CHAPTER 15

AUTOMATIC MEASUREMENT OF THE MORPHOLOGICAL CHARACTERISTICS OF HONEYBEES WITH A COMPUTATIONAL PROGRAM

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Abstract

The use of Big data related to the breeding of honey bees, when administered and processed effectively, will encourage the development of knowledge-based beekeeping, create new markets and business opportunities and further encourage the development of this industry. There have been attempts to fully automate the process of measuring the morphological characteristics of bees (at this stage there are conversions for Measuring wings), but this process for other parts are still completed manually. A survey was made of the possibilities to automate the process of measuring the morphological characteristics in honeybees and the proposed algorithm and program to implement it. Color characteristics of parts of the bee body - tergite and proboscis, through which they can be separated from the background of the image, are analyzed and measured.Distances are determined between the values of the colour components of the object and background. From statistical analysis, it is found that S and V colour components of the HSV colour model are appropriate for the separation of an object from the background . Algorithms and a program in Matlab environment for separating tergite and proboscis from the background of the image and definition of their main sizes are developed. From the analysis of the results, it is found that the major influence on the accuracy of the measurement is of the bee in the image..

Keywords: Honey bee, Morphometric characteristics, Colour components, Measurement algorithm

Introduction

1. Methods for the automatic measurement of morphological characteristics of honeybees

Big data plays a major role in the development of methods and techniques for the proper breeding of honey bees. Bees are of economic importance, not only for their honey and bee products but also from the point of view of the farm, through the pollination of different crops.

Therefore, the promotion of efficient breeding of honey bees, reducing the cost of rearing, reducing the problems associated with them requires the collection, processing, and analysis of large amounts of data.

The use of Big data related to the breeding of honey bees, when administered and processed effectively, will encourage the development of knowledge-based beekeeping, create new markets and business opportunities and further encourage the development of this industry. It is imperative that they make full use of its unique advantages in promoting the development of science and technology through the methods of obtaining, processing and analyzing big data.

Honeybees are spread across Africa, Europe and parts of Asia. They have a wide variety of species and subspecies, which can be identified by morphological characteristics. These characteristics vary depending on the environmental conditions to which they are adapted and live (Snodgrass, 2010; Abou-Shaara et al., 2012; Abou-Shaara et al., 2013).

In recent years, morphometric analysis as a tool for characterizing honey bees has become essential in the search for solutions to the problem of mortality in bees and the collapse of their colonies.

In traditional beekeeping, more and more modern methods of measurement and management are being implemented through various automated and intelligent systems in order to optimize the processes of bee breeding and solve modern problems such as honey bee mortality.

At the current level of development of science and technology, different sensors are used in bee breeding to measure temperature and humidity - video sensors and strain gauges. Different methods are used to communicate these measurements and control the instruments. The usefulness of the application of these systems in beekeeping is related to the food consumed, the survival of the colony in winter, and the production of nectar. Also, measuring and control systems are suitable for precise management of the microclimate in the hives, which greatly improves the conditions for the existence of bees.

The listed problems, methods and technical tools for solving them are related to the collection, processing, analysis, and transmission of large amounts of data via communication lines. These machine learning and artificial intelligence tasks are connected with large amounts of data to be used effectively.

The separation between subtypes is important for the cultivation and preservation of biodiversity (Abou-Shaara, 2013; Abou-Shaara et al., 2013).

The morphological characteristics are associated with the productive characteristics of the bee colony (El-Aw et al., 2012). The morphological characteristics of the bees can be measured by a variety of methods. Basically, these indicators are used to determine the individual characteristics and subtypes, as well as for determining the hybridization with other subtypes.

The measurements are used to determine the influence of the queen bee used for the purity of the subspecies. Studies show that mainly morphological characteristics are affected by environmental factors. For example, in mountain areas, the proboscis is longer than those of bees reared in lowland regions.

There are studies which search for a correlation between the amount of produced honey and separation of subspecies by several morphological characteristics (Meixner et al., 2007; Miladenovic et al., 2011; Abou-Shaara, 2013). Hind wing and cubital index are the most measured part of the bee – manually and by automatic techniques. The final result of the measurement of morphological characteristics largely depends on the knowledge and experience of experts - based on subjective factors.

A general trend in recent years has been the demand for methods to increase the efficiency of this process, resulting in improved accuracy of the estimates, reducing the time in which they are performed, and especially to minimize the subjectivity in the measurement process. Many new hardware and software tools designed to measure the morphological parameters in bees still do not solve most of the problems associated with measuring accuracy in routine processing steps and operations that are performed visually by humans. In the modern era computer-based measurement methods are preferred to accelerate the process.

Suitable devices for obtaining images are video camera, camera, and scanner (Lazarov, 2016). Regardless of popular literature attempts to fully automate the process of measuring the morphological characteristics of bees, at this stage, it is still done by manual way (Mattu et al., 1984; Roth et al., 1999; Tofilski, 2004; Mostajeran et al., 2006; Abou-Shaara et al., 2013; Zlatev et al., 2017).

The work is organized in the following sequence: An overview of the known solutions for automated measurement of morphological characteristics of honeybees and the results are analysed; The materials and methods that were used in the study are presented; the algorithms for automated measurement of key dimensions at tergite and proboscis are developed and tested; the obtained results are discussed and summarized in conclusion.

