# THE PLANT PERFORMANCES VARIATIONS RECORDING

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## ABSTRACT

The goal was to define and design, built and test autonomous system for nondestructive recording (monitoring) of the plants performance variations in real time, in laboratory and field conditions. The concept is based on moving, autonomous platform on which, needed/wanted, systems are mounted for analysis and characterization of targeted objects. Practically, with defined system, visual and $I_R$ portions of spectra should be covered. First pilot tests are made in the field of Rakovica monastery. The main problem of this heritage object, is that it was built on the water terain, on the underground creeks. So, the watering of plants, during summer, can be problem. The idea was to analyse reaction of the plants existing on the monestery field and their reaction to the additional water. The problmw with Serbian monestiries is that they where built near the water wells,on the terein with number of underground creeks.

**Keywords:** plants; noninvasive methodology; plant stress; ecology

**Academic Discipline:** Agriculture, plant stress

**Subject classification:** Ministry of education science, and technological development classification

**Type(Method/Approach):** Noninvasive plant testing methodology development

## INTRODUCTION

Agriculture is moving today towards "precision farming" [3] techniques in which crop management are performed on a local basis, rather than field wide. This requires the ability to detect and identify spatial distribution of crop stress in monoculture plots. Once identified, using multi- or hyper-spectral imaging techniques, local treatment may be applied (e.g., irrigation, fertilization, insecticide or herbicide). The approach has broad implications on production costs and the environment management. Present efforts are directed towards remote sensing applications [1]. Images obtained by this system allow careful study of the various spatial features of objects. Such detailed spatial data distributions are lost when conducting field measurements with a non-imaging (e.g., fiber optics) spectrometer, which integrates a significant extent of the scene [2, 3, and 4].

There are various different spectral imaging and measuring devices for scientific and industrial use [4]. The main differences between the imaging systems are in the accuracy, speed and in the scanning methods. Some systems use spectral domain scanning and others use spatial domain scanning for capturing spectral images.

The aim was, in general, to define and design, and built autonomous system for nondestructive recording (monitoring) of the plants in real time in laboratory and field conditions. Based was already confirmed methodology of quality measurement of preserved trees in Belgrade. The concept is based on moving, automotive platform on which are mounted needed/wanted systems for analysis and characterization of targeted objects. The basis of the designed system is the implementation of autonomous moving head of controlled moving platform. Those systems are known as Alt/Azimuth montage for tracking and object's recording. This enables sensor movement and positioning by azimuth and height. Positioning control (movement) of the montage system could be done in two ways. Thermal imaging recording system (camera) has been installed besides visual tracking camera. Upgrade of system is addition in the form of various spectral portions by using adequate optical filters.

The first system is manual positioning which is in general used for field investigations, when is unpredictable path of objects which is recording or movement of the - platform where is measuring technique. The scheme of the system concept is given in Fig.1

The second way is computer control, where the platform moving by sensors is controlled automatically following given path. This way is used in laboratory or in the surfaces where the path of the objects or platform with sensors is known. Also, automatic control of the sensor holder movement enables to time unlimited recording of the object of interest.

This way, the time series of data from the selected object could be obtained, or commonly using new measuring technique, known as variation analysis.

Another, not less important detail of the projected system for sensor positioning is possibility of precise measurement of the angle under which the wanted object is recording. It is important data for calculating the possible distortions of visual distortion elements of the accumulated information, as well as calculation of existing attenuation in measurement of the radiation in various spectral portions. By simple program solutions, qualitative tracking of target objects is enabled. In the reality, the tracking path is determined by manual shifting of holders, and simultaneously acquiring the path by computer. Making of path models, enables the reproduction of recorded path later anywhere it is possible. It is necessary to pay attention about operating place location

In the original project design, 4 sensor systems were envisaged:

1. Visual tracking system,
2. LCTF sensor for object's surface changes tracking,
3. Thermal imaging system
4. NIR imaging spectrometer

The simplest and basic sensor is the sensor for tracking of the movements and measuring system positioning. Simplified, it is visual camera with large angle zoom objective for precise sensor positioning. By designing, laser pointers are envisaged, for tuning of sensor positioning.

