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Information technology: the global key to precision agriculture and sustainability

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Abstract

The paper reviews developments in technology which are contributing to global improvements in crop and livestock production, in terms of product quality, environmental considerations and the welfare of people and livestock. The means by which we acquire, apply and communicate the requisite information are reviewed under separate headings. These phases are related to the concept of precision agriculture, taken broadly, to apply to both crop and livestock production. The final section deals with current views on future developments.

Keywords: Information technology; Precision agriculture; Food quality; Environmental monitoring; Sensors; Communications standards

1. Introduction

In the 21st century we face a set of common problems but we also have a range of opportunities provided by scientific discoveries and consequent technological advances. The magnitude of some of the problems cannot be underestimated. In particular, we live in a world of rising population, with hunger—if not starvation—the lot of millions of people. It will require all of our skills and imagination to respond in an integrated way to the challenges of maintaining soil fertility; of water shortage in many parts of the world (see Tickell, 1999; Bouwer, 2000); pests and diseases affecting crops and livestock; increasingly rigorous standards for the quality and safety of food and, equally, more stringent standards for the welfare and safety

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of the farming population. In addition we must respond to any changes in systems of crop and livestock production that may be required by global warming.

To combat these problems we must look for international collaboration on an increasing scale, exploiting our ever-deepening understanding of the physical world, aided by an increasing array of tools for exploration of that world. Many of those tools can be considered under the subject heading, Information Technology (IT) since, by definition, IT is concerned with the acquisition, recording and communication of information.

In addition, we have developed—and are continuing to develop—ways of applying the information that we have gathered to a broad range of decision-making in agricultural production, as well as extending our ability to control operations automatically. These techniques can be grouped under the general heading of Precision Agriculture (or Precision Farming), which include applications to livestock production as well as the spatially-variable field operations made possible by the satellite Global Positioning System (GPS).

The following sections of this paper review the IT techniques now available to us, together with their applications to a sustainable, precision farming which is quality oriented, environmentally benign, and responsive to the safety and welfare needs of people and animals.

Finally, it reviews the directions for further progress.

2. Data acquisition

One of our prime sources of information is measurement data. To use a well-known phrase, 'if you cannot measure it you cannot manage it', even though we may have to resort to fuzzy gradations in some circumstances.

In agriculture and horticulture we have a well-established range of instruments for measuring variables such as mass, volume, temperature, relative humidity, gas and fluid flow. All are capable of working reliably in the agricultural environment, with sufficient accuracy for most purposes (Cox, 1997). Usually they are based on a sensor in direct contact with the solid, liquid or gas concerned.

2.1. Remote sensing

A new dimension was added in the 1960s, with the development of airborne and satellite platforms for remote sensing of land surface features. In the 1970s the well-known Landsat series of satellites was in use for biomass sensing and crop/soil moisture sensing, based on spectral analysis of the solar radiation reflected by plants and soils. As the performance of radiation sensors has improved, satellite and airborne receivers have provided increasingly detailed information on the reflected spectra, while fast digital processing of their output data, coupled with data fusion techniques, have led to a variety of powerful, thematic mapping presentations. The maximum size of the image pixels has reduced, too, and can now be 10 m, or less, in the case of satellite and aircraft platforms.

Related, radar-based techniques add to the portfolio of remote sensing tools available to us. Airborne, laser-based radar (LIDAR), operating in the visible and infrared (IR) bands, can provide detailed, three-dimensional information on ground cover, in conjunction with multi-spectral sensors. It can also stimulate plant fluorescence, thereby providing a means to monitor plant health on an extensive scale. Thirdly, it can be used to monitor aerial pollution, through spectrophotometric measurements that have applied for many years in NIR analysis (see Section 2.2).

Ground-based, vertical-looking radar has also been applied to monitoring insect migration (Fig. 1), as a means to track the movement of insect pests, such as the Desert locust (Smith and Riley, 1996), while mapping, airborne, ground-penetrating radar (GPR) can locate sub-surface water supplies in arid regions.

Remote sensing is particularly important for surveys of large forested areas, which are seen internationally as an essential element in a balanced, sustainable global environment, and which can be subject to devastation by initially undetected fires. Forest Ecology and Management (Arvanitis, 2000) provides extensive coverage of this subject.

2.2. Close-range sensing

At closer range tethered balloons, or even small radio-controlled aircraft, have been employed to gather photographic or multi-spectral information on crops and soils, while at ground level IR radiometers have monitored water stress in plants, via the resulting increase in their leaf temperature. Portable GPR equipment in the 500 MHz to 5 GHz frequency range has been employed to estimate the levels of the water table in some soils (Cox, 1997). However, in this area of measurement the NIR region has provided the most abundant applications, since the pioneering work of K.H. Norris at the U.S. Department of Agriculture's Instrumentation Research Laboratory, Beltsville, in the 1960s. Essentially, the spectral reflectance of a material is measured at two adjacent wavelengths, one of which coincides with an absorption wave length of a specific constituent of the material, while the other is an adjacent wavelength which is clear of the absorption band. The ratio of the two reflectances is a measure of the concentration of the target constituent. In particular, this method has been applied to the determination of crop and soil moisture; grain protein; forage quality and the nitrogen content of growing cereals.

