Precision Agriculture: Evaluating Soil Moisture with RGB, Multispectral, and Thermal UAV Sensors in Agricultural Fields

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Abstract

Precision farming is a complex multidisciplinary field, and drone technology is one of the most vital studies at the core of the subject. Through the use of various unmanned aerial vehicles (UAVs), farmers worldwide monitor and observe their agricultural fields. However, these drones are excessively complicated and often poorly labeled, making it difficult for farmers to know what UAVs are required for their intended purpose. This project compared three different types of drone sensors (RGB (red, green, and blue), multispectral (deep electromagnetic spectral), and thermal (heat index)) on their ability to estimate the soil moisture of an agricultural field. Two identical UAVs, one with a thermal sensor and one with RGB and multispectral sensors, were brought to a recently-harvested corn field. There, they each flew a calculated route throughout the area of the field, taking photographs and developing a map of the area. Moisture samples were hand-collected using a soil moisture sensor at 30 sites in the field, and then compared to each UAV's measurements using a correlation coefficient. The RGB sensor was found to have an average correlation coefficient of 0.865, the greatest out of all the sensors, and the individual green value had an exceptionally high correlation of 0.955. However, the multispectral sensor output a correlation coefficient of only 0.063, and the thermal sensor output 0.097. These results significantly demonstrated that the RGB sensor had the superior ability to evaluate the soil moisture of the field, suggesting that farmers should invest in an RGB drone if they wish to monitor the soil moisture of their fields. An extremely important portion of the implementation of precision agriculture revolves around the accessibility of information regarding its technology. Few mediums exist that allow farmers to directly and efficiently receive UAV information and UAV readings of their fields. Hence, efforts concerning precision agriculture information technology are the critically lacking portion of the operation to implement precision farming.

Introduction

The use of drone technology in agriculture is a rapidly developing field; countless advancements have been made within the past decade alone. However, the studies being conducted are convoluted and do not provide the target audience, everyday farmers, with clear, applicable results. This causes many farmers to stray away from precision farming techniques, wary due to the uncertainty associated with AI and new technologies. Unrelatedly, climate change is a rapidly developing concern within agriculture, and weather patterns have been greatly affected due to it. This has led to a worldwide series of droughts and wildfires and has subsequently brought an issue to the forefront of crop farming. The monitoring of soil moisture is an ideal way for farmers to observe and manage the saturation levels of their fields, but large-scale, efficient systems that track the entire field are incredibly rare and expensive. Unmanned aerial vehicles have been proven to be able to accurately estimate soil moisture, providing a useful alternative to manual measurement, but the broad selection of drone sensors stirs confusion among many. To remedy this, a comprehensive comparison of multiple UAV sensors' ability to estimate soil moisture in an agricultural field can be conducted.

Literature Review

Unmanned aerial vehicles are a developing technology, especially in relation to agriculture; for decades, they were not considered to be tools for use in the agricultural industry. However, with the development of drone and imaging technology and an expanding need for precision agriculture solutions, a growing quantity of studies regarding UAVs in agriculture and the environment are being conducted. A number of these focus particularly on the analysis of soil conditions, including moisture and depth, but results are unclear or vaguely communicated. While studies regarding UAVs and their agricultural applications have been conducted, further research would provide the scientific community with a more conclusive understanding of the potential uses of drone imagery in the agricultural industry.

Soil moisture is one characteristic of soil that can be observed and estimated through the use of UAVs. Lu et al. explored the concept of analyzing soil moisture content in steppe environments, flat grasslands in southeastern Europe, using UAV images. It was found that "the surface soil moisture could be estimated based on the brightness of the visible images of the UAV combined with vegetation coverage," supporting the notion that UAV imagery can be utilized to accurately predict soil moisture content (Lu et al., 2020). However, the images taken for analysis were high-quality, 4K, RGB images, which meet the standard expectation for the quality of RGB lenses used in research but do not allow for the analysis of the greater range of data observed using multispectral or thermal imaging. This is due to the sensor collecting data only on the RGB scale, failing to capture the electromagnetic and infrared data utilized respectively by multispectral and thermal imaging systems. This study's application to environmental efforts and the potential increase of industrial efficiency using UAVs may have been of additional value had it included more diverse data obtained by a wider range of UAV imaging sensors.

