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Advances in Measurement of Vegetation Vitality applied for Nature Management

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The possibility of drones' (or unmanned aerial vehicles, UAV) application in crops vegetation aerial control is considered. The corresponding to this task Technical Vision System (TVS) based on dynamic triangulation laser scanning is presented. Application of this TVS for vegetation vitality index detection is explained. Basing on the detected intensity of crops color converted into the specific parameters of the proportional electric signal in TVS' s optoelectronic channel we can derive some practical conclusions useful for further agricultural processing. The computational results examples of such conversion are given in text. The filtration of external noise on the results of this method is assumed, the necessary additional mathematical processing are considered for the Boundary Element Method (BEM), the Monte Carlo Method (MC) and the Finite Difference Method (FDM) are noted; it is observed that BEM offers more precise results. It is shown that precise spatial positioning of the scanning laser beam is of paramount importance for proper system functioning at whole. Several research methods of closed-loop control theory, such as the Pos-algorithm using float or integer data types, PWM signal, etc., for improvement of DC motor's shaft positioning of the Maxon RE-max29 DC motor with incremental encoder with the aim of 3d laser scanning accuracy are introduced.

Keywords*: crops aerial control, unmanned aerial vehicle, vegetation vitality index, laser scanning, dynamic triangulation, electric drive positioning, offset uncertainty*

Introduction

Nowadays almost all areas of nature and industrial management are strongly related with intensive automation. It is broadly recognized that automatic devices transcends the human operators in most of their functions: it faster, more precise, superior in endurance, stronger, transmit more force, has more memory capacity, the access to stored information implies a lower probability of error, so on. The agriculture is one of the strongest branches of society economic activity, so the level of its automation becomes one of the most indicative parameter of progress and economic stability. That was a reason why researchers and industrial companies pay so much attention to implementation of robots and automatic systems into agriculture. There are known many examples of robots use for different agricultural tasks, such as [1, 2]: fruit picking robots, driverless tractor/sprayer, sheep shearing robots to replace human labor; and robots used to automate manual tasks, such as weed or bracken spraying, where the use of manned vehicles is too dangerous for the operators. Recently not only terrestrial robots are in agricultural use, but also the unmanned aerial vehicles (UAV, or drones) or even their groups/swarms [3, 7]. Such kind of automation is useful for many attendant tasks which never were available formerly. We can mention the aerial control of crops geometry, the intensity of irrigation and the degree of plants hydration, etc.

For successful processing of such kinds of tasks it is obviously that UAV must be equipped with appropriate multifunctional Technical Vision System (TVS). One of the TVS [7, 8, 14] prototype is presented on the Fig. 1. This system represents a laser scanning system for 3D-coordinates measurement, based on the principle of dynamic triangulation [5]. Some previous experimentations with earlier versions of scanner prototypes [4, 7] shows us the interesting additional property. The projected laser beam after its reflection from the scanned surface produces the electric signal significantly different depending on the intensity of surface‘s color (see Fig. 2).

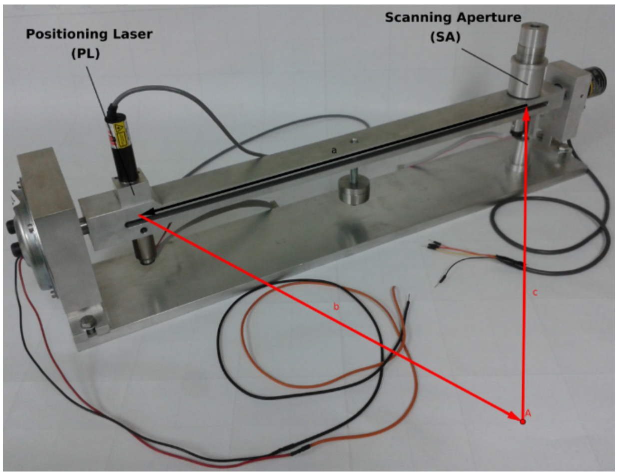
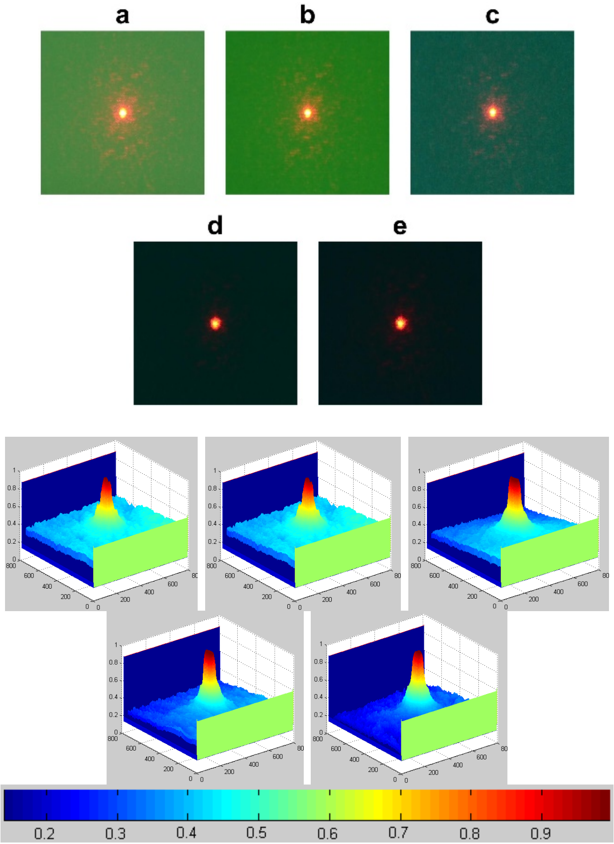


