DATA ASSIMILATION SYSTEMS

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Contents

Summary

Agricultural products and foods are highly diverse and complex in their physical and biological properties. Their fundamental, mechanical, sonic, electrical, and optical properties are described in this chapter. A machine vision system is explained as one example of a sensor for collecting data, and a fruit grading system which gives color, size, shape, defect and internal quality information of each fruit is introduced. The collected information is accumulated in a database and linked with other databases in which distribution and consumption information are stored as a food traceability system. In addition, the database design, data organization, accumulation, and utilization for agricultural products information are described. By this database system, producers, distributors, and consumers are linked to one another for more effective procedures to be performed from the production to consumption stages.

1. Introduction

It is not easy to precisely acquire data relating food, agricultural products, and the environment, because the object properties often change over time and from place to place. Especially, physical and biological properties of food and agricultural products must be carefully measured, because the properties can vary greatly depending on water content and the products themselves are highly diverse and complex in form and composition. In this section, first, some representative physical properties of biomaterials are introduced. Second, a data acquisition system using imaging technology is explained as one sensing system. Recent progress in imaging technologies brings high-resolution information from the X-ray to infrared regions by TV cameras with various sensitivities. The latest research has reported new developments in THz (Terahertz: region between infrared and radio wave) imaging with the expectation of many important discoveries to be uncovered in the THz region. Third, a database system on agricultural production is described, because food traceability is one of the biggest topics to solve the problems on the quality of the food supply system. Linkage method of data collected from sensors, database design for accumulating data of products, and database utilization are described. By this traceability database, it is expected that producers, distributors, and consumers are linked to one another and that more effective bio-production is performed.

2. Physical Properties of Biomaterials

2.1. Fundamental Physical Properties

Most agricultural products and foods are formed of plant parts. While fruits are mostly commonly used, plant leaves, stems, and even flower petals also can be consumed as food, in such forms as leafy vegetables, asparagus, and tea, for example. As fundamental physical properties of plant-based foods, size, shape, surface area, volume, mass, density, and other characteristics are often measured. Some of these properties can be measured mechanically and electrically by the use of micro-switches, potentiometers, encoders, photo interrupters, laser and other sensors. Recently, imaging technologies have been frequently used for the measurement of these properties to obtain two-dimensional data, with high-resolution cameras from which data can be easily input to PCs. Although it is possible to predict object volumes through imaging, a method of static electrical capacity has been adopted for a watermelon grading system to measure volume, density and mass. Other methods are detailed in other reports.

2.2. Mechanical Properties

Mechanical properties of plant and animal materials have long been investigated in the study of biomaterials. Compressive, tensile, and shearing properties of biological materials are measured just like those of non-biological physical materials. Figure 1 shows a stress-strain curve (force-deformation curve) of a biomaterial. Here, stress σ is expressed by Eq. (1)

$$\sigma = P/A \qquad (1)$$

where P is the load and A is the cross-sectional area of the biomaterial, for a load that is perpendicular to the cross section. When the load is parallel to the cross section, the stress is called shearing stress τ. When subjected to a load, the material length increases or decreases by δ. The ratio of the change δ and the original length l is called longitudinal strain ε and is expressed as shown Eq. (2).

$$\varepsilon = \delta / l \tag{2}$$

When the material is deformed by shearing stress, the strain is called shearing strain γ. Strain values are generally small and are expressed as μ or % , without units.

When biomaterial is loaded to produce a stress-strain curve such as that shown in Figure 1, it is deformed as an elastic body up to point A, which means that the deformation is recoverable back to origin O when the load is eliminated. When the load exceeds the proportional limit A (A is assumed to be equal to the elastic limit here), the deformation is increased to point B under the same loading. This B is called bioyield point.

