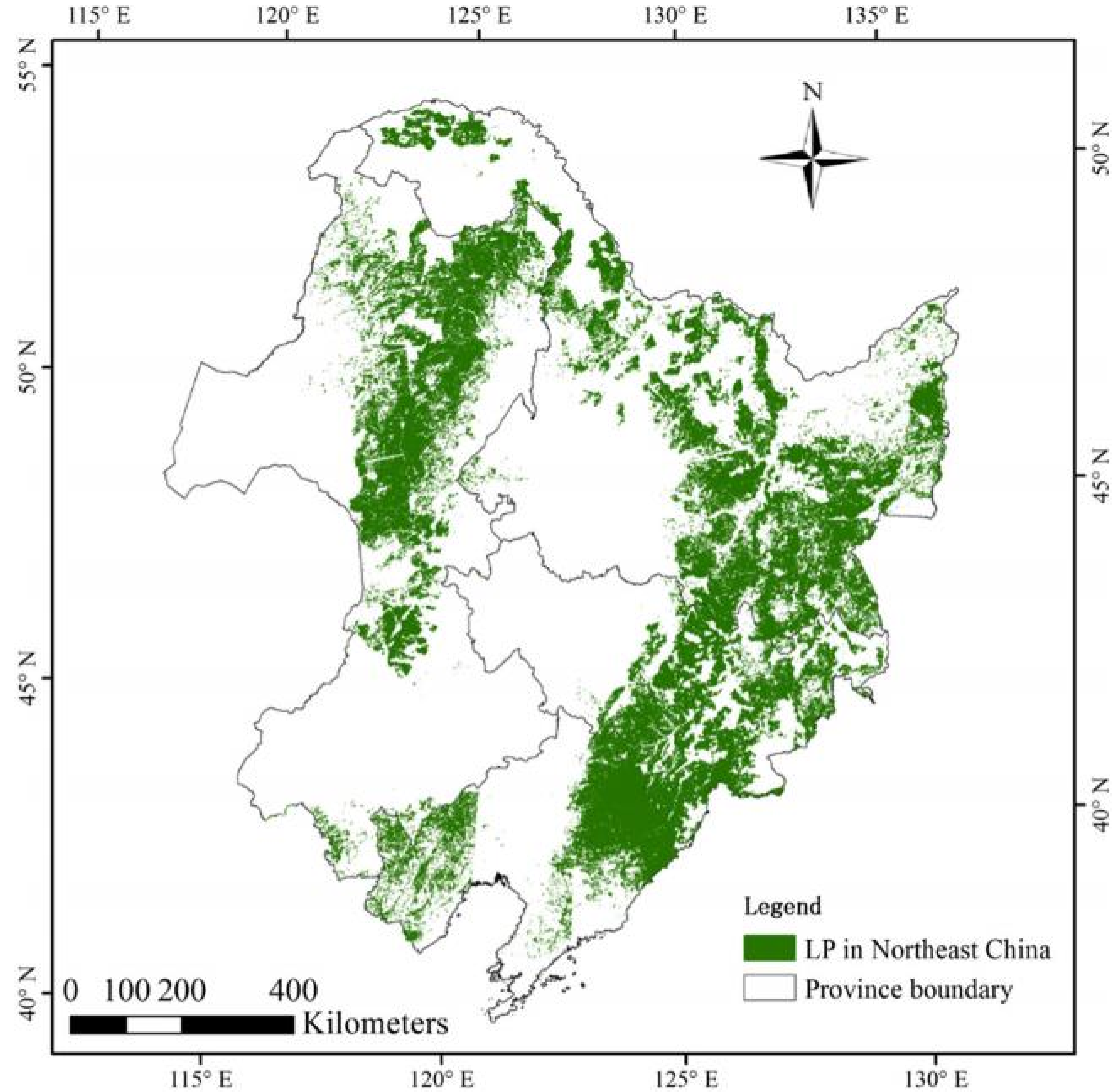

Figure 4. Spatial distribution of larch plantation in Northeast China.

Source: Shang et al., 2018.