More recently, inspection of soils, plants and animals has provided many actual and potential applications of the CCD camera, including crop harvesting and grading (Marchant and Sistler, 1993), livestock monitoring (Frost, 1997) and machinery control (Jahns, 2000). Although the digital camera does not outdate earlier forms of colour and size grading, based on simple photodetectors of many types, its capability to produce digital images suitable for subsequent processing makes it a highly adaptable tool.

Close-range sensing of the shapes and spectral reflectance features of plants and soils is now the basis for many developments in monitoring of crop growth, soil

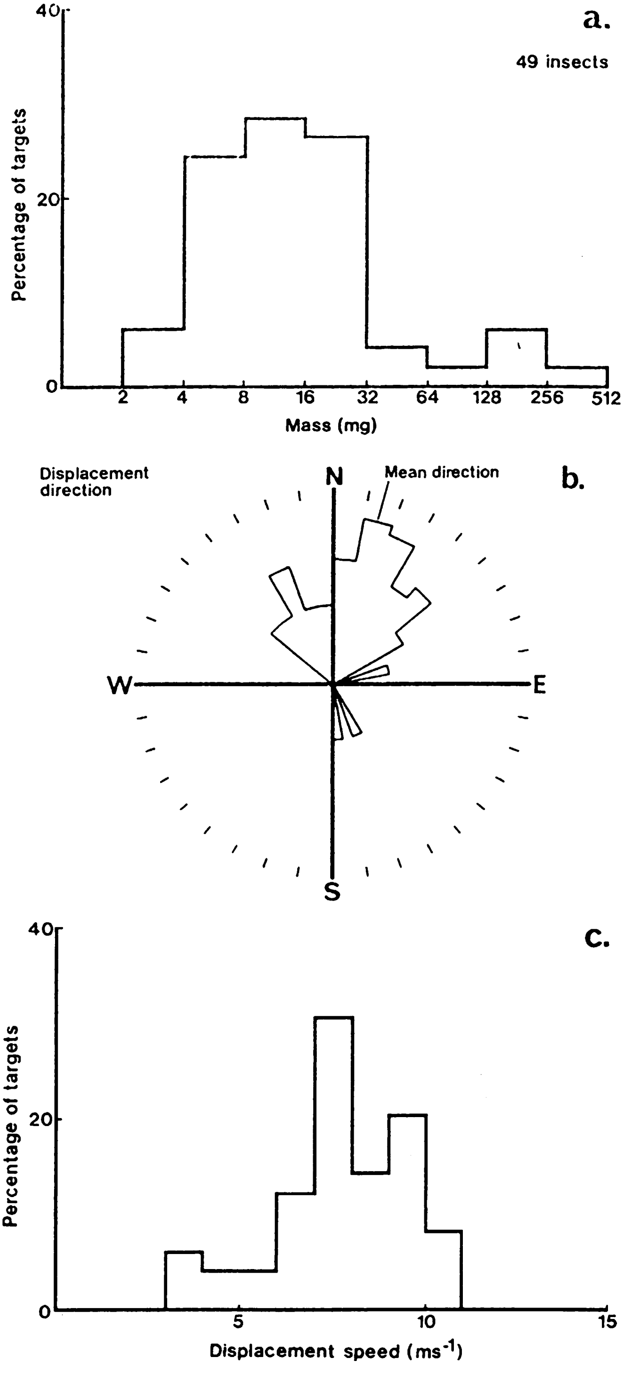

Fig. 1. The capability of vertical looking radar (VLR) to detect the mass, speed and direction of insects flying at altitudes between 195 and 540 m (Smith and Riley, 1996).

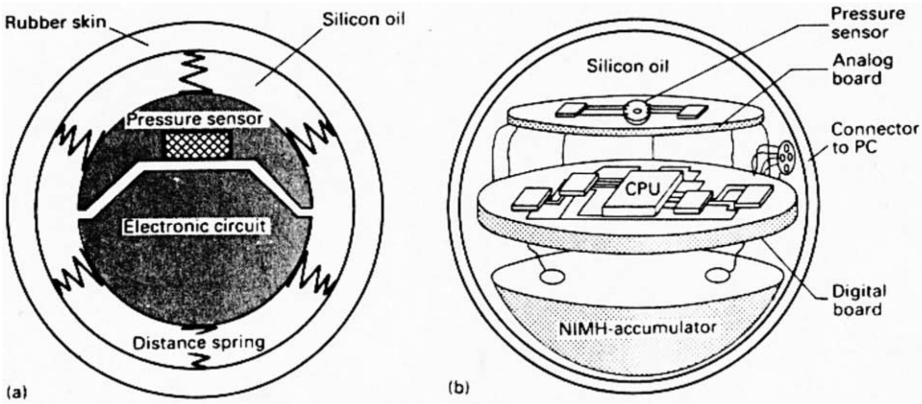

Fig. 2. Pressure measuring sphere: (a) mechanical design; (b) electronic system (Herold et al., 1996).

status and crop/weed discrimination, at rates applicable to site-specific field operations.