In most of contemporary studies mainly front wing is measured. (Miladenovic et al., 2011; Bouga, 2011; Santana et al., 2014; Silvaa et al., 2015). Publications related to the measurement of other parts of bees state that a binocular microscope with an eyepiece micrometer is mainly used. This method is not very high precision, is time-consuming and the measuring depends on the experience (Strauss et al., 1994; Schroder et al., 2002).

El-Aw et al. (2012) offer the measurement of morphological characteristics of bees to be performed with a scanner. They propose Photoshop software to be used for image processing.

A comparative analysis is made between measurements with the proposed simplified method and those with binocular microscope eyepiece measurement with a micrometer.

From the measured three colonies of bees, large differences in measurements were obtained in the first colony between the length of the rostrum and rear wing.

(Lazarov, 2016) states that the results are obtained in increments, then multiplied by a factor depending on the increase to be recalculated in millimeters. Some chitin portions, the length of the front-side length of the proboscis, can not be measured entirely but are divided into 2 parts. All these activities increase the potential for errors. Work on the standard method requires more time to reach the final results. When working with the AutoCAD program , a scanner with high resolution and a computer are required. The dimensions of chitin parts are automatically received in millimeters. The measurements are performed quickly. The objects of measurement are scanned and can be stored for a long time. The results of the control determination sections of graph paper and use of Gauge Block (Certificate of Calibration No.1409914, Mitutoyo Corporation Miyazaki Plant, Japan) gave him a reason to accept that measurements with program AutoCAD are accurate and the program can be successfully applied to determine the morphological characteristics of the body of the worker bees.

(Abou-Shaara et al., 2012) offer a four-step methodology for computing measurements of the morphological characteristics of bees. The first step is collecting samples – taking 15 workers from the colony and exploring 6 colonies. The second step is sample preparation –

bees are frozen or placed in alcohol and prepared on glass slides. The third step involves the measurement – the prepared glass slides are scanned and a computer program is implemented for measurement. The fourth step is data analysis – calculation of the mean values and standard deviations or the use of more complex statistical procedures.

According to the literature, there have been attempts to fully automate the process of measuring the morphological characteristics of bees (at this stage there are conversions for Measuring wings), but this process for other parts is still carried out by hand (Tofilski, 2007). According to the author of (Tofilski, 2008) the development of this measuring system is subject to the interrelated issues - the construction of a model of the measured elements and the construction of an algorithm for operation of the system.

In (Schroder et al., 2002) the authors propose a system for automatic measurement of geometric parameters of the wings of bees. The system consists of a laptop computer and a stereo microscope with an integrated CCD camera connected to the computer via a video adapter installed into the PCMCIA slot. The software offers recognition and measurement of the elements of the front wing and discriminant analysis. The effectiveness of the system proposed by the authors was checked with 469 specimens of 13 species of bees and the reported accuracy in distinguishing species by discriminant analysis was 99.15%. The authors state that training the classifier needs a large amount of information to build a database with information about the species and subspecies of bees.

One of the famous pieces of software for automatic measurement of the wings of insects (including bees) is DrawWing (Tofilski, 2004; Tofilski, 2016). The authors of the software say it has a much better device for discriminant analysis compared to known developments in the field (Strauss et al., 1994; Roth et al., 1999).

Another development related to the automatic measurement of morphological characteristics of insects, including bees is the software MorphoJ (Klingenberg, 2011), which combines the method "Procrustes superimposition" with a number of other methods for analysis of form. The program provides an integrated user interface. The program provides an integrated user interface. The advantage of this software over other renowned software is that it offers multivariate analysis, principal component analysis, discriminant analysis, and multivariate regression. The product is Java-based, which makes it compatible with a variety of operating systems such as Windows, Mac OS, Unix, Linux.

The morphological characteristics of honey bees can be measured for various reasons. Basically, these metrics are used to determine subspecies and individual characteristics, as well as to determine hybridization with other subspecies. The measurements are used to determine the influence of the used queen bee and the purity of the subspecies.

Table 1 lists the more commonly used methods for automated measurement of the basic morphological characteristics of honey bees. Here are the main controlled dimensions. In the column-defined characteristics, it is described what the measurements of the respective part and the literary source are used for, where this study is presented, which is indicative of the importance of this type of measurement.

Table 1. Measured morphological characteristics of honey bees

Dimensions measured	Automated measurement method	Aim of the study	Reference
Tongue, Proboscis	Microscope with video camera	Subdivision of subspecies. Characteristic of the geographical area. Quantity of honey produced.	(Waddington, 1989; Marghitas et al., 2008)
24 morphological characteristics	For the first time, it uses a combination of a scanner and a vector image processing software	A comparative analysis of automated measurement technique and classical laboratory method	(Lazarov, 2016; Lazarov, 2017)
Fore wing	Stereo microscope calibrated with micrometer	Quantity of honey produced. Subdivision of subspecies. Colony Productivity	(Mosterjeran et al., 2002)
Hind wing, Cubital index	Stereo microscope calibrated with micrometer	Quantity of honey produced	(Mosterjeran, 2002; Mosterjeran, 2006)
Tergite 3 and 4	Comparative analysis of used manual and automated methods and their application in different countries	Subdivision of subspecies	(Burga, 2011)
Metatarsus	Stereo microscope calibrated with micrometer	Quantity of honey produced. Colony Productivity	(Mosterjeran, 2006)
Sternite	Stereo microscope calibrated with micrometer	Different size depending on the measurement season	(Mattu et al., 1984)
Proboscis	The indirect features used are suitable for predicting the functional length of the proboscis	Predicting the functional length of the proboscis	(Waddington et al., 1987)
Length of tongue, wing dimensions, cubic vein, number of hooks, hind leg	Measurement of multiple morphological characteristics of honeybees through a scanner and a raster image processing software	A comparative analysis of automated measurement technique and classical laboratory method	(El-Aw et al., 2012)
Proboscis	The authors measured intertegular distance (as a measure of body size) and proboscis length (glossa and prementum, both individually and combined). Using linear models and model selection, we determined which parameters provided the best estimate of proboscis length.	Allometric relationships makes them a potentially useful tool for estimating ecologically important traits that are otherwise difficult to measure	(Cariveau et al., 2016)

