Smartphone-based plant leaf area meter

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Abstract. A portable device is described for measuring an important plant trait – plant leaf area. The principle of operation of the device is based on digital processing of the obtained images by the method of technical vision. It is implemented on the basis of a free cross-platform framework for game development and visualization – the LibGDX software project. An algorithm and a program for the automated determination of the leaf area are presented. The device is autonomous and is based on a smartphone and a gadget for it. The results of his research tests are presented. The purpose of the device is to study the influence of the environment on ecological systems in the field.

1. Introduction
Changes in the environment, such as changes in climate and atmospheric composition, are causing unprecedented changes in the ecosystem. These phenomena have given new impetus to a long tradition of studying the traits of plants, reflecting species ecological strategies and determining how plants respond to the environment [1].

A living organism – a leaf of a plant is the main organ in which a set of photosynthetic processes is carried out and organic matter is formed. These substances serve as the structural and energetic material for the entire plant. The leaf of the plant is most adapted to environmental conditions.

Leaf area is one of the most important plant traits [1-4]. It is often used in the analysis of growth forms [5]. Area is a key feature [6] associated with differences in plant life strategies [4]. It positively correlates with the rate of photosynthesis, nitrogen concentration in the leaves. The area determines the relative growth rate and the lifespan of the leaves [1]. Important physiological characteristics of plants, such as dark respiration, phosphorus capacity of leaves, chemical composition and evapotranspiration, are often expressed in terms of leaf area in plant ecology [7, 8].

2. Problem definition
Among researchers, the method of measuring leaf area using a scanner, a computer and digital image processing is widespread. But he uses complex and, at times, expensive software [9]. In addition, the method is invasive and is used only in stationary laboratories where it is possible to connect technical equipment to a stationary electrical network.

Currently, smartphones, which are widespread among the population, are used as a means of measuring physical. Modern smartphones have enormous computing power, are equipped with a precision video camera, flash and GPS navigator and other useful tools for users. On the basis of a set of gadgets with various sensors of thermal, electrical, magnetic, mechanical and optical quantities,
special applications for smartphones are created, which are already used in the study of environmental parameters in the field [10].

Despite the availability of high-precision measuring instruments based on applications for smartphones, surprisingly few applications have been developed as tools for environmental protection and functional plant ecology [11].

The paper [12] describes a portable device for measuring the area of plant leaves based on digital processing of the obtained images by the method of technical vision.

The hardware of the device consists of a focal fixed video camera connected to an LED flashlight, a specially developed prototype of the control module (on the prototype board of a mobile phone). Also, the device is equipped with an ultrasonic distance measurement module and an angular geodetic module. The control module uses a high-speed processor with a clock frequency of 400 MHz and the possibility of autonomous operation from an autonomous power supply of +3 V.

The estimation of the leaf area $P_a$ was carried out according to the following equations:

$$ P_a = \frac{kN}{R_t} $$

$$(1)$$

$$ L_a = P_a L_p $$

$$(2)$$

where $P_a$ – is the pixel of the control square;

$k$ – is the area of the control square (in this research $k = 400 \text{ mm}^2$);

$N$ – numbers of control squares in a binary image;

$R_t$ – is the total number of pixels of the reference square;

$L_a$ – is the total number of pixels of the test sheet.

The algorithm of the software product includes sequential digitization of the types of reference squares and plant leaves, measurement of the distance to the object of research and the angle of reading the image. Then the image is captured and saved, a specific sheet is selected, and the reference squares are searched. Next, we perform semi-automatic segmentation and binarization of the image, select the parameters of the median filter to eliminate noise, count the pixels of the squares and the area of the leaf under study.

This device was used to examine samples of leaves of tomatoes, eggplant and maple of various shapes and sizes. The main absolute measurement error, according to the authors, did not exceed 0.005 cm$^2$.

However, the device under consideration is difficult to manufacture, requires additional means for measuring the reading angle and distance, as well as the development of special software. Therefore, it has a significant selling price when the device is sold to the consumer. In addition, when conducting field research, the device does not measure the true area, but the projected area of the sheet. Indeed, the sheet is not ideally flat, but deformed, for example, due to the twisting of the sheet. Giving a leaf a flat shape is possible only when it is detached from the stem of the plant.

3. Materials and methods

The purpose of this study is to study the possibility of creating a portable device for measuring the leaf area of a plant based on free software applications for a smartphone and a special gadget for it.

To determine various plant traits, computer vision methods are widely used by counting image pixels in the space of red, green and blue color channels (R, G, B) [12-14].

To implement the computer vision method, to construct a graphical interface for measuring the area of plant leaves, it is proposed to use and combine different modules of the LibGDX software project [15]. The LibGDX project is a free cross-platform game development and visualization framework based on the Java programming language with some components written in C and C++ to improve the performance of certain code. This project has extensive functionality. It currently supports Windows, Linux, Mac OS X, Android, iOS and HTML5 as target platforms. The platform allows you to create and
develop an application on a stationary computer and effectively use all Java tools, such as software applications for visualization of computer graphics, linear algebra and trigonometry tools, etc [15].