By contrast, non-destructive, internal quality evaluation of agricultural products on a commercial scale has not advanced substantially, despite much research performed over many years. The reason is not hard to see. The throughput rates on commercial grading lines can require a quality decision on each object in considerably less than 1 s and flow tends to be continuous. However, Muir et al. (1998) reported work at the Scottish Agricultural College, Edinburgh, in association with a UK engineering company, to market a multi-spectral imaging system for identifying signs of disease and bruising as potatoes travel along a roller conveyor. The potatoes were illuminated with visible and IR light and they were rotated by the rollers so that their entire surface could be viewed by six CCD detectors, covering the wave-range from blue to IR. It was found that the reflected light could reveal bruising of the tubers to a depth of 15 mm, and further that the reflectance spectrum could be related to specific diseases. The system could detect lesions as small as 3 mm in width and the developers believed that potentially the system could detect microscopic blemishes. The commercial prototype was expected to sort potatoes into 2–10 categories at a rate of 10 per second.

In some circumstances there may be agricultural possibilities for the application of magnetic resonance imaging (MRI). This is based on the gyromagnetic properties of the hydrogen nucleus (the proton) in particular, which can be forced into spin by a suitable combination of an applied magnetic field and an alternating electrical field (Cox, 1997). The magnitude of this nuclear magnetic resonance (NMR) is proportional to the abundance of the nuclei in the target area. It has been employed as an analytical tool since the 1960s, and it has found applications in the food industry to measure the moisture and fat contents of food products. When the test object is placed in a magnetic field with a linear gradient, and the frequency of the electric field is changed, it is possible to build up a ‘slice by slide’ internal image of an

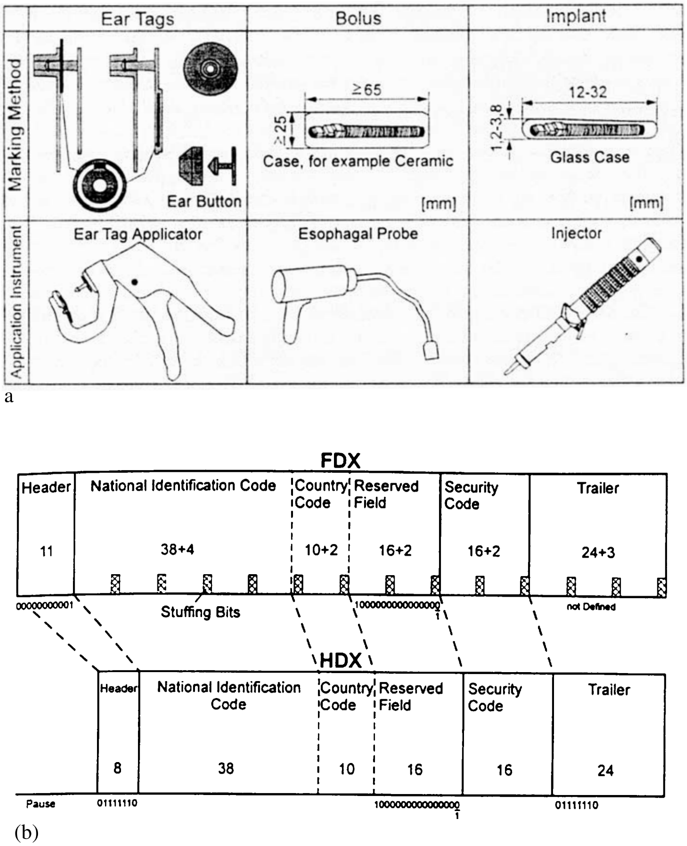

Fig. 3. (a) Animal identification transponders and application instruments: (b) ISO code, FDX and HDX operation modes (Artmann, 1999).

object. This technique has been used to detect internal defects in apples (Chen et al., 1989) but its on-line capabilities are still questionable.

Minimisation of bruising of fruit and vegetables during post-harvest operations is now an important topic, as market quality standards became more stringent. This requirement has led to the development of dummy fruit and vegetables, which pass through the handling processes and record the pressures and impacts to which they are subjected. They can provide information leading to improved design of the handling equipment. An example is shown in Fig. 2 (Herold et al., 1996). It comprises a liquid-filled rubber ball with an embedded fluid pressure sensor and microcomputer. It collects load events exceeding a preset threshold, together with their time of occurrence, and it senses static as well as dynamic loadings.

Finally, a section on close-range sensing requires a reference to the transponders in which many farm livestock carry their individual code numbers throughout their lifetime. This practice began in the 1970s, with dairy cows, as a means to match their

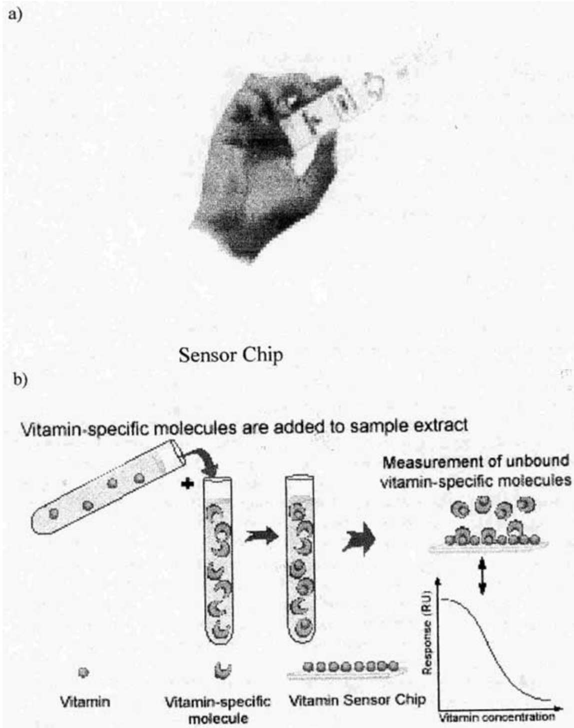

Fig. 4. Surface plasmon resonance system for thc automated analysis of foods: (a) the sensor chip; (b) the procedure. Photo courtesy of Biacore AB (Tothill, 2001).

