DEVELOPMENT OF HARDWARE AND SOFTWARE ARCHITECTURE FOR ANALYSIS AND PROCESSING OF THE FIELD DATA

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ABSTRACT:

This article considers the problem of requiring the hardware and software implementation of complex calculations allowing automating the whole process of analysis and processing of the field data acquired using the sensors installed on UAV. The article reveals and substantiates the necessity of building a flexible architecture of the hardware-software complex. The hardware-software complex is focused on measuring humidity of the surface air layer above the soya field in order to control the irrigation quality. The measurements showed good correlation with the ground humidity factors. MCRI2 index was used to assess the state of vegetation in controlled areas. In the part of the field with high humidity, MCRI2 index was also higher. The results of aerial photo processing, as well as analysis and interpretation of aerial survey data can be further used to take measures to improve the microclimate of crops.

1. INTRODUCTION

There are three main methods of watering the agricultural plantations known in modern agrarian industry: furrow irrigation, large and fine sprinkling and drip irrigation (https://www.agrodialog.com.ua/soya-i-oroshenie.html). Each of these methods has its advantages and disadvantages. Furrows irrigation is simpler and the cost of implementation is minimal. One of the limitations of this method of irrigation is a complex topography. The disadvantages include: high water consumption, unevenness of humidification.

The uniformity of humidification and the quality of irrigation are monitored by agronomist. When watering through furrows, the depth and contours of soil wetting are monitored along the length of the strip at the beginning, middle and end. For this purpose, the borer used to take soil samples for determining its moisture and uniformity coefficient Kp, which at good irrigation should be equal to 0.85 ... 0.9. ("Cawater-info", http://www.cawater-info.net/bk/4-2-1-4-1-1.htm).

Requirement for the soil moisture monitoring has an urgent need on farms. Field soil moisture measurements by agricultural workers are important for irrigation quality control, but these measurements are mainly point measurements and subjective. Areal information on the crops condition can be identified through the use of remote sensing (Welikhe et al., 2017). Satellite-based remote sensing data have also been successfully applied to calculate the soil moisture reserves, total evaporation and other characteristics of water and heat conditions in the study area (E.L. Muzylev et al., 2017). Use of data from measurements of radiometers AVHRR/NOAA, MODIS/EOS Terra and Aqua, SEVIRI/Meteosat-9, -10, MSU-MR/"Meteor-M" №2 of scatterometer ASCAT/MetOp -A,-B provide estimates of soil surface moisture in the region and area of the study. The use of UAV in agriculture can be the main tool for precise agriculture.

Here we consider the possibilities and features of application of unmanned aerial vehicles for aerial photography, measurement of humidity, temperature and heat index with the help of the sensor in the open space, as well as development of hardware and software complex for remote data recording. The object of research is a 1x1.5 km2 irrigation field with soybean cultural plantation in vicinity of Almaty city (Republic of Kazakhstan).

Initially, the UAV was used to perform photogrammetric survey of the study area in the near infrared spectrum.

Analysis and interpretation of aerial survey data can be used for further measures to improve the microclimate of the crops. The work was carried out within the framework of the project "Development of hardware and software complex for remote sensing based on using the unmanned aerial vehicle", and Republican budget program "Applied scientific research in space activities". Planning and development of agricultural production requires consideration and analysis of both the conditions of agricultural crops and the measures used to increase the yield.

In practice, the results of field work are sets of parameters measurements: humidity, temperature and heat index in the open space, obtained with the help of special equipment, at the points of the studied area. Results of the study of the controlled area are carried out using UAV, and then the obtained information is transmitted to laboratory. Through mathematical calculations the analysis is carried out with conclusion on the state of vegetation in the controlled area.

Relevance of work. Today, researchers face the problem of the requirement to implement fast and accurate complex calculations that allow automating the entire process of analysis of field data from the moment they arrive at the laboratory to the fact of making a conclusion about the possibility of further research. The speed and accuracy of calculations determine such requirement to the system as its flexibility and availability of the possible rapid interaction between components, which puts the developer the task of designing a high-quality

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architectural hardware and software complex. From the above it follows that the problem of developing flexible architecture of hardware and software complex for calculating and processing field data is relevant today.

