# Development and prospect of unmanned aerial vehicle technologies for agricultural production management

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**Abstract:** Unmanned aerial vehicles have been developed and applied to support agricultural production management. Compared with piloted aircraft, an Unmanned Aerial Vehicle (UAV) can focus on small crop fields at lower flight altitudes than regular aircraft to perform site-specific farm management with higher precision.   They can also "fill in the gap" in locations where fixed winged or rotary winged aircraft are not readily available.   In agriculture, UAVs have primarily been developed and used for remote sensing and application of crop production and protection materials.   Application of fertilizers and chemicals is frequently needed at specific times and locations for site-specific management.   Routine monitoring of crop plant health is often required at very high resolution for accurate site-specific management as well.   This paper presents an overview of research involving the development of UAV technology for agricultural production management.   Technologies, systems and methods are examined and studied.   The limitations of current UAVs for agricultural production management are discussed, as well as future needs and suggestions for development and application of the UAV technologies in agricultural production management.
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## 1   Introduction

An Unmanned Aerial Vehicle (UAV) is an unpiloted,

autonomous unmanned aircraft that can be remotely controlled or autonomously flown based on pre-programmed flight plans or more complex dynamic automation systems.   UAVs have been developed to support precision agriculture.   Piloted aircraft that carry a spraying system and/or aerial imaging system can cover well over hundreds of hectares of crop fields in a short period.   However, piloted aircraft are not prevalent in all areas, so UAVs are needed as alternatives.   Field operations over smaller fields can especially benefit from the use of UAVs.

UAVs have been developed in a wide variety of shapes, sizes, configurations, and characteristics.   The development of UAVs began in the early 1900's, and the technology in its early stages was used by the military due in World War I and expanded by World War II.

Compared with military applications, non-military applications of UAVs are relatively small but growing rapidly[1]. Typical civil applications of UAVs include firefighting assistance, police observation of civil disturbances and scenes of crimes, reconnaissance for natural disaster response[2], border security[3], traffic surveillance and management[4,5], and scientific research in archaeological prospecting[6]. UAVs were developed and used for crop dusting beginning in the 1980s. Since then and especially in the last decade, the use of UAVs has proliferated in applications of aerial photography and imaging over crop fields to assist with crop production management. To complement remote sensing missions of high-altitude flights from piloted aircraft, UAVs typically fly at low altitudes to acquire the remotely sensed data. For low altitude remote sensing (LARS), the most agricultural UAVs are mini model fixed-wing airplanes or rotary-winged helicopters of low cost, low speed, low ceiling altitude, light weight, low payload weight capability, and short endurance[7,8]. Besides fixed-wing airplanes or rotary helicopters, remote controlled (RC) kites, balloons, gliders, and motorized parafoils have been used for agricultural LARS imaging as well[9-15]. The UAVs for LARS are mostly gasoline- or methanol-fueled, but some of them are electric-powered using rechargeable batteries or solar power. The UAVs using rechargeable batteries typically only support short endurance runs[7,8,16], and the ones using solar power can potentially provide longer endurance[16]. Compared to UAVs for agricultural LARS, the UAVs for pesticide spraying have a higher payload weight requirement but are able to support longer flight endurance[17].

Traditional agriculture treats crop fields with uniform agronomic practices in planting, application of fertilizer, pesticide, harvesting aids, and irrigation. By contrast, precision agriculture manages a crop field in zones based on variations in soil, nutrition, and crop stress considering local field needs. In the last decade, the development of advanced electronics, Global Positioning Systems (GPS), Geographic Information Systems (GIS), and remote sensing have enabled significant advancements to the practice of precision agriculture. Remote sensing, especially from piloted airborne systems, has provided the basis of creating field prescriptions for variable crop seeding, fertilizer/pesticide/harvesting aid application, and irrigation. The agricultural uses of UAVs are more focused on low altitude operation over small fields for site-specific precision farming practice. This paper will provide an overview of the development of UAVs for agricultural operations where technologies, systems and methods are examined. Limitations of current UAVs for agriculture are discussed, and the future of development and application of the UAV technologies in agricultural production management is projected.