milk output to their food intake, thereby providing an early example of precision farming.

These passive devices are energised by an external radio frequency signal from an identification unit, to which they respond by radiating back their digital code numbers (Artmann, 1999). Initially they were mounted on a collar but miniature versions are now in the form of ear-tags and, more recently, sub-cutaneous implants (Fig. 3a). These latest types are now used not only for cattle and pigs but also for domestic animals. Their purpose is to facilitate the traceability of each animal's origin, in the interests of public health as well as animal welfare, and their codes are now internationally standardised by ISO (Fig. 3b).

2.3. Chemical-specific sensors

A different range of sensors with agricultural and horticultural applications has the capability to register the presence and amount of specific chemicals or chemical groups. Solid-state, ion-selective electrodes (ISFETS) have been employed for monitoring and control of individual liquid nutrients (Cox, 1997). More recently, the requirement for increasingly stringent environmental monitoring of air, soils and watercourses has stimulated further developments of sensors which respond to particular chemical species.

Many of these are categorised as 'electronic noses', a name attributed to Gardner (Gardner and Bartlett, 1999). Essentially they mimic our noses in their function, since they incorporate a group of sensors, each of which is partially selective to a particular chemical group. Their electrical outputs have considerable agricultural application (Byun et al., 1997; Morimoto et al., 1997).

Others, classified as biosensors, employ a range of receptor molecules with biorecognition properties (Tothill, 2001). These include antibodies, enzymes, cell receptors and nucleic acids. They are convenient for portable sensors (Fig. 4) or for on-line use, and their range of application is constantly increasing. At the same time their size is being reduced to the scale of 'a laboratory on a chip' (Morgan, 2000).

2.4. GPS and DGPS

Major developments in agricultural practice emerged over the past decade, through exploitation of the position-fixing potential of the American NAVSTAR constellation of satellites. The literature on this system is already voluminous and it continues to grow via conferences and publications of many kinds. It is the basis for extension of the spatially variable field treatments commonly employed by small farmers (Wang, 2001) to large-scale farming (Stafford, 1996). Indeed, it is frequently regarded as synonymous with Precision Agriculture or Precision Farming, although it is not the only source of increased precision in farming as stated in Section 1.

To summarise here, each satellite in a constellation of 24, in known orbits, has an atomic (caesium vapour) clock, which is an international time standard. Time synchronisation of the coded signals transmitted by the satellites provides the basis of the system, which allows a ground level receiver to compute its range from each satellite currently in view, and hence—via the measured range to three or more satellites—to compute its position on the earth's surface. The inevitable errors can be reduced by various corrections (Auernhammer, 1994).

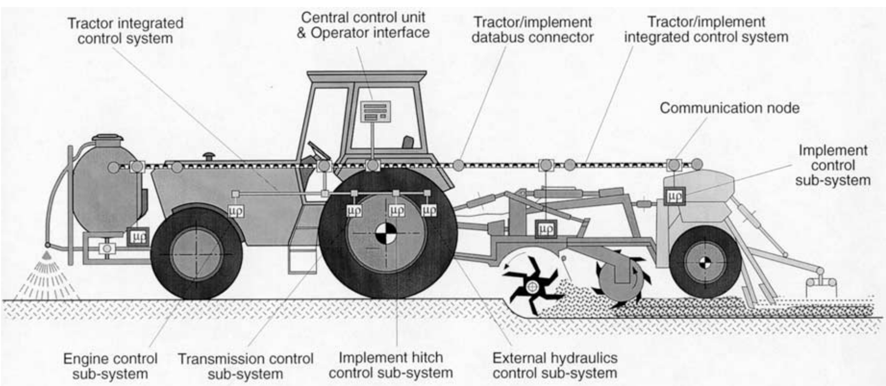

Fig. 5. Proposed structure of integrated control system (after Auernhammer) (Scarlett, 2001).

During the period of Selective Availability of the satellite transmissions to civil users (i.e. downgrading of the potential accuracy available to them) corrections were made possible by the introduction of the differential (DGPS) system. This requires a receiving station, at a precisely known location, which can compare its space co-ordinates with those calculated from the satellite transmissions. The error can then be transmitted by wireless communication to machines in the field.

SA was turned off, by order of President Clinton on 1 May, 2000, thereby restoring the conditions under which Larsen et al. (1994) had demonstrated the ability of GPS to control the location of a field vehicle to plus or minus 2 cm. However, that level of precision (and better) was already available commercially with Real Time Kinematic DGPS equipment and is the basis of current research on field vehicle guidance, or as a steering aid (Van Zuydam, 1999). RTKDGPS employs the two frequency transmissions from each GPS satellite (Kruger et al., 1994).