A large caveat to using multiple types of UAV sensors is the difference in how each records, analyzes, and interprets data. To expand upon current data previously collected on these factors, Bertalan et al. completed an investigation of soil moisture content detection efficiency from a machine learning standpoint. After all images were processed using Pix4D Mapper and predictions were calculated using a myriad of different machine learning algorithms, it was determined that Random Forest algorithms most efficiently analyzed the data (Bertalan et al., 2022). It can be noted, though, that the differences in initial sensing between each sensor were disregarded in favor of the primary matter being tested. While the findings and methods of this study are an ideal reference point for future research, this presents a gap in the literature that has yet to be fully explored.

Along with being used agriculturally, UAVs also have the potential to be used to detect and map archeological sites covered by fields. Agudo et al. researched exactly this, comparing RGB, multispectral, and thermal sensors on their ability to recognize historical crop marks. It is important to note that crop marks are identified by crop depth and subsoil abnormalities instead of moisture, meaning these results relate to but in no way directly represent each sensor's ability to measure soil moisture. The study concluded that "there is not yet a single product (drone plus sensor) on the market that attains optimum results in the field of archeology, as is the case in other fields such as precision agriculture" (Agudo et al., 2019). This implies that there are limited ways to quantitatively assess UAV sensor efficiency and that UAVs are still developing and require new innovations to be fully implemented into the agricultural industry.

UAVs are extremely versatile, making them ideal tools in practically any physically large-scale operation. Through the use of drone mapping and analysis, UAVs can be used for environmental protection purposes, especially those relating to particularly dry or wet climates. Blanco-Sacristán et al. found that UAVs significantly assisted with the mapping and classification of dryland biocrusts (Blanco-Sacristán et al., 2021), and Wolff et al. similarly concluded that UAVs could successfully differentiate between segments of boggy land with different environmental characteristics (Wolff et al., 2023). While these results are very promising for the environmental science community, the vast range of results and overall ambiguity of ecological data are unfit to compare to the preciseness of results required in the agricultural industry. In an agricultural test of a similar theme, direct results suggesting direct action are ideal for use by agrarian professionals.

For the implementation of UAVs in all applicable industries worldwide, significant research into their functions, abilities, and weaknesses is vital. In an attempt to rationalize this overwhelmingly vast amount of data, Zhang et al. analyzed over 200 studies and documented the current state of UAV research. Additionally, the report illustrated the technicalities and inner workings of RGB, multispectral, hyperspectral, and LIDAR sensors along with the types of UAV bases the sensors are attached to (Zhang et al., 2023). This piece highlighted the works of numerous academics in the field of UAVs while simultaneously promoting the future development of UAV technology. However, its lack of detail when referencing certain studies, most prominently those pertaining to agriculture and soil moisture, left questions unanswered and called for clear results from additional research.

Each article analyzed investigates an independent research question and presents its findings about the scientific and technological industries. Additionally, they all had strong, concrete applications and prompted further strings of continued research by other researchers, each filling gaps from the studies before. These articles clearly demonstrated that soil conditions, including moisture, can be estimated using UAVs, but conventional farmers do not have the means necessary to utilize, understand, or apply their findings from this technology. This presents a need: simple, accessible information about UAVs. With a thorough understanding of each of these studies' strengths and weaknesses, a beneficial, comprehensive examination of the soil moisture prediction accuracy of several UAV sensors is a suitable procedure for conduction.

Materials and Methods

Materials:

The two unmanned aerial vehicles collected for this project were one DJI Mavic 3M Enterprise with separate RGB and multispectral sensors and one DJI Mavic 3T with a thermal sensor. Additional materials included one Vernier Soil Moisture Sensor, two Vernier UAV operation devices, one copy of the Vernier Graphical Analysis software, one copy of the Pix4DMapper software, one high-performance laptop, and one agricultural testing site. The agricultural site used was an 8000 square meter corn field that was previously harvested on the same day that the samples were taken. For this project, the independent variable was the unmanned aerial vehicle sensor type used to analyze the site while the dependent variable was the accuracy of each sensor's moisture content estimation. The control used as the standard for comparison was the RGB sensor due to its status as being the most general sensor used for UAV imaging.

