Use of Unmanned Aerial Vehicles in Crop Protection

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***Abstract*—India ranks poorly in farm productivity due to factors including lack of market-appropriate mechanization and other technologies, use of non-standard practices, and growing shortage and cost of farm labor. This paper discusses research and development of UAV-based crop-protection agri-solutions which have been developed and optimized based on local market requirements, such as small land holding sizes and tropical climate operating conditions. In particular, low-volume aerial spraying techniques for target crops (Tea, Bengal gram, Groundnut, and Paddy) and their field validation results are presented. Key results include efficacy, phytotoxicity, efficiency, and water conservation. Currently, commercial field pilots are underway to identify and validate appropriate business model(s) to offer UAV aerial spraying agri-service across India.**

***Index Terms*—UAV aerial spraying, precision agriculture, crop protection, low volume spray**

I. Introduction

Despite having the 2nd largest arable and largest irrigated land India ranks poorly in farm productivity, with yield rates of 27^{th} out of 47 in rice, 19^{th} out of 41 in wheat, and 88^{th} in world in total cereal, as shown in Fig. 1. Total Factor Productivity (TFP) growth of India is < 2%/ annum compared to 6% growth rate of China. TFP accounts for effects in total output not caused by traditionally measured inputs of labor and capital. Fig. 2 shows the agricultural values (in $B) of top 5 counties and overall world average. Growing shortage and cost of agricultural workforce, lack of market-appropriate mechanization and other technologies, and use of non-standard practices have been identified as primary factors contributing to low productivity in Indian agricultural sector.

A. Dwindling Agricultural Workforce

Indian agricultural workforce has been consistently declining, from approximately 65% in 1993-94 to 49% in 2011-12, resulting in net reduction of over 35 million labor force, as shown in Fig. 3. According to a survey conducted in 2011 to assess key reasons behind labor scarcity, top 5 reasons were identified to be: (a) higher wages in other locally available jobs, (b) unemployment during lean season, (c) being considered as low-esteem job in rural areas, (d) migration due to improvement in educational status, and (e) migration to nearby town/city for higher wages [3]. On other hand, rural wages have been growing by 17% on average since 2006-07 outstripping the urban wages. This has an adverse impact on entire crop management cycle (from crop protection, prevention to monitoring & response). The impact is particularly acute in cases of fast-spreading diseases, where farmers struggle to find labor at short notice.

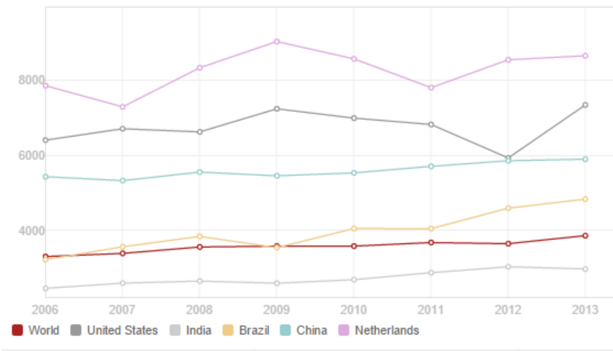

Figure 1. Cereal yield in Kg per hectare [1]

Rank	Country	Output
1	China	1005
2	India	367
3	USA	279
4	Brazil	130
5	Nigeria	122
	World	4771

Figure 2. Value in $billion for year 2014 [2]

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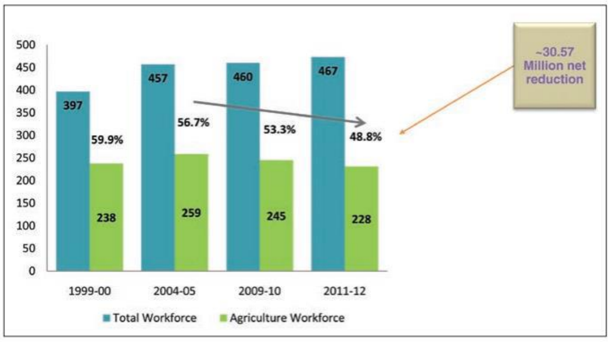