3. Data utilisation

We can utilise the data that we gather by any of the above means in the interests of sustainable precision agriculture. Broadly, we can do this in two ways: first, to monitor and control the machines and equipment that we use, or the environment in farm buildings; and second, to provide inputs to management decision making.

3.1. Monitoring and control systems

In the field, vehicle and implement monitoring and control has advanced rapidly over the past decade, in step with the increasing use of electrohydraulics. On-board sensors monitor a range of engine and transmission parameters, implement draught and position; ground speed; wheel slip; spray rates; seed and fertiliser delivery. The farmer can collect data on workrates, areas covered, fuel consumption and materials applied. Manufacturers are now moving towards comprehensive, integrated monitoring and control based on distributed microprocessors (Fig. 5). Cereal

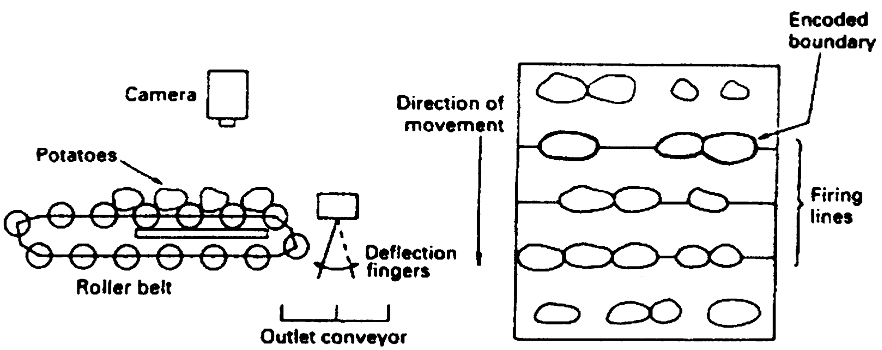

Fig. 6. Thresholded images of potatoes as a basis for size grading (Marchant et al., 1990).

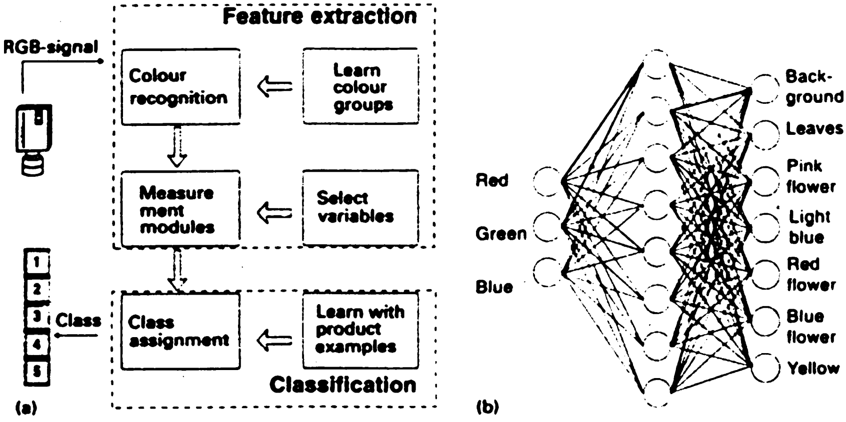

Fig. 7. Automatic grading of ornamental pot plants, based on an artificial neural network. (a) System; (b) ANN (Timmermans and Hulzebosch, 1996).

harvesters operating in both the northern and southern hemispheres are fitted with GPS systems, together with continuous yield monitors of several different types, as a means to determine local yield variations.

The Claas company has also put into serial production an automatic steering system for a cereal harvester (Hieronymus, 2000). This employs a forward-looking, horizontally swept laser beam from a unit that is mounted at one end of the cutterbar assembly, below a photodetector. Reflected light from up to 14 m ahead of the cutterbar returns to the photodetector, which detects the crop edge and operates an automatic control system to steer the harvester along the uncut edge of the crop. The system can work in dusty conditions and it can continue to steer the machine for short lengths where the crop has been beaten down by wind or rain. At other times the driver must take over the steering. This system can take over more than half of the driver's workload. The driver is then free to attend to the other demanding tasks needed to keep the machine working at optimal efficiency.

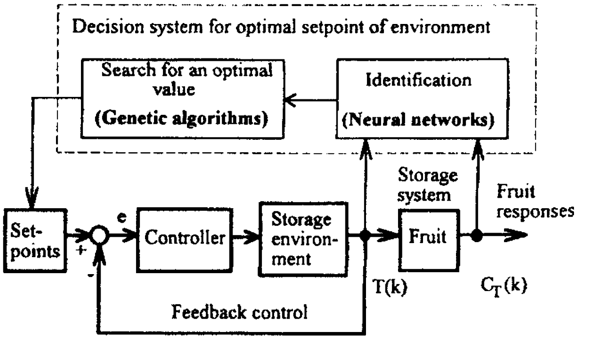

Fig. 8. Optimisation of heat treatment for fruit (Morimoto et al., 1997).