## 2  UAVs for aerial application over agricultural lands

In developing UAV platforms for agricultural use, commercially available RC aircraft have been modified to carry and control the designated equipment. Modified non-military Yamaha UAVs (Yamaha Motor Corporation, Iwata, Shizuoka, Japan) have been developed and used for agricultural applications such as insect pest control in rice paddies, soybeans and wheat[18]. The first system, RCASS (Remote-Controlled Aerial Spraying System), was built in 1983[19]. Subsequently in 1990, the R50 helicopter appeared to have a payload limit of 20 kg and a laser-system for height determination[19]. In 1997, the RMAX was developed[19] and three years later it was equipped with an azimuth and Differential Global Positioning System (DGPS) sensor system. An experiment was conducted to determine the effectiveness of using a UAV for dispersing pesticides to reduce human disease due to insects[20]. In this experiment a commercial off-the-shelf Yamaha RMAX UAV was outfitted with both liquid and granular pesticide dispersal devices, and a series of tests were performed to evaluate the effectiveness of the UAV to perform aerial pesticide delivery. The Yanmar Helicopter Service Co., Ltd (Osaka, Japan) has also developed a series of unmanned helicopters, KG-135, YH300 and AYH3 for pesticide spraying over crop fields.

A low-volume spray system was developed for use on a UAV helicopter which has 22.7 kg maximum payload limit, 1500 m operation ceiling and up to 5-hour

endurance[17]. This helicopter is a fully autonomous, unmanned vertical take-off and landing (VTOL) UAV. The sprayer weighed 7.7 kg and was integrated with the flight control system of the UAV. The integrated sprayer was triggered by preset positional coordinates received from the GPS system of the UAV through a PWM (Pulse Width Modulation) pump speed controller. This spray system has been installed and tested on the UAV (Figure 1). The system has shown good potential for vector control in the areas that are not easily accessible by personnel or equipment. It can also perform low-volume spraying over small crop fields for accurate site specific management.
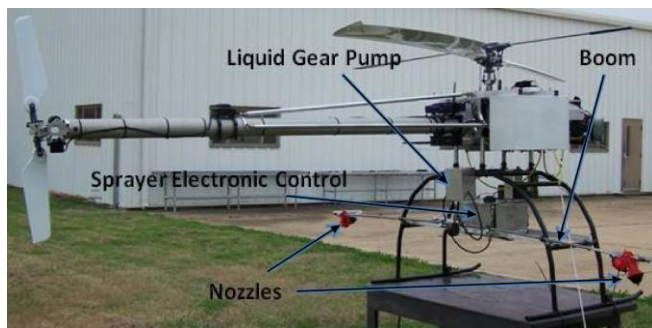


Figure 1　A low-volume spray system integrated with a UAV

## 3　UAVs for agricultural remote sensing

UAV-based agricultural remote sensing systems have been described extensively in the literature. Papers and reports were collected from various sources, particularly from the technical library of the American Society of Agricultural and Biological Engineers (ASABE) and the National Agricultural Library of United States Department of Agriculture (USDA). It was found that in the last decade the publication of papers and reports on UAV development for agricultural remote sensing has progressed steadily (Figure 2). In the first few years (2002-2007) more conference/proceedings papers were produced in the early stages of research and development. In the last few years (2008~present) more peer-reviewed journal papers have been published. This indicates the maturity and progress of the research, development and application of UAV technology for agricultural remote sensing in the last few years.

UAVs used for agricultural remote sensing are mostly low-cost model airplanes with limited payload capability (kilograms to tens of kilograms). These UAVs typically have short flight endurance (less than one hour) and operate at low ground speeds (less than 50 km/h) to carry inexpensive multispectral cameras (at typical cost of less than $5 000) to perform LARS at altitudes less than 300 m over crop fields.
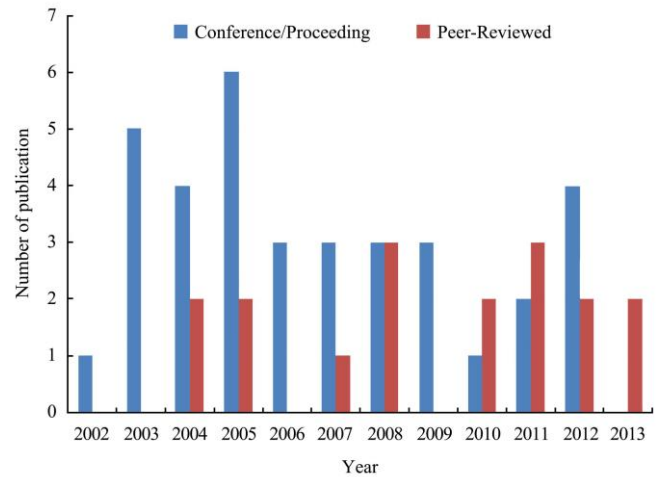