The purpose of the work is to develop and study software and hardware for the complex diagnostics of controlled territories using UAV.

A novelty of the work is the definition of the hardware-software complex architecture and proposed algorithms of processing remote diagnostics data coming from sensors installed on the UAV via communication channels.

One of the advanced directions in which multi-copters are used is the creation of electronic field maps, as well as NDVI vegetation index maps.

Using spectral sensors installed on multi-copters or unmanned aerial vehicles (UAV), it is possible to obtain information not only in the visible spectrum, but also in a qualitatively new type of humidity measurements. All data can be presented with precise coordinates and can be studied and analyzed in detail. UAV imaging is a technology that allows to record and control the state of agricultural land: it is to optimize water consumption, calculate the optimal amount of fertilizers and chemicals applied, create an electronic map of the fields, predict crop yields, planning the laying of drainage systems, etc. Using this technology, we can obtain photographs to analyze the condition of the crop, its thickness and uniformity, as well as the state of vegetation.

Application of UAV simplifies the collection of necessary information about the state of crops (Dolgirev et al., 2019). In contrast to spacecraft, UAVs, in our case multirotors are more mobile and provide details up to several centimeters, when it is possible to study each individual planting bush (Ainakulov et al., 2018).

Many agricultural lands are irrigated with ditches, which are used for watering at certain times. Uneven watering of the field of useful vegetation for human results in loss of yield. In order to create comfortable conditions for the plant in moisten soil and the surface air layer, there is a problem of determining the level of moisture, each square meter of field with its exact geographical coordinates, so that in the future to make adjustments to the watering system. To solve this problem, a technology was developed for remote measurement of the humidity of the surface air layer using the relevant hardware and software system.

In practice, the field was bypassed by agricultural workers to monitor the irrigation system and assess the soil condition. The human factor influences the subjectivity of assessment of soil moisture level, therefore, to automate the process of objective observation and fixing the quality of irrigation, the idea of using appropriate sensors on board the UAV, as well as the development of hardware and software complex for the study of the controlled area, has started-up. As a measuring device have chosen humidity sensors, which due to their compactness and low weight, meet the UAV flight characteristics.

The temperature and humidity sensors DHT11 and DTH22 include two useful indicators that affect the quality of the measuring instruments - thermometer and hygrometer (Figure 1):

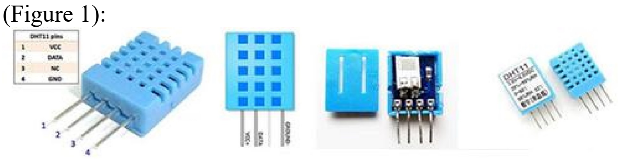


Figure 1. DTH11 sensor in plastic housing

Inside the DHTxx sensors there is a chip that performs analogue-to-digital conversions and divides the digital signal into an analogue one, as temperature and humidity data. This data is very easily read by the microcontroller chip. This microcontroller is designed to control electronic devices, in our case it is a microcontroller based on Arduino UNO, ATmega328.

When connecting to ATmega328 microcontroller based on the Arduino UNO board (Figure 2), a pull-up resistor of 10 kOhm rate should be placed between VDD and Data outputs. The Arduino board has a built-in pull-up, however, they have very low capacity, about 100kOhm.

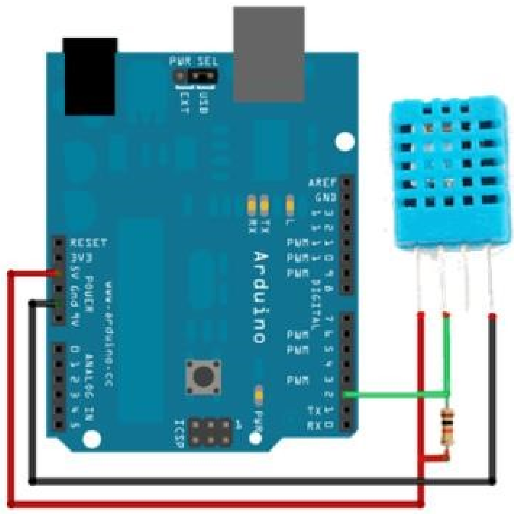


Figure 2. Connecting DHT22 sensor to Arduino

Figure 3 shows the DHT22 sensor connection chip to Arduino Uno board, made by FLProg software, which allows to get the software code automatically.

