Automation of agrotechnical assessment of cotton harvesting machines

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Abstract. The method of rapid evaluation of agrotechnical indices of cotton harvesting machines, based on computer processing of digital images of cotton row before and after machine harvesting, is proposed in the paper. The algorithms and software to solve the problem of assessing the quality of cotton harvester performance and to determine the indices of the agricultural background of the cotton field, based on the analysis of the plot images taken from different angles, are presented. The application of the proposed technique allows significant reduction of time and money to test the machines, rapid evaluation of their performance directly during the tests. The software and hardware developed can be used in test automation, in automatic systems for monitoring and controlling the technological processes and modes of operation of agricultural machinery, in particular, cotton harvesting machines.

1. Introduction

It is known that agricultural engineering is a priority sector of the economy of the Republic of Uzbekistan and it is specialized in the production of machines for the cultivation and harvest of cotton plant and has great potential to export them to the near and far countries. Currently, about 100 types of machines and tools for agriculture are produced at the enterprises of the republic industry. Therefore, the problem of improving the technical level of domestic tractors, agricultural machinery and especially cotton harvesting machines is relevant.

The basic agrotechnical indices (ATI) of cotton harvesting machines (CHM) (an amount of cotton collected in the bunker, the raw cotton left on the plants and knocked down to the ground, etc.) according to the previously valid standard methods [1] are evaluated by the results of laboratory-field experiments at five times repetitions on the test plots of 100 m long. After machine pass, the raw cotton left on the plants and on the ground on the test plots is manually picked up and weighed, the harvested crop in the bunker is weighed as well. Then, according to the results of preliminary statistical processing, the basic ATI of machines are determined as a percentage of the ripe portion of the crop on the test plots. The disadvantage of this method is a labor content and dependence of the...
determined indices on various random factors, significantly complicating field experiments (skills of workers involved in cotton picking, errors at sample weighing, impurities and moisture content of cotton, etc.). In addition, when working according to this method, it is almost impossible to obtain operational information on the quality of machine operation directly during field experiments.

The current standard methods [1] are based on the manual processing of the plants after machine pass, raw cotton left on the plants, knocked down to the ground on the test plots of the area of 10 m² is picked up separately into the bags. The length of the test plots is divided into 4 equal parts (sites) of 1.11; 2.22; 2.78 m long for 90 cm row-spacing and 1.66; 3.33; 4.16 m for 60 cm row-spacing, to assess the quality indices of single and two-fold harvesting, to estimate the total yield, etc. The experiments in reduced plots (compared to the above-described standard methods) are carried out with a tenfold repetition.

The method of seed counting is known, the main distinguishing feature of which is the evaluation of the machine performance not by weight indices of cotton left on the plants and knocked to the ground after machine pass, but by the amount of seeds left in the valves on the plants and knocked to the ground [2]. According to this method, in the experimental field 3 m long sites are chosen with a width equal to the width of the machine; one in each half-diagonal and one in the center of the site. On each selected plot, the agrotechnical state of cotton plant is described with the definition of the required indices (number of plants, number of open and closed bolls, geometrical parameters of the plant, the width of the row-spacing, etc.). Along with the counting, the naturally fallen cotton bolls segments are picked up from the ground. It is known that each cotton variety is characterized by a certain number of seeds in a cotton boll. Taking into account the agrotechnology, this indicator can be somewhat varied. It is determined by counting the average number of cotton seeds in each boll on 30 plants. After cotton picker pass, raw cotton is picked up from each test plot separately from the plants and from the ground to determine the amount of seeds. The basic agrotechnical indices are determined on the basis of seed amount on the plants, on the ground and in the bunker of machine, and on the basis of total amount of seeds in open bolls before the machine pass. The disadvantage of the described method is a great labor content and hand work associated with the counting directly in the field.

As seen from the review, the currently known methods of field evaluation of agrotechnical and other indices of CHM performance are based on manual, labor-consuming processing of rows and plants of the test plot before and after machine harvesting with the involvement of middle and highly qualified specialists. The information obtained during time-consuming and lengthy data processing is usually very limited and does not allow for more detailed qualitative and quantitative assessment of the operation of individual working units of CHM, such as spindles, pullers, the pneumatic transport system, etc.

So, automating the processes of quality assessment of CHM operation and obtaining information about the agricultural background of the cotton field based on the image analysis using the computer vision methods is an important task.