Methods:

Constants for this project included the Vernier Soil Moisture Sensor, the environmental conditions during data collection, the vertical position of the UAVs during data collection, and the date of data collection. The experimental hypothesis for this project was that if RGB, multispectral, and infrared thermal sensors were each used on an unmanned aerial vehicle to detect soil moisture levels at an agriculture field, then the multispectral sensor would estimate the soil moisture content significantly more accurately than the RGB and thermal sensors.

To begin the experiment, the three UAVs were collected and brought to the agricultural testing site, an 8,000 square meter harvested corn field, on a sunny, clear day. There, the soil moisture content was determined by horizontally inserting the Vernier soil moisture sensor blade oriented with one blade directly above the other completely underneath the soil (approximately ten centimeters) at each of the 30 testing spots. These testing spots were pre-determined to be 20 feet apart lengthwise and 80 feet apart widthwise. To collect the exact moisture content, the sensor was connected to the laptop running the Vernier Graphical Analysis program during the moisture sample-taking process. The specific soil moisture percentage amounts were displayed in the program and documented. After the moisture samples were collected, the DJI Mavic 3M Enterprise was flown along a pre-programmed route across the entire field where it routinely took separate multispectral and RGB captures every 2 seconds. This was repeated with the second UAV, the DJI Mavic 3T Enterprise, which flew along the same route and took thermal captures every 2 seconds. This entire process was completed at a single site on one day between 12:00 PM and 1:00 PM. All images were then imported into the Pix4D software where each sensor type developed a digital map of the information. From here, the 30 soil moisture collection sites were pinpointed in the program and the specific numerical values of each UAV's measurements were collected for comparison. To compare a group of vastly different units, a correlation coefficient was calculated to determine the relatedness between each set of data and the measured soil moisture percentage.

Results

Table 1

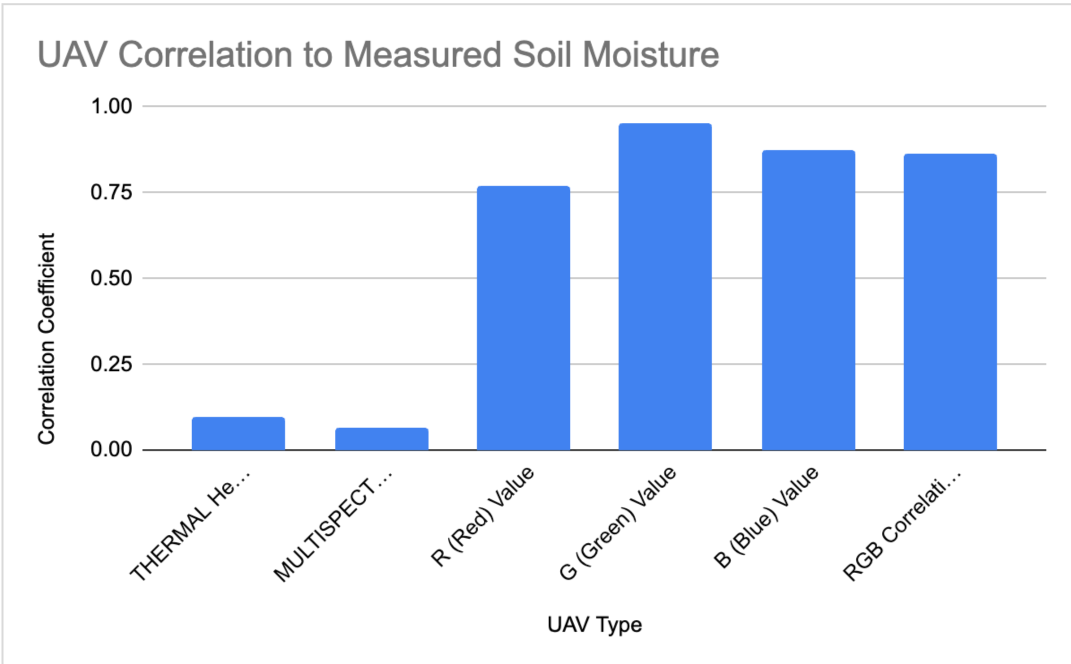
Collected UAV Values and Soil Moisture Percentages