The New Holland Company has demonstrated a self-propelled, unmanned windrower (Rider, 1998), operating on GPS data. Even without the aid of GPS this machine cut a tall grass crop, using a video camera and sensors which kept it on line. The Company also joined with NASA and the Carnegie Mellon University in Pennsylvania, to develop ‘Demeter’—designed as a prototype for large mobile machines operating in rough field conditions. The Company’s plans include a range of unmanned machine operations, based on machine vision.

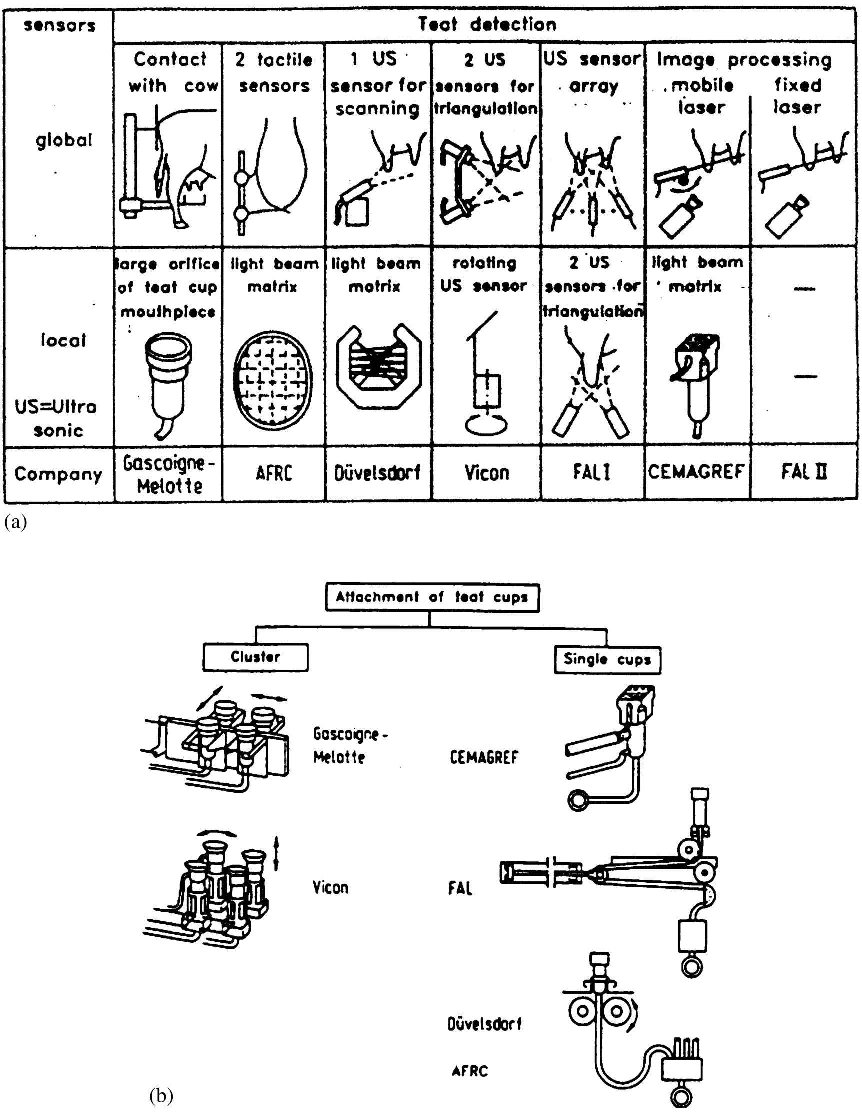

Fig. 9. Robotic milking machines: (a) teat detection; (b) teatcup attachment (Ordolff, 1997).

Monitoring and control systems based on machine vision have many applications in agriculture and horticulture. As already noted, they frequently employ the CCD camera. Processing of the resulting images involves now familiar operations such as thresholding, to remove background detail, and the use of contour-fitting-algorithms—for example, to monitor animal movements (Tillett et al., 1997). It is often the first stage in produce-grading systems (Fig. 6), some of which now employ artificial neural networks and knowledge-based expert systems.

An application of the ANN is provided by Timmermans and Hulzebosch (1996), who developed an adaptable commercial system for automatic grading of ornamental plants grown in pots. The system was required to grade them by size, shape and colour (Fig. 7). The necessary training of the network to recognise and classify the desired quality features was based on the knowledge of human experts. That did not qualify as an expert system in the usual sense, because there was no elicitation of expert rules (knowledge engineering) for incorporation in the software programme. Nonetheless, it proved an effective analogue of the experts' judgements, since its colour misclassification was less than 0.1% at a throughput rate of 3000 plants per hour.

AI techniques are also being applied to crop production in heated glasshouses. This plant production system is costly and there is general concern to reduce its energy requirements on both cost and environmental grounds (Bot, 2001). Optimal control strategies are now being applied to this form of crop production, bringing in fuzzy control and the use of genetic algorithms to search for near-optimal settings (Sigrimis and King, 2000).