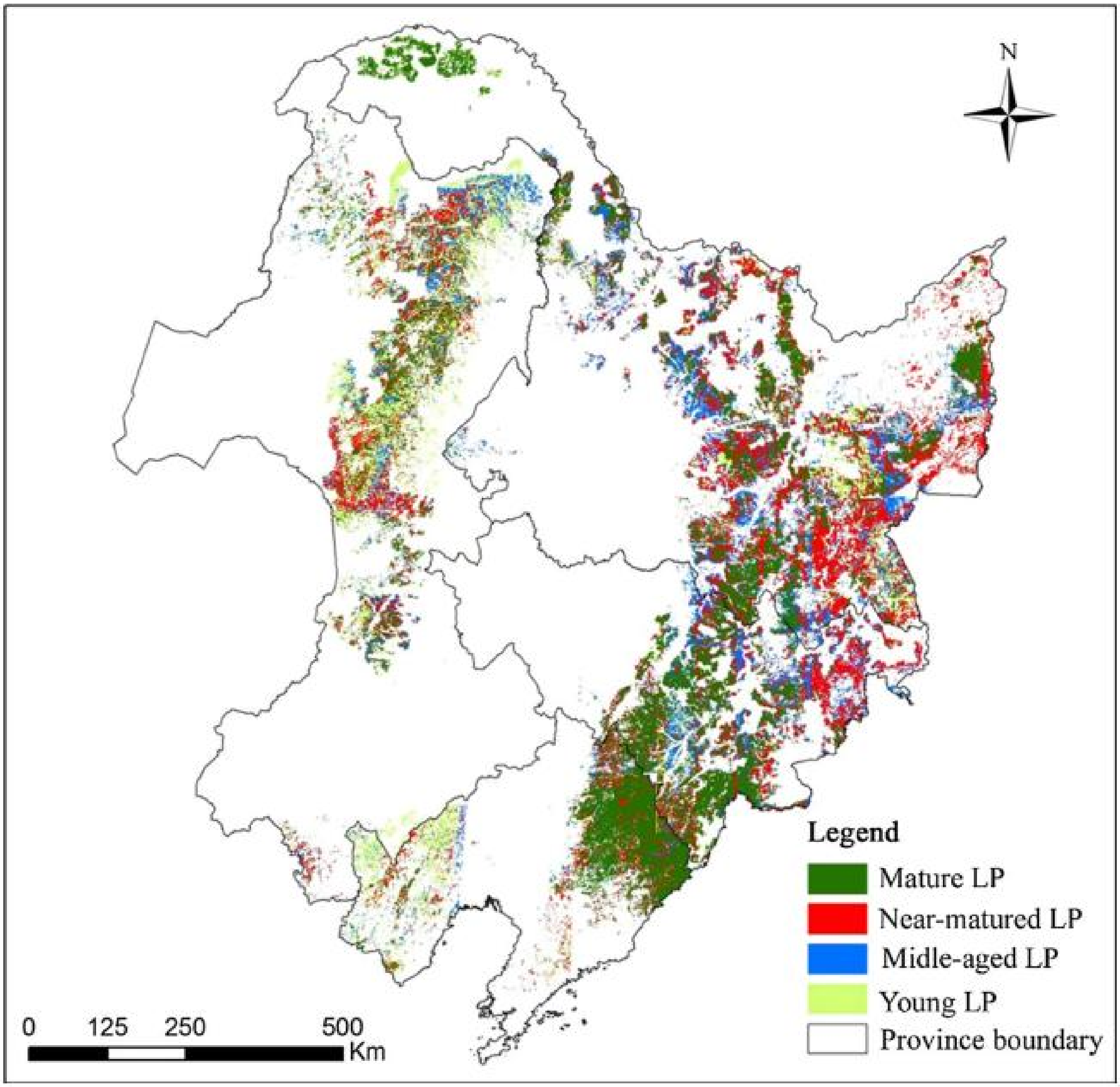

Figure 5. The age-classes of larch plantations in Northeast China in 2010.

Source: Shang et al., 2018.

Figure 4 and Figure 5 give us a direct perspective on the distribution of larch plantations in Northeast China and their age distribution. The temporal and spatial distribution of larch plantations is the key to managing larch plantations, especially converting to larch broad-leaved mixed forests on a large spatial scale. Therefore, the accuracy of the interpretation of the current larch plantations distribution pattern is crucial. The study used an interpretation of man-machine interactional interpretation to determine the spatial distribution of larch plantations. In 2010, the accuracy of larch forest verification and larch plantations distribution interpretation was 92.5% and 86.4%, respectively. The accuracy of larch plantations age classification is 87.2%. These results show that interpretation of man-machine interactional interpretation and detection of changes are effective ways to map larch plantations and assess their age. Through visual identification, the study made a good distinction between larch plantations forests and natural larch forests (Shang et al., 2018).

The accuracy of larch forest verification and larch plantation distribution interpretation is high and reliable. The study states that the total larch plantations area and age composition of the stands obtained by the survey are very close to the results of China's forest resources inventory (Shang, G. et al., 2018). With high accuracy, using multi-source remote sensing data to classify larch plantations is effective at a large regional scale. These data can promote further analysis bases on the study requirement.

2.2 Smartphone application

In this part, I will mainly analyzing the performance of the smartphone in silviculture practice. Smartphones, as potential use of low-cost technology, can implement and improve field data collection to support small-scale forest management (Kennedy, R. et al., 2013). In recent years, smartphone technology has improved dramatically, and now it has become the second computer that can even replace the computer under some circumstances. However, few articles discussed smartphone performance in forestry in recent years. So, I will begin with some cases and personal experience to analyze and discuss smartphone performance in silviculture practice.

2.2.1 Smartphone technology for small-scale silviculture

Silviculture management is defined as being carried out during a planned series of treatments for the total lifespan, species composition, and stand growth of forest stands managed for the purpose of managing establishment (Elliot et al., 2000). Silviculture management requires reliable data collection. However, with a limited budget and technical knowledge limitation, students have a hard time efficiently collect field data. Paper-based forms are the most frequently use method of data collection. Sometimes forest plan requires taking a photo and record GPS coordinates. Forester needs to carry a handheld GPS, paper-based forms, and a camera (Kennedy et al., 2013). These three things are too burdensome. When I collected field data, especially when I did it alone, I needed to switch these three things repeatedly. It is not efficient and may easily make mistakes.

Nowadays, more and more mobile Apps can be used as note-taker or data collection. These Apps can replace paper-based forms recording. Smartphone has a high-definition camera that can replace the digital camera, which is heavy, vulnerable, and expensive. The smartphone comes with GPS. Map application owns GPS coordinate system. Most importantly, most mobile apps and computers can communicate with each other. Which means we only need to enter the data once. Figure 6 and Figure 7 are the data collection for street tree inventory from two perspectives. The App that was used is a google map. Google map provides an essential data collection function in its App. It is suitable for the low budget inventory, especially for students. There are a few essential steps using google map as an inventory tool:

1. Preparation: before carrying out an inventory, I will prepare information that needs to be collected and set up forms on the computer.