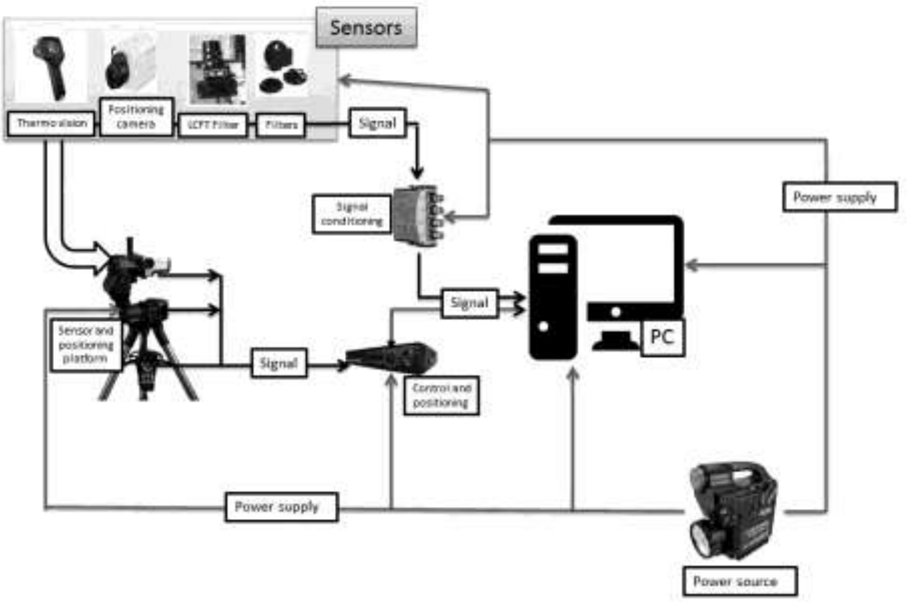


Fig.1. Schematic view of designed sensor system/1/.

Practically, with defined system, visual and $I_R$ portions of spectra should be covered, what is schematically presented in Fig. 2. By development of new methodologies, named hyperspectral object analysis, tracking of changes on objects without destruction is enabled. The disadvantage of these methods of analysis is the uncertainty of the performances of the media where radiation propagates. In the planned investigations or research, relatively small distances are between sensors positions and observed points; therefore, the influence of media could be treated as negligible.

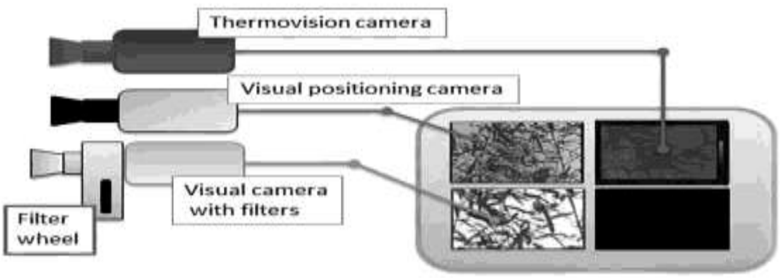


Figure 2. Visual information covered by the system

The system is designed that visual CCD camera of high sensibility plays a role of a sensor. Measurements are perfomed in defined spectral portions, which are selected by filtres. The filtres are set in specialised rotational holder which enables simultaneous measurements with all selected filters. The intensity of the whole obtaned 2D picture is measured in defined spectral range. Plant activity (or leaf activity) are calculated based on it.

The second method of measurement, when instead of natural plant irradiation the laser of defined spectral wavelengths is used for excitation. The measurements of the response of the plant to the changes, is the same as by using natural light (solar).