Figure 2　Publications of UAV platforms for agriuclutral remote sensing

An RC model fixed-wing airframe was assembled to carry a digital still camera for imaging small sorghum fields to assess the attributes of a grain crop[21]. The UAV platform had a payload of 750 g and was powered by methanol (10 cc 4 stroke glow fuel). The imagery acquired from this platform was used to support crop field mapping and growth monitoring.

A low-cost sailplane was assembled into an electrical-powered RC UAV platform to perform agricultural LARS[22]. The developed UAV platform had a 0.5 kg payload and carried a small single board camera or a digital still camera over a target area. The system successfully captured aerial images of several locations for different agricultural studies.

An UAV platform was built on a low-cost, low-speed and light-weight fixed-wing airframe to perform rangeland aerial photography[23]. The UAV platform was integrated with engine, avionics (RC servos and autopilot), and image sensor (camera). The UAV was powered by methanol and had a payload capacity of 1 kg to accommodate a 35 mm SLR (single-lens reflex) camera in the compartment of the fuselage. The same airframe was developed to carry a low-cost agricultural

multispectral camera[8] (Figure 3).   This UAV platform was assembled and tested at the USDA, Agricultural Research Service (ARS), Crop Production Systems Research Unit (CPSRU), and was originally flown for fire ant mound distribution mapping by the scientists at the USDA, ARS, National Biological Control Lab (NBCL).
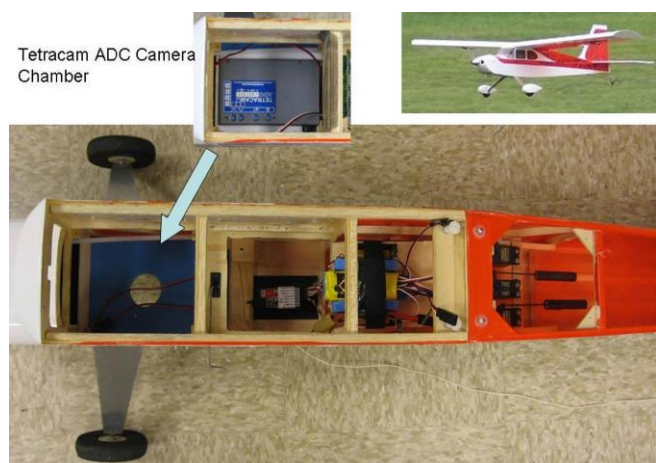


Figure 3    Sig Kadet Senior UAV (Sig Manufacturing Company, Inc., Montezuma, IA, USA) assembly and camera placement

A single digital camera with a red-light blocking filter was mounted in an inexpensive, fixed-wing UAV airframe to acquire color-infrared (CIR) images over variably-fertilized winter wheat fields[24,25].   The RC UAV was powered by gasoline and had a payload of 4.5 kg.   It was controlled by the autopilot software to image the fields at predefined waypoints.    This UAV remote sensing platform was flown at low altitudes (<220 m) to image two treated winter wheat fields to verify the technology for site-specific agricultural management.

A commercially available hobby-type RC fixed-wing airframe was modified for electric propulsion and support of the payload for low-altitude aerial thermal infrared imaging[26].   A light weight thermal camera was mounted on this UAV.   This platform was successfully used in detection of cotton response to irrigation and crop residue management.

