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SELECTED PHYSICAL PROPERTIES OF PLANT MATERIALS AND THEIR DETERMINATION

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Abstract. The article is focused on the utilization of physical properties of plant materials mainly for describing their quality and behavior. Examples of interaction between study materials (via their properties) and tools are presented. The development of agriculture depends mainly on utilization of the new knowledge and discoveries in individual sciencies. A feedback between new knowledge and their practical utilization is vital for the next development of agriculture. The reason for emphasizing physics and its knowledge is a reality because the physics disposes of the measuring methods and practice that enables study problems to be well discribed and characterized. Because the most information we acquisit by measuring and observing merely, the higher accuracy of measuring and processing leads to a higher accuracy of results and a higher accuracy of formulated proceedings. A few examples of measuring the properties of plant materials are presented.

Keywords: physical properties, roentgenogram, spectrometry, internal damage of grain

INTRODUCTION

From point of view of physical objects, e.g. live and inanimate objects, we must anyhow characterize each of the objects very often by enumeration of their properties, which are quantified. There are physical or chemical quantities. Each set of quantities can discriminate objects each of other. The perfection of discrimination depends on the content of the set of properties. All these properties must be observed by our sensors directly. In reverse each property must by converted by a suitable convertor into a form which can be observed. It means that senzors are in many cases the means that quantificate the properties and convert them into suitable mode for the next processing and observation. Accordingly the accuracy of obtained results depends on the accuracy of used senzors and the measurement methods. And even if, in the area of senzors, a big advance in their construction was made, accuracy and reliability under the influence of semiconductor technology and informatics. Most of senzors do not provide only a value of study quantity but simultaneously the quantity is processed (smart sensors). It means that at the outlet of senzor we have more information than the value of the only study quantity. This is the trend of measuring now and in a near future. These senzors are a cheap appreciation of used semiconductor technology and therefore they can be widely spred in agriculture.

Commonly we can say that the plants and plant materials can be described by the next groups of properties:

- mechanical (Young's modulus, strengh, hardness, density, elasticity, deformation, shape, dimension, etc.),
- heat (specific heat, thermal conductivity, thermal diffusivity, heat capacity, termal expansion of matters, etc.),
- acoustic (speed of waves, wavelength, damping, etc.),
- electrical (capacity, resistance, conductivity, magnetic properties, semi-coducting, etc.),
- optical (refraction, index of refraction, reflection, polarization, optical density, etc.),
- other (viscosity, humidity, resolution, etc.).

Measuring of properties come out mostly from their definition. Accuracy of measuring is various in different properties. There exists a big group of measuring methods, some of the properties which do not go out from a definition (because a study property depends on other properties), but measuring (quantification) of these properties is based on the exact definition of the conditions and procedure of measuring (for example determining falling number or SDS test for quality of wheat evaluation). Most of these properties describe materials and objects as compact bodies very often through their cover properties. For examle, most of the systems for remote sensing utilize the optical properties of materials (by measuring scattering radiation) to their characteristic for a long distance. Characterization the „inside" of object is made by X- ray radiation mainly and thus an image inside of the object is presented in the form of roentgenogram or a digitalized file for next processing [1,7,10].

Optical properties of materials, reflectance, colour and etc. characterize not only its outside but often also inside of the studied objects (humidity, maturity etc.). Most of senzors for measuring optical properties are based on measuring of scattering radiation in few spectral wavelength. This way the resolution of details obtained image is higher.

Most of the systems for remote sensing work this way and obtained data are used as entering data e.g. for the system of precision agriculture. In this case the agriculture mechineries are navigated and controlled in the field via satelit set. The activity of machinery depends on actual conditions in the field. We must discriminate the motion of machinery on the field, their lokalization, from other working activity. Both are managed via satelits. The present accuracy in position of the machinery in the field is 6 m. This system is developed and tested in few states in Europa, mainly for the protection of plants by pesticides. A lotion of pesticide is mixing with air and small drops of aerosol arise. These drops are floating in the space and they have to adhere on leaves of plants. Therefore the drops must be very small and their size depends mainly on a construction of nozzles. The second problem is a transport of aerosol drops on the leaves under external conditions (mainly temperature and wind).

We must say that not only physics but also informatics offer their utilization in agriculture. For example, very known the method of image analysis and recognic objects is a general method for processing entering data. Accordingly it is used in checking and control systems not only in agriculture, where this method is used for example for checking eggs (cracks in shell of eggs). In the end we can say that agriculture and agriculture engineering use, for their activities, most of the based physical principles at first directly or secondly intermediately by means of senzors that measure the properties of materials and objects. These properties and their quantification serve to create the characterization of these materials and describe and express their quality. It needs systematicly make not only the research and development of new preperties materials but it is need also systematical transfer of all new information from source to the end users. This is one of the roles of the universities and research institutions.