Figure 1. Technical Vision System



Relative scale of Reflectance of laser intensity on different pigmentation color.

Figure 2. Reflected Laser Beam on Surface

Such a property can be simple and efficient instrument for selective remote inspection of degree of crops plants hydration. The hydratation rate of plants normally can be estimated [7] by intencity of pigmentation (green color intencity). Firstly, this parameter should be converted into electrical signal with incorporated properties under measurement, and then must be implemented the apropriate signal processing method with the aim to extract this incorporated information, the color intencity in our case. Due to high predisposition of this method to external noise, it is necessary to implement additional mathematical processing to extract desired information. We previously [4] did consider the Boundary Element Method (BEM) as a good method to determinate the reflectance of the different color surfaces (as example, the plant leafs). Precision of the method was compared with the Monte Carlo Method (MC) and the Finite Difference Method (FDM) in [4]; and it is observed that BEM offers more precise results. Obviously, for good resolution of mobile laser scanning system mounted on drone in this practical application it is necessary to provide additional measures for more firm and exact positioning of the scanning laser ray on the desired point. Such a point in this application can be considered each individual plant leaf, or even its special zone. Of course, this problem is not a trivial challenge, especially taking to account the remote character of this scanning, and possible significant value of striking distance, as well as the dynamical character of this kind of 3D measurement. The general configuration of such aerial system is presented on Fig. 3.

Figure 3. Drone X8+ using
the Technical Vision System

Flying above the crops, such drone can reach in an easiest and fastest way the any area of plants at any height, count them and scan its surface from the side regularly not observable from the ground. This information can be operatively transmitted to the center of information analysis, and can form the detailed systematized informational dataset about the crop at whole.

The mathematical framework of vegetation vitality index (VVI) detection, as well as TVS mounting on UAV and system functioning at all was already considered in [7].

Consequently, the main goal of the present paper is the herein described research of the additional possibilities to increase the accuracy of laser ray positioning by means of special control of DC motor in laser positioner driver (LP on Fig. 4), in order to get the possibility to position the scanning laser ray on the particular area of plant, for example its leaf, taking to account the dynamic character of the working process. As the part of this research were additionally considered the combined influence of several physical parameters on the goal availability. Such influence was physically simulated at laboratory.

Static vs. Dynamic Triangulation

The use of the triangulation method in laser scanning systems can be kind of Static or Dynamic [5]. The static triangulation refers to the mode in which neither the positioning laser (PL) nor the scanning aperture (SA) are moved. More detailed information about the technical functionality of the PL and SA can be found in [6]. In order to extend the measuring range of the laser scanner, the dynamic triangulation was developed, which is shown in Figure 4.