2. Pin (location): since the smartphone pin function works poorly, I will pin every tree location for data collection. Google map has real-time HD maps, which I can locate trees on the map and pin them. These pins are for data entry.
3. Field measurement & data entry: after I measure tree data on the site, I can enter those data and upload pictures through the smartphone. The coordinate has already form when I pin the location. The data will update to a google map on a computer and classify information automatically.
4. Further study use: after I finish measurement and data entry, the inventory section is completed. Google map provides a data export function for further study use. I can export the data on Google Maps into excel format in my preference classification.

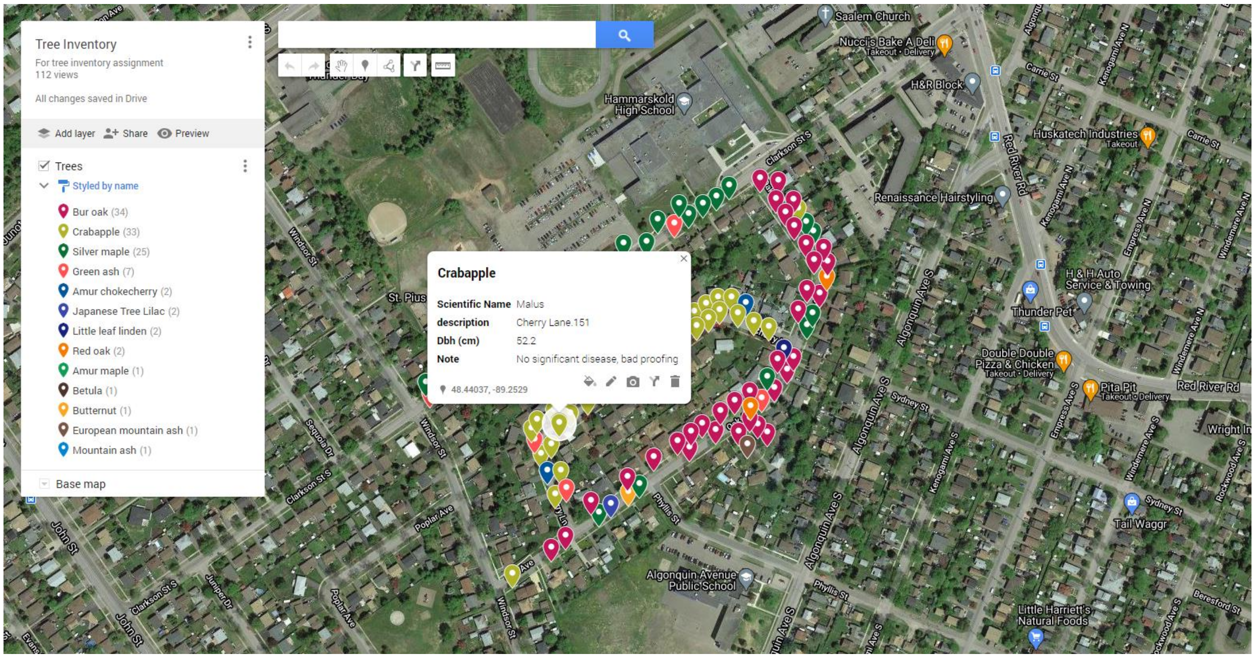

Figure 6. Data collection for street trees inventory- computer perspective.

Figure 7. Data collection for street trees inventory- smartphone perspective.

However, limited by the internet, a lot of smartphone Apps can not be operated. Most of the forest areas do not cover by the internet. Google map, on the other hand, has a powerful function that solves this problem. Google map provides an offline operation, using GPS signal to locate your phone. If you download the offline map in your area, you can identify your location even if you do not have internet. With this function, we can still use Google Maps to inventory without having internet.

2.3 UAV-Borne LIDAR and other technologies

In recent years, with the development of unmanned aerial vehicles (UAV) and alternative remote sensing platform technology, more and more companies and individuals using LIDAR to carry out forest surveys at a significant low cost. LIDAR is called light detection and ranging. It is also a technology of remote sensing. However, compared with remote sensing, it can provide horizontal and vertical information with high spatial resolution and vertical accuracy. Typically, we can use remote sensing to obtain 2-D information while using LIDAR to get 3-D information.

Over the last decade, the use of UAVs to capture ultra-high-resolution images has increased significantly. After we purchase the hardware, we can record images at a low cost at any time. The motivation for using UAV data is to explain some forest parameters such as canopy height, canopy coverage, tree position, number of trees, tree density, tree height, stem volume, and tree species (Thiel et al., 2016).

2.3.2 A case study of the performance of UAV photograph-based and airborne Lidar-based.

Remote sensing technology evolves rapidly in recent years, especially in the field of drones. In the study "*Comparison of UAV photograph-based and airborne Lidar-based point clouds over the forest from a forestry application perspective*," Christian Thiel and Christiane Schmullius used UAV and Lidar technology, which compare with each other, to show the data precision. In this study, they introduced a concept, point clouds. What are point clouds? What is the relationship and differences between point clouds and Lidar? Before I move on to this study, you should have some basic ideas about point clouds and Lidar. This will help you better understand the article.

Point clouds are a number of points to represent objects or space. They are the datasets. Each point represents the X, Y, or Z geometric coordinate on an underlying sampled surface. Point clouds are a way to collate many single spatial measurements against a dataset to represent the whole. With color information, the point clouds become 4D (David Gray, 2021). Lidar, on the other hand, is a remote sensing process that collects measurement data and uses it to create

3D models and maps of objects and environments. Lidar uses ultraviolet, visible, or near-infrared light to measure spatial relationships and shapes by measuring the time it takes for a signal to reflect off an object to a scanner (David 2021). We can use Lidar to create point clouds. However, not all point clouds are formed by Lidar. Point clouds can be made from images acquired with a digital camera. This technique is called photogrammetry. One difference that distinguishes photogrammetry from LiDAR is RGB. The photogrammetric point clouds have RGB values for each point, which result in a colorful point cloud. On the other hand, when it comes to accuracy, there is nothing better than Lidar (David 2021).

