Low-Altitude Remote Sensing with Unmanned Radio-Controlled Helicopter Platforms: A Potential Substitution to Satellite-based Systems for Precision Agriculture Adoption under Farming Conditions in Developing Countries

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ABSTRACT

In developing countries with small and medium farm holdings, satellite-based remote sensing is found unsuitable for precision agriculture technology adoption, due to low spatial and high temporal resolution of imagery. Image acquisition system mounted on unmanned helicopter platforms can provide user-specified and near-real time images for quick assessment of the crop and soil status giving enough time for preventive measures. Use of appropriate sensor combinations to acquire geo-referenced images being corrected for orientation information, will make the system more flexible in terms of system integration, specific applications and total costs. Reflectance indices and band ratios obtained through Low-Altitude Remote Sensing (LARS) systems can precisely represent the soil and crop parameters for crop monitoring, crop status modeling and output predictions. As a multi-dimensional application tool (e.g. for agriculture, disaster prediction and assessment etc.), the unmanned helicopter based LARS system posses lower pay-back period, further facilitating its adoption in developing countries. This paper gives an overview of the necessities and assimilation of unmanned helicopter based LARS system, emphasizing its specific applications and adoption potentials for farming conditions in developing countries.

Key words: Remote sensing, unmanned helicopter, LARS system, crop parameters, precision agriculture

1. INTRODUCTION

The current situation demands for quick analyses of soil and crop status followed by preventive measures to protect the crop from possible crop damages. The Precision Agriculture (PA) assisted by cutting-edge technology has been found capable of fulfilling such requirements. PA can be defined (Whelan and McBratney, 2000) as the process of matching resource applications and agronomic practices with soil and crop requirements as they vary in space and time within a field. PA is the information and technology based management system which works on information collected about crops and surrounding factors influencing the crop growth and yield. Modern technologies associated with GPS (Global Position System), GIS (Geographic Information System), yield monitoring devices, soil, plant and pest sensors (NESPAL, 2002), and remote sensing, will promote widespread PA technology. Especially, due to the inherent specific conditions associated with the farming systems in the developing world such as small and fragmented land holdings, diversified crop selection and rotations etc., mixed and integrated cropping practices have restrained to realize the benefits of PA technologies assisted with remote sensing.

The need for a simple, real-time image acquisition system to substitute the satellite-based remote sensing, to foster the benefits of PA technology adoption in the developing world, has been well realized by most researchers and planners. The authors carried out a comprehensive study to explore the prospects of LARS system with unmanned helicopter platform to acquire aerial photography suitable for PA technology use in developing countries.

2. REMOTE SENSING TECHNOLOGY USED IN PA APPLICATIONS

Sabins (1996) described remote sensing as the science of acquiring, processing and interpreting images that record the interaction between electromagnetic energy and object. In principle, remote sensing is based on the characteristics of the object towards the electromagnetic energy of the sun. Reflected energy, the portion of the sunlight bounces off the object (plant leaves), is the primary medium of information for the remote sensing system, which is readily identified by remote sensors.

2.1 Applications in Crop Monitoring

PA is mainly dependant on two spatial requirements, such as: i) Position of the VRT (Variable-rate Technology) equipments, and, ii) Crop variables information. The position accuracy is taken care by highly precise GPS receivers, whereas, the crop information is preferred to be collected through remote sensing imagery (Rickman et al., 2003). Images are used to identify stressed areas in the field by first establishing the spectral signature of healthy plants and comparing them with that of the underlined crop parameters (Nowatzki et al., 2004; Lu, 2003) by developing models and algorithms such as correlations between chlorophyll concentration and the NDVI (Normalized Vegetation index) value for agricultural crops (Zhao et al., 2005).