UAV helicopters have been developed for agricultural remote sensing.   Compared with fixed-wing UAVs, UAV helicopters provide flexibility and less space restriction by allowing vertical take-off and the ability to land vertically, hover, and fly forward, backward, and laterally.   These advantages in maneuverability allow UAV helicopters to inspect isolated small fields closer to obstructions that would be difficult for fixed-wing UAVs to handle.   In general, an autonomous UAV platform was prototyped to demonstrate the flexibility and reliability of the technology in sensing agricultural fields[27-29].    The system was equipped with an inexpensive agricultural multispectral camera, and navigation was set up with a computer program based on the extend Kalman filter (EKF).    With this navigation system, the UAV automatically followed predefined waypoints and hovered over each waypoint to acquire high resolution field images.    To reduce UAV image processing turn-around time for site-specific management, a rapid, automatic UAV image georeferencing method was developed[30,31].    This georeferencing method did not require use of ground control points.    By continuous estimation of position and altitude of the UAV from the navigation system and calculation of the camera lens distortion model, the acquired images could be automatically georeferenced to transform the aerial imagery from the camera frame to the mapping frame rapidly.

A miniature RC helicopter was assembled to carry a pair of digital stereovision cameras to image citrus trees to determine the health and estimate the yield of the fruit[32,33].    The UAV had 1.5 kg payload using the full battery set.    Light-weight agricultural infrared cameras (0.5-1.0 kg) were used in the UAV for LARS over crop fields to keep weight within a reasonable range.    A mini RC helicopter was equipped with a light-weight agricultural multispectral camera to perform LARS, acquiring high resolution CIR images to estimate the yield and total biomass of a rice crop[34].    An electric-powered, short endurance UAV helicopter was evaluated for site-specific management[7,14].    Flight control for this UAV provided capability of auto take-off and auto landing, which greatly facilitated the operation via ground control.

Spray UAV helicopters have been adapted for agricultural remote sensing.    Compared to the UAVs for LARS mentioned above, spray UAV helicopters are more expensive and heavier but as a result can carry heavier

payloads such as high-performance cameras. Yanmar YH300 spray unmanned helicopter was modified to carry a high-definition digital multispectral CCD (charge-coupled device) camera, the MS2100 (formerly DuncanTech Ltd, Auburn, CA, USA) to survey agricultural fields[35,36]. Yanmar YH300 UAV helicopter and MS4100 camera were also integrated to monitor crop status for precision agricultural operations[37-40]. In this platform the equipment for spraying (chemical tank and nozzles) was removed. An adjustable pan-head was then installed under the fuselage to mount the camera. The pan-head could be controlled for pan and tilt direction for versatility and to improve the efficiency and accuracy of remote sensing imaging[41].

A hyperspectral imaging sensor was mounted on Yanmar AYH-3 spray unmanned helicopter to collect information over corn fields for prediction of maize yield and feed quality[42-43]. The hyperspectral imager had a spectral wavelength ranging from 400-100 nm and spectral resolution of 10 nm. The models built from the field data collected by the UAV hyperspectral imaging platform were precise in prediction of the crop attributes, especially nutritional components.

Multi-rotor microdrones have been used in agricultural management recently. A quad-rotor microdrone mounted with a 6-channel multispectral camera was used to provide images for crop row characterization for site-specific weed management[44,45]. A six-rotor microdrone was also mounted with the 6-channel multispectral camera to provide images for detection of HuangLongBing (HLB) in citrus trees[46]. Results indicated that the UAV imaging system was capable of acquiring images at desired spatial resolution with different flight heights to achieve a better detection accuracy compared with a similar imaging system on piloted aircraft.

High-performance UAVs have also been developed for use in agricultural remote sensing. The NASA's (National Aeronautics and Space Administration) Pathfinder-Plus UAV (AeroVironment, Inc., Monrovia, CA., USA) was developed to carry two complementary high-definition digital cameras for agricultural surveillance[16,47]. A Hasselbald 555ELD camera (Victor Hasselblad AB, Gothenburg, Sweden) was mounted to collect high-resolution color images for qualitative interpretation and mapping of agricultural fields. A DuncanTech MS3100 camera (formerly Duncan Tech Ltd, Auburn, CA, USA) was also mounted to collect high-resolution CIR images for quantitative analysis of canopy spectral response to crop ripeness. This UAV weighed 318 kg and had a payload limit of 67.5 kg. It had up to 15 hours of flight endurance capability using eight solar-electric motors and could fly up to 25 000 km high with low flight speed (< 50 km/h). For monitoring and surveillance over coffee crop fields, this UAV remote sensing platform flew slowly and hovered over designated areas for extended periods at an altitude of approximately 6500 m, providing high-resolution images for analysis of coffee ripeness to determine harvest timing.