IR spectrum in this portion gives the information about temperature distribution on the surface of the observed objects or process. As difference from other IR analyses, the result of these analyses is the picture, visual information, and the intensities of the measured IR radiations are presented by color.This aproach obtain the information about the temperature distribution on the observed object. Current thermal imaging systems use third generation of micro bolometer-semiconductor sensors, which are without cooling, what present significant progress by using different applications. New detectors enable the recording with larger wavelengths, what enables more qualitative picture, measurements of higher resolution and eliminations of the influence of solar reflectivity. The resolution of the obtained picture is 640x480 pixels, what fits to the modern systems for image processing.

These facts point that thermal imaging picture carry more information than the common image part of the spectrum. The results of the object images in the visible and IR part of spectra give the whole information on the recording object character. Thermal imaging camera-device generate image which is rely the most to the emissive component of the spectral radiance, to the own IR radiation of the recorded objects as well as to the quantity of the radiation which recorded objects generate and emits.

Thermal imaging device enables conversion of the spatial conversion of the inhomogeneous distribution of the flux radiation of the objects in visible image, by using of the selected color palettes in the visible portion of the spectra. The flux distribution of the object own radiation is the case of the difference in the distribution of the temperature ΔTi /or emissivity ($\Delta\varepsilon_\lambda$). The facts is that every body radiate respective heat quantity, if is on the temperature higher than absolute zero. Every part of the electromagnetic spectra carry definite information about object or about the process where it is generated, Visible part of the spectra carry data about morphologic parameters, as very specific color information. The thermal performances of the processes are manifested in IR portion of the electromagnetic spectra; IR thermography is common method for temperature mapping objects.

## EXPERIMENT

Response of a plant leaf to plant water status and environmental parameters can be presented by an energy balance scheme (2) which mainly consists of net radiation, sensible heat mostly by convection, and latent energy by evaporation across the leaf surface. For a leaf, energy generated from metabolic processes can be neglected. In this research the assumption was that leaf temperature depends on air temperature, relative humidity, solar radiation, leaf resistance, and boundary layer resistance. By utilizing proper sensors, we can study the relationship between these parameters. Air temperature, relative humidity, and solar radiation could be easily measured. Leaf temperature can be measured remotely using an infrared thermometer (IRT) by detecting infrared energy emitted. In other words, plant water status affects to leaf resistance and temperature. First pilot tests are made in the field of Rakovica monastery. The main problem of this heritage object, is that it was built on the water terain, on the underground creeks. So, the watering of plants, during summer, can be problem. The idea was to analyse reaction of the plants existing on the monestery field and their reaction to the additional water. The problmw with Serbian monestiries is that they where built near the water wells,on the terein with number of underground creeks.

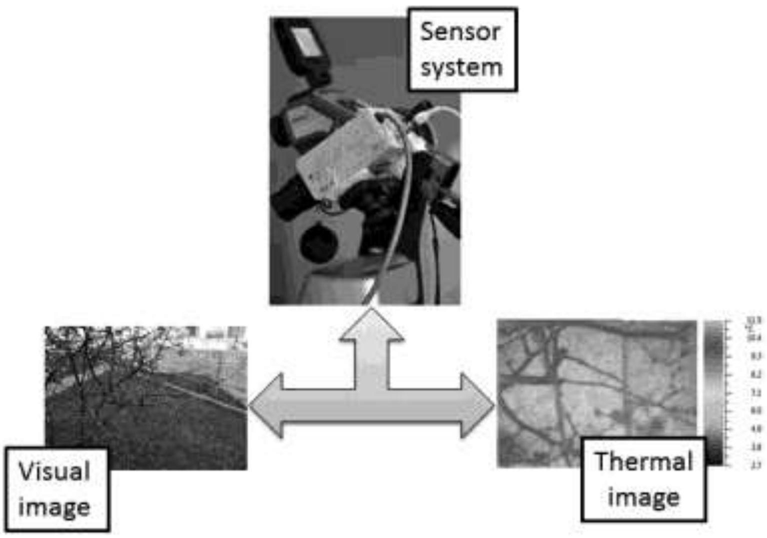


Figure 3. Used system

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The image in TV system presents objects and the scene, where image contrast is the result of the object emmisivity and radiation under various temperatures. The obtained information by thermal vision system, present the scene of the IR portion of spectra under field of view based on image contrast between irradiated energy from the surface of the observed objects.