2. Problem statement

The essence of the proposed new method [3] and methodology is to digitally capture a plot of the cotton row before and after machine harvesting, and in further processing the received images on a computer using the developed program [4]. The program is based on a comparative assessment, analysis and calculation of the color difference (in percentage terms) of digital images on a plot of the cotton row before and after machine harvesting; it allows one to quickly evaluate the basic indices of CHM performance directly during field tests. There is a possibility to obtain an extensive statistical material on the crop left on the plants and on the rows, and a number of other data to evaluate the performance of machine as a whole and its individual working units.

The aim of this study is to develop a method of rapid computer assessment of the cotton field agricultural background and ATI of CHM.

To achieve this goal the following tasks have been solved:
• data collection in the field for computer processing;
• development of algorithms and image processing programs;
• conducting field studies for a comparative assessment of the results of the method of rapid computer-aided assessment of the cotton field agricultural background and the ATI of CHM.

3. Data collection in the field
The use of modern information technologies for collecting and processing data on the agricultural background of the cotton field allows one to create automated software that significantly reduces the time and costs. The results of preliminary studies and field experiments make it possible to more specifically determine the following main components of the developed methodology.

The input data for the developed computer system are the images of test plots of cotton fields taken from the sides and from the top before and after machine harvesting. Consider the method of collecting these data in the field in more detail.

For field survey, the following equipment is necessary:
• a digital camera with a resolution of at least 3.2 MP;
• a tripod for the camera;
• a background panel consisting of a blue rectangle (150x180 cm) of light-absorbing material, framed on the sides and the bottom with a white stripe of 10 cm wide. There is a place in the upper left corner for marking the plot; the fixing points for their subsequent allocation by the operator are located in the lower corners of the blue rectangle;
• an auxiliary panel to create a shadow on the shooting site;
• a step-ladder to take photos from above.

The conditions of data collection in the form of images depend on various factors, of which the weather and the relief are the most important ones.

In the day time, to avoid the shadows and flare on the image, it is necessary to protect the site to be photographed from direct sunlight by auxiliary (protective) panel. Further, these shortcomings will be eliminated by the pre-processing of the images. In cloudy weather, the sites are photographed without an auxiliary panel.

Regardless of the relief of the row, the background panel must be installed perpendicularly. At photographic survey of the test plots the following requirements are set:
• in frontal photography, the reference points of the background panel should be clearly visible on the image;
• when taking pictures from above, the reference points on the ground should be clearly visible on the image;
• in the foreground there should be no foreign objects, including branches and cotton plants from the neighboring plots;
• photography of the test plot from all sides should be made relative to the reference points hammered into the ground;
• in sunny weather, the area being photographed should be completely shaded;
• the entire area of the test plot should enter the frame.

4. Image analysis algorithms
To solve this problem, the image processing methods and the computer vision methods are used [6-9]. Obtaining information about the agricultural background of the cotton field involves the following tasks:
• normalization of the image of the field plot (scale, rotation);
• image segmentation;
• search for objects of a given form (edge detection) on the image.

To bring a set of images to the same scale, the operator should highlight the reference points placed in the lower corners of the blue rectangle of the background panel. To bring the image of the field to
the perpendicular state, the coefficients of straight line consisting of the blue and white boundary points of the background panel are determined and the angle is rotated.

The segmentation of the field plot image, first of all, is necessary to determine the proportion of white color in the image, and to highlight the main stem of cotton plant. This procedure is carried out on the basis of the domain extension algorithm [5].

The search for objects of a given shape on the image is performed according to the form features based on the analysis of moments and on the basis of Hough transformations [5].

4.1. Algorithm to highlight the cotton plots on the image
The basic indicator to assess the performance of CHM is the area of cotton on the image before and after harvesting (on the plant before harvesting, left on the plant and knocked down to the ground after harvesting). The decision trees algorithm C4.5 [6] is chosen to solve this problem.

The training sample for the algorithm has been formed by manual highlighting of cotton areas on the image (figure 1). Next, a preliminary processing of the training sample is performed, which presents the process of removing repetitions and contradictions, and, on the basis of the sample obtained, a decision tree is constructed using the C4.5 algorithm. Figure 2 shows fragments of the resulting tree. The results of the developed algorithm are shown in figure 3. Here, the original image is an image not used in training the algorithm.