Application of remotely sensed images in evaluating crop status has been utilized in many aspects of crop growth and vegetation with sound accuracy; such as: i) Soil properties mapping using linear coefficient (Shonk et al., 1991), vegetation indices (Weigand et al., 1994), automated mapping (Leone et al., 1995) and spectral band cloning (Daniel et al., 2002); ii) Nutrient management in terms of, total nitrogen estimation in wheat and soybean (Hache, 2003); selection of spectral bands for the nitrogen content analysis (Ferwerada, 2005) and nutrient distribution based management zones (Yang and Anderson, 1996); iii) Pest detection by digital colored photographs in corn (Brown and Steckler, 1995), mite detection in apple (Penuelas et al., 1995) and rice brown plant hoppers detection (Yang and Cheng, 2001); iv) Water stress identification by estimating daily evapotranspiration from images (Carlson et al., 1995), further improvement of the technique by Clay et al. (2006) and the creation of indices such as crop water stress index (CWSI), water deficit index (WDI) and thermal kinetic window (TKW) index (Moran et al., 2005); v) Yield predictions from remote images for corn (Chang et al., 2003), cotton (Thomasson et al., 2000), wheat (Doraiswamy et al., 2003) and investigations are on for crops like rice, sugarcane etc.; and, vi) Crop residue estimation using RADARSAT images (McNairn et al., 1998) and using Landsat images (Thoma et al., 2004) etc.

In addition, all microwave spectrum based remote sensing is utilized for soil moisture monitoring (Wignerson, 1996), based on synergistic use of active microwave instrument of the ERS satellite (Zribi et al. 2003). However, many researchers are of opinion that, additional applications possible through remote sensing technology in PA still remains uncovered, may be due to lack of research interest, unavailability of technology and lack of supports from private and government organizations.

2.2 Limitations

Satellite remote sensing has held out much promise for within field monitoring (Stafford, 2000) but has so far failed to deliver its potential. Problems include higher temporal resolution, due to longer satellite re-visit times, cloud cover, total cost, poor spatial resolution and lack of proper techniques and facilities to process imagery to take farm productions (Steven, 1993). Lamb and Brown (2001) indicated that the low resolution images of satellites, only beneficial for large scale studies, are not appropriate for the small size farmlands, as some of the individual farmlands could be represented by few pixels of the image, making unfavorable for PA technology adoption. Also, satellites have limited operational flexibility to use as a real time monitoring or management tool. In the developing countries, where, rain-fed farming mostly practiced, further restrain the applicability of remote sensing images, as optical satellites are unable produce cloud free images of crops under overcast conditions. Also, the weather-unaffected microwave spectrum based radar satellites are not popular (Blumberg et al., 2002), as they are lacking of systematic technology, empirical models and studies for field applications, and has to be purchased.

Adoption of the satellite based remote sensing for PA is also influenced by the perceived risk in future farm yield after adoption (Kim and Chavas, 2003; Koundouri et al., 2006). The perceived risk could include in-time availability of good quality images, supported technology and security for better output in terms of crop yield and net return etc.

3. LOW-ALTITUDE REMOTE SENSING (LARS) TECHNOLOGY

LARS, a new concept of remote image acquisition system, captures imagery at lower heights, being controlled from ground. Mostly unmanned helicopters are used for mounting LARS systems to get higher resolution for better quality images. Better quality image, with greater details of crop and soil status, is a basic requirement of PA technology to facilitate for better analysis and recommendations. As mentioned by Rickman (2000), the system equipped with appropriate sensors and data acquisition tools, can be flown over an area and precisely map its plant quality and soil make up including mineral variation and organic carbon content etc.

Moreover, resolution and quality of the images can be varied either by simply varying height of the helicopter (5m to 1 km) or by mounting camera of required specification or both. The system can be organized in no time to acquire and supply images to researchers and planners in a near-real time basis. A LARS system can be monitored by an individual, having knowledge of software and flying an unmanned helicopter. Moreover, the system can be assembled with locally available materials and resources, requiring low repair and maintenance costs.