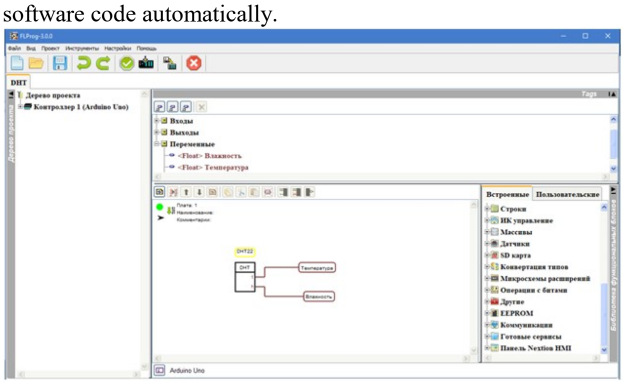


Figure 3. Electric circuit and visual programming DHT22 to Arduino Uno board

In order to obtain correct measurements of the environment physical properties, consideration was given to the fact that the air flows produced by rotors can very much distort the measurements of sensors. Location of sensors on multi-rotors is one of the most difficult solutions. The work (Roldán et al., 2015) described the modelling of aerodynamics of the air flows from quadrocopter in order to determine the optimal place to install the measuring equipment (Figure 4, 5).

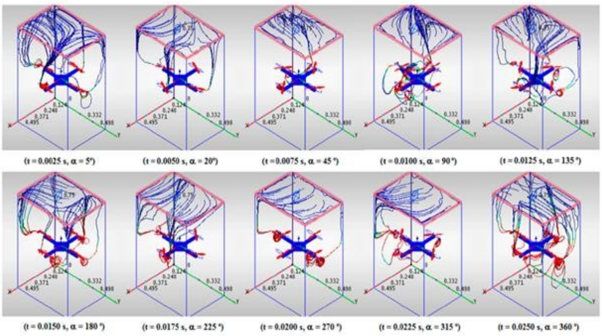


Figure 4. Air streams above quadrocopter

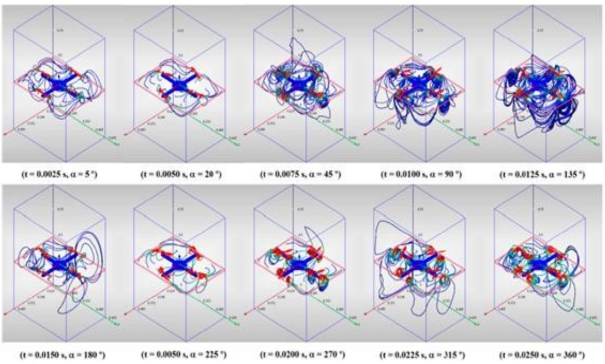


Figure 5. Air streams under quadrocopter

As a result of modelling and testing of quadrocopter in the greenhouse, the optimal location of sensors and the upper center of quadrocopter were determined (Figure 6).

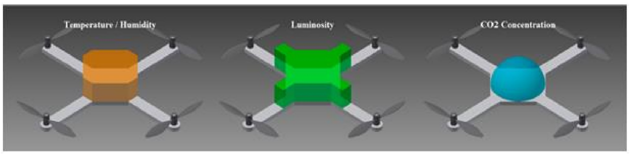


Figure 6. Optimum sensor arrangement

Analysis of researches was conducted by foreign authors devoted to the problem of determining the microclimate of particular type of vegetation of agricultural purpose (Roldán et al., 2015) (Figure 7), as well as the characteristics affecting the productivity of agricultural crops. Most of the researches was carried out inside the greenhouses.

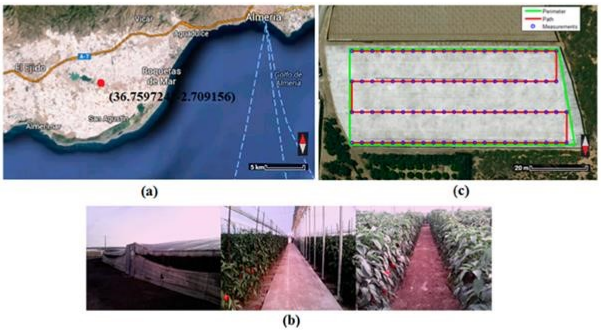


Figure 7. Experimental greenhouse

2. HARDWARE AND SOFTWARE SCHEME FOR MEASUREMENTS IN INFRARED SPECTRAL RANGE

In order to obtain data in the infrared (IR) spectral range and minimize costs, the optimal UAV package has been developed to perform remote measurements using DHT11 humidity sensor mounted on a multi-rotor. The use of such sensors is relevant, as the physiological state of vegetation depends on the level of humidity of the ground layer, and the lower air layer.