Back to the article, this study's primary purpose is to examine the potential use of photogrammetry, compare it with Lidar inaccuracy.

To get a high quality of UAV photograph-based data, the study used UAV X8000 (Figure 8) to acquire images. Due to technical and legal restrictions, the flying activity area was divided into seven sections. The area of each section is about 25 hectares. Each sector's flight time was 7-10 minutes, and the flight speed was set to 8min/sec. Before the experiment, the researchers uploaded the flight route of the UAV. After takeoff, the drone was switched to autopilot mode (Thiel et al., 2016). Five essential steps should be paid attention to (Thiel et al., 2016):

1. Detects stable points in the image (for different viewpoints and illuminations).
2. Generate a descriptor for each point to find the correspondence between images.
3. Resolve camera position parameters.
4. Use bundle adjustment to find the position of the camera.
5. High-density surface reconstruction and texture mapping.

Figure 8. UAV- Logo-team Geocopter X8000.

Source: Thiel et al., 2016.

PhotoScan is commercial software that generated a sparse point cloud and image alignment in this study. Figure 9 is the image mosaic based on 490 Tetracam mini MCA2 images. Figure 10 shows the UAV point clouds image of the 4-ha subset of flight sector 1. In Figure 10, the height distribution of this sector can be identified. Through tree height, the forest types and their growth conditions can be estimated.

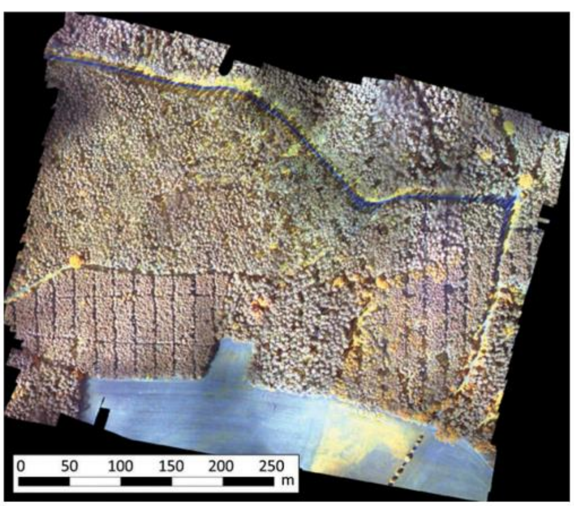

Figure 9. The image mosaic is based on 490 Tetracam mini MCA2 images.

Source: Thiel et al., 2016.

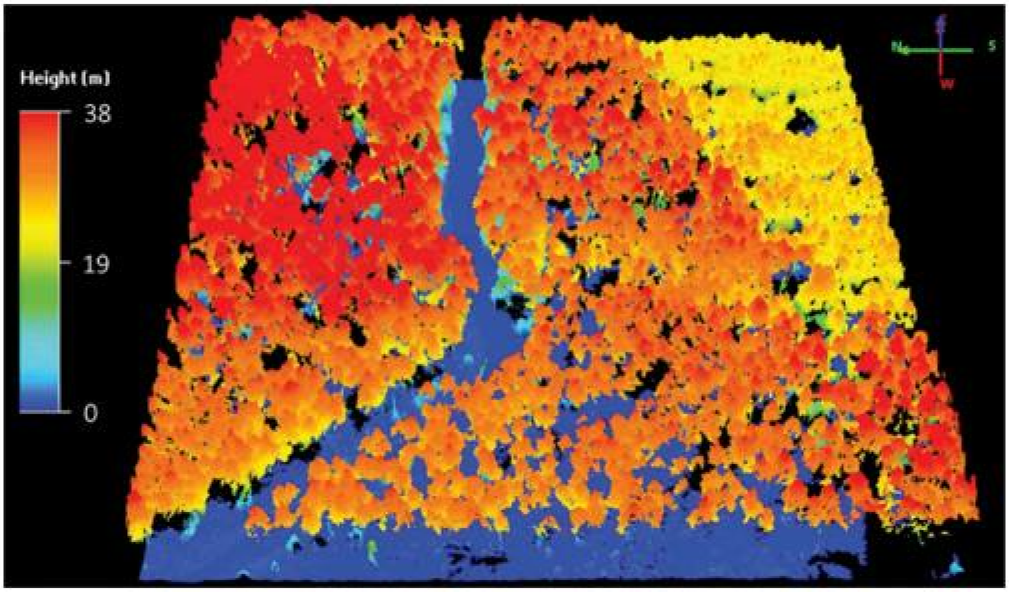

Figure 10. UAV point clouds image of the 4-ha subset of flight sector 1.

Source: Thiel et al., 2016.

Lidar data is available on the website. In this study, Lidar and UAV data were collected in the same year but with different collection seasons. Figure 11 shows the same subset as Figure 10, but in the winter season (Thiel et al., 2016.).