3.1 Available Systems and Operational Requirements

Various unmanned LARS platforms, such as: kites (Giannopoulos et al., 2000; Aber et al., 2002), balloons (Seang, 2006; Amoroso and Arrowsmith, 2000), high-clearance tractor (Bausch, 2002), unmanned aero planes and helicopters (Eisenbiss, 2004; Sugiura et al., 2002; Swain and Jayasuriaya, 2007) etc. are used for remote image acquisition. The radio controlled unmanned helicopters and aero planes work on the similar principles in terms of the acquisition of the images and geo-referencing systems. The application of radio controlled aero plane, needing a lunching pad for landing and take off, is restricted compared to unmanned helicopter. However, the complicated helicopter system, more unstable in air, needs a skilled operator for flying. Still, radio controlled helicopters are preferred over other remote image acquisition platforms including aero plane (Schwarz and El-Sheimy, 2004) for mapping small areas (Table 1).

As indicated by Sugiura et al. (2002) the major drawbacks of unmanned helicopters are limited payload capacity and precise control over working speed of the system. Thus, mounted systems operation has to be programmed properly to neutralize the effect of wind speed. The low payload capacity of the system is adjusted by selecting light weight mounting equipment and tools. Stombaugh et al. (2003) suggested replacing heavy weight professional digital cameras with light weight, low cost, commercial digital cameras. As the individual images acquired by the LARS system covers small area, geo-referenced images can be mosaic for mapping whole farmland and targeted areas. GPS is used in aerial platforms for obtaining aircraft location information (Hayward et al., 1998), for geo-referenced video-based remote sensing images (Thomoson et al., 2002) and in VRT system guidance (Fadel, 2004). Buick (2002) proposed the guidelines to select proper GPS receivers for specific applications.

Sugiura et al. (2002) installed RTK-GPS as the positioning sensor, and an inertial sensor that provided posture (roll and pitch angles) of the helicopter used for LARS system. A geomagnetic direction sensor (GDS) was also installed for absolute direction information. Evan-Tzur's (2005) theory of using a GPS system in conjunction with an Inertial Measurement Unit (IMU) enabled photogrammetric mapping even without ground control points. Further, Xiang and Tian (2006) attempted to make the system automatic and real time. But, the major challenge of bringing the LARS system from the researcher's handbook to the farmer's doorstep at affordable cost still remains a distant reality.

Table 1: Comparative benefits of remote image acquisition platforms

Systems/ Facilities	Equipment			Applications (size and structure)			
	GPS /INS	Laser	Camera	Large Areas	Small areas (< 2-4 km^2)	Route mapping	Complex buildings/ structures
Aircraft	Yes	Yes	Film based and digital	Yes	Yes/No	Yes	No
Helicopter	Yes	Yes	Digital	No	Yes	Yes	No
Terrestrial system (car, train)	Yes	Yes	Digital	No	Yes/No	Yes	No
RC-Helicopter	Yes	Yes	Digital	No	Yes	Yes	Yes

3.2 LARS System Integration

3.2.1 Hardware and System Configuration

LARS system consists of image acquisition sensor, GPS receiver, altitude and orientation sensors and a real-time monitoring systems (Figure 1) mounted on an unmanned helicopter platform.