The analysis of known research related to the measurement of morphological characteristics of bees shows that for this purpose the following methods are used:

Classical – using a stereomicroscope and a magnifying glass;

Computer – using software products for general-purpose and specialized.

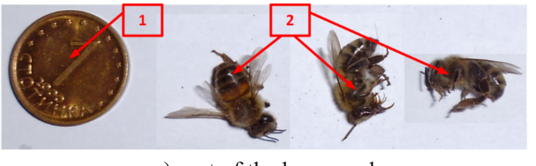
Development and research into the measurement of morphological characteristics of bees includes improvements to existing or creation of new methods for manual, automated and automatic measurement. The main characteristics, which are the fous of these studies, relate to the measurement of parameters of the wings.

After a review of publications on this topic, it is found that there are few publications in which automatic way measure ment of other body parts of bees such as tergite, foot, proboscis. They are important for determining the subspecies, the productivity of the bee colony, the influence of the geographical area.

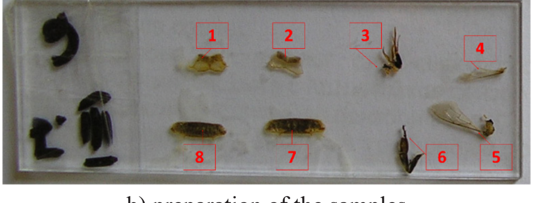
2. Material and methods used in this study

Figure 1 shows part of the bees used in this work and one of the prepared samples. The sample consists of the front right wing, rear right wing, right hind leg, third and fourth tergites, sternit and proboscis.

Samples were prepared in the laboratory of the section "Beekeeping" at the Trakia University – Stara Zagora, Bulgaria.



a) part of the bees used
1-reference object with diameter 16 mm; 2-honey bees



b) preparation of the samples
1-Sternite; 2- Sternite; 3- Proboscis; 4- Fore wing; 5- Hind wing; 6- Metatarsus; 7-Tergite; 8-Tergite

Figure 1: Samples used in the study – general view

The verification of the influence of the angle of rotation of the object on the accuracy of measurement is made by the unit of relative measurement error reversed ε,%.

Table 1 is a description of the analysed functions of the distance between the colour components. Those used are the distance of Mahalanobis (Mahalanobis), Euclidean distance (Euclidean), a distance of Manhattan (Cityblock), Chebyshev distance function and Fisher distance (Fisher discriminant ratio) (Tofilski, 2004).

The resulting distances are processed with the method of correspondences analysis (CA) (Kazlacheva, 2011; Kazlacheva et al., 2014) of the software Statistica. Informative colour features are determined on the basis of a certain available methodology (Georgieva et al., 2015; Mladenov et al., 2015; Dimitrova, 2016; Zlatev et al., 2017).

Table 2. Distance functions used in the study

Designation	Formula	Description
Mahalanobis	$d_{st}{}^2 = (x_s - y_t)C^{-1}(x_s - y_t)'$	C – covariance matrix
Euclidean	$d_{st}{}^2 = (x_s - y_t)C^{-1}(x_s - y_t)'$	x and y are the compared vectors
Cityblock	$d_{st} = \sum_{j=1}^{n} \lvert x_{sj} - y_{tj} \rvert$	
Chebychev	$d_{st} = max_j\{\lvert x_{sj} - y_{tj} \rvert\}$	max – maximum
Fisher discriminant ratio	$d_{st} = \frac{(\bar{x} - \bar{y})^2}{SD_x{}^2 + SD_y{}^2}$	SD – standard deviation

The OCTAVE (GNU Octave)Program Platform was selected because it offers a high-level programming language, interactive algorithm development environment, visualization, data analysis, and calculations. Octave is compatible with Matlab (The Mathworks Inc.) and is used in many areas such as signal processing, imaging, spectral characteristics, and research systems for automatic control. There are a number of toolboxes containing embedded features, including imaging libraries. Vector and matrix operations (which are key to engineering calculations and image processing), are supported. This programming environment offers a quick algorithm development that focuses the user on the problem solver rather than the details of the program code.

The analysis of the developed algorithm aims to determine the extent to which its output variables are affected by moderate changes to the input data.

Algorithm testing can provide a general assessment of its accuracy, as well as detailed information to overcome errors at different input data values.

There are a number of methods for analyzing algorithms (Tofilski, 2011; Klingenberg, 2011; Abou-Shaara et al., 2013; Zlatev et al., 2017). One of these is by changing the input parameters by ± 10%.

