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Feeding a Hungry World: The Potential for Unmanned Aircraft Systems

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The fusion of next generation sensors and advanced information systems, combined with advances in unmanned aircraft systems that have emerged through aerospace engineering technologies, will contribute to the challenge of feeding our future world in a sustainable manner. Without these advances, the world may find itself short of food and perhaps on the brink of global conflict.

By current estimates, there will be 9 billion people on Earth by the year 2050. Our ability to produce the amount food and fiber required to sustain this growing world population is a major concern. Projections indicate that the world will face a 69 percent gap between crop calories that are produced in 2006 versus those likely required for the year 2050. The magnitude and difficulty of meeting this challenge, along with the implication of not meeting this crop production challenge in terms of global instability, clearly presents it as one of the key Grand Challenges of the 21st Century.

A well-recognized strategy for meeting this Grand Challenge is to close the yield gap through agricultural intensification using new production technologies and practices that will increase food production per same unit of land area. Unfortunately, intensification of agriculture has potentially adverse impacts on environmental and ecological sustainability.

Research and development are currently underway to advance agricultural technologies leading to practices that minimize adverse impacts while maximizing crop yields. One promising approach has been described as precision agriculture [1]. Precision agriculture is a farming concept based on observing, measuring, and responding to spatial and temporal variability in natural systems such as topography, soil, and weather, integrated with variability in crop and livestock production systems. In this case, the large acreage crop production systems are complex and require timely data across multiple space/time scales to feed optimization routines that produce either a preferred management strategy or prescription for improved agronomic production. In a sense, agriculture is embracing big data.

The opening of National Air Space to *unmanned aircraft systems* (UASs) will be a game changer for the agricultural industry. It has the potential to make a significant contribution to closing the yield gap through agricultural intensification, while at the same time improving environmental and ecological sustainability. The fundamental premise is that UASs gather timely plant, soil, production, and environmental information and improve the response time for agriculture production and natural resources management.

The major challenges for crop production are water, nutrients, insect pests, disease, competing weed plants, plant and animal genetics, and making timely decisions. Some of these challenges can occur rapidly and unexpectedly, and if not dealt with promptly, result in a potentially significant loss of crop yield. UAS technology will offer an unparalleled opportunity to place crop and soil sensors, robotics, and advanced information systems at more timely and desired field locations as an integral part of precision agriculture technologies, thereby increasing production and improving efficiency of agricultural operations. This will lead to increased sustainability and security of food production, efficient water resources management, and deployment of new information systems based on integrated terrestrial and aerial sensor networks.

Agricultural Applications of UAS Technology

Satellite and high altitude remote sensing have played a key role in precision agriculture since their inception about 25 years ago. However, these systems are expensive and are often not available to the agricultural community for timely information gathering and decision-making. Recently, the advent of smaller, less expensive UASs has provided new capabilities in spatial, spectral, and temporal resolution, which many researchers around the world are now attempting to put to use. Beginning in 2002, the first agricultural application of UAS remote sensing took place above the Kauai Coffee Company plantation in Hawaii with NASA's solar-powered Pathfinder-Plus Unmanned Aerial Vehicle (UAV) [2]. Color images were analyzed to map weed outbreaks and to spot irrigation and fertilization anomalies. Multispectral and hyperspectral imagery was also used to assess coffee crop maturity.

Since the inaugural Pathfinder-Plus mission, many subsequent research efforts have been made to analyze UAS capability for agricultural applications such as crop yield and biomass, water stress, nutrient deficiency, and plant status and condition. These UAS operations include both autonomous and remotely-piloted fixed-wing planes, single-rotor helicopters, and multi-rotor helicopters. In these studies, image processing techniques provided usable data in the form of major biophysical parameters such as the normalized difference vegetation index (NDVI), photochemical reflectance index (PRI), normalized green-red difference index (NGRDI), and leaf area index (LAI). In addition, research is underway to utilize UAS platforms as an aid for inventorying nursery and Christmas tree crops, and aerial imaging platforms to aid in identification of citrus diseases.

Realizing that agricultural intensification implies challenges in terms of sustainability, applications of UAS remote sensing capabilities can also be found in natural resources management. These include areas ranging from forest inventory to ecological conservation. Research studies have been undertaken by Rango and Vivoni to explore rangeland hydrological applications with unmanned aerial vehicles [3], and parameters of oceanic and coastal area management have been tested using UAS platforms in coordination with the Integrated Ocean Observing System.