MATERIAL AND METHODS

Roentgenography

Visualization of the interior of various objects is often made by X-ray radiation. The image of inside the object is called a roetgenogram. A flat film and photochemical processing are commonly used for making roentgenograms. On the other hand there are a few types of detectors of X-ray radiation making the roetgenograms electronically. This is very important for more (extensive) measuring and processing.

A group of nondestructive methods for detection of internal damage is based on the utilization of short waves radiation, mainly X-ray radiation [1,10]. Passing radiation is absorbed by the material of the object and its value is registered on a flat film or special sensor. In a principle each point of this image is proportionate to the absorption X-ray radiation by this point of object. Garret and Lenker,1984 presented the fundamentals of X-ray absorption for some agricultural applications. From the three mechanisms of X-ray absorption (the photoelectric effect, positron-electron pair production and Compton scattering) the first is suitable for the application in X-ray detection systems. X-rays are absorbed by the electron cloud of an element and each layer (course) of the cloud contributes to the absorption process in photoelectric absorption. Absorption commonly depends on the kind of material and its properties. Absorption is regarded as constant in the scanning process and absorption edges may be a cause given zone to absorb differently, depending on the total length of the X-ray passing the material. Problems with absorption edges are especially in dense materials.

Very often Beer´s Law has been used to describe the X-ray absorption process:

$$I = I_o \exp(-\mu L), \qquad (1)$$

where:

I – X-ray photon intensity striking the detector,

I_o – initial X-ray photon intensity,

μ – X-ray absorption coefficient,

L – projection transect length through the object.

The coefficient μ is not constant and depends on the absorption of pure solid and water. Dense materials selectively absorb lower X-rays in polychromatic X-ray sources. It means that the "average" wavelength entering the scanned plane I_o is rather longer than to plane and strikc the detector I. For roentgenogram records very often flat film is used, which has a good resolution (about 50 lines per mm and more). It mainly depends on the dimension of fotosensitive emulse grains [4]. For example a photo has the resolution 100 lines per mm. But processing a roentgenogram lasts time. For processing of the film a wet process is often used. The quality and resolution of roentgenograms is depends on the quality of the film and at the first on the way of its processing. For the next processing on a computer, the roentgenograms on film have to transduce to binary a digitalized file (for example by scanner).

Detectors of X-ray radiation (their construction and function) also depend on the form of output roentgenograms (how the obtained image is presented). We must remember that all the processes that make a base of detection, quantification and registration of X-ray radiation are the **examples of the interaction of photons of X-ray radiation and the electron internal path of the atom. During this process the photon of radiation is absorbed by an atom detector.** For detection of photons the secondary effects of this absoption are very often used, i.e.:

- photoeffects,
- ionization of gases (leads to rise of electrons and ions),
- luminiscence where part of energy radiation is changed into photons of visible or ultraviolet light that are detected subsequently,
- increasing an electrical conductivity of individual materials (i.e.generating of electrical charges electron-hole pairs in semiconductors.

These detectors very often record intensity of X-ray radiation and the position of a greater number of interactions in a certain time. The simple detector of this type is a mosaic or matrix of small photodiodes. These elements create a linear or flat system. For example, the cross section of the detector in figure1 shows very well the principle of this type of detectors. The detector is created in a solid state on silicon substrate as a matrix of photodiodes with cirrcuits CCD. The distance of each diode in the matrix is 40μm approximately. The sensitive area of this detector is 2 x 3cm (oldest version) and its resolution is 550 dpi (it is 11 line per mm).The latest version of this type of sensor has the sensitive area 2.5 x 3.6 cm. Its resolution is1050 dpi (it is 21 line per mm) and has 2 520 000 pixels. The physical size of one pixel is 20 x 20 μm. It allows a resolution of the smallest object on roetgenogram 0.03mm for biological material and 0.02mm for inorganic material. The physical dimensions of this detector (latest version) are: 3.2 x 4.2 x 0.6 cm (width x length x thickness).