Source: NSSO, FICCI Research

Figure 3. Indian agricultural workforce over 1999-2012 [3]

B. Fragmented Land Holding

Average land holding size of farmers in India is less than 5 acres (2 Hectares) and continues to get fragmented further due to socio-economic factors. As a result, majority of farmers are unable to leverage advantages of larger scale operation, including large machineries and expensive technologies which are developed for western markets. They are looking for market-appropriate mechanized solutions to reduce labor dependency and improve efficiency and quality of service. Fig. 4 shows the average number of machinery across various land holding sizes in India, according to which 80% of farmers (< 2 Ha holding) utilize little to no machinery in their farming practices. According to [3] ratio of mechanization is < 40% during farm preparation to crop irrigation, up to 60-70% in harvesting, and < 5% in all other activities.

Items	Average number of Farm Equipment/Machinery possessed per 1000 farmer households in land class (hectares)							All size
	<0.01	0.01-0.40	0.41-1.00	1.01-2.00	2.01-4.00	4.01-10	>10	
Plough	49	292	568	775	889	1030	1189	569
Harrow, Seed-drill, Sprayer & Duster	64	165	354	481	685	1051	1512	389
Thresher	2	19	43	53	74	106	198	44
Power Tiller	0	1	4	15	33	75	148	13
Tractor	2	2	22	25	75	189	375	29

Source: NSSO Report (2005) No. 497(59/33/5);

Small and Marginal Farmers

Figure 4. Farm mechanization has eluded small and marginal farmers (SMF) [4]

C. Recommended v. Farmer Practice Gap

Precision Agriculture, defined as application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for improving production and environmental quality, can play a significant role in optimizing cost, wastage, and improving overall productivity. It has been noted by several researchers that patterns of variation on large and small-scale farms are very similar, and hence, precision farming can be relevant irrespective of scale, although management system used may differ in its level of sophistication and approach [5]. This is in line with Government of India's initiatives to double farmers' income by 2022, including via introduction of value-driven technological interventions. Due to high dependency on weather and growing complexity of operations, farmers in India are also increasingly seeking guidance on field-tested best practices to improve yield and minimize risks and costs.

II. Crop Protection

Basis direct and indirect interactions with farmers and discussions with agricultural experts, development of market-appropriate mechanization technologies and integration with PA techniques in crop protection was identified as a high-impact intervention. Efficient and intelligent crop spraying provides multi-pronged benefits, including (a) improvement in crop management efficiency, (b) improvement in sustainability, (c) reduction in labor dependency, (d) timely response in time-sensitive emergencies, (e) improvement in field workers' health and safety, (f) promotion of recommended practices, and (g) ease of accessibility in difficult terrains.

A. Role of Mechanization

Currently, approximately 70% of Indian farmers use knapsack sprayers, 20% use power sprayers, and remaining 10% use motorized, tractors-based, and other variations of ad-hoc spraying techniques. These approaches involve manual pesticide intervention and lack knowledge-driven optimizations, which renders them prone to wastage resulting from inefficient application of pesticide, spillage etc. Furthermore, majority of farmers in India apply severe under-dosage (up to 20% of recommended amount) and rely on either preventive (i.e., schedule-based) or ad-hoc (i.e., last-resort) spraying, both of which render sub-optimal results.

Large mechanized devices and complex PA solutions of western markets are unsuitable for Indian markets due to small land holding sizes and cost sensitivity. For example, common global practice in aerial spraying includes manned fixed-wing planes and unmanned helicopters, both of which were designed for spraying over large areas (hundreds to thousands of acres of land) and hence lack low-volume spraying techniques such as high-accuracy drift management and targeted spraying capabilities. Both practices also require significant clearing space (including runway in case of planes) and are extremely expensive for adoption in Indian agricultural marketplace.

Unmanned Aerial Vehicle (UAVs) offer a great opportunity for greater productivity and ROI while reducing dependency on hard labor, especially in small to mid-size farms, as outlined in Fig. 4.