To fix and straighten a plant leaf, a special holder has been developed, in the form of a gadget for a smartphone. It consists of two flat, hinged-connected plates in size, inside which a leaf of plants is placed, without detaching it from the stem. The first plate is made of transparent anti-reflective glass; the second is made of plastic with a white surface serving as a background for the studied plant leaf. On the second plate, a removable swivel joint is fixed, consisting of a fixed adapter of the angle of inclination, ending with a removable bar for installing and fixing the substrate near the plant, by pressing it into the soil. The rod is made of aluminum alloy and consists of two halves 120 mm long and 3 mm in diameter. The boom is easily assembled with a threaded joint. The elements of the gadget in an inoperative state were fixed on the free plane of the smartphone with the help of textile fasteners. The end of one of the rods, which is in contact with the soil when the holder is installed, is made in the form of a cone and coated with an anti-corrosion varnish.

The plant leaf under study was placed between the holder plates. They flattened the leaf of the plant. In this case, the plates were fixed using an elastic latch. With the help of the swivel joint, the angle of inclination required for sheet shooting was set. The tilt angle was measured with a smartphone using the free NixGame application installed on it [15]. The tilt angle was remembered. When receiving an image of a plant leaf, the smartphone was mounted on a tripod - Tripod 3120 with a holder for a smartphone. The tilt angle of the smartphone was set equal to the angle of the sheet holder plates.

Leaves with a rugged profile of the houseplant Hedera Helix were used as the object of research.

4. Results and discussion

The measurement of the area of plant leaves was carried out according to the following algorithm (figure 1).

![Figure 1. Algorithm for measuring the leaf area of a plant.](image-url)
As a language for the development of the logical part of the device, the Java programming language was used, with some components written in C and C++ to improve the performance of certain code, used in the application of the LibGDX software project. When acquiring an image, one of the two digital cameras of the smartphone is selected, which is used to capture images of the plant leaf (figure 2 a).

**Figure 2.** Fragments of a screenshot explaining the operation of the algorithm: a) obtaining an image; b) highlighting the sheet on a uniform background; c) determination of the unit of measurement; d) display of the measurement result.
When receiving an image, one of the two digital cameras of a smartphone with the required resolution is selected, which is used to capture images of a plant leaf (see figure 2 a). The camera is selected by pressing a virtual button, for example, FRONT CAMERA. Using the virtual button TAKE PICTURE, an image is obtained from the selected camera, which is currently active. When you press the NEXT button, the program goes to the stage of selecting the sheet surface.

At this stage, the color image is converted into a spatial representation of a different color - black and white. The transformation of the image is segmented by analyzing the intensity distribution of black and white on the histogram. This makes the leaf images stand out more clearly against the background. The histogram is a graph with brightness located on the x-axis with a maximum size of 256 pixels (see figure 2 b). After that, using the slider under the graph, we select the pixels of the desired brightness from 0 to 256, where 0 is black, and 256 is absolutely white. At this stage, select the pixels of the plant leaf area, without the background, using the SELECT AN AREA virtual button. If necessary, to re-obtain a better image, a return to the initial state is provided (virtual BACK button). The transition to the next stage of setting the minimum unit of area measurement is also carried out with the help of the virtual button NEXT.

On the background plate of the plant's leaf holder, a square with a unit area of 1 cm2 was previously placed in a free space (see figure 2 c). Using three virtual buttons in the form of a plus, we move the image to the area where the square of the unit area is located. Next, we scale the image of the square, for a more accurate measurement of the minimum length of the square, zooming in or out with the virtual buttons BRING CLOSER or MOVE AWAY. Pressing the MARK button marks a point on the image at the beginning of the side of the square. The user needs to make two such points so that the distance between them is 1 cm. For greater clarity, the image shows a measuring square that displays the minimum unit of area, and not a line equal to 1 cm. After the user marks the second point, the application will immediately calculate the distance between the points marked with a marker and will square it. This determines the value of the minimum area in pixels.

Then the number of pixels of the previously selected leaf area is divided by the value of the minimum plant area. Thus, the result of measuring the area in cm2 is determined. In this case, this area is 14.35 square centimeters (see figure 2 d).

The proposed leaf area meter is specially designed for determining the area in difficult field conditions, where there is no stationary power supply. It includes simple and user-friendly functions for area measurement. Thanks to the design of the plant leaf holder, it is highly resistant to unwanted dirt and shadows during the measurement procedure.

In the future, it is planned to carry out the necessary work to develop a methodology for metrological verification and the very verification of the meter, as a means of measuring physical quantities.

5. Conclusion

The proposed leaf area meter is specially designed for determining the area in difficult field conditions, where there is no stationary power supply. It includes simple and user-friendly functions for area measurement. Thanks to the design of the plant leaf holder, it is highly resistant to unwanted dirt and shadows during the measurement procedure. In the future, it is planned to carry out the necessary work to develop a methodology for metrological verification and the very verification of the meter, as a means of measuring physical quantities.

An experimental prototype of an autonomous portable device for measuring the area of leaves without detaching them from plant stems has been developed. Its implementation is based on various modules of the free software project LibGDX, written in the Java programming language with some components written in C and C++. This will reduce the cost of the device and make it affordable for the consumer. Research tests carried out have confirmed its reliability, repeatability of measurement results and high sensitivity to the measured value. Thanks to the simple control functions of the measurement procedure, the area determination device can be freely used in monitoring plant physiological traits, photosynthesis process, environmental research and educational process. It can find
application in other areas of scientific research, where it is required to autonomously determine the area of flat objects with high accuracy.

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