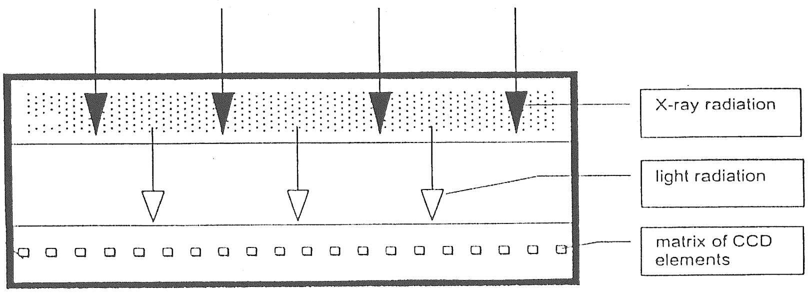

Fig. 1. Scheme of the sensor for direct making X-ray image acquisition. Incoming X-ray radiation is changed to longer wavelength radiation (with lower energy) that fall on the matrix of CCD elements without their damage

This detector is a current device for direct making of X-ray image acquisition. X-ray radiation passed of object (or any material that is located on the cover or up the cover of detector) is captured in the special layer that converts falling X-ray radiation with shorter wavelength into radiation with longer wavelength (with lower energy). The radiation out- coming from the layer is captured by a matrix of photodiodes with CCD circuits. These produce an electrical current equal to the intensity captured X-ray radiation. The data from this detector create a digitalized image in a computer. A thickness of the layer causes the decreasing resolution (spatial resolution) of roentgenograms, obtained by this way. At the present time photodiodes working without their damage are used at energy of radiation approximately 40 keV.

Very important attribute of each roentgenogram is its resolution. For comparison, a roentgenogram on the flat film has maximum resolution 50 lines per mm [4] (it is depending on dimension of grains fotosensitive emulse and the way of the film development). It represents approximately 2500 dpi. For the next processing on a computer, the roengenogram on a film have to transduce to binary file a digitalized (for example by scanner). The electronic roentge-nogram (direct making roentgenogram) has the smaller resolution, approximately 1000 dpi, [8]. The senzor direct making of roentgenograms (without film) where we obtain roentgenogram in a form of binary file size 190 kB or 400 kB for the latest version the sensor. An exposition is in the range from 0.02 to 0.6 second and the digitalization passes in real time. The delay between the end of exposition and appearance of the images on a screen is 0.2-0.9 second. Time of exposition depends on the kind of material (its properties and thickness).

Although X-ray of used radiation is „soft" the electrooptical elements of senzor are protected against its effect by special material that transduces X-ray radiation with short wavelength into optical radiation with longer wavelength (with lower energy). The elements of matrix of senzor can not process the radiation with bigger energy without a damage. At present time are used the elements of matrix that are processing X-ray radiation with energy 31 kVe without their damage are used [2]. It brings on higher resolution of senzor. Last year [9] displayed a senzor made by CMOS technology that is cheaper. A similar sensor for detection of X-ray radiation was developed [5]. The roentgenograms in digital form are processed by standard means for image analysis.

Special silicon p-n junction photodiodes have been developed for application in the vacuum ultraviolet, extreme ultraviolet and the soft X-ray (XUV, wavelength range from 180 nm to 0.1 nm, energy range from 7eV to 12keV) spectral region.

Unlike common p-n junction diodes, these diodes do not have a doped dead-region and have zero surface recombination resulting in near theoretical quantum efficiencies to XUV photons and other low energy particles. The AXUV diodes are **internal photoelectric devices** and hence are less sensitive to minute vacuum system contaminants than conventional XUV, detectors based on the external photoelectric effect. These diodes are fabricated by an ULSI (Ultra Large Scale Integrated Circuit). Their construction is shown in figure 2. When these diodes are exposed to photons of energy greater than 1.12eV (wavelength less than 1100 nm) electron-hole pairs (carriers) are created. These photo generated carriers are separated by the p-n junction electric field and a current is proportional to the number of electron-hole pairs created flows through an external circuit.

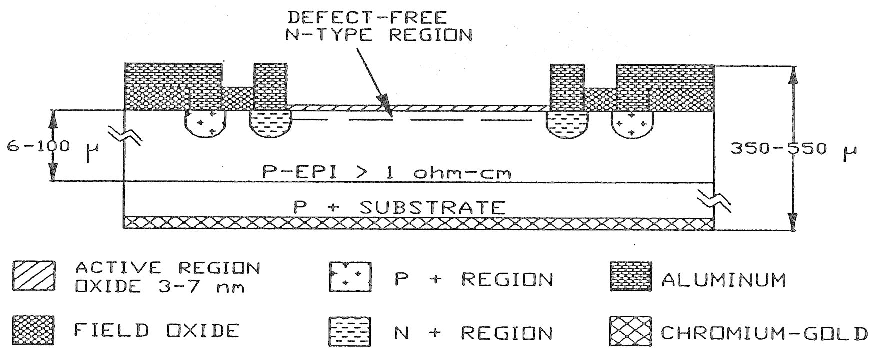

Fig. 2. Scheme of the silicon photodiode. X-ray radiation is falling through extremely thin (from 3 to 7nm) protective entrance window on the doped active **n** region without its damage