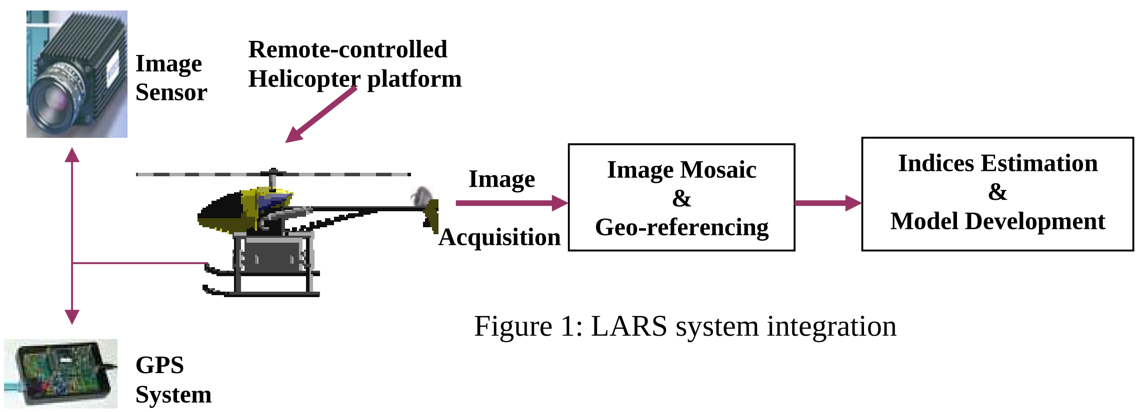

Figure 1: LARS system integration

Image Acquisition Sensors

Image acquisition sensors, the primary system responsible for maintaining image quality as well as resolution in LARS system, are passive in nature (camera photography type) as it does not produce its own illumination rather use the illumination of sunshine. Availability of very high resolution cameras (Table 2) made it possible to achieve fine resolution level, best suited for PA technologies (Renslow, 2005). Wider range of spectral bands such a Near-infrared (*NIR*), Thermal infrared bands with the visible band such as Green and Red further facilitate in accessing crop and soil parameters. Swain & Jayasuriya (2007) used a multi-spectral camera with three spectral bands (*G*, *R* and *NIR*) mounted on an unmanned helicopter platform to correlate nitrogen rate with NDVI values for rice cropping.

Table 2: Image acquisition sensors and specifications

System	Geometry		Sensor Heads		Image format		Image Recording		Inertial/GPS Components	
	Line	Frame	Single	Multi	Large	Medium	Syn-chronous	Syn-topic	Optional	Mandatory
ADS40	Yes		Yes		Yes		Yes			Yes
DMC		Yes		Yes	Yes		Yes		Yes	
Ultracam		Yes		Yes		Yes		Yes	Yes	
DSS		Yes	Yes			Yes	Yes		Yes	
DIMAC		Yes	Yes				Yes		Yes	
HRSC-Ax	Yes		Yes		Yes		Yes			Yes
3-DAS-1	Yes			Yes	Yes		Yes			Yes
Starimager	Yes		Yes		Yes		Yes			Yes

Thomoson et al. (2007) used thermal imaging sensor mounted on small-scale aerial platform to assess crop water stress in cotton cropping area. Laser scanners (Nagai, 2003) was used and compared with CCD image in LARS platforms, though it would be difficult to maintain the flying track of an unmanned helicopter. Multi-spectral camera, one of the most expensive components of a LARS system, should be substituted with cheaper options. Kaizu and Noguchi (2007) developed a low-cost dual spectral camera system, which consisted of a pair of monochrome cameras with filters capable of acquiring different wavelength images of targeted objects.

Altitude and Orientation Sensors

Altitude and orientation readings of the image acquisition system are used to mosaic the images for whole field mapping. Most common sensors recommended for helicopters are, accelerometer, gyroscope, magnetometer, compass, sonar, radar, barometric altimeter, Doppler-effect sensor, GPS receiver, Vision sensor etc. There are some sensors, purchased as black-boxes, capable of measuring multiple parameters to produce a combination of orientation, position, and dynamics information e.g. Inertial Navigation Systems (INS), which usually combine accelerometers, gyros, magnetometers, and compasses (Santana and Barata, 2005), and also GPS/INS systems, combines inertial navigation with GPS.

Illumination Sensors

Variation of sunlight level could affect the models as well as final recommendations in monitoring agricultural crops. So, it is necessary to keep record of sunlight illumination level attended during experimentation. The system either mounted with the platform, keeping continuous record of illumination levels, or recorded at certain time interval during the extent of operation. Effect of illumination level can be minimized by estimating indices between values of individual spectral band of an image, at a particular time. Kim et al. (2000) measured ambient illumination using 4-channel SKR-1850A radiometer (Skye Inc.) for on field crop stress detection.

Real Time Monitoring System

Images and location information can be provided to server in real time basis from the LARS system. These can be carried out with internet (Bluetooth/Wireless communication) or through mobile devices (GPRS/GSM) using SIM cards and accessories. However, real time application will be expensive, in terms of expensive supporting equipments and sophisticated technologies. But, near-real time monitoring approach can easily be achieved at lower cost with the LARS system, where image and attitude information stored with the mounted microprocessor and storing device and downloaded afterwards.

