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REVIEW ARTICLE

Application of unmanned aerial vehicles in earth resources monitoring: focus on evaluating potentials for forest monitoring in Ethiopia

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ABSTRACT

Application of unmanned aerial systems was limited to the military until the last decade when we see dramatic growth of interest by civilian users. Among the many fields of application of unmanned aerial vehicles (UAVs), forestry has diverse uses ranging from forest cover assessment to species classification and real-time forest fire monitoring.

Inspired by the potential uses of the technology, this study is a review of literature on the types and uses of UAVs, the challenges and opportunities, current experiences and the future prospects of using UAVs for forest resources monitoring in Ethiopia.

The study has identified potential uses of UAVs for forestry applications. It has also shown that there is perceived need for accurate, demand-based and cost-effective tools for forest resources monitoring in developing countries including Ethiopia. Hence, the use of small UAVs in the forestry sector in Ethiopia is believed to be a supplementary method to the existing methods of spatial data capture for filling the gap of information and improving the quality of forest information that is needed to comply with international standards.

The results of this study indicate that Ethiopia can make use of the technology and improve its forest information system. However, while doing so, rules and regulations must be put in place to avoid the challenges that come along with introducing the technology. If properly used, the technology will enhance the forest management decision-support system of the country.

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Introduction

Drone or unmanned aerial vehicle (UAV) is a lightweight flying device similar to an aircraft; however, different from an aircraft since it is not operated by a pilot on-board. Based on how its movement is controlled, it can be an autonomous or a remotely piloted type. Broadly classified, small unmanned aerial systems (UAS) use a platform less than 10 kg in weight (Watts, Kobziar, & Percival, 2010). There are different models of UAV; however, most of them are hand-launched and operated remotely. A UAV is the aerial platform component of UAS, which also has a ground control station and communication components. Based on the types of wing, UAVs might broadly be classified as fixed-wing or rotary-wing type. The fixed-wing UAS move horizontally and need a larger open space for take-off and landing. On the other hand, the rotary-wing UAS move vertically; thus, requiring a small open space for landing.

Originally, UAS were used for military applications like reconnaissance and surveillance. Furthermore, a significant part of the civil applications of UAS technologies has been aerial photography and remote sensing for many decades (Colomina & Molina, 2014). However, they are becoming widely used in civil applications, especially in recent years. Now, UAS are becoming important in many fields like agriculture, cultural heritage management, search and rescue missions, infrastructure inspection, natural resources management and urban planning. These diverse applications are linked with the recent advances in the platform and sensor technologies (Budiyono, 2008). Image handling and processing systems have also shown improvement and provide opportunity for increasing interest in the use of UAS in many sectors. Therefore, such a huge interest in the use of UAS has grown because of the improvements in the technology and the increasing demand for timely and accurate information to cope up with the changing environment (Puliti, Ørka, Gobakken, & Næsset, 2015).

Because of climate change, sustainable forest management is becoming a global concern. Consequently, countries are encouraged to generate accurate forest information on a continuous basis to ensure that they have reduced net greenhouse gas emissions to the atmosphere. That is the reason for the institutionalization of the Reducing Emissions from Deforestation and forest Degradation plus (REDD+) schemes and other international conventions. Those conventions

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require the member countries to quantify and report the reduced greenhouse gas emission because of reducing deforestation and forest degradation as well as ensuring sustainable forest resources management. For many years, this task has been carried out using the complementary methods of ground-based surveys and remote sensing data analysis. However, the use of UAS maybe a much better method since it provides accurate, flexible and cost-effective techniques (Banu, Borlea, & Banu, 2016; Colomina & Molina, 2014; Puliti et al., 2015).

Located in the horn of Africa very close to the Sahara desert, Ethiopia is one of the countries that has suffered from the impacts of climate change. The country is one of the signatories of the REDD+ negotiations and other international environmental conventions. Ethiopia has been striving to combat the impacts of climate change since it is vulnerable to recurrent drought and other environmental crises. As a result, it has designed and implemented a strategy that emphasizes restoring degraded lands and sustainable forest management called the Climate Resilient Green Economy strategy.