For example, the cracks in grains or seeds are in most cases an internal damage of these objects. This damage results from the destructive effect of external forces (harvest, transport) as well as of internal stresses. Mechanical damage of grains can be defined as a state of dissturbance of the natural continuity of particular tissues of grains [7]. This kind of grain damage is presented visually mainly by internal cracks. Its detection and quantification is possible by various methods [6]. Indirect methods give no information about the damage (where it is and what is its nature and size). From the direct methods, X-ray radiation is very often used and outputs are the roentgenograms (radiographs) that show the inside of the grain. An image processing technique for detecting stress cracks in grain is widely applied. It depends on the way the images are obtained.

At the present time new elements of matrix that are processing X-ray radiation (directly) with energy 31 keV without their damage are used. These elements bring new possibilities and a better resolution. In this case, the CCD elements were manufactured from new materials and advance technology was used [2]. The resolution of these electronic roentgenograms is smaller in any case (approx. ten times) than roentgenograms on the flat film. It is their mine disadvantage. Next two figures document the very simple possibilities and properties of electronic roentgenograms.

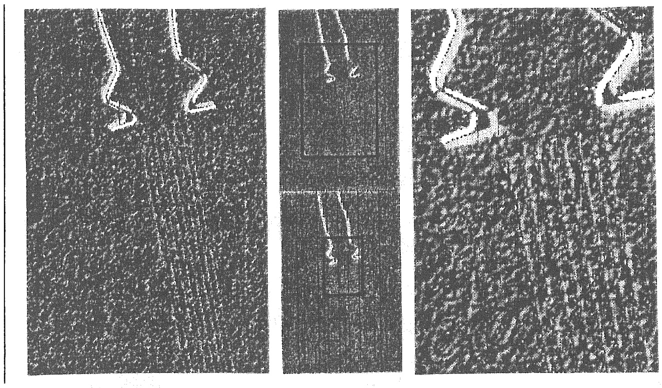

Fig. 3. Images are roentgenograms of the electric resistance strain gauge (tenzometer) and represent possibilities of magnification and resolution of the roentgenograms. White lines in the roentgenograms are the wires. Thick lines have the diameter 0.3 mm and thin lines 0.02 mm.

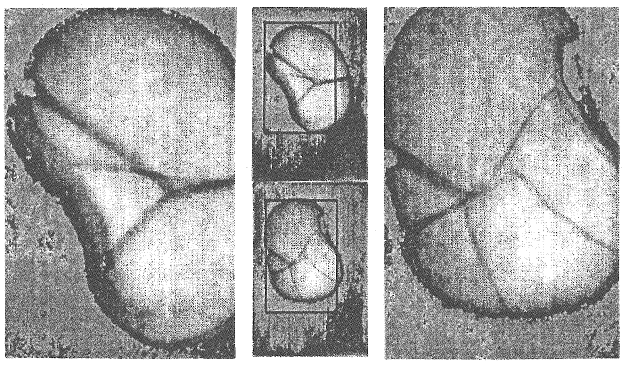

Fig. 4. The roentgenogram shows the seed being damaged by an external impact. The dark lines are cracks in the seed. The image to the left shows possibilities of the magnification made by computer. The seed length is 13.5 mm

Spectrometry

Measuring the burden gases emission within the agriculture activity is increasingly significant with respect to the international obligations. Agriculture is a specific sector producing 95% of total ammonia quantity in the world. It was necessary to suggest and to verify methods of ammonia concentration continual measuring in the housing facility and outdoor environment, [3]. The measured air sample is taken – off at a certain instant of time for the purpose of investigated ammonia values comparison. For example – spectrometer is a suitable apparatus for this comparative measuring.

All the spectrometric methods are based on the knowledge, effects and reactions resulting from the interaction between electromagnetic radiation and material. Therefore there are two reagents. One of them (radiation) is measured to find out its features. At the same time there are observed reactions to the interaction. It is important that the acquired data inform us about examined substance atoms and molecule internal structure or, if it is necessary, its concentration in the mixture with other substances. Interpretation of radiation influence upon a substance is can be realized on the basis of its dual hypothesis: wave – corpuscular character, when radiation has, according to this theory, wave properties and simultaneously properties of energy elementary quantum flux – **photons** – moving as particles of certain wavelength in accordance with the de Broglie's relation. The result of interaction between the electromagnetic radiation and the substance depends also on their properties and particularly on the radiation energy.