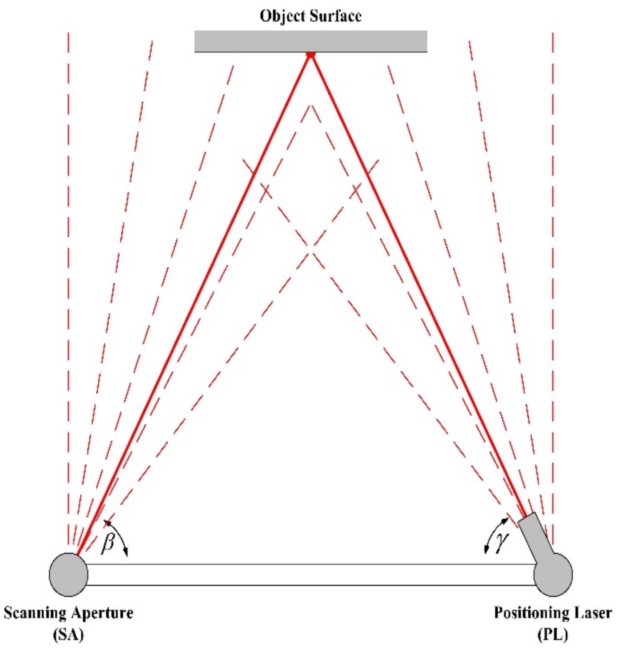


Figure 4. Dynamic Triangulation

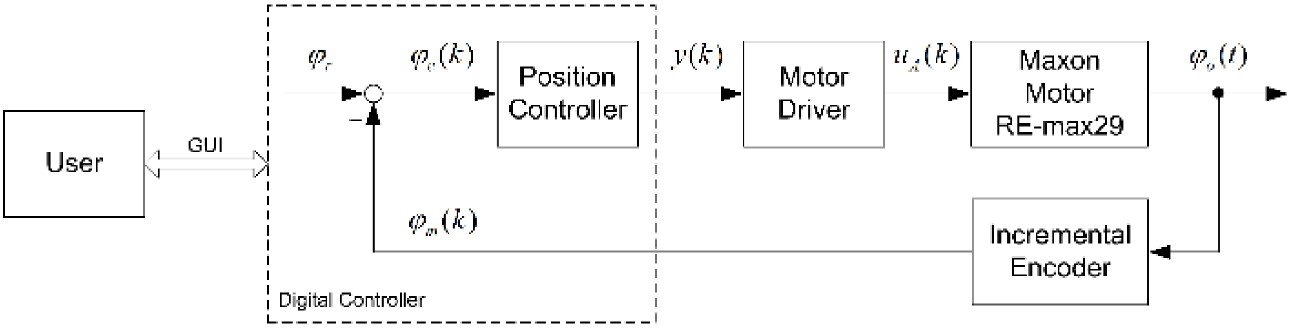


Figure 5. Closed-loop position control

Dynamic triangulation uses a variable PL angle (γ) and a variable SA angle (β) to define the measurement range regardless of the receiver image sensor size. Actually, such laser scanning principle was designed exactly for purpose to obtain a wider field-of-view on the compact rotatory device. The positioning laser (PL on Fig. 4) system directs the laser beam under the angle γ to the observed object, the laser beam is reflected on the object surface by mixed specular-diffuse reflection model, and received by the scanning aperture (SA) under the angle β. Using equation

$$d = a \cdot \frac{\sin\beta \cdot \sin\gamma}{\sin(\beta+\gamma)} \qquad (1)$$

and

$$q = \frac{d}{\tan\gamma} = a \cdot \frac{\sin\beta \cdot \cos\gamma}{\sin(\beta+\gamma)} \qquad (2)$$

The two-dimensional coordinates of a reflected laser spot on the surface of the measurement object are determined.

Proposed Positioning Algorithm

In order to practically realize the proposed position control, the Maxon RE-max29 DC motor with incremental encoder is configured in closed-loop, as shown in Figure 5. Using the digital controller and the incremental encoder, all variables of the control-loop are discretized in time and quantized in amplitude. The absolute angular error φ_e is calculated by the difference between the reference angular position φ_r and the measured angular position φ_m and afterwards converted to the relative angular error φ_e' using following relation [7]:

$$\varphi_e' = 100 \cdot \frac{\varphi_r - \varphi_m}{\varphi_r} \qquad (3)$$

The controller output variable y_{φ_r} is calculated, using an amplification factor K_P [7]:

$$y_{\varphi_r} = K_P \cdot 100 \cdot \frac{\varphi_r - \varphi_m}{\varphi_r} \qquad (4)$$