Correspondence analysis. The analysis is performed with a table with frequencies, C, of size mxn where m is the number of rows and n is the number of columns. The vectors w_m and w_n give the marginal probabilities of being the row and column classes respectively, while S gives the joint probability distribution of rows and columns. Therefore M gives deviations from independence. These deviations, squared and appropriately scaled, are summed up to yield the chi-squared statistic in C. The data processing steps with the Correspondence Analysis method are presented in Table 3.

Table 3. Stages of data processing with the Correspondence Analysis method

Stage	Formula	Description
A	$w_m = \frac{1}{n_C} C1$	From Table C weights are calculated by rows w_m
B	$w_n = \frac{1}{n_C} 1^T C$	From Table C weights are calculated by columns w_n
C	$n_c = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij}$	n_c is number of observations, 1 is a vector column of ones with the dimensionality of the data
D	$S = \frac{1}{n_C} C$	Table S is calculated as C is divided by the sum of the elements in it
E	$M = S - w_m w_n$	Table M of S and weights are calculated
F	$W_m = diag\left\{\frac{1}{w_m}\right\}$ $W_n = diag\left\{\frac{1}{w_n}\right\}$ $M = U\Sigma V^*$	Table M is decomposed with a generalized decomposition of singular values. The diagonal elements of W_n are $1/w_n$ and those that are not diagonal are 0, where $U^* W_m U = V^* W_n V = I$
G	$F_m = W_m U\Sigma$ $F_n = W_n V\Sigma$	Factor coefficients for the rows and columns of the matrix C are determined

The influence of the angle of rotation of the object on the measurement accuracy is checked by means of the relative measurement error module ε,%, which is determined by the following relationship (Klingenberg, 2011; Georgiev et al., 2014; Zlatev et al., 2017):

$$\varepsilon = \left| \frac{L_{meas} - L_{ref}}{L_{ref}} \right| . 100, \% \quad (1)$$

where L_{meas} is a dimension measured by the proposed algorithm; L_{ref} - measurement by reference method.

3. Results obtained and discussion

An algorithm for measuring morphological characteristics of the bees has been developed. The proposed algorithm and its implementation are based on express, contactless measurement of elements from the body of bees using image processing techniques. It should be emphatically stressed that its establishment is not intended to replace or substitute authorized and approved in practice methods for measurement of these dimensions.

Table 4 shows the resulting distances which separate the object from the background using the colour features of six colour models – RGB, HSV, Lab, LCH, XYZ, CMYK.

Table 4. Distances between colour components for object and background

D	Mahalanobis		Euclidean		CityBlock		Minkowski		Chebichev		FDR	
A / CC	T-B	P-B	T-B	P-B	T-B	P-B	T-B	P-B	T-B	P-B	T-B	P-B
R	1,758	1,766	34,006	43,634	42,757	53,726	34,006	43,634	31,004	40,430	2,091	2,600
G	1,752	1,771	34,387	37,785	42,914	47,428	34,387	37,785	31,480	34,394	4,310	6,552
B	1,778	1,746	38,940	38,440	48,387	47,148	38,940	38,440	35,831	35,675	4,538	7,892
H	1,666	1,706	0,388	0,324	0,458	0,393	0,388	0,324	0,368	0,302	0,462	0,953
S	1,795	1,786	0,190	0,268	0,237	0,321	0,190	0,268	0,176	0,255	0,790	1,462
V	1,767	1,768	0,166	0,198	0,209	0,250	0,166	0,198	0,151	0,180	2,577	3,184
L	1,762	1,765	37,517	42,535	47,385	53,327	37,517	42,535	33,979	38,637	3,961	5,642
a	1,698	1,617	5,713	8,254	7,152	9,781	5,713	8,254	5,150	7,757	1,536	0,853
b	1,772	1,755	9,759	10,419	12,406	13,135	9,759	10,419	8,781	9,457	1,093	1,165
L	1,762	1,765	14,712	16,680	18,582	20,913	14,712	16,680	13,325	15,152	3,961	5,642
C	1,768	1,770	7,593	11,214	9,580	13,482	7,593	11,214	6,894	10,611	0,027	0,019
H	1,684	1,732	136,390	115,048	165,118	142,763	136,390	115,048	127,287	105,520	0,757	1,726
X	1,696	1,707	2,370	2,364	2,829	2,807	2,370	2,364	2,236	2,230	2,484	3,288
Y	1,688	1,710	2,552	2,511	2,999	2,922	2,552	2,511	2,430	2,398	2,627	3,513
Z	1,722	1,663	2,554	2,490	2,890	2,714	2,554	2,490	2,479	2,446	2,643	3,362
C	1,782	1,769	33,415	46,333	41,012	54,554	33,415	46,333	31,070	44,363	0,409	1,019
M	1,755	1,704	24,936	27,832	31,349	34,693	24,936	27,832	22,661	25,457	9,278	13,810
Y	1,775	1,723	46,758	37,010	59,227	47,171	46,758	37,010	42,295	33,282	3,545	10,411
K	1,767	1,762	45,293	51,179	56,675	64,237	46,758	37,010	41,408	46,424	2,789	3,669

D-distance; A-area; O-object area; CC-colour component; T-B-tergite-background; P-B-proboscis-background

Figure 2 presents the results of correspondence analysis in removing the tergite from the background. It is seen that with the largest distances are the colour components of the HSV colour model.