For the gaseous substance concentration specification it is more suitable to use interactions with an energy change between the substance and radiation. These interaction are based on the fact that atoms and molecules are able to change their energetic state through the energy acceptance or radiation. Generally, the substance energy change (its particles) is considered in the following form:

- **absorption**, i.e. substance energy increasing, when this energy is converted into the substance by the electromagnetic radiation (its absorption by the substance)
- **emission**, i.e. substance energy decreasing, when this energy is radiated from the substance in the form of the electromagnetic radiation.

All this energetic changes can be detected by some suitable spectrometric method. Quantification of he interacting electromagnetic radiation is usually provided by the evaluation of radiation absorption of the substance.

The radiation applied in practice has the wavelength approximately from 0,1 nm to 1 m. The spectrometry categories are:

- roentgen (0.1-200 nm),
- ultraviolet and visible (200-800 nm),
- infrared (0.8-500μm); **NIR** = 0.8-2.5 μm; **MIR** = 2.5-50 μm; **FIR** = 50-500 μm,
- electron paramagnetic resonance (0.5 mm-1 cm),
- nuclear magnetic resonance (1 cm-1 m).

Measuring ammonia concentration in the air was made by the spectrometer M 500 with range 2.5-16.6 μm (4000-600 cm^{-1}). It is apparatus medium level quality and consist of double-ray design, i.e. one IR ray is divided by means of single-ray optics and microcomputer correction of the background. Figure 5 represents the basic diagram of the used apparatus.

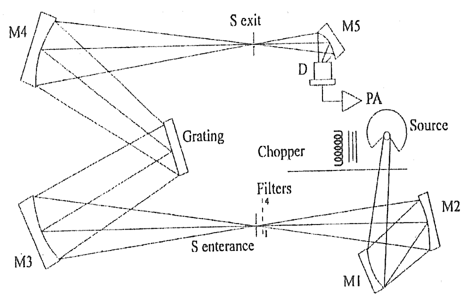

Fig. 5. The measuring space is a site where the cells with samples are placed. Its length is physically limited in the apparatus by **S** entrance and **S** exit and is max. 77 mm. **M 1, 2, 3, 4** are mirrors; **D** is passed IR radiation detector; **PA** is detector signal amplifier

Few trials conducted by the Spectrometer M500 were focused to:

- determination of substance type (in mixture),
- determination of substance concentration.

The gaseous mixture sampling for concrete measuring was performed into bags and the sample of gas was withdrawn from the bags to the cell. Moreover continual measuring of ammonia concentration (emissions) was carried out by another verified method. Each spectrogram consists the water absorption bands 2.63-2.86 and 5 to 7.7 μm. The carbon dioxide is placed from 4.16 to 4.35 μm. The ammonia presence is evident mainly in the range of 2.7-2.94 and 5.26-7.14 μm.

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WYZNACZANIE WYBRANYCH WŁAŚCIWOŚCI FIZYCZNYCH MATERIAŁÓW ROŚLINNYCH

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Streszczenie. W artykule omówiono zagadnienie wykorzystania właściwości fizycznych materiałów roślinnych pod kątem opisu ich jakościowego zachowania się. Zaprezentowano przykładowe badania związków interakcyjnych pomiędzy materiałami roślinnymi (poprzez ich właściwości fizyczne) oraz zastosowanymi narzędziami pomiarowymi. Rozwój rolnictwa zależy głównie od wykorzystania nowych osiągnięć naukowych i odkryć w poszczególnych dyscyplinach nauki. Relacja pomiędzy postępem naukowym a jego praktycznym zastosowaniem stanowi zawsze impuls do kolejnego rozwoju rolnictwa. Dowodem podkreślenia roli fizyki jest możliwość dysponowania fizycznymi metodami pomiarowymi, umożliwiającymi dokładny opis i charakterystykę badanych zjawisk. Ponieważ większość informacji pozyskujemy poprzez pomiary i obserwacje, większa dokładność pomiarów i procesów prowadzi do wyższej dokładności wyników i wyższej dokładności formułowanych procedur. Praca zawiera kilka przykładów pomiarów fizycznych właściwości materiałów roślinnych.

Słowa kluczowe: fizyczne właściwości, rentgenogramy, spektrometria, uszkodzenia wewnętrzne ziarna