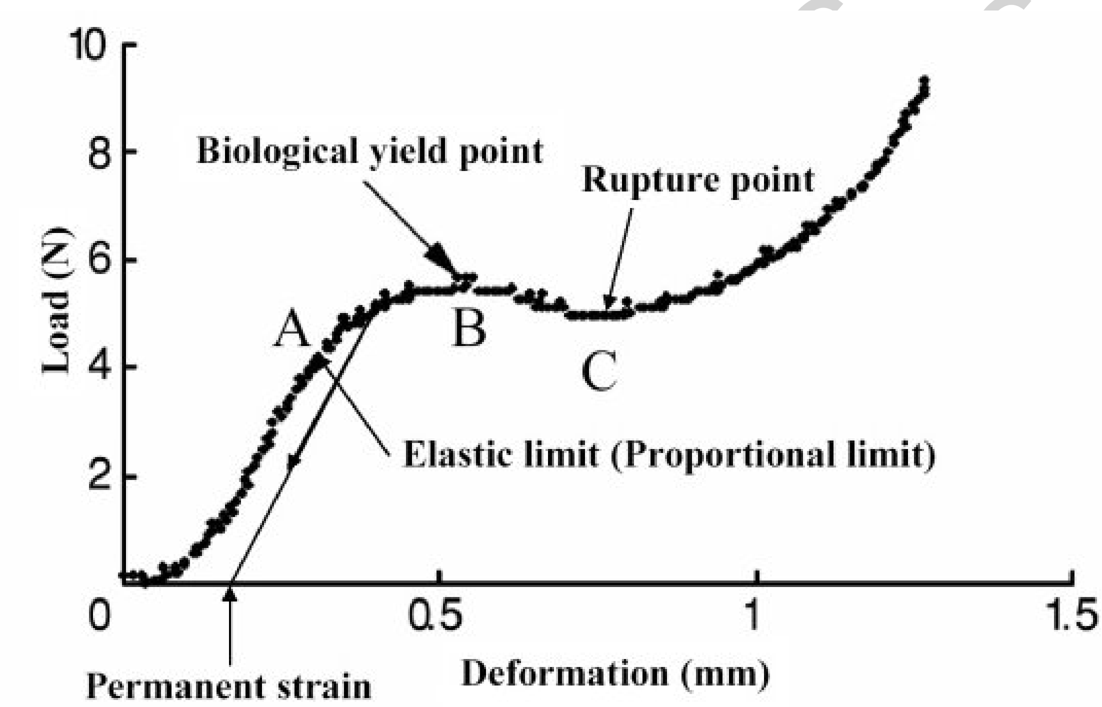

Figure 1: Stress – strain curve of biomaterial.

If the load is further increased, the deformation reaches rupture point C. It is said that the bioyield point B and the rupture point C correspond to micro-structural and macro-structural ruptures, respectively. In the elastic region from O to A, ratio of stress σ to strain ε is called the modulus of longitudinal elasticity (Young's modulus), as shown in Eq. (3), while the ratio of shearing stress τ to shearing strain γ is the modulus of transverse elasticity (modulus of rigidity), as shown in Eq. (4)

$$E = \sigma / \varepsilon = Pl / A\delta \tag{3}$$

$$G = \tau / \gamma \tag{4}$$

When the material is loaded, not only longitudinal strain ε but also latitudinal strain ε'

are generated and the ratio of the two is called Poisson's ratio, as shown in Eq. (5).

$$1/\mathrm{m} = \varepsilon/\varepsilon' \tag{5}$$

According to reports, the values for the modulus of longitudinal elasticity of potato, carrot, apple fruit and soy bean are 3.1 Mpa, 4.9 MPa, 6-18 MPa, and 12-15 Mpa, respectively, and their values for Poisson's ratio are 0.475, 0.45, 0.155-0.312, and 0.253-0.321, respectively. These values change with variations in plant variety, moisture content, cultivation conditions, or preservation conditions and can be determined from precise measurements obtained using strain gages or imaging technologies.