B. Role of Precision Agriculture

Besides improving efficiency, UAV based systematic & methodological delivery mechanisms could help in wastage reduction, improving work conditions, and promoting best practices by embedding knowledge-based sprayer controls into UAV operations. By integrating crop and farm condition monitoring and detection techniques, such as multi-spectral and thermal sensing to determine pest and disease conditions, UAVs could serve as integrated crop management platforms to devise and deploy optimal countermeasures. This would enable a new paradigm in aggregation of agri-services and balancing of supply chain from plant to *Panchayat* (community organizations in Indian villages) and beyond.

III. UAVs Based Low-Volume Aerial Spraying

A comprehensive survey of state-of-art in UAV platform, aerial spraying, and low-volume spraying techniques was conducted to identify feasibility and trends. Accordingly, goal was set to develop UAV and related technologies to enable integrated crop protection to improve intervention times, address unmet need of field labor, and aggregate services and balance supply chain. Compared to traditional spraying techniques mentioned above, low-volume UAV spraying was selected to improve efficiency by 20x, reduce water and labor dependency by 10x, enable timely intervention, improve accessibility in difficult terrains, and help promote recommended agri-practices. Besides autonomously delivering pesticide using low-volume spraying technique, additional performance metrics included crop-specific optimizations to achieve high efficacy (pest control benchmarked against current practices), toxicity management (sustainability goals), overall operational efficiency (productivity goals).

A. UAV Aerial Spraying

Even though UAV-based spraying has attracted significant attention over the last few years, current systems lack (a) proven spray drift management techniques, (b) crop-optimum system configurations and settings to guarantee QoS to farmers, and (c) rigorous simulation framework to derive operational parameters under varying weather and flight conditions.

Therefore, technology development was divided into design and optimization of autonomous UAV sprayer platform and R&D of aerial spray characteristics to enable low-volume aerial spraying. UAV development focused on autonomous operation, platform stability, high payload capability, and endurance. Spraying techniques focused on spray patternation and flow to derive selection and placement of nozzles, optimum discharge rate and pressure settings, and integration with flight plans to manage drift and achieve uniform coverage. Simultaneously, modeling and simulation framework is being designed to scale up spraying operations under the influence of varying external factors, such as weather conditions and changes in UAV design, speed, and altitude. Examples of UAV design changes include type and number of motors, type and rotational speed of propellers, and dimension and configuration of frame structure.

B. Technology Development

Strategic collaborations were formed with (a) leading UAV designers to co-develop UAV platform, (b) CSIR National Aeronautical Laboratory, a Government of India R&D organization, to experimentally characterize aerial spraying, (c) Tata Group companies to model and simulate sprayer design and operation, and (d) UAV service startups to perform field trials for technology validation.

Fig. 5 shows the block diagram of UAV sprayer system and its operational components. The UAV platform has been enhanced to enable automated, high-precision spraying such that at pre-programmed waypoints along trajectory an on-board controller triggers actuator(s) to control the amount and properties of dispensation. The trajectory and waypoint-based control is programmed via the Field Computer. The platform has also been modified to fly safely at low altitude above crop canopy (< 2m) and achieve high stability despite factors such as sloshing of pesticide liquid and ground effects due to proximity to surface. The team has integrated and validated advanced features, such as speed-based flow control, terrain navigation, and auto-resumption post re-fueling to enhance autonomous operation.

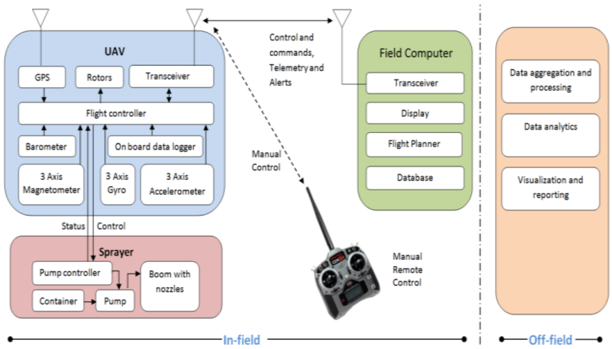

Figure 5. Block diagram of UAV sprayer system

The sprayer module comprises sprayer controller, pump(s) to generate desired pressure and flow rate, nozzles, anti-slosh container, and assorted sensors as shown in Table I. Advanced sensing is used to design the intelligent sprayer system with closed-loop controls for autonomous operation, such as auto-return when tank is empty or battery is running low.