A wider range of applications of AI to agricultural systems can be found in Hashimoto (1997), Farkas (2000). These include the use of plant responses to modify environmental control strategies—the so-called 'speaking plant' concept—Murase et al. (1997). Morimoto et al. (1997) applied this concept to stored fruit (Fig. 8). Morimoto and Hashimoto (2000) added fuzzy control. Thysen and Kristensen (2000) include a paper on pattern recognition (Perez et al., 2000) employing shape analysis techniques for detecting broad leaf weeds in cereal crops. The aim is to facilitate patch spraying of weeds, in the interests of herbicide economy and environmental safety.

In the livestock sector, the advance of monitoring and control systems has led to the development of robotic milking machines (Ordolff, 1997) now being marketed by several European manufactures. Essentially, they require means for automatic attachment of the teatcups which connect each cow to the vacuum milking line. The cups must be applied firmly but gently to the cows' teats, avoiding damage to the cow and the likely consequent damage to the machine. The economic justification for these expensive units is that they offer each cow the opportunity to be milked more often than the usual procedure (twice a day). This is beneficial for the cows and it increases milk yield. The extra cost can be recovered through labour savings, it is believed.

This means by which the cows' teat positions are determined and teatcups are attached vary from manufacturer to manufacturer (Fig. 9). A recent commercial system (Kimm and Heyden, 2000) employs a database in which the geometry of each cow's udder is stored. These data are updated daily to take account of changes in udder height and teat position. The cow is identified as it enters the milking stall, since it carries one of the transponders referred to in Section 2.2.The cow's position is determined by ultrasonic range sensors on each side and to her rear, while the final placement of the teatcups is controlled by a light-sensor matrix and ultrasonic sensors in the cup gripper. When all four teacups have been attached to the cow, the attaching device travels to the next milking place and the next cow.

3.2. Modelling

Much data gathering is related to the need for quantitative inputs to management aids of several kinds. Field data on crop yields are the inputs to the now familiar yield maps produced from spatial yield data. See Godwin et al. (1999) for examples of the data-gathering techniques, Oliver (1999) for the interpolation techniques (geostatistics) and Blackmore (2000) on the interpretation of trends from year to year.

Decision support systems (DSS) of many kinds have been described in the scientific literature. Recent examples can be found in papers presented at the first European Conference for Information Technology in Agriculture—Rijgersberg and Top (2000), Jorgensen (2000), Madsen and Ruby (2000), Jensen et al. (2000). Others relate to habitat creation or sustainability. Gilbert et al. (2000) provide an example of the former type.

Simulation models provide insights into the relationships between variables and their influence on the behaviour of systems, also of many kinds. In the DSS context these are exemplified by three recent publications: Parsons (2000), Sells and Audsley (2000), Shaffer et al. (2000). Parsons employed genetic algorithms for optimal decision making. Sells and Audsley used a whole-farm planning tool to optimise

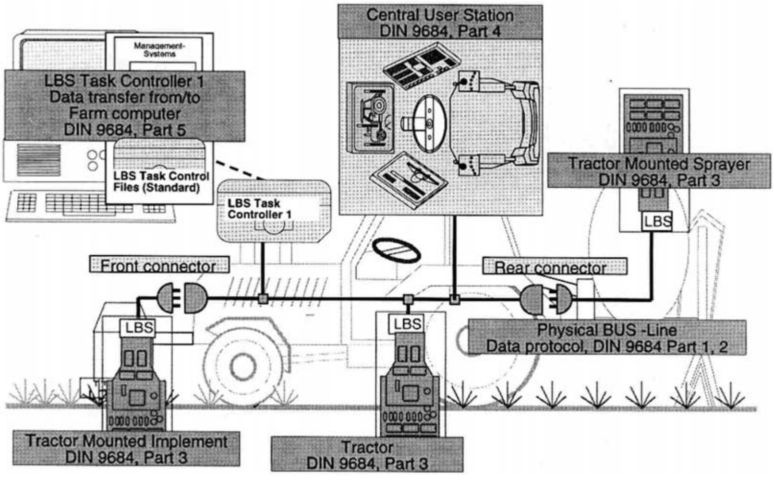

Fig. 10. Agricultural BUS system: tractor-implement unit (Speckmann and Jahns, 1999).

profit within environmental restraints. Shaffer et al. applied object-oriented programming (OOP) to the simulation of integrated whole farms.

In the environmental context, significant use is being made of computational fluid dynamics (CFD) as a means to model (and, hopefully, to control) the spread of airborne contaminants, in particular (Quinn et al., 2001).

Ultimately, the value of all these modelling systems depends on their validation and testing by reference to measurement data. The requirement to subject these models to such validation cannot be overemphasised. Furthermore, no model predictions can legitimately exceed the accuracy of the available test data!

4. Communication of information

This is the final—and crucial—phase of IT. Information must be transferred to the right target, and in the right way, or it will be at the best ineffective and at worst potentially hazardous.

This process can be examined under three sub-heads, as follows.

4.1. Data interchange: machines

In Europe, German agricultural engineers have taken the lead in establishing standardised data transfer on field machines (Speckmann and Jahns, 1999). They have developed LBS (Fig. 10), which is a version of the Controller Area Network data bus (CAN) developed by the Bosch company in the late 1980s. LBS is now a German (DIN) standard.