In response to the international conventions, Ethiopia needs to generate reliable forest information that conforms in quality to the international standards and can be ready to be reported whenever required. The existing ground-based methods of forest data collection are costly and slow to meet the time limit of reporting. On the other hand, satellite remote sensing methods based on the freely available Landsat images do not meet the quality criteria. This is mainly because Landsat images have too small spatial resolution to correctly identify and interpret trees. As a result, the information generated using these images has low accuracy.

Cognizant of the current trend of development, it seems that Ethiopia can benefit from the emerging UAS technologies to generate reliable forest information at the required time frames. Hence, this study was intended to explore the existing facts about applications of UAS technologies in forestry in various parts of the world to identify the potentials of the technology and initiate case studies to test if they can be adapted to the settings in Ethiopia.

Methods

This study focuses on review of the recent scientific publications in the field of UAS and their applications, particularly in forestry. Then, significance of the technology for forest resource monitoring in Ethiopia was evaluated based on the international experiences and existing realities in the country. A systematic approach was employed to search for all relevant scientific papers that relate to the topics.

A bibliographic survey on the Google Scholar and Scopus databases of scientific publications has been carried out. The keywords used in the search process include various combinations of the alternative nomenclatures of the system, fields of application and the name Ethiopia, which is the focus of this paper. The options of nomenclature that were used as keywords include "unmanned aerial systems", "unmanned aircraft systems", "unmanned aerial vehicles" and "drone" since these are the commonly used terms in scientific papers. The various application areas related to the interest of this study were agriculture, flood control, wildlife monitoring, wildland forest fire management, forestry, hazard management, remote sensing, coastal wetland mapping, mapping of invasive species and environment. Furthermore, the keyword "Ethiopia" was used to specify existing literature related to the uses of UAS in the country.

The review was organized according to the applications. The papers in each category were reviewed in accordance with these sections. A synthesis of the established global knowledge base in the use of UAS for various applications with emphasis on forestry has been made. The current experiences, legal frameworks, possible challenges and opportunities of using UAS in Ethiopia were reviewed. The existing methods of forest inventory in the country, their limitations and the prospects of future inventories were examined. Finally, feasibility of the technology in forest monitoring was evaluated based on international experiences and the local settings.

Types of UAV

UAVs are classified into various types based on different criteria. Most of the criteria for classifying UAVs include size and payload, flight endurance, flight range, altitude and capabilities. These characteristics are interrelated. Most of the time, large UAS carry more payload, fly at a higher altitude, move a longer distance and hence have better flight endurance and capability than small ones.

Based on wing types, UAVs are classified into the following five major types. The first type are the rotary-wing UAVs, which use batteries and have shorter flight times (Paneque-Gálvez, McCall, Napoletano, Wich, & Koh, 2014). This type of UAV includes the helicopter, quadracopter, octocopter and other varieties of multicopters. This type of UAV has the advantage that it needs small space for landing as compared to the fixed-wing UAV.

The second type of UAV are the fixed-wing UAVs, which are more suited to applications that demand longer flight endurance. They require large space for take-off and landing. As a result, they are not suitable for areas crowded with tall objects like buildings, trees, wind farm vanes and other infrastructures. However, they have simple structure, which is easy for maintenance (Klimkowska, Lee, & Choi, 2016).

The third type of UAV are the groups of lightweight aerial systems called blimps such as balloons and airships, which are lighter than air and have long flight endurance, fly at low speeds and generally are large sized (Gupta, Ghonge, & Jawandhiya, 2013).The fourth group of UAV are the flapping-wing UAVs, which have flexible and morphing small wings, similar to birds and flying insects.