Figure 3 presents the results of correspondences analysis for separating the proboscis from the background. In this case, once again, the colour components from the HSV colour model are suitable for this purpose.

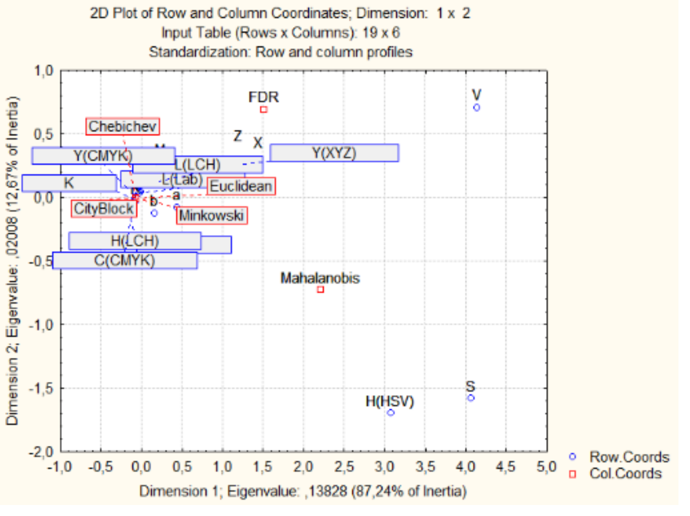


Figure 2: Selection of colour features for separation of tergite from background

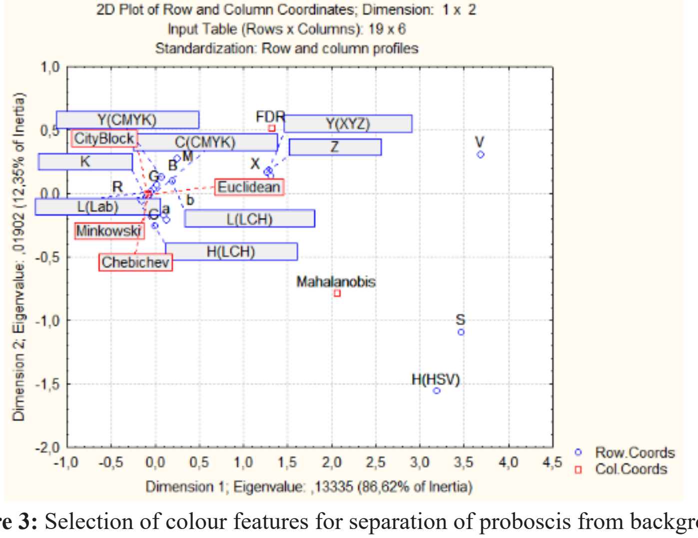


Figure 3: Selection of colour features for separation of proboscis from background

An algorithm for automatic measurement of the main dimensions of tergite. The algorithm for measuring the main dimensions of the tergite is described in Table 5. The original RGB image is transformed into a HSV colour model. Experimentally it has been found that the separation of the tergite from the background in the image is a suitable V (HSV) colour component. The image is transformed into black and white. This conversion is defined as the threshold of binarization, which depends on which pixels will be converted into white and which in black. To remove image noise as points, small objects, it is filtered with a filter of type "Disk". The short and long axes of the tergite are determined by calculation procedures. The distance between the excrescences is defined as defined peaks in the resulting contour around the object. Functions for displaying the results and writing to a file for archiving and subsequent processing of data of the tergite have been introduced.

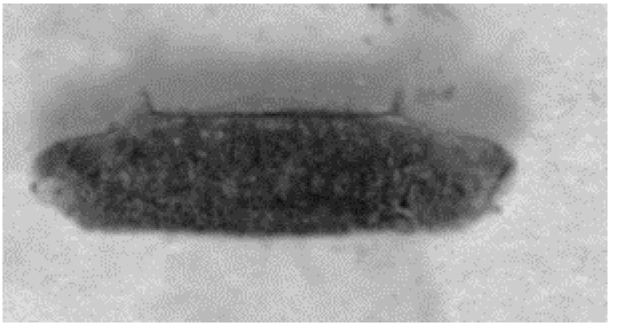
Table 5. An algorithm for measurement of dimensions of tergite