Coordination and automation of remote data recording from the humidity sensor and GPS receiver was performed on five different points of the surveyed soybean field area. An electronic scheme for remote hardware humidity measurement at an altitude of one meter using the multi-rotor was developed and created. Data were taken from the sensors using the Arduino software and recorded on a microSD in text format. Data from the humidity sensor were transmitted to laboratory for the further processing using the Arduino software.

3. METHODS OF AERIAL SURVEY DATA PROCESSING AND EXTERNAL ORIENTATION

The use of UAV for the needs of agricultural producers is a necessity in increasing their work efficiency, saving energy and water. Information about the field condition allows to use optimal methods of irrigation process control as well as to reduce operating costs due to correct water distribution.

The aircraft is equipped with a sensor to obtain quantitative estimates of the humidity in monitored area. The acquisition of area humidity characteristics of the field is carried out by remote measurements based on sensors and microcontrollers, using available software, but does not always lead to the desired results in data processing. Data becomes especially important when synchronization of the measuring instruments is carried out, when several operations must be started simultaneously on several devices. For example, the ratio of biomass to the amount of moisture consumed is important and, with known exact geographical coordinates of each unit of the growing crop, action can be taken on them as point by point.

UAV with a sensor mounted on it to take pictures and record humidity factors of the surface air layer in the open space. The object of the study was an irrigation field with soybean culture (Figure 9). In order to trust the UAV's instruments and record the properties of the environment, the measurement technology was used, with the help of which ground-based and remote measurements were made simultaneously.

The first photogrammetric survey of the field was made by camera, in the infrared spectral area. An upgraded SONY NEX 5N camera (Geoscan, https://www.geoscan.aero/ru/about/), with matrix and remote color filter film (Instructables, https://www.instructables.com/id/Night-Vision-Camera-1/#intro/) was used to make the aerial photographs. The remote measurement of soil humidity reflects the electromagnetic radiation of the soil surface. The near infrared spectrum of radiation is absorbed by water molecules in the soil surface layer and in the air layer one meter above the ground surface, where the reflected radiation shows the value of surface humidity.

Survey was carried out with a built-in humidity sensor mounted on UAV, in five points located on the envelope system.

Measurements were taken at the ground surface and one meter from the surface for 2 minutes at each point (Figure 9). During measurements at points «1», «2», «4», «5» a little rain drizzled, at the control level «3» a column was flowing, and part of the field was illuminated by the sun, the second part was in the shadow of the cloud, the wind was west to 3 m/s.

Coordination and automation of remote data recording of the humidity sensor and GPS receiver was carried out at five separated ground control points, which also served as control points for the data array obtained from the survey in the infrared range of the field area spectrum.

Measurement data from humidity sensor was recorded every 2 seconds. For the clear experiment, the readings from the sensors at each measurement point were made every 2 seconds during minutes, then these data were processed in the processing office (table 1).