3.2.2 Software and Data Analysis

LARS system requires its own software algorithm set up to carry out image processing and manipulation for production decisions and recommendations. The area covered within individual image in LARS system is smaller, as compared to that of satellites, may be not useful and uneconomical for taking production decisions for crops. Therefore, to map the whole study area, a number of images have to be taken geo-referenced and mosaic. Gaps and uncovered areas were attended by collecting overlapped images over the whole area. Instead of using different software for individual processing stages, single software (Price and Alli, 2005) can be designed to carry out the process uninterrupted, reducing total time as well as cost involved. Available software would be capable of achieving centimeter level accuracy from LARS imaging system.

Models and relationship would be developed by comparing spectral index values of the image with that of crop and soil parameter levels from the control fields. Indices, such as NDVI, SAVI, RVI (Sama and Stombaugh, 2005) etc. and ratio(s), such as PVR (Warren and Metternchicht, 2005) etc. of multiple bands from an image could be used to neutralize the effect of illumination level of the sunlight (Table 3). The models, relationship coefficients and equations will be used in real field situation to detect the soil and crop parameter levels and monitor crop growth.

3.3 Cost Benefits Analysis

Initial investment required for the proposed unmanned LARS system is marginal as compared to commercial satellites and manned aerial vehicles (Eisenbiss, 2004). Unmanned helicopters based LARS platforms are also available in developing countries produced by local manufacturers. So, the spare parts can be easily acquired, supported with repairing facility in the locality. The availability of supporting software and data analysis techniques with the system will further reduce the operating cost. As computational power and perceptual requirements are important factors to increase the cost of the system, when costs need to be reduced, algorithms and sensors (Santana and Barata, 2005) have to be chosen carefully. Payback period can be estimated and optimized to make the system affordable for individual farmer or for a group.

Table 3: Vegetation indices and ratio(s) used for imagery analysis

Abbreviation	Name	Vegetation Index
NDVI	Normalized Difference Vegetation Index	$NDVI = \frac{NIR - RED}{NIR + RED}$
RVI	Ratio Vegetation Index	$RVI = \frac{NIR}{RED}$
GNDVI	Green Normalized Difference Vegetation Index	$GNDVI = \frac{NIR - GREEN}{NIR + GREEN}$
PVR	Photosynthetic Vigor Ratio	$PVR = \frac{GREEN}{RED}$
SAVI	Soil Adjusted Vegetation Index	$SAVI = \frac{NIR - RED}{NIR + RED + L} \times (1 + L)$
DVI	Difference Vegetation Index	$DVI = NIR - RED$

Note: L: Amount of visible soil, ranging 0 to 1 (usually 0.5)

4. SUITABILITY AND ADOPTION POTENTIAL OF LARS SYSTEM

4.1 Recent Developments in LARS System

The LARS systems with unmanned helicopter platforms used in precision agriculture studies have been reported carry out discretely, being confined to a limited number of research stations, universities and government supported organizations. Iwohari et al. (2005) used unmanned helicopter images to develop 3D-GIS maps of the cropping land. A laser scanner was used to get two dimensional (2D) data of the field crop and produced 3D-GIS images by transferring laser scanner co-ordinates into global co-ordinates corresponding to the helicopter position and posture data. These images can be further used to monitor crop growth and to maintain crop yield by optimizing the process involved in producing 3D-GIS maps.

Sugiura et al. (2007) mounted a thermal band camera on unmanned helicopter platform to estimate soil water status in paddy fields and correlation was obtained between the thermal image temperature and soil moisture content. The coefficient of determination (r^2) for moisture content and temperature model at 10.00 a.m. and 3.00 p.m. were 0·69 and 0·64 respectively (Figure 2). The r^2 between moisture content and difference in temperature was 0·42. The development was intended assisting in proper irrigation scheduling and monitoring water stressed situations for rain-fed cropping. Ishii et al. (2005) developed a system that can generate a map regarding crop status obtained by mounting an imaging sensor on an unmanned helicopter. They achieved an accuracy of 38 cm using RTK GPS receiver and GDS unit. The maps were accurate enough to be used for variable rate nutrients and pesticides application for the farmland.