Stage	Description	Pseudocode
A	Loading of the original image	i=imread('Image.jpg')
B	Leveling the object in the image	i=imrotate(i,angle)
C	Conversion in HSV colour model and extraction of V component	i1=rgb2hsv(i); i2=i(:,:,3)
D	Conversion of the image in black and white	i3=im2bw(i2,0.19) The threshold for segmentation is determined experimentally
E	Filtering of the image	h=fspecial('disk',6); i3=imfilter(i3,h)
F	Removing of noises	i3=bwareaopen(i3,1500,4)
G	Obtaining of the object dimensions	stats = regionprops(i3,'all')
H	Finding of the contour of the object	B = bwboundaries(i3);
I	Finding of the long axis of the contour	for k1 = 1:length(B1); b(k1,:) = B1(k1,:); end; s1=b(:,2); t1=-b(:,1); k1=round(length(t1)/4); k2=round(length(t1)/1.33); x1n=s1(k1); y1n=-t1(k1); x2n=s1(k2); y2n=-t1(k2); ds=sqrt((x2n-x1n)^2+(y2n-y1n)^2)
J	Finding of short axis of the contour	for k1 = 1:length(B1); b(k1,:) = B1(k1,:); end; s1=b(:,2); t1=-b(:,1); k1=round(length(t1)/4); k2=round(length(t1)/1.33); x1n=s1(k1); y1n=-t1(k1); x2n=s1(k2); y2n=-t1(k2); ds=sqrt((x2n-x1n)^2+(y2n-y1n)^2)
K	Determining the distance between excrescences	for k1 = 1:length(B1); b(k1,:) = B1(k1,:); end; s1=b(:,2); t1=-b(:,1) k1=round(length(t1)/4); k2=round(length(t1)/1.33); x1n=s1(k1); y1n=-t1(k1); x2n=s1(k2); y2n=-t1(k2); ds=sqrt((x2n-x1n)^2+(y2n-y1n)^2)
L	Visualization of the results	Displaying lines for the main dimensions and displaying measured values, Functions Figure, Line and Text
M	Summarizing the results in a table and saving in a file	The table is stored in the workspace and by function Save is saved in a file with measurements, converted to millimeters, mm.

Figure 4 shows an example of the work of the algorithm to measure the main dimensions of the tergite. The measurements are presented in pixels.

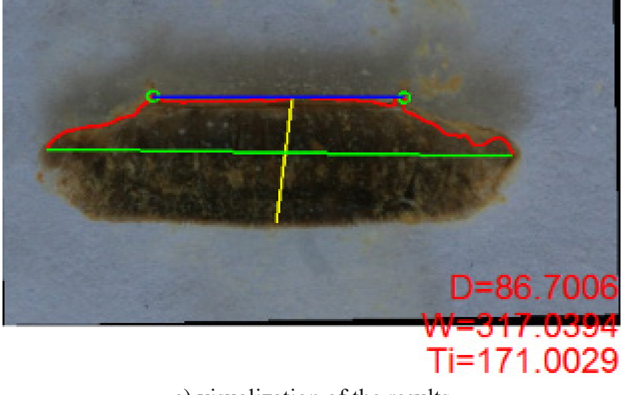
The image from V (HSV) color component is converted to binary one.

After applying the treatments set out in the presented algorithm, the results are displayed.



a) V (HSV) color component

b) black and white image



c) visualization of the results

D-short axis (Longitudinal diameter); W-long axis; Ti-distance between two peaks of the tergite

Figure 4: Stages of the work of the algorithm for automatic measurement of tergitee

The rotation of the object of a certain angle does not affect the two main sizes - long and short axis of the tergite. It affects mainly the measured distance between the two appendages.

Figure 5 shows the results of the algorithm check, with the angle of the object in the image being changed ± 10% relative to the horizontal axis, whereby the measured values are obtained with a small error relative to the reference measurement.

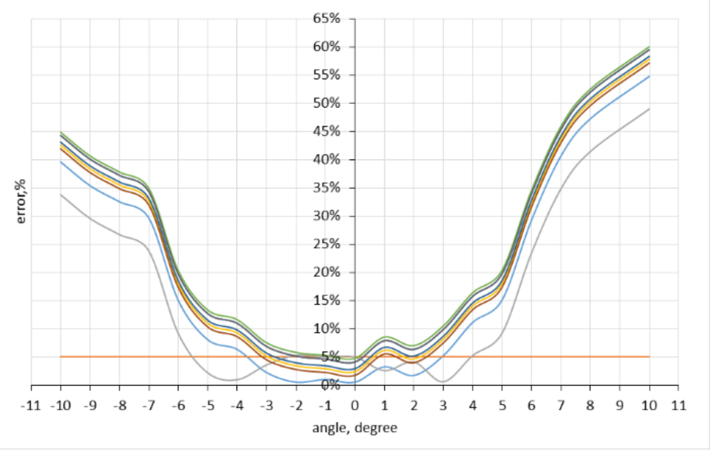
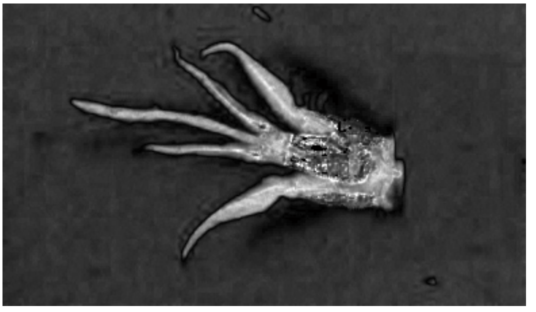


Figure 5: Relative error in altering the angle of tertiary with ±10°

The results of this analysis show that - with an error of up to 5% - the algorithm operates at an angle of rotation of the object relative to the horizontal axis from -2° to +1°.

An algorithm for automatic measurement of the main dimensions in proboscis. The algorithm for measuring the proboscis is built in the same manner as that for determining the main dimensions of tergite. The difference is that instead of the V (HSV), the S (HSV) colour component is used and uses an indexed image, rather than black and white.