TABLE I. List of Sensors Used in Sprayer Module for Autonomous Operation

Sensors	Purpose
Voltage	Monitors payload battery voltage to detect failures
Current	Monitors payload battery current to detect pump and battery failures
Flow rate	Detect (a) container empty (b) pump failure, and (c) sloshing
Liquid level	Detect (a) container empty (b) pump failure, and (c) sloshing
Pressure	Detect (a) container empty (b) pump failure, and (c) battery issues
Sonar	Maintain spray altitude above crop canopy
Temperature & Humidity	Monitor ambient temperature and humidity to optimize sprayer parameters
GPS	Introduce speed-based flow control to ensure uniform spraying

Initially, lab tests were conducted to characterize the spray pattern and properties of various nozzle types in isolation, validate design specifications supplied by manufacturers, and benchmark properties across makes and models. Fig. 6 shows the methodology used, where MgO-coated slides were utilized to analyze the count and distribution of droplet sizes and placements.

Figure 6. Nozzle spray measurement: Measurement tools and setup

Next, nozzles were mounted on to the UAV in variety of configurations, e.g. on-boom and under-propeller placements, and swath width and uniformity measurements were conducted to measure the impact of external factors, such as wind conditions, nozzle overlaps, UAV motion, and UAV downwash. Fig. 7 and Fig. 8 show the methodology, in which combination of water-sensitive sheets and MgO-coated slides were utilized to analyze the count and distribution of droplet sizes and placements.

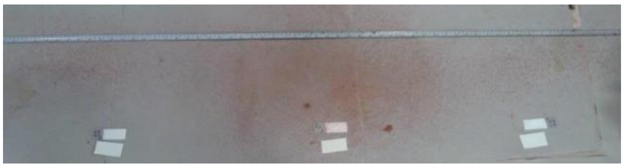

Figure 7. Drift and swath measurement

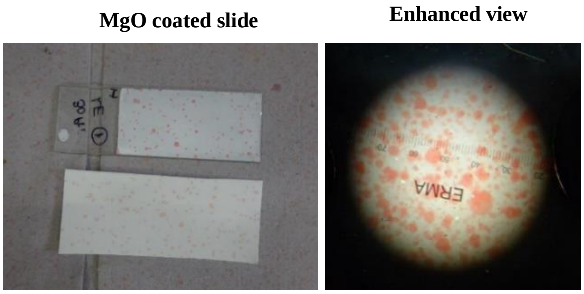

Figure 8. Droplet size and count measurements and analysis of statistical distribution

This was followed by sophisticated experiments at CSIR NAL to profile UAV downwash and spray patternation in lab settings and extensive field trials across multiple crop types and geographies to validate those lab results. Fig. 9, Fig. 10, and Fig. 11 show examples of measurement tests and experiments whose data is being leveraged to derive field-optimum configurations and also to develop a comprehensive modeling and simulation framework for UAV aerial spraying. The field trials additionally considered the impact of external factors, such as UAV motion and weather conditions (temperature, humidity, wind speed), while validating the measurement results.