Swain and Jayasuriya (2007) developed linear models to estimate nitrogen deficiency level in rice crop. The r^2 of 0.90 was achieved with NDVI index plotted against nitrogen rate variations. The relationship between crop yield and NDVI index, estimated from the images acquired by multi-spectral camera (G-R-NIR) mounted on the unmanned helicopter platform, showed a linear relationship with r^2 of 0.95.

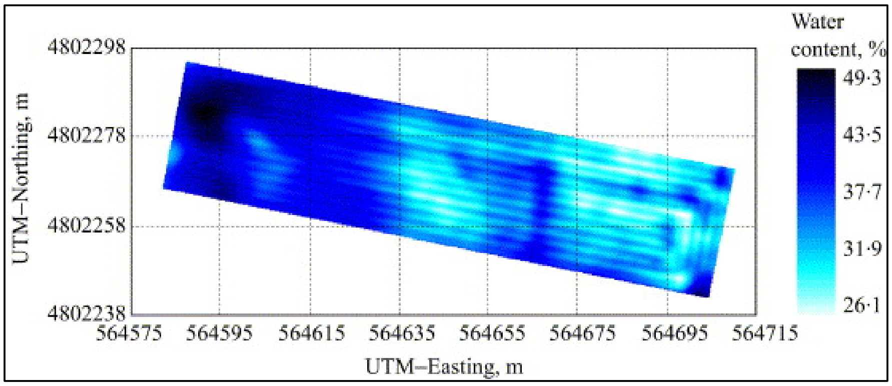

Figure 2: Soil moisture content estimation with LARS images (Sugiura et al., 2007)

4.2 Scope for LARS Technology

4.2.1 Technology Transfer

In satellite-based system, image acquisition, processing and analyses, and implementation are generally carried out in discrete manner by different groups. This process is rigorous and may not be suitable for some agricultural crops with a critical cropping period ranging 4 to 6 weeks. The technology transfer should be inline with the acquisition of equipment in agricultural context (Pineiro, 2007). In contrary, the LARS system with helicopter platform, which has near real-time features, the trend will be improved significantly by insisting the researchers to simultaneously transfer the critical technology to farmers and service providers. This will also enhance the fast improvement of skills in farmers and service providers.

4.2.2 Cropping Pattern Improvement

With precision, real-time technology available to monitor their crops, the farmers will be more confident in carrying out extensions and experimentations on crop varieties and cropping patterns. By which, farmer will be able to better understand of their farmlands and able to select correct crops and crop rotations, ensuring long term benefits (Maynard et al., 1997). The technology will bring the experts to the farm gate for regular consultation.

4.2.3 Ease of Operation

Timeliness and ease of operation, which are the major principles of precision agriculture technology, will be boosted through the adoption of LARS system. In an automated LARS system (Xiang and Tian, 2006), the VRT equipment can directly get the crop information and will apply the required crop nutrients and protection materials in real time basis with least supervision from the professionals. This system is capable of pulling the professional to the agriculture sector.

4.2.4 Cost Sensitivity

One time initial investment on LARS system will ensure long term benefits to the individual farmer and its locality. The system not only used for the crop scouting, can also be extended to disaster management (evacuation information, assessment and relief activities), emergency services and environment protection activities, which will further enhance applicability of the system. The multiple application capability of LARS system will reduce the payback period, encouraging the service providers to invest on the system in developing countries.

4.3 Potential Applications of LARS System

Major application areas of LARS images are mapping and modeling of land and crop attributes, inland and marine aquaculture, mangrove area management, water quality evaluation (parameters, such as: chlorophyll concentration, total suspended solid, temperature etc.) in water bodies, peat and lowland areas, land reclamation, irrigation management in watershed areas etc. Its applications can be further extended for urban planning, soil erosion, air pollution monitoring, meteorological surveys, mountainous area mapping, oil spill detection and military applications etc. The system is suitable for natural disaster issues, such as: accessing and predicting the flood threats, drought severity, cyclone, land slide and rescue operations etc.