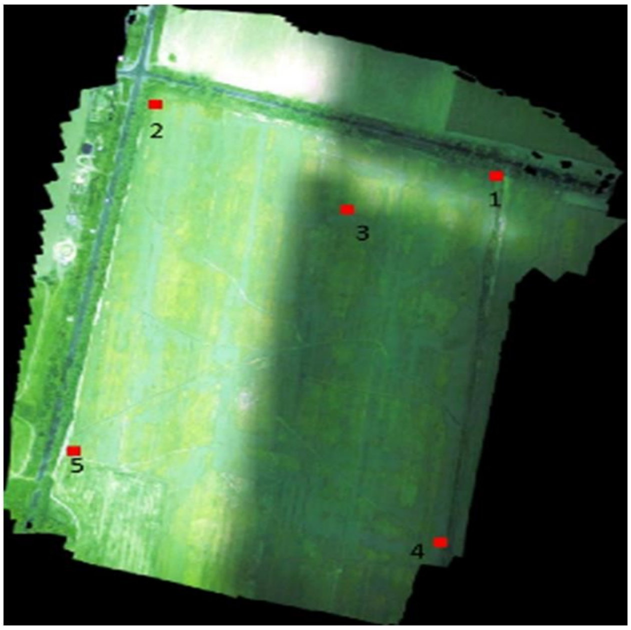


Figure 8. Irrigated soybean field (1x1.5 km^2) with ground measurement points

To determine how the humidity of the surface air layer changes at height of 1 meter, the regression analysis of the data with the obtained data on the ground was carried out (Tables 2-4). The measured humidity data were averaged on the basis of the number of records within 2-minute time period (60 indicators). Determination coefficient is equal to 0.83, which indicates that the data obtained are consistent.

Station	Mean value					
	Temperature on Earth and at H=1m in C		Humidity on Earth and at H=1m in %		Heat Index on Earth and at H=1m	
1	22.38	22.81	44.47	33.83	21.83	22.03
2	21.57	21.33	52.37	45.35	21.15	20.71
3	23.69	23.00	33.50	28.41	22.99	22.10
4	22.48	22.86	52.92	37.18	22.17	22.17
5	22.73	22.40	31.44	26.15	21.88	21.38

Table 1. Measurement data averaged by humidity sensor DHT11

Regression statistics	
R multiple	0.91
R-square	0.83
Rated R-square	0.77
Standard error	3.62
Observations	5

Table 2. Regression statistics

Dispersion analysis	df	SS	MS	F	F value
Regression	1	192.298	192.298	14.654	0.0314
Remainder	3	39.366	13.122		
Total	4	231.665			

Table 3. Dispersion analysis of humidity sensor measurements on Earth and at 1m height

	Co-effi-ci-ents	Stan-Dard error	t-sta-tis-tics	P-va-lue	Lo-wer 95%	Up-per 95%	Lo-wer 95.0 %	Up-per 95.0 %
Y-in-ter-sec-ti-on	4.856	7.83	0.62	0.579	-20.064	29.776	-20.064	29.776
X I va-ri-ab-le	0.682	0.178	3.828	0.031	0.115	1.25	0.115	1.251
Y = 4.8 +0.682 X								

Table 4. Regressional relationship

The regression dependence Y = 4.8 +0.682*X indicates that the greater the value of X, the greater the Y, i.e. there is a direct correlation between them. In addition to the humidity data, the ambient temperature and heat index are read by the sensor. Foreca.com data from the meteorological station in the nearest settlement were used to compare the obtained readings for ambient temperature on the date of survey (Table 5). Both daily and hourly data were obtained for correct comparison with the aerial survey time. The figures were matching and correspond to 22° C.

Land stations	1	2	3	4	5
Survey time	29.08.2018 14:00-14:10	29.08.2018 13:45-13:55	29.08.2018 13:00-13:10	29.08.2018 14:30-14:40	29.08.2018 13:20-13:30
Tempe-rature, °C	Actual 22 °C; air humi-dity 38%; pressure 691	Actual 22 °C; air humi-dity 38%; pressure 691	Actual 22 °C; air humi-dity 38%; pressure 691	Actual 22 °C; air humi-dity 38%; pressure 691	Actual 22 °C; air humi-dity 38%; pressure 691

	mmHg; raining	mmHg; raining	mmHg;	mmHg; raining	mmHg; light rain
Wind	West, 3 m/s	West, 3 m/s	West, 3 m/s	West, 3 m/s	West, 3 m/s

Table 5. Weather in Almalybak on 29.08.2018, data registered at Almaty station

A joint data analysis of IR survey and sensor readings was made. The measurements at points «2» and «5» in the sunlight part of the field show relatively high values of the reflected IR signal (in Table 6 these points are highlighted in blue). At that, the higher the humidity value, the higher the value of reflected IR signal (near infrared wavelength range). In the shadow part of the field the intensity of IR radiation is lower, about twice as much. This is due to the fact that part of the field was in shadow of the clouds. Clouds are known to partially absorb the solar radiation.