The fifth class of UAV are the Vertical Take-Off & Landing (VTOL) UAVs, which do not require takeoff or landing run (Watts, Ambrosia, & Hinkley, 2012). These UAVs are typically used in situations where limitations of terrain require this specialized capability. However, high power requirements for hovering flight limit the flight durations for VTOL UAV, except in the large sizes for which increased lifting capabilities accommodate large fuel capacity. The advantages of VTOL UAV are the portability of the platforms for remote area operations without the necessity for runway complexes. These platforms are useful in rescue operations in a complex urban structure environment (narrow streets, buildings, etc.).

Thus, there is a choice to select the most appropriate technology that conforms to the prevailing environmental settings and purpose.

UAS sensors

Most of the UAS have inbuilt sensors, which record the red, green and blue (RGB) part of the electromagnetic spectrum. However, in recent years, introduction of additional sensors has enhanced the efficiency of capturing additional data. This was achieved by including the red-edge, near infrared and thermal infrared spectral bands and laser scanning systems (Colomina & Molina, 2014; Zahawi et al., 2015).

Innovations in sensor technology have fostered the successful implementation of UAS for forestry applications. For example, infrared sensors, including the thermal imaging systems, were used for forest fire monitoring (Allison et al., 2016; Hoffmann et al., 2016; Martínez-De Dios, Merino, Caballero, & Ollero, 2011; Merino, Caballero, Martínez-de-Dios, Maza, & Ollero, 2012; Scholtz et al., 2011). Predicting canopy cover and studies related to wood volume and biomass estimation became possible using laser scanners (Getzin, Nuske, & Wiegand, 2014; Zahawi et al., 2015).

This development in sensor technology has paved additional opportunity for studying the status of natural resources and the challenges facing them. This will enhance the potential uses of UAS technologies for multiple user groups, including forestry professionals, by providing more spectral data that can be applied to a wide range of uses.

General applications of UAS

The original purpose of UAS technologies was for military, patrolling international borders and governance (Budiyono, 2008; Callam, 2015; Finn & Wright, 2012; Gregory, 2011; Muchiri & Kimathi, 2016; Wall & Monahan, 2011). Through time, UAS technology has become important in many application fields. It is applied in management of crops, fisheries, forests and other natural resources among others (Jeanneret & Rambaldi, 2016).

In the agricultural sector, UAS have gained interest in precision agriculture to increase production (Simelli & Tsagaris, 2015). Scientists used UAS to study nutrient content of crops. For instance, UAS were used to estimate the amount of nitrogen status of turf-grasses in the University of Pisa, Italy (Caturegli et al., 2016). According to Shi et al. (2016), UAS technology was used to measure plant height of crops like maize and sorghum. UAS were also used in different countries to study plant biophysical properties like leaf area index and yield, and the growing environment. The technology has been used to investigate weed, pest and disease infestations. For example, small UAS were used to detect symptoms of disease and pest attacks on oil-bearing trees in Greece (Psirofonia, Samaritakis, Eliopoulos, & Potamitis, 2017). Planting patterns in sugarcane were supervised using UAS imagery in Nicaragua, Central America (Luna & Lobo, 2016). Promising results were obtained indicating huge potential of the technology in precision agriculture in the future (Felderhof, Gillieson, Zadro, & Van Boven, 2008).

The use of UAS is also becoming common in flood control; natural hazard management and infrastructural changes (Galarreta, Kerle, & Gerke, 2015; Giordan, Manconi, Remondino, & Nex, 2017; Perks, Russell, & Large, 2016). Studies show that UAS were used to identify disaster damages and serve humanitarian response services during disaster events in flood-affected Asian countries like Taiwan and China (Feng, Liu, & Gong, 2015; Popescu, Ichim, & Stoican, 2017; UNOCHA, 2014).

Moreover, the emerging technology has been applied for coastal wetland mapping and environmental management (Boon, Greenfield, & Tesfamichael, 2016; Klemas, 2015). Due to the excellent spatial resolution of products from UAS, they are preferred choices for cadastral mapping (Crommelinck et al., 2016).