Figure 6 shows the steps of operation of the algorithm for measuring the proboscis. The image from S (HSV) color component is converted to binary one. and this two-dimensional image is binarized. The results are displayed, the length of the proboscis is set along the longest axis of the object. It is observed that as in tergite, the change in the angle of the location of the object in the image also affect measurement accuracy. The measurements on the figure are presented in pixels. In the analysis of algorithms it is found that the measurement of the main dimensions in tergite and proboscis of honey bees is accurate to within 5% deviation ±1.5° the longest axis from the object to the horizontal axis of the image.



a) S (HSV) colour component

b) indexed image

c) visualization of the results, W-proboscis length

Figure 6: Stages of algorithm work

Figure 7 shows a graph of the module from a relative error in measuring the length of a shoe according to the angle of the object's position relative to the horizontal axis. An error of up to 5% is obtained by changing the angle of the object relative to the horizontal axis up to ±1.5°.

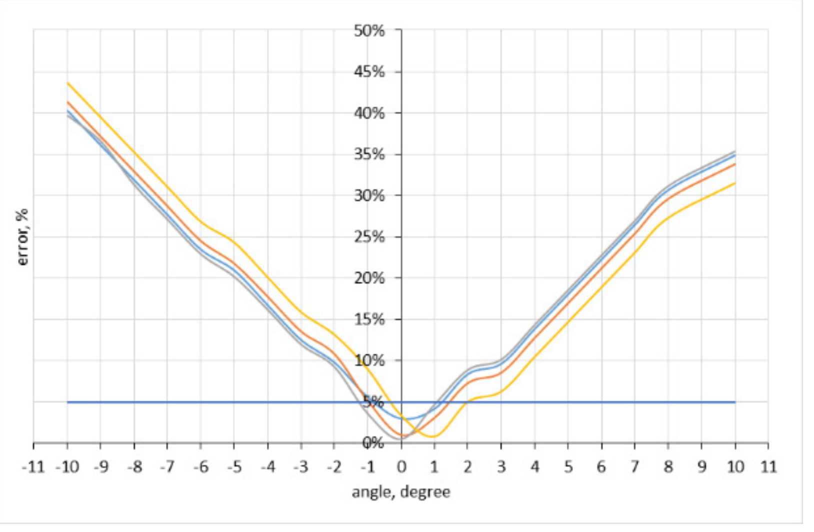


Figure7: Relative error when changing the angle of a proboscis with ±10°

The advantages of automated methods for measuring the basic morphological characteristics of honeybees compared to the standard methods for determining these sizes can be summarized as follow:

✓ Standard measurement methods for morphological characteristics of honey bees include the use of a stereo magnifying glass and a microscope. These methods do not achieve high accuracy and the correctness of measurement will depend on the experience and qualification of the lab worker;

✓ Developed methods for automated measurement of morphological characteristics of honey bees where color digital images of individual parts of a bee, such as a rear right foot, a front wing, a tergite obtained with a video camera or scanner, are handled using accessible software products such as PhotoShop, CorelDraw, ImagePro;

✓ The authors of the known developments offer software products and automatic measurement algorithms that have functions of binarization, extraction of properties and classification of parts of insects, including bees, which can easily be adapted to other measurement software programs;

The advantages of automated systems for measuring the basic morphological characteristics of honey bees are undoubtedly many, as they have, in the main, huge potential, comparatively low cost of equipment, lack of complexity of management, speed, and high productivity. These provide greater reliability and security when performing measurements which make it easier for farmers and workers to save physical labor and time.

Creating new and optimizing existing mathematical models and statistical methods are also the main areas of work in this field. The implementation of these algorithms is important for retrieving, transforming and using information to determine the basic dimensions of a honey bee to use in behavioral analysis of these insects.

Developments and studies in the measurement of morphological characteristics of bees include the improvement of existing or the creation of new methods for manual, automated and automatic measurement. The main features of these studies are related to the measurement of wing parameters.

(Waddington, 1989) investigated the length of the tergite of bees using an indirect indicator - the morphometric characteristics of the bee left wing and head width. The authors report that the indirect features used are appropriate for predicting the functional length of the scapula. In this way, the size of the difficult to measure puppy can be determined by the relatively easy to measure parts of the bee.

The method proposed by (El-Aw et al., 2012) for measuring multiple morphological characteristics of honey bees (length of the tongue, wing dimensions, cubic vein, number of hooks, hind legs) with scanner and Photoshop software shows that measurements of those parts of bees can be measured with sufficient precision compared to the classic method using a stereo magnifying glass.

The method presented in the present work complements these studies by offering automated measurement of the less-regarded parts of the bees – proboscis, and tergite. The method proposed herein may be further developed to use indirectly to determine the size of a tergite and a proboscis in other more easily measurable parts of the bee.

One such trait, proboscis length in bees, is assumed to be important in structuring bee communities and plant pollinator networks (Cariveau et al., 2016). However, it is difficult to measure and thus rarely included in ecological analyses. We measured intertegular distance (as a measure of body size) and proboscis length (glossa and prementum, both individually and combined).

Using linear models and model selection, we determined which parameters provided the best estimate of proboscis length. We then used coefficients to estimate the relationship between intertegular distance and proboscis length, while also considering family. Using allometric equations with an estimation for a scaling coefficient between intertegular distance and proboscis length and coefficients for each family, we explain 91% of the variance in species-level means for bee proboscis length among bee species.

The predictive nature of allometric relationships makes them a potentially useful tool for estimating ecologically important traits that are otherwise difficult to measure. Here we take this approach to develop a predictive allometric equation for proboscis length in bees.

There are software products that use techniques for obtaining, processing and image analysis.