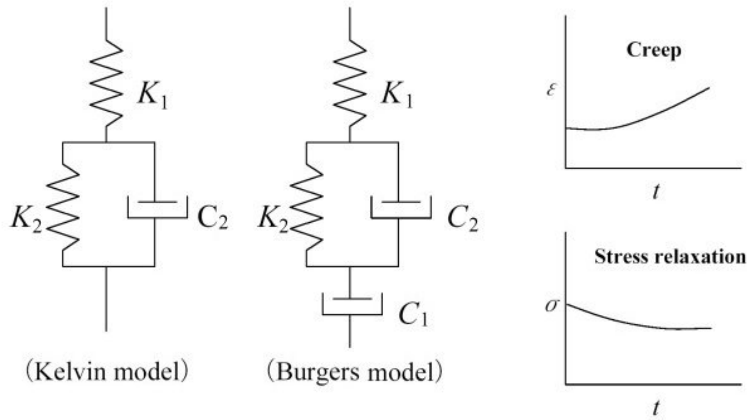

Figure 2: Viscoelastic model and creep stress relaxation

Many biomaterials are often considered not as perfect elastic bodies but as viscoelastic bodies. Some different viscoelastic models have been reported such as the three- and four-element models, which are called the Kelvin model and the Burgers model, respectively and both models consist of springs and dashpots for elasticity and viscosity as shown in Figure 2.

When a material is loaded at a constant force, its deformation increases with elapsed time; this is called creep and the resulting strain is expressed by Eq. (6), using the Burgers model,

$$\varepsilon = \sigma/k_1 + \left(\mathrm{s}/c_1\right) + \left(\sigma/k_2\right)\left(1 - e^{\left(-k_2/c_2\right)t}\right) \tag{6}$$

where k is the spring constant and c is the viscosity coefficient. For example, an apple fruit loaded with a force of about 90g was reported to have values for k_1, c_1, k_2, and c_2 of 0.13kg mm^{-2}, 11.17kgs mm^{-2}, 0.397kg mm^{-2}, and 0.679kgs mm^{-2} respectively.

When a material is subjected to a constant deformation, its stress decreases with elapsed time; this is called stress relaxation. Apple skin was reported to have values for k_1, k_2, and c_2 of 0.0629kg mm^{-2}, 0.307kg mm^{-2}, 2.93kgs mm^{-2}, respectively, with the strain decreasing with time t as expressed in Eq. (7) using the Kelvin model,

$$F(t) = 0.235 + 0.048e^{(-t/7.9)} \tag{7}$$

When an agricultural product is grasped or is placed on a slope, it is necessary to measure the friction coefficient. This coefficient depends on the water content of product. It was reported that the kinetic friction coefficients for corn or wheat on an iron plate, or for soybean on a glass plate, were in the range of 0.2-0.4 when the water contents of the grains were less than 20 %, but that the coefficients increased by 10% when water contents exceeded 30%. In addition, the rolling resistance and repose angle of agricultural products sometimes must be measured. These coefficients also depend on surface roughness.

2.3. Sonic properties

It is reported that the resonance frequency of pineapple fruit varies from 100Hz to 200Hz with maturity and that apples, strawberries, cherries, and other fruits have their own frequencies of vibration. Due to variations in sonic property, fruit quality can sometimes be predicted. For example, the thumping sound of a watermelon is well known to be useful in judging the maturity of the fruit; FFT (Fast Fourier Transform) analysis of the power spectrum density has shown higher peak frequencies containing more frequency components for unripe watermelon, and decreasing peak frequencies containing fewer frequency components with increasing maturity.

2.4. Electrical Properties

Because the electrical resistance of food and agricultural products changes with water content, it is possible to measure water content by measuring electrical resistance. Generally speaking, the electrical resistance of highly hygroscopic materials such as agricultural products can be expressed by an equivalent electrical circuit of resistance and condenser as shown in Figure 3.

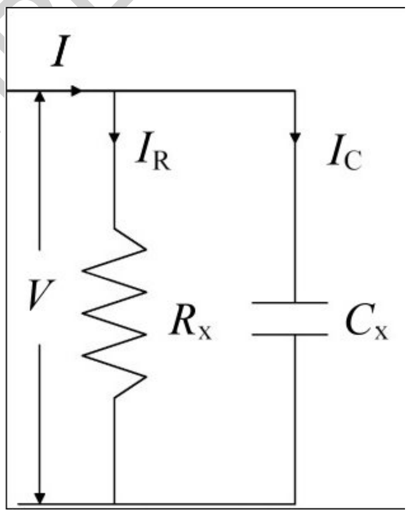

Figure 3: Equivalent electrical circuit.