Figure 9. Standalone nozzle flow visualization

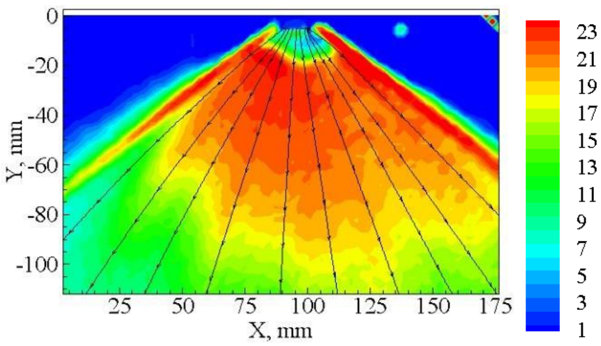

Figure 10. Standalone nozzle flow characterization

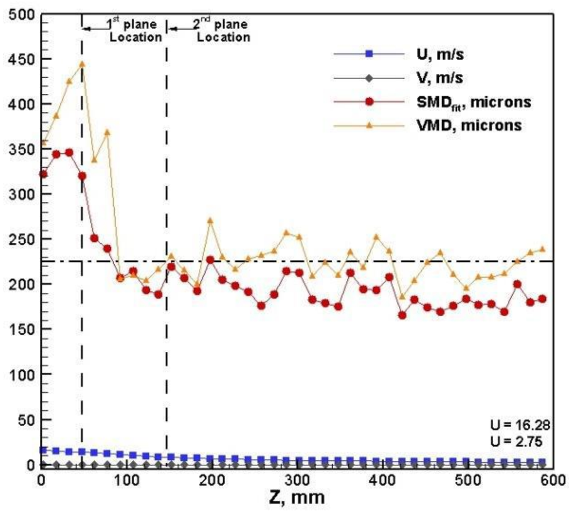

Figure 11. Planar measurement of nozzle spray

Together, lab results and field observations were used to derive crop-specific (based on crop pattern, pest characteristics, etc.) system configurations, flight settings (e.g. UAV speed and altitude) and sprayer settings, which significantly improve drift control and penetration to ensure uniform coverage and to minimize wastage. Future plans include integration of remote sensing capabilities for early detection of pests and diseases to enable targeted spraying (instead of the current practice of blanket spraying).

C. Field Pilot - Results

Field trials have been successfully completed for one complete season for 4 different crops and Fig. 12 shows the milestone reached for each of them. Table II shows the efficacy results benchmarked against current farmer practices and their potential impact on Indian agricultural markets.

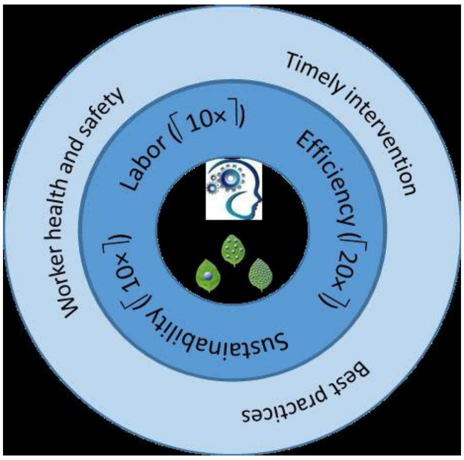

Figure 12. UAV spraying: milestones achieved

TABLE II. FIELD TRIAL RESULTS

Crop	Efficacy (% control)		Total land cover (MHa)
	Farmer practice	UAV spraying	
Bengal gram	91	91	10
Tea	95	93	0.5
Groundnut	100	87	1.4
Paddy	84	75	44

D. UAV Spraying Agri-Service

UAV-based low-volume spraying was launched as an agri-service in 2 states (Karnataka and Madhya Pradesh provinces) in India from Nov. to Dec. 2017 covering over 425 acres of Bengal Gram (a lentil variety) crop (Fig. 13). Since farmer practice varies across geographies, crop varieties, and even farmer preferences, service launch was also utilized to demonstrate the benefits of recommended dosage and practices (improvements in efficacy and persistence).

Figure 13. Launch of UAV spraying as an agri-service

IV. CONCLUSIONS

UAV-based crop protection leverages emerging technological trends, including advances in Autonomous Things and rapid diffusion of digital technologies, to provide several unique advantages in development of PA solutions for small to medium land holding sizes. For UAV-based low-volume spraying, crop-specific customization is key to improve efficacy and efficiency, reduce toxicity, and achieve low-volume spraying.

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