Station	Humidity	IR channel
RU1	33,83	80
LU2	45.35	213
M3	28,41	86
RL4	37,18	88
LL5	26,15	190

Table 6. Parameters of the surface air layer based on remote measurement with an IR camera and humidity sensor

Obtained data in IR spectrum range, have high spatial resolution of 5 cm, according to the results of the processed images can conclude that soybean growth has some unevenness, and also there is a certain dependence of soybean growth condition from humidity of the surface air layer (Figure 12). Additional control parameter of vegetation state was calculation of MCARI2 index (improved modified chlorophyll absorbshen ratio index) under orthophoto plan of aerial survey in near infrared zone. (Razakova et al., 2019) If high photosynthetic activity is associated with a large phytomass of vegetation, the areas with large values of MCARI2 index correspond to the part of the field with high humidity values of the surface air layer.

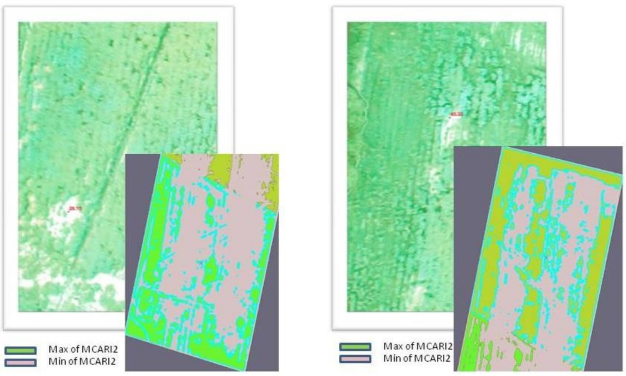
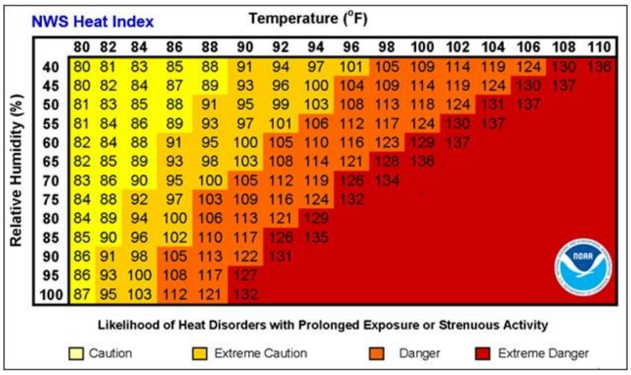


Figure 9. Fragments of images obtained from the aerial survey at humidity of the surface air layer A-26,14; B-46,33.

Areas of field B-46.33 with relatively high humidity values have a higher MCARI2 index (Figure 9) and the leaves have a richer green colour.

Sensor installed on UAV records another indicator, the so-called heat index. The Heat Index is a measure of how much it really feels when relative humidity depends from the actual air temperature (National Weather Service, https://www.weather.gov/safety/heat-index/).



NWS Heat Index — Temperature (°F) / Relative Humidity (%)

RH (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution / Extreme Caution / Danger / Extreme Danger

Figure 10. Heat index, (°C = (°F – 32) /1,8)

The table above (Figure 10) is taken from the National Weather Service (USA) server. Outdoors, as relative humidity increases, the first smoke appears and eventually a thicker cloud cover, reducing the amount of direct sunlight reaching the earth's surface.

4. CONCLUSION

As of data taken both in the infrared range of electromagnetic radiation and with the help of humidity sensor it is possible to quickly monitor the humidity level of the surface air layer, as well as assess the condition of crops. Complete coverage, precise geographic location and objective field climate indicators provide the information basis for crop irrigation decisions. Agricultural producers can make the reasoned decisions for uniform irrigation.

The growth rate (biomass increase) of the crop is directly proportional to soil moisture. Use of the obtained thermophysical parameters of the lower surface air layer with the help of UAV gives the following possibilities: uniform distribution of the crop watering; increase of potential yield; reducing of production costs. The technology of obtaining conditioned data on humidity with minimum expenses on the basis of the developed architecture of hardware and software complex is offered.

Thus, the hardware and software complex developed by us allows automating the whole process of analysis, processing and interpretation of field data taken with the help of sensors installed on UAV.

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