In the figure, R_x and I_R are a electrical resistance and a current, while C_x and I_C are a capacitance and a current respectively. When direct current is sent to this circuit, the resistance is easily obtained because it is not necessary to consider current through the condenser. From the electrical resistance, the water content of the product can be predicted; this method is implemented in one such system used to measure water content of wood surfaces. When alternating current is sent through the surface, there are two methods to measure the resistance: a high frequency resistance method and a high frequency capacitance method. As an example, it is reported that the10 MHz frequency can be used to most precisely obtain the relation between water content of husked rice and electric capacity.

There is a report that describes relation between equivalent capacity and impedance and between equivalent resistance and complex dielectric constant through the frequency range of 10Hz-13MHz for apples, persimmons, watermelons, pears, tomatoes, and other fruits. It was also observed that the electrical properties of fruits depend on freshness and internal quality, with decreasing resistance and increasing capacitance corresponding to injury and rot.

2.5. Optical Properties

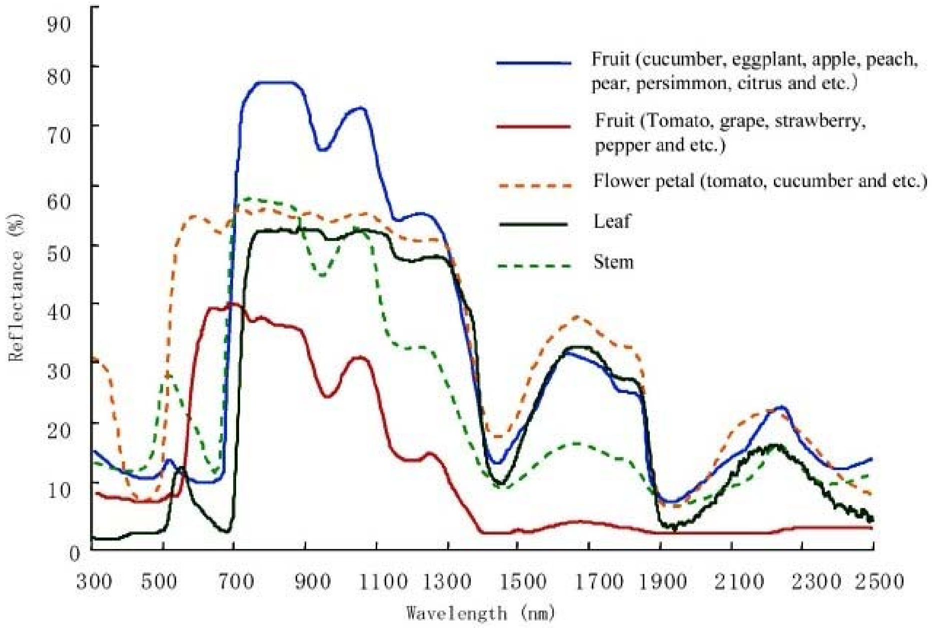

Figure 4: Spectral reflectance of plant.

Figure 4 shows the typical spectral reflectance of various plant parts in the near ultra violet, visible, and near infrared regions. It is well known that plants need the photosynthetically active portion of light (in the 400 to 700 nm waveband region, mostly red and blue light) for photosynthesis, and it is for this reason that their leaves reflect green colors. In the figure, an absorption band is observed at around 670 nm the plant parts contain chlorophyll. The fruit and flower colors depend on the plant variety. The reflectance of some flowers in the ultra violet region is of interest because the percent reflectance is high at around 300 nm. Based on this observation, it is thought that the sensitivity of some insects' vision includes the ultra violet region. Insects may have evolved this ability to discriminate the flower from other parts of the plant to obtain honey and pollen. In the near infrared region, there are many absorption bands due to water at 970, 1170, 1450, and 1950 nm, and all parts of the plant have higher reflectance here than in the visible region. The absorption bands at 970 and 1170 nm are not due to flower petals and leaves but to fruits and stems. This absorption depends on the thickness of the object, since flower petals and leaves also have the absorption bands at 970 and 1170 nm when measured with several layers of leaves and flower petals. These wavelengths can be used for discriminating them from the other parts of the plant in the near-infrared region.