To improve the step response of the controlled DC motor, the absolute angular error φ_e is related to the maximum positioning angle of $360°$. Thus defines the controller output variable y_{360} [7]:

$$y_{360} = K_P \cdot 100 \cdot \frac{\varphi_r - \varphi_m}{360°} \qquad (5)$$

As the initial measured angular position $\varphi_m(0) = 0°$, the initial values are calculated for both controller output variables [7]:

$$y_{\varphi_r}(0) = 100K_P \qquad (6)$$

$$y_{360}(0) = \frac{100}{360°} \cdot K_P\varphi_r \qquad (7)$$

Equation (6) and (7) shows, that the initial controller output variable $y_{\varphi_r}(0)$ not depend and that the initial controller output variable $y_{360}(0)$ depend on the reference angular position φ_r. Thereby, for $K_P \geq 1$, the initial controller output variable $y_{\varphi_r}(0) = 100\%$, regardless of the reference angular position φ_r. The initial controller output variable $y_{360}(0)$ instead will be higher, the greater is the reference angular position φ_r or the amplification factor K_P. These prevent unstable oscillatory step responses, when the initial absolute error is too small [7].

Experimentation Realization and Results

Experiments were performed to control the motor shaft angle of the Maxon Motor RE-max29, the setup is shown in Figure 6.

Table 1 presents defined experimental parameters, constants and measured values. Six experimental factors (Table 2) and 15 arrangements of these factors (Table 3) were defined. By varying the parameters K_P and φ_r from Table 1, 5 measurements were taken to calculate the relative angle error average $\bar{\varphi}_e'$ for every arrangement (called Test), which are summarized in Table 4. For every test, it was chosen two different amplification factors K_P of the used controller output variable (4) and (5) and three different reference angular positions φ_r of 1°, 5° and 90° [7].

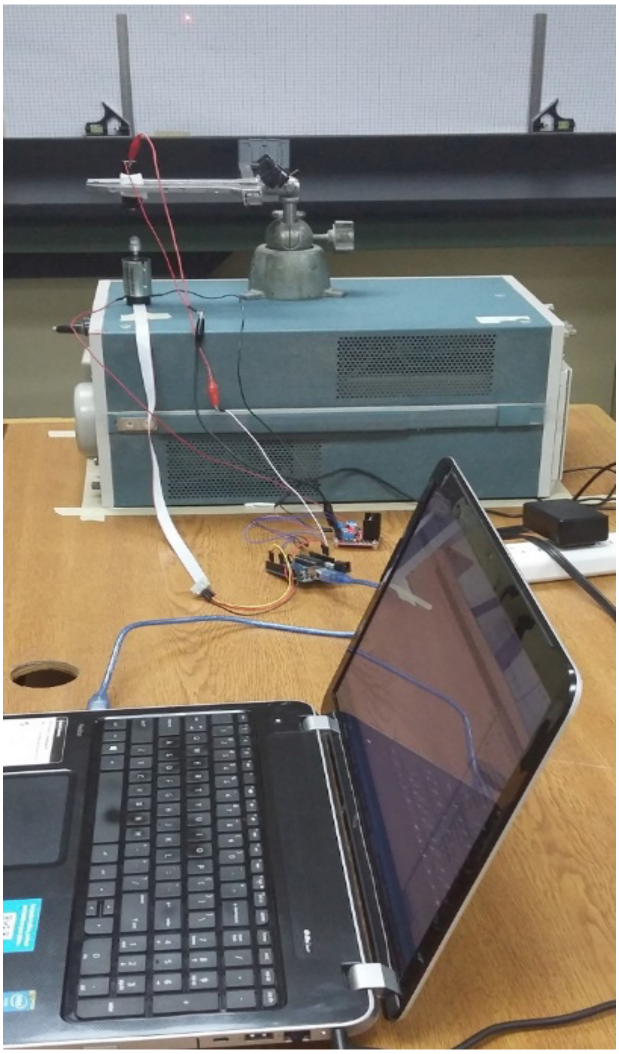


Figure 6. Experimental setup

Table 1. Experimental parameters, constants and measured values

Symbol	Description	Unit / Value
φ_r	Reference angular position	°
K_P	Amplification factor of Pos-algorithm	-
ppr	Pulses per revolution of encoder	4000
f_{PWM}	Frequency of PWM signal	980Hz 1000Hz
K_{ref}	Reference value for Pos-algorithm calculation	φ_r 360°
φ_m	Measured angular position	°
φ_e'	Relative angular error	%
$\bar{\varphi}_e'$	Relative angular error average	%

Table 2. Experimental parameters, constants and measured values

Factor	Name	Description	1	2	3
A	-	Pos-algorithm data type	Float	Integer	-
B	-	Timer1 Mode of Operation	CTC	Fast PWM	-
C	f_P	Execution frequency of Pos-algorithm	100Hz	200Hz	500 Hz
D	K_{ref}	Reference value for Pos-algorithm calculation	φ_r	360°	-
E	digit	Resolution of Integer Pos-algorithm	-	3 digits	-
F	K_{PWM}	Resolution of PWM signal	255	16000	-