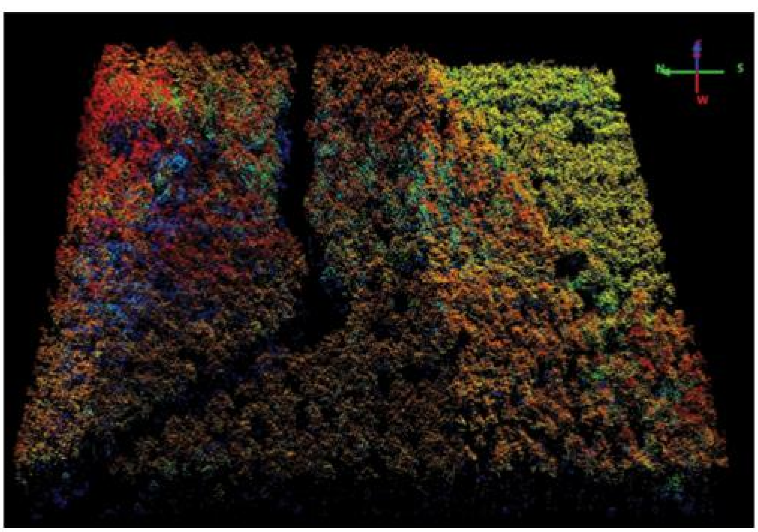

Figure 11. Image of the 4-ha subset of flight sector 1 (the same as Figure 10).

Source: Thiel et al., 2016.

After a complex analysis and comparison, the study indicated that there is a high similarity between UAV photograph-based and airborne Lidar-based inaccuracy. Compared to Lidar, UAV data can improve tree detection since it has more geometrical details. UAV image data can be used in areas where Lidar data is unavailable or needs to be acquired frequently (Thiel et al., 2016).

2.4 Decision Making

Decision-making is a crucial part of silviculture practice. With all the information we gather with our technologies, how can the manager makes a proper decision to carry out the silviculture activities? After the manager gets the information, the next step is to summarize the information and make a silviculture practice plan based on the information. Forest management plans focus not only on timber production but also on the value of recreation, facilities, wildlife, and forests' role in obtaining sustainable water resources (Riedl, L. et al., 2000). We have a variety of tools for information gathering. As the basic tool for information collection, they are the indispensable basis for our designated silviculture practice plan. Forester should learn how to use them and help us specify silviculture practice plans. In this part, I will introduce how to use GIS and other technologies from different perspectives to support our decision-making, giving you insight into silviculture decision-making.

2.4.1 Peer review: MapModels: a new approach for spatial decision support in silvicultural decision making.

MapModels is a new and flexible exploratory data analysis and modeling tool for spatial decision-making problems (Riedl et al., 2000). The study introduces a method calls spatial decision support systems (SDSS). It is a valuable tool for analyzing multiple complex spatial decision problems based on computer systems (Riedl et al., 2000). SDSS can help operater analysis and operate the field data that gathered to assist in solving specific problems. SDSS is computer-based that combines database management systems with analytics and business research models, graphic displays, table reporting capabilities, and decision-maker expertise to help solve specific problems (Riedl et al., 2000).

The use of MapModels is demonstrated by determining the purpose of particular stand management. The importance of the "timber production," "recreation," and "rockfall prevention" goals, as the management goals of "water production" and "conservation of biodiversity," are considered necessary for the entire forest area (Riedl et al., 2000). You need to determine your stands. When foresters rely on human thinking's analytical ability, it is difficult to solve complex spatial decision-making problems sufficiently. Using MapModels to support spatial decision-making in forestry planning, allows users to build and analyze decision-making problems. MapModels enable users to adapt analysis methods, decision rules, and models to solve specific problems without resorting to specialized computer programming (Riedl et al., 2000).

In general, when forester obtains forest stand information but do not know how to analyze and make a decision, he can use software such as MapModels or other commercial software products to assist him in decision-making base on our objective.

2.4.2 A case study of GIS Coop: networks of silvicultural trials for supporting forest management under changing environment.

This article introduces in detail the use of GIS technology by the GIS Coop to formulate forest management strategies. This study aims to describe the experimental project of GIS Coop, introduce the network and currently available data, and show how the GIS Coop network can be developed to meet new demands related to current environmental and economic changes.

In the study, forest management system choice is mainly based on its economic benefits and its relative abundance in the French forest landscape. The purpose of this study is to collect data and adapt or validate forest dynamics models to determine and support current and future forest management practices (Seynave et al., 2018). To achieve this goal, four networks were established in pure (50% of the French forest is made of monospecific stands) stands of Maritime pine (*Pinus pinaster Aiton*), Douglas fir (*Pseudotsuga menziesii Mirb*), Laricio pine (with the two varieties: Corsican pine: *Pinus nigra subsp*. *laricio var. Corsicana* (Loudon) (Seynave et al., 2018).

In all forest management systems, experiments manipulated key factors: forest density and its evolution from plantation/renewal to harvesting. This factor is related to the competition between trees and population growth at the stand level. It is an essential element in the process of tree regeneration, stand growth, and death. Figure 12 is two stand site examples of this study. The site images were obtained by UAV. Image a shows the site where four competitive level factors were tested. Image b shows the site where two factors (competition and improved genetic) have seven treatment categories (Seynave et al., 2018). The seven treatment categories were open growth, low competition, medium competition, intense competition, maximum competition, increasing competition, and decreasing competition. Image c illustrates differences in tree opening and closure characteristics under different forest densities. Image d was cross-tested with the competition level factor.

Although GIS applications are only a tiny part of this study, it can tell you intuitively the test site's situation. According to the GIS application pictures, we can classify the trees according to their different growth conditions. This study shows that different silviculture treatments will produce different stand conditions, especially stand density.