There are many other properties in agricultural products such as fluorescent properties, heating properties, and fluid-mechanic properties which also depend on the conditions of agricultural products.

3. Sensors and Data Acquisition Systems

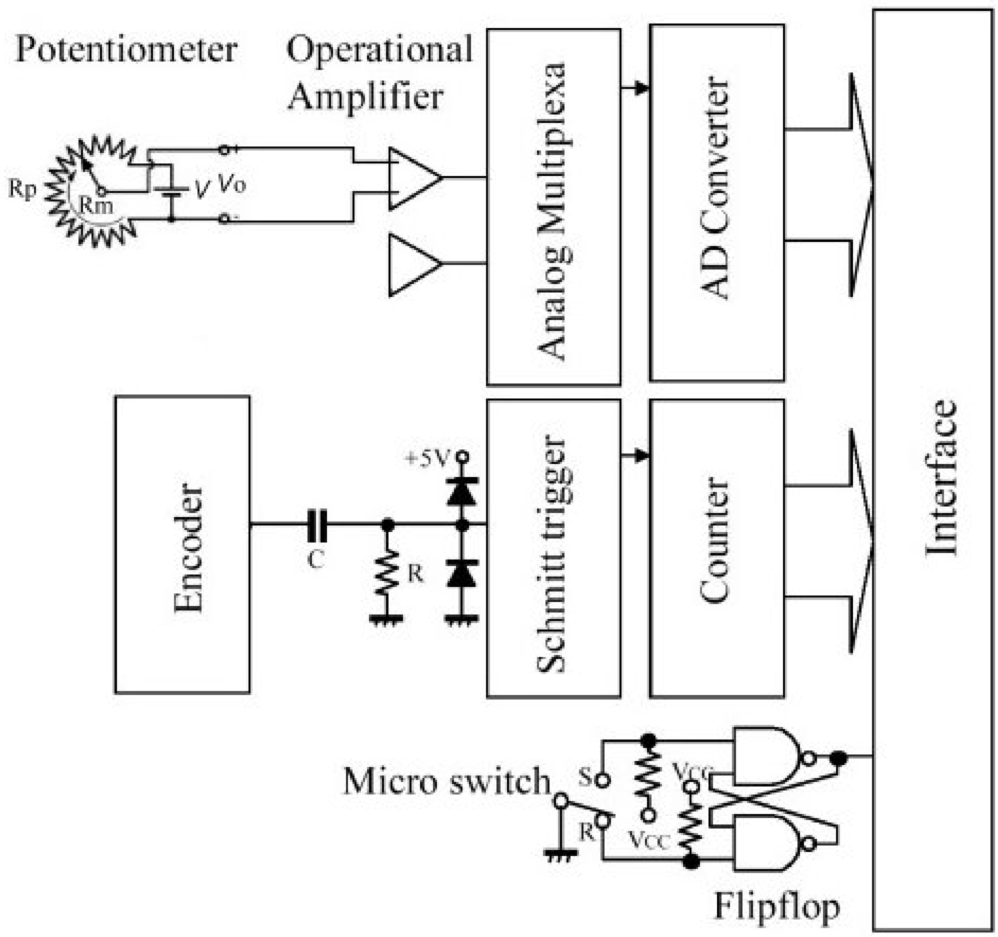

Figure 5: Input from sensor.

To measure soil, plant, animal, biomaterial and environmental conditions, many kinds of sensors are used. These include the microswitches, photoelectric sensors, potentiometers, encoders, strain gauges, pressure sensors, infrared sensors, ultrasonic sensors, position sensitive devices, laser range finders, TV cameras, GPS (Global Positioning System), geomagnetic direction sensors, gyroscopes, thermometers, hydrometers, and others. Because the signals are usually input to a PC (personal computer), an AD (analog to digital) converter is used for analog signals, while a digital counter circuit or flip-flop circuit is often used for digital signals after an electric waveform is modified. Figure 5 shows an example of a block diagram for signal input.