UAS have also attracted wildlife ecologists in many parts of the world, including those in African countries, for wildlife monitoring and rangeland management (Christie, Gilbert, Brown, Hatfield, & Hanson, 2016; Hodgson, Baylis, Mott, Herrod, & Clarke, 2016; Rango et al., 2009; Wich, 2015; Wolf, 2017). This approach was found to be a cheaper and safer technique of studying a vast area of wildlife and their habitats than ground-based techniques (Gonzalez et al., 2016; Linchant, Lisein, Semeki, Lejeune, & Vermeulen, 2015).

Forestry applications of UAS

This paper emphasizes on assessing the possible areas of application of UAS in the forestry sector. Several studies carried out in various parts of the world indicate that UAS have ample potential in assessing forest resources. This is mainly because UAS provide the possibility of making a non-destructive and accurate measurement of many attributes of trees (forests). The current growth of the UAS technologies has put great hope that the technology can be used to study forest dynamics, stand species composition, disturbances and other attributes of forests (Banu et al., 2016). The following paragraphs explain some of the most common uses of UAS in the forestry sector, which are thought to be good lessons for Ethiopia and other countries of similar desire.

Several research works done by different scholars reveal that UAS were applied in estimation of dendrometric parameters. Studies in Canada and European countries (Goodbody, Coops, Marshall, Tompalski, & Crawford, 2017; Hird et al., 2017; Puliti et al., 2015; Torresan et al., 2017) have shown that UAS were capable of estimating tree height, crown width, basal area, stem number; and modelling gross stock volume and above ground biomass. The research findings of Zahawi et al. (2015) revealed that UAS technologies are viable for monitoring tropical forest restoration in Costa Rica. Findings of this study revealed that UAS are able to predict canopy height and above-ground biomass at the same level of precision as LiDAR systems.

UAS are also used for tree species classification and quantification of spatial gaps in forests. Burchfield (2014) used UAS for mapping of invasive trees and shrubs in Eastern Kansas of the US. Similarly, multi-temporal UAS imagery differentiated tree species in southern Belgium (Michez, Piégay, Lisein, Claessens, & Lejeune, 2016). The possibility to fly at any required time and acquire high spatial resolution imagery provides the opportunity to study plant identification, which has been difficult using ordinary satellite remote sensing systems. Getzin et al. (2014) used UAS images to analyse canopy gap patterns of forests in Germany. Such a study of spatial gap patterns of forest canopy is relevant as a biodiversity indicator. In addition, UAS were used to determine canopy height of a mixture of uneven-aged broadleaved stands with a predominance of oaks and even-aged coniferous stands in Belgium and the US (Dandois & Ellis, 2013; Lisein, Pierrot-Deseilligny, Bonnet, & Lejeune, 2013).

Other studies have indicated that UAS have potential for post-fire recovery monitoring and forest protection. Scientific investigations indicated that UAS have contributed to wildland fire monitoring, especially in difficult topographic settings (Cruz, Eckert, Meneses, & Martínez, 2016; Ollero & Merino, 2006). It is used to generate information about the vegetation condition, water stress and risk indices before a fire happens. During the fire incidence, UAS that have infrared and visible sensors are important for fire detection and monitoring. In recent studies, these sensors were mounted on UAS to study the structure of ongoing forest fires (Casbeer, Beard, McLain, Li, & Mehra, 2005; Martínez-De Dios et al., 2011; Merino et al., 2012). In these studies, UAS were used to detect real-time behaviour of forest fire like the location and shape of the fire front, the rate of spread, and the fire flame height. A recent study indicated that UAS helped to monitor forest health and to map forest diseases. For example, the visible and infrared sensors were used to produce pest infestation maps in Germany (Lehmann, Nieberding, Prinz, & Knoth, 2015).

Furthermore, researchers have found that UAS are vital tools for 3D reconstruction for growth modelling (Gatziolis, Lienard, Vogs, & Strigul, 2015) and studying biodiversity (Sandbrook, 2015). The technology helped to study seasonal patterns of change of wetland vegetation (Marcaccio, Markle, & Chow-Fraser, 2015). Thus, UAS have significance in studying habitat conditions and understanding the status of biodiversity.