Table 3: Arrangements of experimental factors

Test	A	B	C	D	E	F
1	1	1	1	1	1	1
2	1	1	2	1	1	1
3	1	1	1	2	1	1
4	1	1	2	2	1	1
5	2	1	1	1	1	1
6	2	1	2	1	1	1
7	2	1	1	2	1	1
8	2	1	2	2	1	1
9	2	1	1	1	2	1
10	2	1	2	1	2	1
11	2	1	1	2	2	1
12	2	1	2	2	2	1
13	2	2	1	2	2	2
14	2	2	2	2	2	2
15	2	2	3	2	2	2

Table 4: Relative angular error average for 15 tests [%]

K_P	φ_r	3	4	7	8	11	12	13	14	15
1	1°	94.60	100.0	100.0	100.0	-	-	-	-	-
	5°	4.76	100.0	100.0	100.0	-	-	-	-	-
	90°	0.68	10.10	8.78	9.54	-	-	-	-	-
10	1°	96.40	100.0	91.00	85.60	-	-	-	-	-
	5°	7.36	5.64	9.84	7.44	-	-	-	-	-
	90°	0.56	0.94	0.56	0.68	-	-	-	-	-
100	1°	-	-	-	-	100.0	100.0	100.0	100.0	100.0
	5°	-	-	-	-	13.40	5.88	11.60	5.64	12.88
	90°	-	-	-	-	1.22	0.62	0.74	0.14	1.62
200	1°	-	-	-	-	-	-	100.0	100.0	100.0
	5°	-	-	-	-	-	-	12.00	17.20	4.76
	90°	-	-	-	-	-	-	0.66	0.52	0.28
250	1°	-	-	-	-	56.80	55.00	-	-	-
	5°	-	-	-	-	9.12	10.96	-	-	-
	90°	-	-	-	-	0.40	0.64	-	-	-
500	1°	-	-	-	-	-	-	-	-	11.60
	5°	-	-	-	-	-	-	-	-	4.16
	90°	-	-	-	-	-	-	-	-	0.22

Experimentation Analysis

Table 4 contains the relative angular error averages $\bar{\varphi}_e'$ of all successful tests. Tests with an unstable step response of the DC motor resulted in invalid test results, which were eliminated from this table. It must be noted, that these tests used equation (4), which results in an initial controller output $y_{\varphi_r}(0) = 100\%$, regardless of the reference angular position φ_r. However, the acceleration of the DC motor shaft should be reduced, the smaller is the absolute angular error φ_e, which results in equation (5) [7]. Thus, the initial controller output variable $y_{360}(0)$ depends on the reference angular φ_r, resulting a stable step response of the DC motor, which are represented by the successful executed tests [11].

Test 3, 4 contain the Pos-algorithm using the float data type and Test 7, 8 and 11 – 15 the Pos-algorithm using the integer data type. Since in Test 3, 4 and 7, 8 the experimental factor $D = 2$ and the reference angular position $\varphi_r < 360°$, an amplification factor of Pos-algorithm $K_P > 1$ was chosen. Test 3, 7 use the same execution frequency of $f_P = 100Hz$, like Test 4, 8 use the same execution frequency of $f_P = 200Hz$. Between Test 3 and 7 and Test 4 and 8, the relative angular error average $\bar{\varphi}'_e$ remains approximately the same, which confirms the functionality and equality of the Pos-algorithm using float or integer data types [7].

A significant improvement can be noted, when using the PWM signal with high resolution $F = 2$, a high execution frequency of Pos-algorithm $f_P = 500Hz$ $(C = 3)$ and a high amplification factor $K_P = 500$, used for Test 15 [7].

Conclusions

The paper presents a new application for a Technical Vision System (TVS) used in combination with a drone for measuring the vegetation vitality of plants and crops. The emphasis of present paper is the accurate positioning of the laser beam in the TVS field of view by using a closed-loop control algorithm to reduce the laser beam positioning error after control. Experimentation was performed using different experimental factors and different arrangements of these factors, to analyze the influence of every factor.

A first improvement of the DC motor step response was achieved using equation (5) instead of (4). Thereby, the initial controller output variable $y_{360}(0)$ is reduced the smaller is this absolute angular error. This leads to a stable DC motor step response and successful executed tests.