Synthesis of the literature developing and exploring applications of UASs in agriculture and natural resources points toward applications that involve high-value crops in which value density (i.e., economic value per unit area) is fairly large. This makes considerable sense, since this would be the most logical entry point for a new, perhaps moderately expensive technology. However, there is a compelling need for the consideration of UAS technologies in the production of food and fiber in the cornbelt areas of the Great Plains and Mid-west regions of the US. Here, large expanses of land present their own unique challenges in continuously monitoring crop conditions for making timely management decisions.

In terms of management of large parcels of land, UASs can help to address and resolve several challenges, including multiple crop rotations and irrigated production. To date, producers have relied largely on limited terrestrial sources of data, provided by limited wire-based connectivity requirements. In the case of wireless systems, the limits are associated with the high cost, density, and connectivity of the sensor networks [4]. There has also been some movement toward satellite-based sources of data to help inform the grower for management and decision-making. While terrestrial sources of information and remotely sensed information derived from satellites are important, a better “bird’s-eye view” and timelier source of data will eventually be needed to progress toward meeting the yield gap challenge across the large expanses of the Great Plains and Mid-west.

Examples of UAS Platforms

Researchers at the University of Nebraska – Department of Biological Systems Engineering, in partnership with the University of Colorado – Aerospace Engineering Sciences Department, have explored the unique demands created by UAS deployment, especially across large agricultural land areas. Initial studies focused on the evaluation of flight path tracking performance using the SwiftPilot (Figure 1) which is an autonomous navigation system [5] developed by BlackSwift Technologies, and is integrated into the Tempest fixed-wing aircraft (Figure 2) manufactured by UASUSA, Inc. Flight path performance is an important variable in terms of placing sensors in an efficient manner to support the extreme data demands of precision agriculture. Initial results of this collaborative research show great promise for currently available autonomous navigation systems guiding a single engine, fixed-wing unmanned aircraft for placement of sensors at specific locations over large parcels of agricultural land [6].

The SwiftPilot is a state of the art flight computer (i.e., embedded processor) serving as a lightweight, customizable, and low-cost autopilot. The 70 x 34 x 27 mm package weighs 34 grams and utilizes a 6-axis inertial measuring unit, global positioning system, a dynamic pressure sensor for airspeed, and a static pressure sensor for determining altitude. The SwiftPilot allows access to every control loop using a cascaded proportional-integral-differential (PID) controller through the SwiftPilot SDK unit, allowing high level algorithms for performing robust trajectory planning and flight path following [7].