UAS can also support participatory forest management efforts, particularly in developing countries. It can serve as a means of evaluating the impacts of intervention and as a planning tool for new actions. These applications of UAS are believed to enhance community-based forest management schemes in the tropics given external assistance and funding is provided to the poor communities living in these parts of the globe (Paneque-Gálvez et al., 2014).

Opportunities for using UAS

In recent years, UAS technologies are evolving rapidly and becoming appropriate for multiple applications. There are various reasons that make the technologies relatively preferred. UAS applications research carried out in many sectors has shown that the emerging interest in these technologies is related to the reduced size of the vehicles, affordability in terms of cost, low energy consumption, flexibility, minimizing of risks and the resulting high spatial resolution data (Banu et al., 2016; Christensen, 2015; Colomina & Molina, 2014; Gaitani, Burud, Thiis, & Santamouris, 2017; Hird et al., 2017; Puliti et al., 2015). As a result, a diverse range of end users including foresters makes use of these technologies.

Advances in UAV platform design have contributed to innovation of small UAS that fly at low altitudes to provide very fine spatial resolution images (Anderson & Gaston, 2013; Yuan, Zhang, & Liu, 2015). The cost of data collection and processing using UAS is lower than that of equivalent methods that provide the same accuracy as terrestrial LiDAR and airborne laser scanning systems (Lisein et al., 2013; Puliti et al., 2015).

Besides, UAS technologies are important because they are flexible (Yuan et al., 2015). Mission planning and flight altitude are controlled based on real needs of users. The flight paths are designed to meet the objectives of the flight mission (Colomina & Molina, 2014). Hence, this technology is an efficient method of spatial data collection for a multitude of applications in the forestry sector ranging from species classification to forest fire monitoring and volume or biomass modelling. The technique attracts attention of many professionals since it has the ability to generate data to study a wide area of land with lower cost and better efficiency than ground-based systems.

The other advantage of UAS relates to low energy consumption (Banu et al., 2016). Small UAS use either fuel (gas) or battery as a source of energy. Although the batteries or fuel needs to be charged frequently, the energy required for a mission is small. Therefore, its low energy requirement contributes to the wide acceptance of the technology.

However, the main reason for the growing interest in using UAS technologies stems from the fact that they provide high spatial resolution images based on a demand-based temporal pattern. Applications like cadastre, urban planning, species classification and yield estimation that require detailed information benefit from these technologies (Colomina & Molina, 2014; Gaitani et al., 2017).

Moreover, the use of UAS is a safer method. It does not risk causalities since no human life is endangered during the process. This characteristic of UAS is ideal for military applications. The lack of on-board operators allows UAVs to be used in politically sensitive areas in which the deployment of human soldiers would create too much controversy. Hence, UAS are considered as a highly preferred technology for risk management (Banu et al., 2016; Muchiri and Kimathi, 2016). Therefore, UAS are important in monitoring forest fire and disease outbreaks, especially in areas with rough topography where terrestrial movement is restricted (Watts et al., 2010).

The current use of UAS in forestry applications is under experimental phase and its contribution to the sector will be realized in the near future (Banu et al., 2016). Furthermore, most of the experiments were carried out in European countries and the US. Based on these lessons, further studies have to be conducted in the local settings of developing countries as well so that the UAS can provide service to all potential users. This tests the appropriateness of the technology and provides feedback for further modifications in the UAS to meet local conditions.

Challenges associated with using UAS

UAS could play an important role in complex humanitarian emergency services as they can be used for surveillance in difficult or inaccessible areas. However, there are also risks associated with human welfare if they are misused (Boyle, 2015). Legal and ethical restraints have to be maintained to make use of the potentials of UAS. Some of the potential risks of UAS technologies are mentioned later. Furthermore, this section explains the possible means of mitigating the challenges to use the potentials of the technology properly.