Sample ID	Measured Soil Moisture %	THERMAL Heat Units	MULTISPECTRAL (TGI) Mean Index	R (Red) Value	G (Green) Value	B (Blue) Value	RGB Correlation Average
A	33.10%	0.02	0.0287	147	110	73	
B	38.60%	0.02	0.0056	152	114	76	
C	30.40%	0.02	0.0353	138	109	72	
D	34.50%	0.02	0.0561	149	111	74	
E	42.30%	0.03	0.0929	151	125	78	
F	43.30%	0.02	-0.0234	153	126	79	
G	33.80%	0.03	0.0295	146	110	73	
H	33.40%	0.02	0.0016	148	110	73	
I	32.80%	0.02	-0.0171	144	108	72	
J	39.10%	0.02	-0.009	156	115	74	
K	41.20%	0.34	-0.014	149	124	76	
L	34.70%	0.45	0.0106	151	111	74	
M	39.90%	0.45	0.0005	150	116	77	
N	31.20%	0.04	0.0619	147	111	72	
O	42.30%	0.05	0.0453	152	125	78	
P	44.60%	0.06	-0.0006	153	127	79	
Q	35.90%	0.05	0.0277	146	112	73	
R	33.00%	0.04	0.0163	144	111	72	
S	42.90%	0.03	0.0321	150	124	78	
T	35.30%	0.02	0.0268	148	112	74	
U	29.40%	0.04	-0.0064	139	108	71	
V	45.20%	0.04	0.0611	148	127	81	
W	36.50%	0.02	0.0848	147	112	74	
X	52.30%	0.02	0.0128	156	142	82	
Y	40.60%	0.02	0.0141	150	123	74	
Z	34.20%	0.67	0.0167	147	111	73	
AA	40.70%	0.78	0.0693	150	123	74	
AB	40.60%	0.88	0.1332	150	123	74	
AC	39.00%	0.92	0.0006	149	116	72	
AD	39.50%	0.94	0.0212	149	115	72	
Correlation	**Measured Soil Moisture**	0.09747044419	0.06333137313	0.7682423631	0.9548024453	0.8723221426	0.865122317

Note. Each UAV output a unique unit of measurement with thermal resulting in heat units, multispectral resulting in TGI mean index, and RGB resulting in separate red, green, and blue values. The correlation coefficient, which is a value between -1 and 1, indicates the degree of linear association between two sets of data. A correlation coefficient of 1 indicates a perfect positive linear relationship, a coefficient of -1 indicates a perfect negative linear relationship, and a coefficient of 0 indicates no linear relationship.