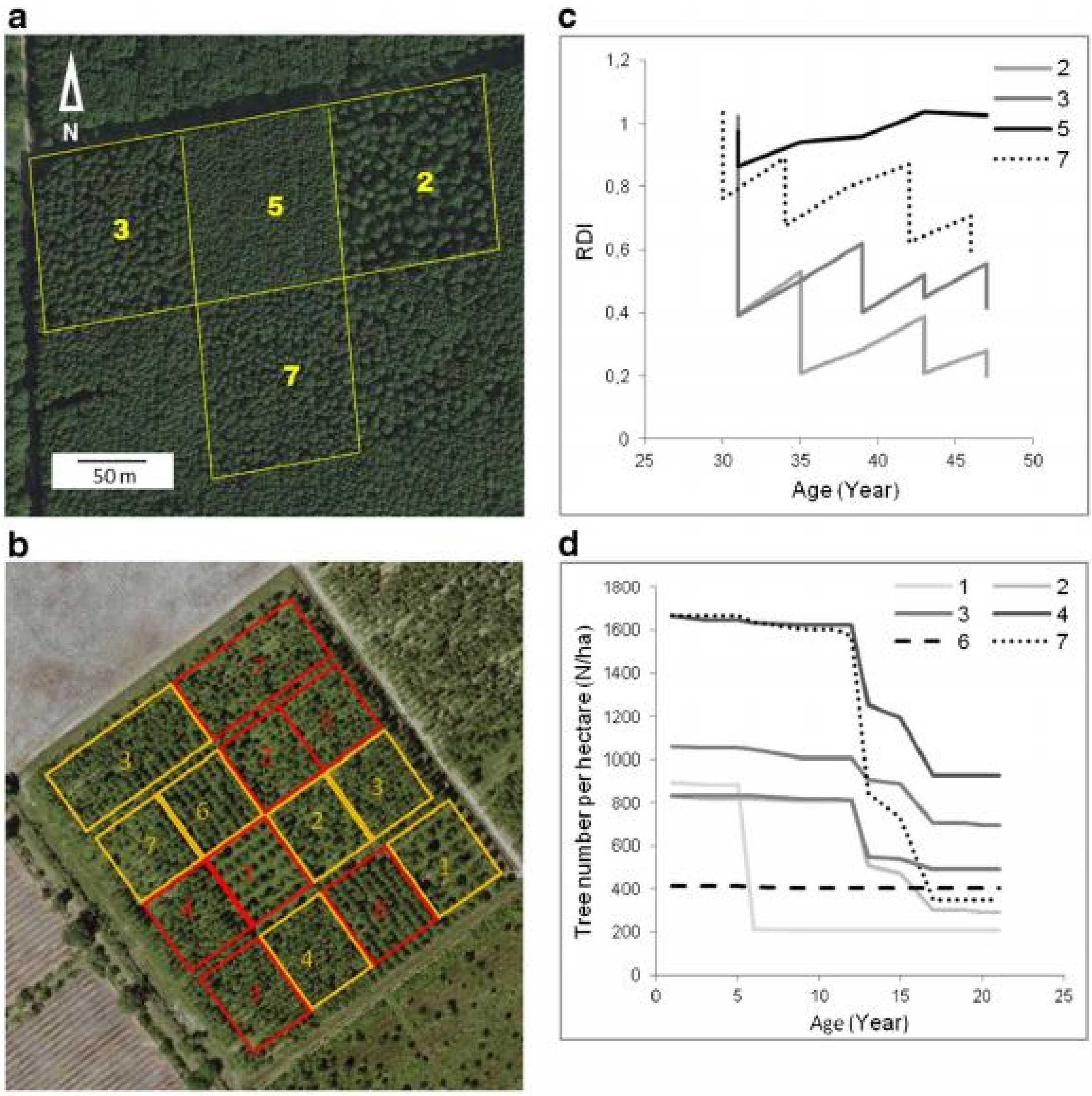

Figure 12. Two examples of stand site of GIS coop organizations.

Source: Seynave et al, 2018

Due to a lack of understanding of relevant knowledge, this study's interpretation is only at the GIS and silviculture level. In this study, the explanation of GIS application only accounts for 5% of the study. Combined with the previous article, GIS applications take up a small part of the study. However, its role in the study is immeasurable. It is the fundamental part of the article and the source of the original data. And the time to collect information also takes up a lot of experimental time.

2.4.3 A case study of a GIS decision support system for regional forest management to assess biomass availability for renewable energy production.

GIS and related technologies, their application is not only in data acquisition, but more importantly, through related application software to generate more data. This article uses GIS data, combined with related software (Free and Open Source for Geospatial (FOSS4G)), to estimate the availability of forest biomass for energy production in Alpine regions and support management decisions (Zambelli et al., 2012). FOSS4G is the annual global event hosted by OSGeo since its inception in 2006. Its predecessor is rooted in the GRASS and MapServer communities and can be traced back to the beginning of this millennium. FOSS4G is the implementation technology for a decision support system to maximize information sharing and share development. DSS was developed by combining geospatial databases and geographic information system technologies (Zambelli et al., 2012).

The purpose of the study is to use GIS technology to obtain geographic information, combined with FOSS4G, to develop suitable roads, and to provide support for the felling and transportation of biomass in a mountain area.

In the process of formulating the road, this study used a variety of software, including GRASS 6.4 Geographic Resources Analysis Support System for raster processing; PostgreSQL 8.4.4 and PostGIS 1.5.1 for vector processing; Python 2.6.5 for GRASS scripting connection to

DB through psycopg2, and basic computation using numpy scipy (Zambelli, P. et al., 2012). Figure 13 shows the feasible roads that can meet the objective of the program. To evaluate the difference in distance and height between each pixel and the closest point on the nearest road, the cluster map obtained by Identify and the map obtained by Pointify were analyzed using PostgreSQL and PostGIS. Figure 14, on the other hand, is to reduce calculation time. The search is only performed on the pixels in the 50m buffer around each interval (Zambelli et al., 2012). PostgreSQL-PostGIS provides an effective tool for working with vector data and its attributes.