Environmental challenges

Topography and winds on the high mountains might disturb the system or create noise in the products. The UAS platforms may collide with tall buildings and trees and cause problems unless governed by specific regulations.

Big data problem

The speed at which we convert data into meaningful information does not balance with the trend of data generation. The available analysis techniques are not efficient in making use of all the contents in the UAS-collected data. The often unstructured, heterogeneous big data require a smart interplay between skilled data scientists and domain experts (Wolfert, Ge, Verdouw, & Bogaardt, 2017). Therefore, skill capacity development to process and extract relevant information is a requirement for organizations to make the best use of the potentials of the technology.

Responsibility

UAS, like any aerial remote sensing system, require detailed flight planning. Although, it is an unmanned system, the crewmembers involved in the flight mission have to be known and responsible for what will happen during the flight.

Legal issues

There should be strict rules and regulations that govern how the UAS should function. A study conducted in Africa, Caribbean and Pacific countries indicates that some countries have well developed regulations that provide a workable environment for UAS operations while other countries do not have rules and regulations designed for UAS that are operational in their territories (Jeanneret & Rambaldi, 2016). Absence of regulations will open up room for misuse of the technology. The study has indicated that other countries have banned the use of UAS, which will influence their benefits from the technologies. This measure might be taken because of observed challenges of misuse of the technology. We suggest that well-established regulations will bring the extreme views of different countries together as long as the technologies provide service and are properly used to benefit the community.

Air safety and security issues

The military uses unmanned aircraft for intelligence, surveillance and reconnaissance, as well as direct attack on targets. When everybody can buy and fly UAS, it will be a convenient situation for misuse like terrorist attacks. The UAS may also collide with other flying objects or among themselves unless properly regulated. Therefore, we anticipate that the government of Ethiopia take the issue seriously and develop regulations that inhibit misuse of the technology. Otherwise, it will be a disaster to allow them to fly everywhere.

Privacy

The use of UAS might be disturbing when they fly over an area where people do not want to recognize their presence. The fact that they fly at low altitude close to the earth's surface enhances the effect. Rules and regulations should address this issue.

UAS regulation of every country should address all these challenges (Anderson, 2012). Each country has to set well-thought-out regulations to avoid human-induced problems and reduce the effect of natural challenges. The UAS regulations should take into account the international laws and be enforced accordingly. This technology will create misery to the global community unless regulated by national and international laws.

Anderson (2012) stated that there will be good uses and bad ones, but the same is true of any tool. The user has to exploit the good things and regulations need to limit the associated challenges. Our experience with regard to the current situation of UAS conforms to the suggestion. Hence, we recommend country-specific functional rules need to answer these issues so that the technologies can provide the anticipated services without being influenced by the suspected challenges.

Current uses of UAS in Ethiopia

Limited literature exists about the application of UAS in Ethiopia. Few reports indicate that UAS have been used in Ethiopia for various purposes. For instance, the US deployed surveillance UAS in Ethiopia to monitor the security of many African countries in 2011 (Ahmed, 2013; Sudan Tribune, 2013; UN, 2013). The US established a UAS military base in Arba Minch, a town about 500 km south of Addis Ababa (Whitlock, 2012; *The Japan Times*: 14 January 2016). However, it was also reported that the US stopped its mission at the beginning of 2016 (*The Japan Times*: 14 January 2016). A similar report indicated that UAS technologies helped the fight against tsetse fly in Ethiopia (Engadget, 2016). Drones have also been used to map and support the construction of railway systems in Eastern part of the country (Lopez, 2016).

The use of UAS in forestry in Ethiopia has not been recognized despite the huge potential that they can provide to the sector. Therefore, this study suggests that Ethiopia should learn from experiences of other countries and use the technology to supplement the efforts of enhancing its forest information system, which has suffered from the limitations of ground-based and satellite remote sensing technologies. The ground-based techniques, although excellent in terms of accuracy, require long time to collect data and are expensive. On the other hand, satellite remote sensing techniques, especially those with low and medium resolution sensor systems have limited image quality (i.e. spatial, spectral, temporal and radiometric) and are influenced by environmental conditions like the atmosphere. In addition, products of some satellite remote sensing are expensive to be used for national forest inventories (NFI) in the context of developing countries like Ethiopia.