5. LARS BASED PA FOR DEVELOPING COUNTRY FARMERS

Most of the developing countries in Asia and Africa are characterized by high population density (Alagusundaram et al., 2003), which will reach 6.7 billions in the year 2025 with an increase of around 30% more people, to be fed with available cultivated areas (PRB, 2005). In digits, the annual productivity has to be grown at the rate of 2.5 to 3% (Gunnaatilleke, 1998 as cited by Singh, 2003) to fill the gap between supply and demand in developing world. Cutting-edge technology, such as PA, would be one of the options for developing country farmers to feed the whole population. Today, less than 5% of the population in the USA produces enough food for the entire population of over 260 million (Opara, 2004), using modern technologies integrated to agriculture sector.

In contrary, developing country farms are characterized by low level technology in small fragmented land holdings, mixed or diversified cropping, without capitals for bigger investments and devoid of professionally skilled workers. Furthermore, rain-fed agriculture is predominately practiced (around 80% area) in the developing countries (FAO, 2003), further restricting the applicability of satellite-based remote sensing for overcast seasoned-crops.

Low-cost LARS system (Figure 3) can be the best possible solution for the farmers in developing countries supported with flexible controls, higher precision, and timeliness in operation. Medium to large scale farmers in the developing countries will be the potential users. As for early adoption, farmers growing cash crops such as sugarcane, orange, oil palm, cassava etc. and widely cultivated crops such as rice, wheat, maize etc. can be considered leading to short- and long-term benefits. Crop monitoring parameters, such as: pest and water stress detection, nutrient deficiency identification etc. can also be determined using the proposed LARS system imagery. Excess application of nutrient and pesticides, which is a common practice among the farmers in developing country, can be evaluated and controlled. This will ensure long term preservation of soil fertility, better crop quality, reduced input cost and environmental pollution, leading to maximized crop yield and profits.

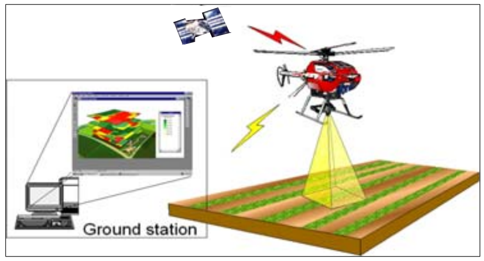

Figure 3: Proposed LARS system with unmanned helicopter platform
for farmers in developing countries

The adoption of LARS system as well as PA in developing countries can be explained in terms of Type-I and Type-II errors given in Table 4 (Cook et al., 2003). Type-I error occurs when a farmer fails to act in a way which is a potential benefit, for example: failing to adopt the new technology at correct time. Type-II error occurs when a farmer does something that is harmful or at least non-beneficial, for example: applying excess nitrogen causing environmental pollution as well as reducing net profit due to higher input costs.

The site specific information will reduce the chances of error caused by generalization within the areas which are significantly variable. For example, the knowledge that nutrient should be applied to one location but not to another location, or knowledge of accurate cropping pattern. These types of errors mostly occur with the farmers in developing countries with least knowledge on the crop requirements. The LARS system with unmanned helicopter platform can eliminate both types of errors due to an early warning system received by farmers.

Table 4: Type-I and -II errors of technology adoption

Action	Benefits occurs	No Benefit occurs
Act	Correct Action	Type II error: Loss caused
Do not Act	Type I error: Lost opportunity	Correction in action

6. CONCLUSIONS

Precision agriculture technology for small and medium farm holding needs better data acquisition system in place of remote sensing satellite imagery. The LARS system with radio-controlled unmanned helicopter platform is capable of providing the vital crop and soil information for PA in terms of high spectral and spatial, with lower temporal resolution images at an affordable price. Use of appropriate combinations of sensors for image acquisition, detection of location and orientation, altitude, illumination level etc. would make the system more flexible for better system integrations and specific applications. By system automation, real-time image acquisition and processing, recommendations can be made available for sound production decisions. The multi-dimensional application of the system will have lower pay-back periods, appropriate for farming conditions in developing countries. The farmers should avoid Type-I error of lost opportunity and should adopt the LARS system and PA technology for their farming. More research is required to estimate the break-even cost of the system leading to full scale PA adoption in developing countries.

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