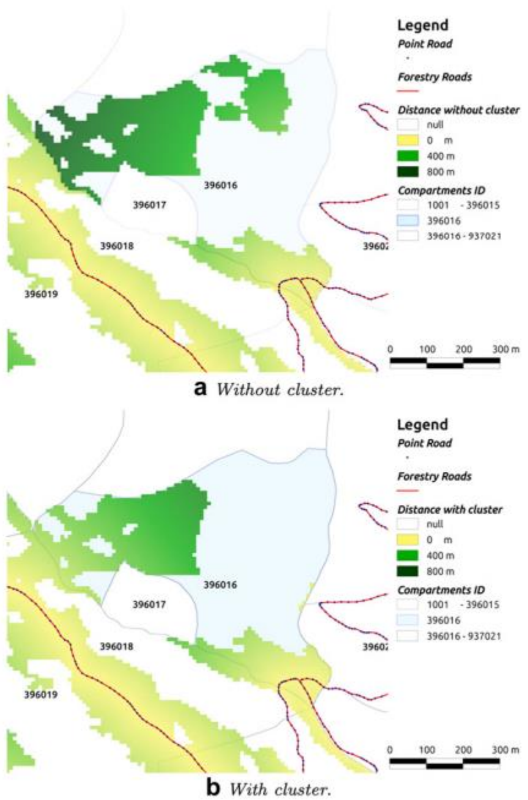

Figure 13. Forestry roads that are produced by (a) PostgreSQL and (b) PostGIS.

Source: Zambelli et al, 2012.

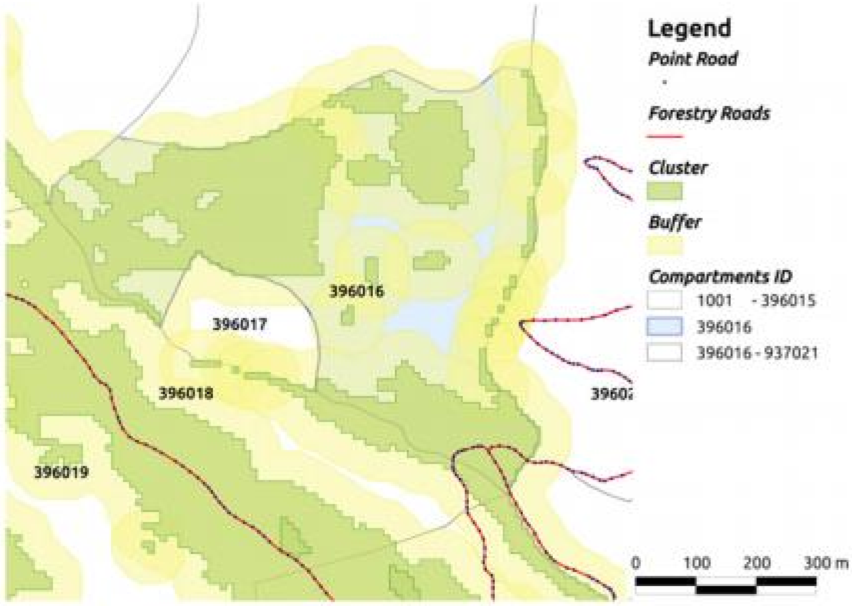

Figure 14. A combination of software produces forestry roads.

Source: Zambelli et al, 2012.

This study presents preliminary results from the first FOSS4G software-based method developed to estimate the forest biomass used for energy production, considering logging techniques in Alpine areas. This method is based on GRASS and PostgreSQL-PostGIS software. The combination of a geographic information system and a geographic database allows you to build methodologies using the tools provided by these two software. However, the study did not show us how to use the software. QGIS is also a software that applied in this study but did not discuss in detail. I have experience running QGIS, and it was not easy to get an accurate result. We may need to resampling multiple times to get the high accuracy map or result.

3.0 RESULTS

Before discussing the advantages and disadvantages of each technology, I must emphasize that none of these technologies is superior to others. They can play their benefits under certain circumstances.

I have shown the uses of GIS and remote sensing, smartphone, and Lidar and discussed their performances. In this part, I will discuss more about their advantages and disadvantages. Some advantages and limitations have been discussed in previous sections, and I will emphasize again and compare them with each other. It may give you some idea about which technology should be used in a particular circumstance.

GIS and Remote sensing

GIS and remote sensing are the most frequent tool for data collection in forest management. 1. GIS can visualize spatial information which forester can have a perceptual intuition of the ground site (Foody 2007). The most basic appearance of the forest stand can be showed by GIS. 2. With the help of various computer software, like ArcGIS and QGIS, GIS can be used for a vast range of tasks involving geography (Seynave et al., 2018). The map or ground information produces by GIS or remote sensing are needed to be analyzed by software. This is a vital step to digitize graphics data (Liu et al., 2005). 3. GIS has high accuracy and presents better predictions and analysis. Geographic information systems can also display, query, understand, visualize, and interpret data in a variety of ways. These data reveal relationships, trends, and patterns in the form of globes, maps, graphs, and reports (Wulader 2004). Remote sensing, on the other hand, 1. can provide free, clear, and stable images. This data was previously required to be purchased. But now, these data are more publicly available. One of the largest remote sensing data websites is Earth Explorer (https://ers.cr.usgs.gov/login). Earth Explorer provides tons of data from various satellites. 2. Satellite remote sensing covers every corner of the world of geographic information. Each image covers a large area. 3. Also, Remote sensing has good historical data. Earth Explorer has Landsat data since the 1970s.