When using UAS, the country has to make sure that there is no misuse of the technology. Hence, proper legal systems have to be set and implemented to limit the use of the technology for development endeavours only. Currently, Ethiopia does not have formalized regulation for managing the use of UAS (Jeanneret & Rambaldi, 2016) except that a permit should be applied for from the ministry of communication prior to a flight. This is valid both for commercial and private UAS use. Due to volcanic activity in many parts of the country, particularly along the rift valley system, recalibrating the flight compass is required before each flight. The maximum flight altitude for a drone in Ethiopia is conventionally limited to be 150 m (Drone Traveller, 2016). These are the working principles in Ethiopia as far as UAS are concerned; however, the country has not yet declared a formal regulation.

Potential forestry applications of UAS in Ethiopia

The country had conducted only two NFI in its history. The older one, which was carried out from 1994 to 2004 was almost a lost opportunity. The inventory is known as the Woody Biomass Inventory and Strategic Planning Project or the woody biomass inventory for short. The data are non-existent and there is no responsible body to the sources of data. There is no officially documented data to be referred to currently. As a result, change monitoring becomes impossible. A new NFI project has been implemented since 2013 and is underway. This new NFI was initiated from scratch and has its own limitations. The field-based data collection had very few sampling sites, which are less than 650 for a country of more than 1 million square kilometres of land area. Moreover, the remote sensing data used for this NFI were Landsat 8 images, which have limited spatial resolution. The use of UAS will solve the problem of getting high-resolution images for selected resource rich hotspot areas and enhance the quality of the NFI data. The anticipated system requirements for the NFI are the remote sensing technologies that provide quality images, which in turn are less costly, flexible and frequently acquired to provide time-series imagery for change detection and growth monitoring. While medium resolution images like Landsat products provide a wall to wall coverage, UAS data will be used to get detail information about forest attributes.

On the contrary, the country needs to produce verifiable information to be reported for the international REDD+ Measurement, Reporting and Verification (MRV) systems and other conventions. Data quality is a requirement in these systems. This implies that there should be some innovative techniques to enhance the drawbacks of the conventional data acquisition techniques in terms of cost, time and accuracy.

Hence, the emerging UAS technologies have huge potential to contribute to the effort towards generating reliable forestry information in the country. This is mainly because UAS have great potential to provide high spatial resolution data at the required time. Studies show that other African countries like Zambia and Tanzania have identified UAS as potential tools for MRV of REDD+ activities (Day, Gumbo, Moombe, Wijaya, & Sunderland, 2014; Mauya et al., 2015). Thus, we are convinced that UAS can enhance the efficiency and quality of the forest information systems of Ethiopia.

We suggest that Ethiopia should adopt the UAS technologies for supporting the NFI and do its best to generate as much detail information as possible. Research institutions and universities should conduct experiments and provide evidence to support the optimal use of the system.

Conclusions

The use of UAS is critically required in Ethiopia due to the poor situation of forest information in the country. The field-based forest inventory, although accurate, has limitations of exaggerated costs of finance and time. On the other hand, local estimates using satellite remote sensing have suffered from accuracy problems and lack of coherence. Therefore, the new UAS technology will contribute to improving accuracy of estimates and reducing data collection costs.

Globally, there is ample evidence on the possible uses of UAS in forestry. Those lessons can be adopted and customized to the Ethiopian conditions and need to be used to supplement the existing methods. However, care should be taken into account when using UAS in rough topographic settings as the systems have very limited range of flight altitude. Besides, UAS regulations should also be set explicitly so that the national security is not endangered.

Disclosure statement

No potential conflict of interest was reported by the authors.

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