Figure 1. The image of the test plot (a) and manually highlighted cotton areas on this image (b).
Figure 2. Fragments of trees for images taken from the side (a) and from above (b) in the RGB color model.

Figure 3. Images of test plots (a) and highlighted areas of cotton using the trees for the images taken from the side (b).
4.2. Algorithm for determining the number of green bolls

This algorithm is based on the analysis of images of the considered plot taken from different angles; it consists of the following three stages:

1) detecting the edges on the images;
2) detecting the ellipsoid objects on the images;
3) determining the number of these objects by analyzing their location on the images of the plot, photographed from different positions.

Numerous algorithms for detecting the edges on the images are described in the literature. However, the best and therefore the most common one is the Canny’s algorithm [7]. The reason for this is a more accurate (compared to other known algorithms) detecting of edges on the images, and the fact that as a result of its application, the contours on the images are obtained of one-pixel thickness.

At the first stage of the algorithm – determining the number of green bolls to detect the edges, the Canny’s algorithm has been used, which consists of the following three steps.

1. The original image is smoothed by applying a Gaussian filter, which reduces the effect of noise.
2. The Sobel operator is applied to the resulting image.
3. Based on two threshold values from the set of potentially boundary points, the edges are detected on the image.

Figure 4 shows the result of the first stage of this algorithm.

At the second stage, elliptical objects are detected on the image using the Hough transformation [8].

Figure 5 shows the result of the second stage of this algorithm on a model image.
At the third stage, the count of ellipsoid objects detected at the previous stage is conducted on all three images of the plot, and the number of green bolls is determined by analyzing the color of the areas of these objects. To make a final decision to refer the detected objects on the images to the amount of green bolls, the following rule is introduced, which takes into account the information content of each angle:

\[
\alpha_i = \begin{cases} 
0, & T(x_i, y_i) < t; \\
1, & T(x_i, y_i) \geq t,
\end{cases}
\]

\[
T(x_i, y_i) = k_1 \cdot L(x_i, y_i) + k_2 \cdot R(x_i, y_i) + k_3 \cdot U(x_i, y_i),
\]

where \( L, R \) and \( U \) equal to 1 if the ellipse is highlighted in the corresponding coordinates on the images taken from the left, from the right and from above, otherwise they equal to 0; \((x_i, y_i)\) are the coordinates of the center of gravity of the \( i \)-th ellipse on the image taken from the left; \( w \) is the image width of the plot; \( k_i \) is the weight angles \( \sum_{i=1}^{3} k_i = 1 \), \( \sum_{i=1}^{3} \alpha_i \) is the number of green bolls on the considered plot of the cotton field; \( t \) is the number of ellipses on the image, detected by the Hough transformation.

Figure 6 shows the result of the third stage of this algorithm on the images of one plot.

As a result of the third stage of this algorithm, it is stated that out of 21 detected ellipsoid objects on a model image (figure 5), 13 of them are green bolls. In figure 6, the red boxes indicate the points of green bolls on the images.

5. Field tests
An automated computer system to assess the performance of CHM and an agricultural background, based on the algorithms described above, has been developed. Testing of the system has been carried out with the field images on the Experimental Field Base of JSC “BMKB Agromash” in Kuyichirchik district of the Tashkent region when assessing the ATI of the MX-1.8 CHM. Comparative analysis of the results of the system with the results of the methods of seeds counting has been done [3].

The results of the tests have shown that the completeness of cotton picking when determining the ATI of CHM system is 90.43% against 88.2%, determined by the control method. The amount of raw cotton knocked down to earth, determined by the system, is 6.07%, and by the control method - 4.2%. When determining the amount of cotton left on the plants the difference in indices is 4.1% (3.5% and 7.6%, respectively).

6. Conclusion
Results of studies on the development of the methods for rapid assessment of CHM performance indices using computer processing of photographs, which makes it possible to obtain preliminary test results directly in the field, confirmed the advanced character of research. According to field experiments, the completeness of cotton picking determined by the developed method is 90.43 %. The
deviation from the indices obtained by the standard method is 2.23%; in our opinion, it is due to the partial overlap of the cotton bolls when taking the photos from above and from the side.

The effectiveness of the new technique is to significantly reduce the time and money for machines testing, the ability to assess the indices rapidly during testing, to eliminate the influence of subjective factors on the measurement results. The software and hardware developed can be used in test automation, in automated systems for monitoring and controlling technological processes and modes of operation of CHM.

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