Recently, TV cameras have become a common measurement tool in agriculture, because of their comprehensive two-dimensional data. Figure 6 shows typical connections between a TV camera and a PC. Conventionally, analog RGB signals are input to an analog image grabber board, but more recently, digital RGB signals are input to a digital grabber board through a IEEE1394 or camera link connections. The most recent inputting systems need only a specific processing unit with basic PC functions, or just a PC with Ethernet or USB2 connection without any grabber board. Here, a typical machine vision system designed for measuring biomaterial is introduced as one of the sensors.

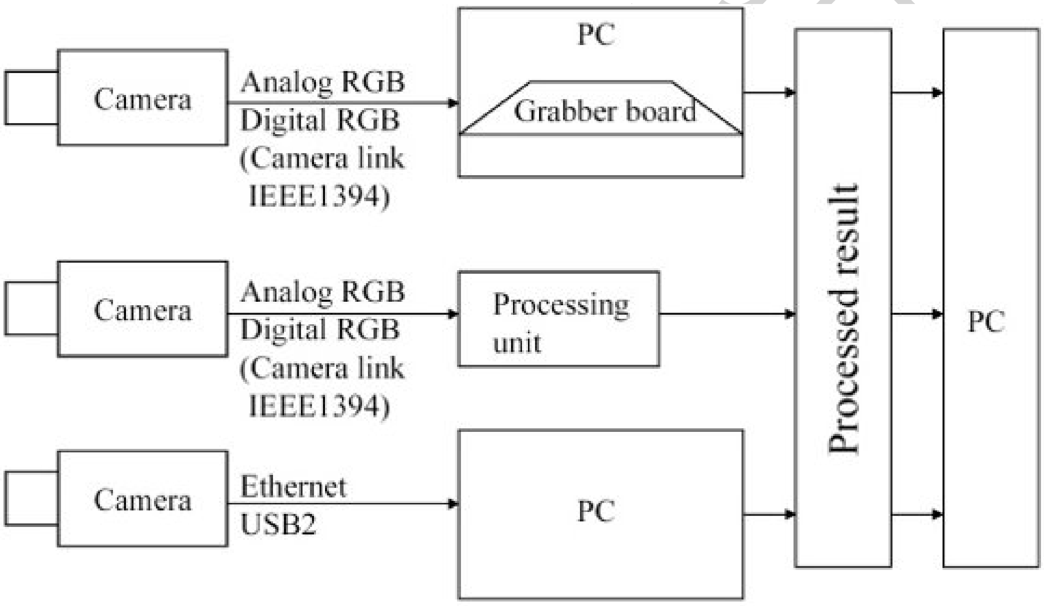

Figure 6: Interface between TV camera and PC.

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Biographical Sketches

Naoshi Kondo is a professor of Department of Mechanical Engineering, Ehime University, Japan. He had worked at Faculty of Agriculture, Okayama University, Japan as an assistant professor and an associate professor for 15 years since 1985. He developed many harvesting robots (grape, tomato, cherry tomato, cucumber, strawberry and etc.), chrysanthemum cutting sticking robot, and crop management robots in the position as professor. He moved to SI Seiko Co., Ltd. since 2000 and has developed automated fruit grading machine systems and preprocessing machines by use of machine vision systems as a manager of department of technology development and as a director. He contributed to commercialize the fruit grading robot and the real time soil sensor. He is now working on robots and automation systems in agricultural fields at Ehime University since 2006.

Kazunori Ninomiya is a research leader at department of technology development, SI Seiko Co., Ltd. He got Ph.D regarding "Speech recognition" from Yamagata University. Especially he studied clustering of nonlinear space which used the study model. After he joined the company since 2000, he has developed agricultural information systems on fruit grading systems and preprocessing machines (oranges, apples, pears, persimmons, kiwis, potatoes, tomatoes, eggplants, leeks, and etc.) by use of machine vision systems.