## 4   Limitations of current agricultural UAVs

UAVs are effective tools for improving agricultural management. However, our experiences indicate that current UAV technologies have the following limitations for practical implementation in agriculture.

### 4.1   Technical decisions

In the market, there are many manufacturers and vendors for various UAVs from industrial products to hobby-type model aircraft. Due to the lack of standard protocols of UAV development for agricultural applications, it is difficult to decide which UAV is appropriate for any single project both technically and economically.

### 4.2   Cost

The industrial systems, especially spray UAVs, are typically expensive for individual farmers. Interested farmers may need to contract as group to receive the service. In hobby shops, inexpensive airframes can be purchased and assembled with engine and avionics components. A light-weight, low-cost camera can be integrated into this assembly to typically build up a short endurance UAV LARS platform. Although the costs of the aircraft and the camera could be minimized, the assembly and integration require significant labor and time even for highly skilled technicians and engineers,

which may increase total cost.

### 4.3　Payload

Payload size and weight are critical factors for UAVs. When deciding on an appropriate UAV for a specific application, the designated payload needs to be carefully configured to determine if UAV structure needs to be modified or optimized to accommodate it. When the UAV is ready, mechanical and electrical systems need to be configured. Payload design, mechanical, and electrical accommodation for UAVs have no general engineering guidelines to follow.

### 4.4　Operation

Most UAVs do not have the capability of automated take-off and landing. Therefore, skilled operators for RC control are required. Autonomous flight based on georeferenced coordinates is therefore a highly desirable component for practical use of UAVs in agriculture.

### 4.5　Reliability

4.5.1 Sensitivity of communications

UAVs are preferably operated in areas without wireless networks. Cellular phones and PDAs nearby may interfere with the communication between the ground station and the UAV in flight.

4.5.2　Mechanical failure

The mechanical structure of many UAVs was not manufactured to be strong enough for agricultural operations. It is thus imperative that durability be assessed, but this is often difficult to do prior to purchase or setup of the UAV system. Our experience with a UAV helicopter configured for low volume spraying was a failure of the landing gear structure, resulting in damage to the rotors, landing gear, and servos on the rotor head. The repairs were costly in labor, time, and materials requiring special parts and knowledge of servo operation for proper repair. This significantly delayed the research project and confidence in use of UAVs for spraying was lost by the agricultural research developers and potential users.

4.5.3　Electronic failure

A supposedly 'fail-safe' electronic guidance system malfunctioned, causing a UAV to crash. The electrical UAV helicopter being used for remote sensing crashed from an altitude at about 7.6 m when communication was suddenly lost due to the electronic failure on the UAV. The UAV was supposed to hover above takeoff zone if the communication was lost but the failsafe function also failed. The crash resulted in a bent tail rotor assembly.

## 5　Prospect of the future development

In the past, especially during the last decade, UAVs have been developed for use in crop dusting and LARS in agriculture. In the next ten years or so the newly developed UAVs with new systematic design, construction methods, sensors and algorithms will be customized and adopted for agricultural uses.

### 5.1　Systems

The newly developed systems will be extremely easy-to-use especially for untrained and unfamiliar users. The systems will provide the platforms to equip state-of-the-art off-the-shelf sensors and devices that collect high-quality information on crop status for rapid remediation.

In order to facilitate the RC operation of UAV flight, UAVs will require capability of autonomous operation in take-off and landing. With this capability UAVs will be able to provide a fully autonomous flight mode with waypoint navigation in flight control. Development of the advanced features of automated computation of flight paths, survey parameters, and take-off and landing paths will be the key for deploying UAVs for agriculture.

More UAV platforms will integrate spray and remote sensing. By developing and implementing rapid image correction and processing algorithms, the integrated UAV platforms could be developed into a real-time or near real-time crop growth monitoring and control system. The spatially variable information extracted from rapidly processed remotely sensed images can be used to direct the operation of the sprayer immediately (real-time) or a short time later (near real-time).