Figure 1

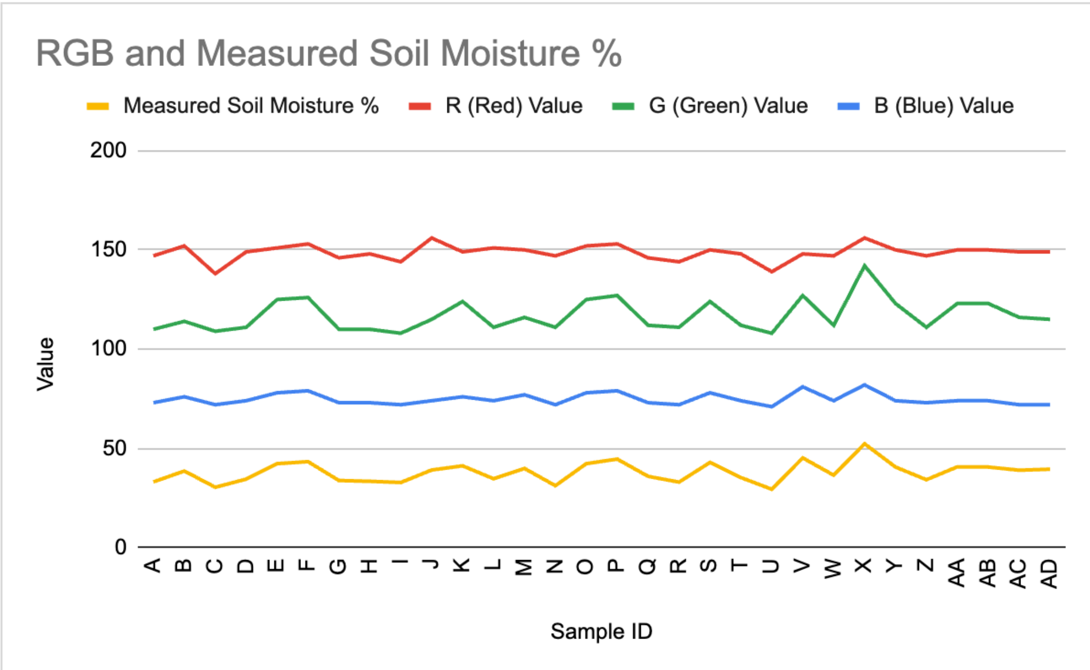
UAV Correlation to Measured Soil Moisture



Note. The correlation to the measured soil moisture % was calculated for each UAV sensor type, with separate values for the red, green, and blue components of the RGB sensor and an average RGB correlation value for balance.

Figure 2

RGB and Measured Soil Moisture %



Note. The soil moisture percent was graphed among the individual red, green, and blue RGB values to highlight their similarities.

The results from the collected data state that the average RGB correlation coefficient was the greatest out of the three sensor types at approximately 0.865. The thermal data, with a much lesser correlation coefficient, reached 0.097. The multispectral set of data had the least amount of correlation to the measured soil moisture at only 0.063. Out of the three subdivisions by which the RGB values were calculated, the green value had a very close correlation to the measured soil moisture with a correlation coefficient of 0.955. This relationship is modeled in Figure 2. However, the red value receiving a correlation coefficient of 0.768 led to the aforementioned average RGB value of 0.865.

Discussion and Conclusions

The hypothesis that the multispectral UAV sensor would result in the most accurate soil moisture prediction was not supported by the data collected in this project. The multispectral sensor had a correlation coefficient of only 0.063 when compared to the measured soil moisture, implying that the TGI readings had nearly zero numerical connection to the soil moisture percentage. The thermal sensor provided similar results with a correlation coefficient of 0.097. The RGB camera, however, produced uniquely significant results with an average correlation coefficient of 0.865. Its green value had an especially significant result of 0.954, signifying a very heavy correlation between the green values detected by the drone and the moisture values that were manually collected.

The conclusion these results suggest is that RGB sensors are the ideal UAV sensor to be used when estimating soil moisture. As soil moisture is an increasingly significant factor in farming due to global warming and proliferating droughts, monitoring soil moisture becomes a priority for many farmers worldwide. Knowledge of preferred UAVs is a crucial factor in thousands of farmers' transition to precision agriculture. Drones and their affiliated sensors tend to be very expensive, selling for multiple thousands of dollars, so it is very important for farmers to know which type is best fit for their operation. The presented correlation is direct, clear, and efficient, three vital components necessary for a technological system to be implemented in the agricultural industry. While accessible, easy-to-understand UAV data exists for agricultural professionals, the lack of simple software they can use to assess their property and receive feedback regarding requested management practices presents an underdeveloped step in the implementation of precision farming.

This experiment's raw results were lengthy, confusing, and not ideal for a farmer to process on their own. As a continuation of its work, an assessment of how complex drone data can be condensed and simplified to suit the needs of agriculturalists would be a mindful and important step in improving the public's understanding of UAVs. In this future project, potential errors made can be reduced by using a fully mechanical, entirely consistent soil-moisture gathering system. The manual soil moisture readings were hand-taken using a high-level soil moisture sensor, yielding accurate but inconsistent results. Additionally, different UAV image processors capable of providing more relevant and structured results that directly compare separate variables with each other would likely be this project's program of choice.

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