The performed measurements are primarily directed to the investigation of the plant reaction to the external impulse in this case additional water. The recordings which follow after the time of conditioning or the plant reaction to the water adding are clearly registered by thermal imaging device. Watering can be a tricky thing. With the sweltering heat of summer, combined with a sunny day, plants can start to show symptoms of stress. One's first reaction is to water, but sometimes over-watering can be just as detrimental to a plant's health as under-watering. Symptoms of both over and under-watering can look very similar.

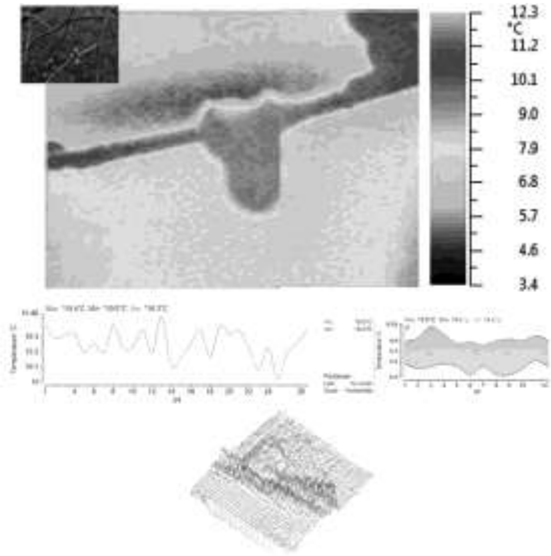


Figure 4. Thermal image and corresponding temperature analysis

In the figures beside visual and thermal records possibilities of determination of lineal distribution of the temperature, as measurements of the trends of temperature maxima and minima, measured on objects.

Analysis shows completely different temperature distributions (histograms) of the leaf surfaces, as distribution of the leaf temperature before watering (Figure 5-A) and after (Figure 5-B).

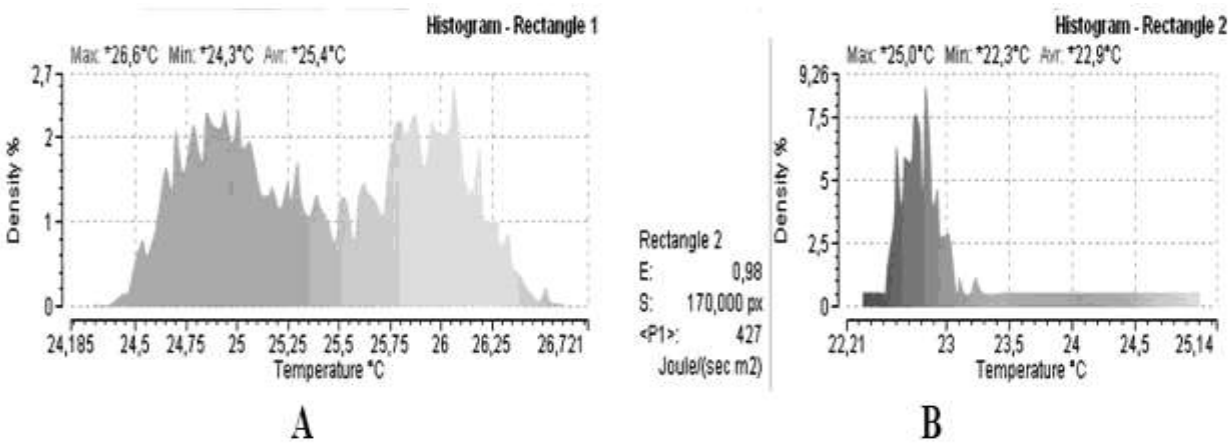


Figure 5. Temperatures histograms before watering A, and after watering B

The same tendency shows the linear temperature profiles before and after watering, Figure 6 a and b.