### 5.2　Sensors

The imaging sensors are the most important devices for remote sensing on UAVs. The development of the imaging sensors for agricultural UAVs will be of better quality imagery at less cost, size, and weight. For example, the multispectral camera shown on Figure 3 has been manufactured as a more compact light-weight

version for accommodation by a Parafoil UAV (Figure 4). Simultaneously, the industry has developed a mini 6-band MCA (Multi-Camera Array), which is good for direct imaging of fields[44-46] and also for customizing a spectral imaging system on UAV for leaf/canopy spectral imaging, when the principal bands/wavelengths are determined after analysis of hyperspectral data.    However, a hyperspectral imager in comparable cost and size is not yet on the market.



Figure 4    Hawkeye UAV with ADC-Lite multispectral camera
(Tetracam, Inc., Chatsworth, CA, USA)

Besides sprayers and cameras, UAVs will be used with other special sensors for specific tasks.    For example, LIDAR (light detection and ranging) optical sensor could be configured on a UAV in a multi-sensor platform for agricultural field survey and crop height profiling.    Other sensors such as chemical sensor, environmental sensor, and weather sensor (spray drift detection and local climate characterization) will be also, individually or collectively with other sensors, configured on a UAV to meet the requirements of the specific project and service.

### 5.3    Crop production

With the genomics revolution, the DNA (DeoxyriboNucleic Acid)s in crop plant varieties are concerned with how it influences the growth of the plants under different conditions of soil, weather, nutrition, and pests.    Plant breeders want to associate the performance of the plants with the DNA information.    However, using only using genotyping technologies limit the ability to make the association.    Therefore, phenotyping is a needed technology.    Phenotype is the physical

characteristics of an organism resulting from its genes and environment and how they interact.    A phenotype can be anything responding to environmental factors such as plant height, chemical composition, and crop yield. Measurement of plant phenotypes is a challenging task. To uncover subtle effects of genes for the plant traits may require many repeated measurements.    Remote sensing platforms can contribute to the measurement for inversion of parameters of soil and crops from the acquired spectral data.    The remote sensing measurement platforms can be space-borne, airborne, ground on-the-go, and even microscoping in lab.    UAVs definitely are a powerful tool for phenomics studies by routinely measuring variables such as plant height, canopy cover, and canopy temperature throughout the growth season.

### 5.4    Standards

In order to be consistent in developing UAV platforms for agriculture uses agricultural professional societies should work together with UAV industry to develop protocols, guidelines and standards.    This may be the next task of agricultural UAV professionals and groups.

### 5.5    Other considerations

Nowadays new energy technology has developed rapidly.    New UAVs powered by biofuels will appear for agriculture uses, and more electric-powered UAVs will be manufactured.    With the development of battery technology, small UAVs will be produced to meet the requirement of long-duration, low-speed, and low-altitude monitoring and surveillance of agricultural fields. Lighter weight and high efficiency solar cells will allow longer flight duration of electrically powered vehicles.

## 6    Implications and suggestions

UAV is a hot topic in research, development and application of many fields now.    Media refers it as "drone".    It sounds like a dream in science fiction. Actually it is nothing but an aircraft with a computerized pilot (flight controller) not a human pilot.    For agriculture available UAVs are still limited in payload and endurance.    This means that at least in the next decade human piloted aircraft and ground equipment (tractor mounted) will still dominate and UAVs will only

be used to inspect and treat small pieces of field, especially where the large equipment cannot reach. In this way we would suggest for those who prepare to develop UAV for research or service in agriculture:

1) Consider if UAV is really the technology to develop and to use for the problem to solve. Basically, if you can use regular systems (manned aerial and ground systems) to solve the problem, you do not need UAV.

2) Start with the simplest UAV if you decide to have a UAV to solve your problem. Do not have a "desired" system at the very beginning with 50 kg payload, 10-hour endurance and so on. You will lose your investment if the expensive one crashes. Always remember that you need training at the very beginning. Get the simplest one. Spend six months to a year to play and feel comfortable with it.

3) Get your desired UAV and start to design your own system (spray or remote sensing or both) as long as you are comfortable with your training UAV. Study well the flight control system of your new UAV and the interface of servos. Carefully design your system to adapt to the requirements of the UAV power and payload.

4) Evaluate your system to see if the performance is satisfactory. Typically, in agriculture, the least expensive devices (sprayer, camera) are used due to the limitation of the available UAVs. The quality and performance of the devices, in general, cannot compare with the ones used in regular manned aerial and ground systems. The goal of evaluation is to see if the system is good enough to solve your problem.

## Disclaimer

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