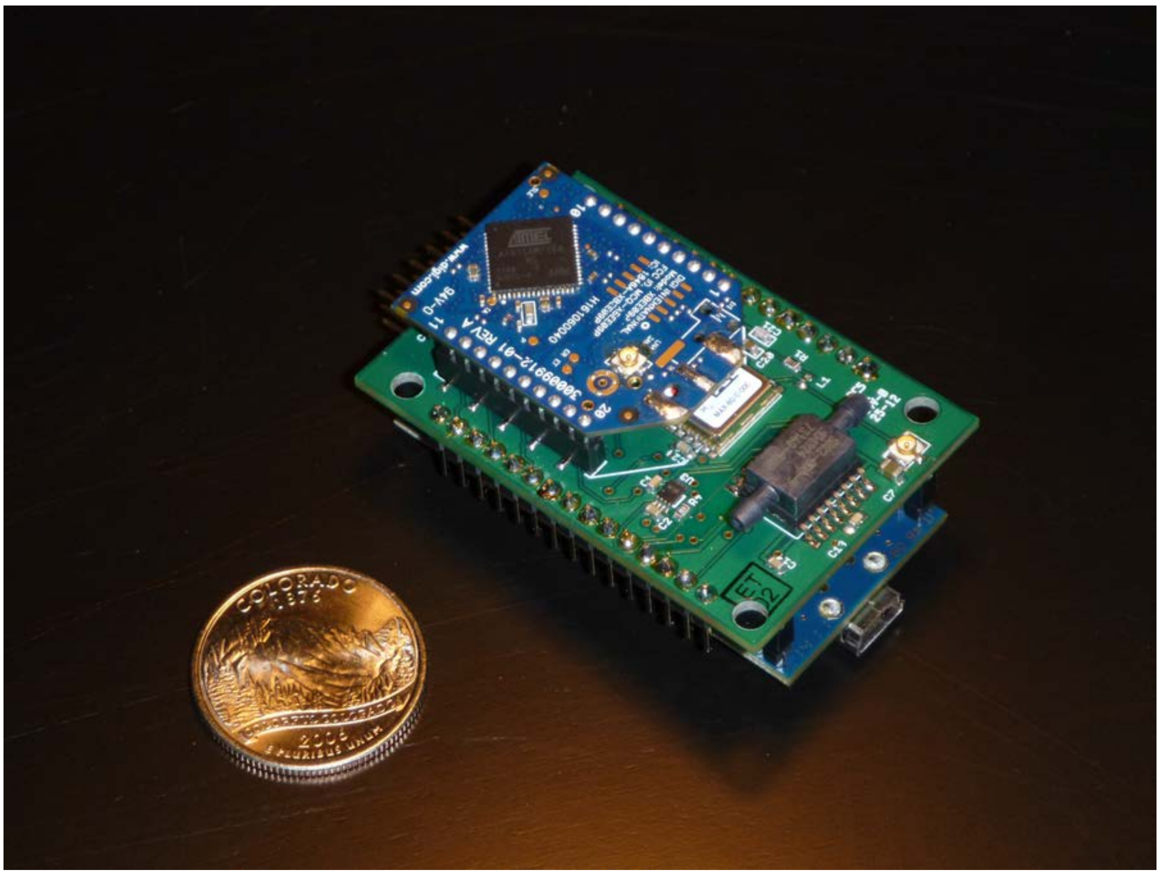

Figure 1. SwiftPilot Autopilot System

The Tempest unmanned aircraft (Figure 3) is light-weight but strong, made primarily of fiberglass with carbon-fiber composite for reinforcement in the wing spar and the lower surface of the wing. The detachable wings have a span of 3.2 m with a maximum gross takeoff weight of 6.8 kg. A smooth under-surface and a folding propeller enables landing in grassy fields and road surfaces with no landing gear. The Tempest utilizes an in-runner electric motor with a gearbox manufactured by Neu Motors, a Castle Creations ICE speed control, a Graupner propeller, and a 10,000 mAh lithium polymer battery manufactured by MaxAmps, providing flight time of approximately 45 to 75 minutes depending on the cruise speed setting [7].

The Future of UAS

A few of the application areas in which robotics, information systems, and unmanned aircraft can contribute to agriculture and natural resources include:

- Crop sensor systems for agricultural production applications employing precision agriculture
- Sensor deployment for hydrologic observatories and natural resource management
- Standards and performance verification in support of the agricultural industry
- Crop scouting, ranch, and livestock management involving weed scouting and cattle health
- Water management applications for flood assessment and irrigation management
- Soil moisture and vegetation type to define stage of crop growth and presence of weeds
- Management and application of pesticides through space/time resolution and crop dusting
- Remote sensing platform with multi-spectral sensors to extend information bandwidth
- River tracking, riparian status, and water area coverage after storms and extreme events

Figure 2. A Tempest Unmanned Aircraft System ready for Agricultural Research

Realization of these, as well as many other applications, will require continued creative research and development in the process of data fusion of information and sensor systems, as well as the integration of technology capable of placing the sensors at the desired location and time into the UAS. Perhaps the effectiveness of an aerial sensor system will depend on its ability to both 1) cover a large expanse of land, and 2) levitate over desired areas of the agricultural operation. In addition, to achieve the long range potential of precision agriculture, the UAS will need to carry an appropriate sensor and data storage package, remain on a given target area, and work in tandem with on-the-ground robots via wireless communications such as mesh net radio systems [7, 8].

Currently, fixed-wing UASs have the longest range, with a flight time of hours (comparatively, multi-rotor copters can have flight times as low as only 20 minutes). Multi-rotor copters have the advantage in hovering over a target area, but may be more susceptible to environmental conditions that restrict flight. Terrestrial robot systems, especially small ones, may also have short operation times due to energy demands and our current state of energy system density (lithium polymer batteries being the state-of-the-art). Yet another extension of this vision includes the concept of a UAS collaboration network, in which multiple

UASs work together (perhaps even employing swarm technology), along with an array of terrestrial-based robots, to realize an integrated, collaborative framework that achieves outcomes that are not possible with only single-mode robotic systems.

Figure 3. Preparing the Tempest for an Agricultural Test Flight

In order to meet the evolving global demands for food and fiber into year 2050, research and development on UASs will need to advance. It is interesting to note that the UAS industry has identified precision agricultural applications as the single largest market opportunity through year 2025 [9]. This will involve research and development on information systems, sensor technology, and integration into efficient airframes that support collaborative networking across multiple space and time scales. Of course, it will also require the engagement of our best and brightest human resources.

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