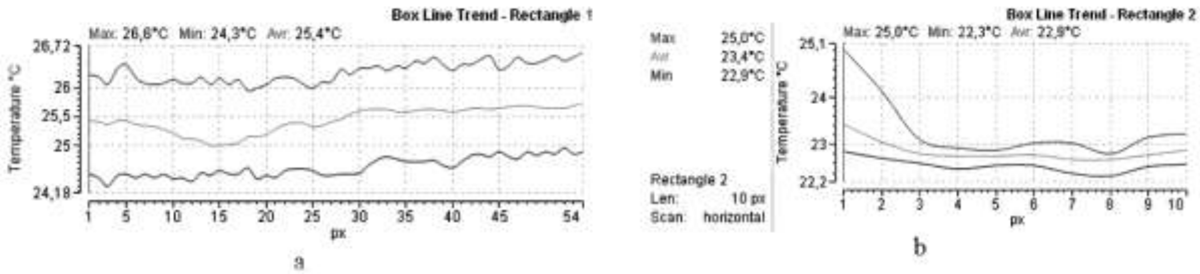


Figure 6. Linear temperatures profiles of the tested leafs

After watering, the leaf shows the temperature decrease in the cumulative sense. The of temperature trends on the measured objects, show clearly trend of temperature decrease after water adding to the objects of investigation. It should be expected that the sensor of higher resolution will performed more qualitative results and more detailed insight in the level and tendency of changes. All measurements were under the same conditions of the environment. It could be supposed, with high level of certainty, where the error (uncertainty) is of the same level and what is more important, in the same direction. In measurements, Al-thin film foil was used, to avoid sun light.

As a result of this study, single leaf temperatures measured with an infrared thermometer can provide a rapid means of assessing the plant water status. The comparison of infrared thermometer and infrared gas exchange fluorescence system analyzer may give better results in understanding the response of leaves against stress in future experiments.

## CONCLUSION

Most methods for studying heterogeneity are not capable of giving quantitative information on leaf and plants variations or are at best of rather coarse resolution labor-intensive or interfere significantly with the natural leaf behavior (especially microscopic and chamber methods). The increasing availability of sensitive infrared imaging systems opens up the possibility of high resolution studies variation over leaf and plant surfaces and their dynamics.

Nevertheless there remains a need to investigate the quantitative relationship between temperature variation over a leaf surface, as obtained by thermal imaging, and stomatal conductance.

This paper describes the use of infrared thermography as a flexible and powerful technique for the quantitative study of spatial and temporal variation of stomatal conductance in plant leaves and presents a new calibration approach based on model surfaces of known conductance as internal references, thus reducing reliance on environmental measurements.

This paper presents a new technical approach for thermography studies of over leaf and plant surfaces in order to estimate the possible damage of the plants. It is a logical development from the crop water stress index approach of but is based on a number of key innovations. In particular it uses a simple reformulation of the leaf energy balance involving temperature measurements on reference surfaces of known conductance to water vapors to allow absolute calibration of temperature measurements. This avoids the need for direct measurement of environmental variables such as incident radiation absorbed, humidity, and wind speed. The calculations presented here, together with the observations on actual temperature variation with stomatal conductance, show that when used in a relative mode infrared thermography has comparable, and in many circumstances better, resolution than that quoted for other methods currently available. It should be noted, however, that absolute calibration is rather sensitive to errors in estimation of reference surface temperatures, implying a need for accurate information on emissivity of the different surfaces (reference and leaf). Nevertheless, the good correlation between porometer measurements and calculated conductance's does support the validity of the approach and that the energy balance of the reference surfaces is similar to that of the *Phaseolus* leaves. The approach is therefore particularly suitable for quantitative studies of spatial and temporal variation of conductance over single leaves or for the screening of large numbers of leaves remotely for stomatal conductance.

The presented analysis provides a basis for optimizing the conditions for maximal sensitivity of the technique in such studies. Furthermore, as a remote technique it does not interfere with stomatal function. Even though the effective spatial resolution is of the order of a few millimeters, the technique will be a valuable complement to chlorophyll fluorescence imaging of photo synthesis to allow a rigorous analysis of relationships between photosynthesis and stomatal conductance.

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