Practically, there are proven methods for measuring the size of morphological characteristics in bees, using the software products Corel Draw, AutoCAD, PhotoShop.

The use of software in two main areas – the development of their own programs using programming languages or measurement with those which have a graphical user interface.

The creation of software for processing and analysis of images using programming languages such as C or Delphi, requires knowledge of compiling the programs and experience of measuring, but on the other hand, this way of working is flexible and the algorithm can be modified according to the needs of the particular user.

Using software with a user interface allows for quick and secure measurement and does not require programming knowledge to work with it. These software products have the disadvantage that they lack flexibility and they can be configured according to the requirements of the measurement.

The selection of software and how to work with it depend on the capabilities of those who use it. Essential for this choice are two factors – flexibility and ease of use. In the development of systems for automatic measurement of morphological characteristics of insects and beekeepers, interconnected problems arise – the construction of a model of the measured elements and the construction of an algorithm for the functioning of the system.

The software system proposed here for automated measurement of two major parts of bees partially solves these problems. More studies can be made on the application of the measurement system and other less-measured parts of bees with automated systems. When applying this adapted measurement approach, it is also possible to determine the dimensions of the measurable parts of the bee.

For the most part, the methods used to analyze the behavior of bees are subjective or require considerable processing time. The accuracy of diagnosis is not high and depends on the expert's qualifications. That is why the creation of highly efficient automated technologies for determining the morphological characteristics of bees is a priority goal of current research in this field.

There is little research on the impact of the environment in which honey bees are grown. The question of whether obtaining, processing and analyzing data on the behavior of bees, through their morphological characteristics, can be implemented expressly, efficiently, with a small number of computational operations, remains open and unclear.

An approach for determining the morphological characteristics of honey bees based on color digital imaging data has been adapted based on extracted features and recognition and measurement of the morphological characteristics of bees.

From the study conducted to determine the size of parts of bees, using an image acquisition, processing and analysis technique, it was found that this can be realized with a total error of less than 10%, which is an indication of sufficient accuracy in the analysis of the morphological parts of honey bees.

Analytical dependencies are derived through distance functions. They have been shown to be effective in solving the bee size determination task within the study.

The results were obtained to improve and complement those reported in the available literature. They can be used to refine the approaches and methods used so far to determine the morphological characteristics of bees, as input to determine the causes of their mortality and the collapse of their colonies.

The proposed methods and software tools could be used in the development of mobile applications and methods for remote measurement, in the express determination of the morphological characteristics of bees.

4. Conclusion

Based on a detailed analysis it was found that morphometric measurements are an important criterion in the selection programs of worker bees. The common way to measure chitin body parts in honeybees is through a stereo microscope with an eyepiece micrometer. At the current level of science and technology, semi-automatic measurement of body parts of bees are made. There have been attempts to fully automate the process of measuring the morphological characteristics of bees (at this stage, there are conversions for Measuring wings), but this process for other parts is still done manually.

Bee body parts (tergite and proboscis), are measured and analyzed by color characteristics. these parts can be separated from the background of the image. Separation functions are defined by colour components. These components can be used to separate an object from a background. From statistical analysisit is found that the S and V colour components from the HSV colour model are appropriate for the separation of an object from the background .

The present work is adapted to an automated measurement approach applied to the basic morphological characteristics of honey bees by analyzing color images, which is studied with two main parts of the bees - tergite and proboscis.

Algorithms were developed and programmed in a Matlab environment for separating the tergite and proboscis from the background of the image and definition of their main dimensions through selected colour components of the HSV colour model. These algorithms complement the existing ones. Other parts of the body were measured besides the bee's wing. From the analysis of the results, it is found that the major influence on the accuracy of the measurement is the angle of the bee body part in the image.

The main dimensions in tergite and proboscis of honey bees is accurate to within 5% deviation $\pm 1{,}5^{o}$ the longest axis from the object to the horizontal axis of the image.

The results presented in the paper can be used as a basis for building databases, in part the morphological characteristics of bees. The measurement accuracy and efficiency of the proposed algorithms and procedures can be the basis for obtaining high quality data, suitable for machine learning and solving the problem of data standardization, regardless of the region of cultivation, geographical, features, traditions of breeding and feeding of bees.

Bees are important to the world economy because they pollinate basic crops from agricultural production.

A recent problem is their decline in recent years. In connection with this problem, various technical and technological methods and means for analyzing the behavior of bees have been developed.

These analysis tools generate large amounts of data that need to be processed in order to retrieve information to analyze the causes of the problem of falling bee numbers and finding ways to solve the problem.

A good way to solve the problem of large volumes of data is through the methods of modern Big Data science. Using Big Data Analysis methods, data from multiple sources can be quickly analyzed and used to retrieve information related to identifying causes of bee mortality and colony decay.

Getting effective solutions to bee-breeding problems involves creating standardized data. This data can be used as a benchmark when compiling effective decision-making algorithms related to effective bee breeding. When compiling databases of benchmarks, it is necessary to take into account the geographical differences in bee rearing sites, genetic differences, specific practices for rearing in different regions. A significant difference is also the language differences - the languages spoken in different countries and the sharing of information through them.

When creating databases of standardized data useful for beekeeping, problems with the organization of data, the form of such data, the quality and informativeness of the data, the rights to use them are more common. It is also necessary to create databases of supporting information for beekeepers.

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