However, 1. GIS is expensive, especially the development of analysis programs is more costly. The software which provides a variety of functions corresponding to different analysis needs is expensive. Student cannot afford. 2. GIS operator requires professional knowledge. If a non-GIS group runs GIS, the result might suffer. 3. GIS analysis involves an amount of data inputted to be practical for a task in which there may have changes of error (Kahila- Tani 2019). These errors greatly influence the accuracy of the result. To avoid errors, operator needs to resample times and analysis to get a reasonable result. 1. Remote sensing is expensive, too. Most remote sensing data is open to the public. However, if you want to get the high spatial resolution images (to increase the result's accuracy), these require a high cost for purchase. 2. If you have explored the database of remote sensing, you will find that some of the images were covered by cloud. Clouds may hide ground features which affect the accuracy of results. 3. One of the biggest problems that student may encounter is that student may only solve one image to get the information. Still, it requires sorting through many images to obtain helpful information.

Compared with other technologies used in silviculture practice for data acquisition, GIS and remote sensing can provide the site's most accurate information. However, they also require professional skills to operate GIS and remote sensing software to obtain high accuracy result. For student or beginner, they need to spend months to learn to run the software since tons of errors will come along and we need to know how to deal with them. GIS and remote sensing are the best choices for a large area of forest management data acquisition since they provide the most significant and largest geo-information database, and they have the most potent geo-information analysis software. They can reduce lots of time on information acquisition and data analysis.

Smartphone

Smartphone technology in forestry applications is a combination tool. 1. Smartphone is handy and convenient. Smartphone has GPS, an information collection sheet, and a camera. These are the essential tools for a ground survey. Smartphone also has Apps that help us record data or provide particular GPS function for locating. 2. Among three types of technologies that were introduced, the smartphone is the most inexpensive one. Budget is crucial for students. Under limited conditions, students can use the smartphone's convenience as much as possible to collect data. 1. However, the smartphone needs to enter data manually. This has caused its data storage speed to drop, making it unsuitable for large-scale data acquisition. 2. Limit by the smartphone running speed. It can not replace the computer to carry out analysis works. It can not finish the whole data collection process independently.

Luckily, with the development of smartphone applications, more applications have developed to help smartphones interact with a computer which makes it convenient for data input. For students, the smartphone is the first tool for data collection due to its low cost, convenience, and ease of operation compared with other technologies.

UAV Lidar

UAV Lidar technology has become increasingly popular in recent years. Among the three technologies, 1. UAV Lidar is a relatively low cost suitable for individuals, groups, and small companies with a budget to afford it. 2. UAV Lidar can produce very high spatial resolution maps, which can even compare with GIS and remote sensing maps that need to be purchased. 3. It can replace the sensor to adapt to the different requirements to achieve the management goal. 4. The most important feature for UAV Lidar is its flexible availability. It can be placed anywhere and can take off at any time. It can even detect the blind area of GIS and remote sensing. The function of UAV Lidar is mighty, but it also has minor flaws. 1. Since the Lidar sensor relies on the UAV to drive, sometimes the image will be blurred due to the flight's shaking, leading to geographic distortion. 2. Nowadays, the management of UAV flights is stringent in some areas. We need to obtain a flight permit before performing information-gathering tasks.

UAV Lidar is currently one of the most widely used tools. Its budget and practicality are very suitable for small and medium-scale forestry surveys. For a student, buying a UAV Lidar seem to be impractical. Renting a UAV appears to be a better option, but it is challenging to rent Lidar lenses. UAV can carry a camera (like a smartphone) to obtain a high-definition local area top view. That is very helpful for forest stand structure analysis.

4.0 DISCUSSION

GIS, remote sensing and Lidar technology have been widely applied in silviculture practice. Smartphones can not be used in a formal silviculture practice due to their limitations. But portable products such as smartphones and tablets have great potential that replaces other technologies. Many companies and scientists have proposed the concept of the cloud. Cloud is the use of powerful network transmission technology to transmit data in real-time. In the 4G era, it was envisaged to use the cloud for real-time data transmission. But 4G speed was not as fast as expected, and these cloud application projects were stopped. Now the 5G era is approaching. We can imagine how the cloud will perform in silviculture practice.

In the application of cloud technology, smartphones and other portable products will become carriers of data transmission. The smartphone's role is no longer simply to record data. It will become more straightforward, a screen. But this screen allows you to do the same thing as in an office, even in the forest, if there is a 5G signal. In other words, we can use the mobile phone to control the computer. After we collect data on the site, we do not need to return to the office. We can use software for data analysis while collecting data with a smartphone. Cloud technology is very beneficial to our students. Most cloud technologies exist in the form of leases. When the technology is perfect, the price will tend to be reasonable. It is very suitable for students and small and medium-sized enterprises. The traditional form of GIS-computer software will be broken. As for UAV Lidar, it is a portable device. Its role will be further amplified in the 5G era.

Back to the thesis, GIS and remote sensing are still the most widely used among all technology. The advantage is that it can collect data on a wide range of forests. Combined with the software, it can analyze different management objectives. The cost of UAV Lidar is relatively lower than that of GIS and remote sensing. The advantage of UAV Lidar is that it can conduct small and medium-scale forest stand data at any time, any place, and under any weather conditions. It can intuitively present the analysis data to the researcher. The application of smartphones in silviculture practice is only limited to data collection, but the analysis of data must rely on computer software.

5.0 CONCLUSION

I have introduced GIS and remote sensing, smartphone, and UAV Lidar. GIS and remote sensing, and UAV Lidar can help analyze stand structure, produce the 3D image, and record data like density and tree height. A smartphone is a tool for recording data. The smartphone itself does not have any analytical capabilities. The data collection process is time comsuming, especially data analysis. When there is an error in the exported data, or the accuracy is low, the data needs to be continuously re-analyzed or even re-collected. As a forestry student, it is vital to master an application of data collection and analysis. Data collection and analysis are the basis for formulating forestry management plans, and foresters should master this skill.

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