LBS provides data communication between electronic control units (ECUs) to exchange data between sensors which monitor the machine's engine, its transmission and connected implements, for effective co-ordination of their operation. There is also a related American standard and, in time, there should be an agreed ISO version.

4.2. Data interchange: machines and people

This can be in the form of information to a machine operator, or to the farm manager, for decision-making or record purposes. Today the former category includes the Graphical User Interface (GUI) which we all associate with the digital computer. Within the past decade graphical displays have been introduced into the driver's cabs of cereal harvesters, then to larger tractors. Initially, they were rudimentary in their level of 'user friendliness' and sometimes difficult to interpret because of their location in the cab. However, the latest in-cab displays are more conveniently located in a console, grouped with electrohydraulic controls and indicator lights, to provide an ergonomically satisfactory arrangement as indicated in Fig. 9a and b 'Central User Station'. In general, the importance of the Human Machine Interface (HMI) is becoming better understood, since accident statistics in agriculture do not show the decline that has occurred in many other industries, despite increasingly stringent safety regulations. Berge (2000) comments on this point. Agricultural workers are particularly vulnerable in this respect, since they often work alone with powerful machinery in conditions that can be hazardous. Apart from these considerations, well-designed controls can reduce the driver's fatigue and can improve his performance, as Kutzbach (2000) has noted.

The safe and reliable transfer of data from field machines to the farm office for management purposes is also of increasing importance, as farm managers seek to improve efficiency in a competitive environment and to provide the detailed information on their operations required by administrative agencies of various kinds. For field machines Auernhammer et al. (2000) therefore advocate the integration of the LBS/DIN system with GPS and an implement indicator (IMI) which makes the identification of implements automatic. However, they recognise that its adoption requires co-operation among all the major suppliers of tractors and implements, if this is to become an 'open' system.

The means of transferring digital data from machine to office has been mainly the plug-in card of the PCMCIA type, although radio transmission offers another option, in suitable conditions. The amount of data can be substantial: Stafford (2000) has pointed out that Precision Agriculture, in particular, is information-intense.

4.3. Information exchange: people to people

Methods of information transfer (including data transfer) have been revolutionised by the development of the Internet, despite the ever-present threat of computer viruses and other well-known problems. The speed at which textual and graphical information can now be relayed around the world has transformed many aspects of our lives to our considerable (if not universal) advantage. This revolution is ongoing, as we all know. However, it raises ethical issues relating to system design, privacy and other important aspects of computer systems, as discussed by Thomson and Schmoldt (2001).

5. Future developments

Many aspects of the future developments of agriculture were discussed at the AgEng2000 Conference of the European Society of Agricultural Engineers, held at Warwick University, UK in July 2000, The Conference opened with an address by the Director-General of all the UK Research councils, Dr John Taylor. He introduced the attendees to an emerging world of globally collaborative e-science, with communal databanks of 10^{18} bytes; data transfer rates of 10^{12} bits per second, and online, collaborative modelling. He also quoted predictions that over the next two or three decades computers will exceed people in brain capacity. Subsequent keynote speakers introduced the following predictions.

Crop genetic manipulation—in the interests of growth efficiency; stress tolerance and food quality for human and animal nutrition—will require physical or chemical sensors to monitor microclimate and pest infestation, possibly augmented by 'indicator' plants. These plants would be genetically tailored to signal changes in their environment in ways that could be monitored in real-time (in other words, an extension of the 'speaking plant' concept). They would provide inputs to management models. Improved growth efficiency could lead to more precise control of crop inputs, in association with detailed terrain mapping, linked to position sensing. Some of these advances would be relevant to the built and recreational environment, as well as production agriculture in a global economy (Pollock, 2000).

In dealing with strategic themes in agriculture and bioresource engineering in the 21st Century, Jongebreur (2000) included progress in precision agriculture; intelligent climate control, involving electronic communication with models and databases, without human interference; biomonitoring.

Krutz and Schueller (2000) foresaw that the coming decade will feature multi-disciplinary research teams of scientists and engineers, working on new materials, biosensors, bioelectronics and microelectromechanical systems.

Bunch (2000) had found little evidence that agricultural engineers had made significant contributions to the welfare of the increasing numbers of resource-poor farmers around the world.

To take the last view first, the difficulties of helping those people are immense. Nevertheless, IT has been applied to these problems with funding by national and international agencies, including the Food and Agriculture Organisation (FAO). While these projects may be limited to the supply of DSS for planning authorities or field advisory services (for example, Amha et al., 1994; Crossley, 1998) they can help to provide the first steps towards a more secure and better standard of living for the people concerned.

6. Conclusions

For the economically more developed world, the possibilities are both challenging and exciting. We can look forward to massive increases in computing power and data transfer rates between globally distributed computers. We can expect an equal increase in multi-disciplinary research, particularly in the sphere of bioengineering.

IT has a central role in these developments. We need the spread of knowledge and skills that it engenders, worldwide. It fosters the essential communication between all those concerned with food production and the environment from research through to the farmers and field workers in the general sense, everywhere.

The material cited in this review provides evidence of worldwide exploitation or the potential of IT and, equally, of the promotion of precision agriculture in its broadest sense. It is also evident that skill and imagination (vide the Introduction) are being applied in adapting technology to the complex requirements of food production and the rural environment more generally.

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