Furthermore, the functionality and equality of the Pos-algorithm using float or integer data types was confirmed. For this purpose, two equal Pos-algorithm using two experimental factor arrangements were applied: one using floating-point data types (Test 3, 4 in Table 4) and one using fixed-point data type (Test 7, 8 in Table 4). Comparing Test 3 with 7 and Test 4 with 8, it can be seen, that the relative angular error average $\bar{\varphi}'_e$ remains the same.

A significant improvement of the DC motor step response was achieved by using a high PWM duty-cycle resolution and a high execution frequency of the Pos-algorithm, which must be both as high as possible, to realize a quasi-continuous control. Thereby, the best experimental results are given by Test 15 in Table 4 for a amplification factor of $K_P = 500$ [7].

This promising laboratory result encourages us for in situ field testing. It mean that achieved positioning accuracy can lead in practice to the adequate laser ray positioning on crops, and further work on enhancement of UAV operating range in considered practical application.

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Аннотація

Досягнуті результати в оцінці рослинності для управління природними ресурсами

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Розглянуто можливість застосування дронів (або безпілотних літальних апаратів, БЛА) в повітряному контролі вегетаційних показників сільськогосподарських культур. Відповідно до цієї задачі представлена система технічного зору (СТЗ) на базі динамічного триангуляційного лазерного сканування. Пояснюється застосування цього СТЗ для визначення індексу життєвої сили рослинності. Виходячи з виявленої інтенсивності кольору сільськогосподарських культур, перетвореного в конкретні параметри пропорційного електричного сигналу в оптоелектронному каналі СТЗ, ми можемо отримати ряд практичних висновків, корисних для подальшої обробки сільськогосподарської продукції. Результати обчислювальних результатів такого перетворення наведені в тексті. Передбачається фільтрація зовнішнього шуму результатів цього методу, розглянута необхідна додаткова математична обробка методом граничних елементів (BEM), методом Монте-Карло (MC) та Методом кінцевої різниці (FDM); що BEM пропонує більш точні результати. Показано, що точне просторове позиціонування скануючого лазерного променя має першочергове значення для правильної роботи системи в цілому. Наведено кілька дослідницьких методів теорії управління у замкнутому контурі, такі як Pos-алгоритм з використанням плаваючих або цілих типів даних, сигналу ШІМ тощо, для поліпшення позиціонування валу двигуна постійного струму Maxon RE-max29 з додатковим кодером, з ціллю підвищення точності 3-мірного лазерного сканування.

Ключові слова: *повітряний контроль сільськогосподарських культур, безпілотний літальний апарат, індекс життєздатності рослинності, лазерне сканування, динамічна тріангуляція, позиціонування електроприводу, відносна невизначеність*

Аннотация

Достигнутые результаты в оценке растительности для управления природными ресурсами

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Рассмотрена возможность применения дронов (или беспилотных летательных аппаратов, БПЛА) в воздушном контроле вегетационных показателей сельскохозяйственных культур. Согласно этой задачи представлена система технического зрения (СТЗ) на базе динамического триангуляционного лазерного сканирования. Объясняется применения этого СТЗ для определения индекса жизненной силы растительности. Исходя из выявленной интенсивности цвета сельскохозяйственных культур,

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преобразованного в конкретные параметры пропорционального электрического сигнала в оптоэлектронном канале СТС, мы можем получить ряд практических выводов, полезных для дальнейшей обработки сельскохозяйственной продукции. Результаты вычислительных результатов такого преобразования приведены в тексте. Предполагается фильтрация внешнего шума результатов этого метода, рассмотрена необходима дополнительная математическая обработка методом граничных элементов (BEM), методом Монте-Карло (MC) и методом конечных разностей (FDM) что BEM предлагает более точные результаты. Показано, что точное пространственное позиционирование сканирующего лазерного луча имеет первостепенное значение для правильной работы системы в целом. Приведено несколько исследовательских методов теории управления в замкнутом контуре, такие как Pos-алгоритм с использованием плавающих или целых типов данных, сигнала ШИМ и т.д., для улучшения позиционирования вала двигателя постоянного тока Maxon RE-max29 с дополнительным кодером, с целью повышения точности 3-мерного лазерного сканирования.

Ключевые слова: *воздушный контроль сельскохозяйственных культур, беспилотный летательный аппарат, индекс жизнеспособности растительности, лазерное сканирование, динамическая триангуляция, позиционирование электропривода, относительная погрешность.*

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