The Past, Present & Future Of Image Processing Systems Engineering - A Personal Perspective

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Abstract

This paper will discuss a series of pioneering projects in which machine vision technology has been developed and applied to specific measurement and inspection tasks. It covers the period 1975 to date and starts with a brief account of the design of one of the first stand-alone microprocessor and solid-state camera-based systems. The final section contains personal, speculative predictions on the future of image processing systems engineering. The remainder of this paper is written in the first and second person as it reports personal experience and opinion. Most of the projects have involved the development of the hardware and software of complete systems.

Keywords: Image Processing Systems Development, Remote Sensing, Image Analysis

An Early Remote Sensing System

Research carried out by the author in 1975 in collaboration with Dr F.M. (Fred) Cady had led us to realize the potential power and flexibility to be gained by combining a microprocessor with a charge-coupled device digital camera. With funding from DSIR, the New Zealand Scientific Service, we developed a system to be flown in a light aircraft to calibrate and compensate satellite imagery for the effects of the atmosphere. Multi-spectral images were to be captured at the same time as a satellite overpass to enable this to be done. Satellite remote sensing has many advantages over non-orbital means of remote sensing. Our project was to develop a flying fast area digitising scanner (FADs) to demonstrate the practicality of remote sensing with solid-state arrays. The first system developed was based an 8080 microprocessor and a Fairchild CCD 202 100x100 element CCD camera of our own design. The camera incorporated a Peltier-effect thermoelectric cooling device and a solid-state temperature sensor. Together with a feedback temperature controller they allow the CCD array to be maintained at a predetermined temperature in the range –12°C to +30°C. Within the array each element can be characterised by a dark current and a gain. By operating the array at a fixed and controlled temperature a simple two point calibration is sufficient. The data rate from the camera, 10,000 8 bit words in 100 ms, is faster than the maximum data storage rate then available from inexpensive tape storage systems. The microcomputer random access memory (RAM) was therefore used to provide buffer storage. Since the basic instruction cycle time of the 8080A microprocessor would not allow data to be stored at the required rate, a direct memory access (DMA) controller was developed). The microcomputer system incorporates an Intel SBC8080/10 single board computer, 16K of RAM and 4K of PROM). Figure 1 shows a block diagram of the system.

In late August 1979 the system was installed in a Rockwell Turbo Commander aircraft of New Zealand Aerial Mapping Services and test-flown along part of the Hawke's Bay coast north of the Wairoa River. This work culminated in a successful flight trial and numerous well received publications including [1] [2] [3]. Example early images will be shown at the conference. A system design for a high-resolution, multi-spectral, multi-camera system was subsequently developed [4].

UCIPS – An Early Interaction Image Processing System

In spite of its modest hardware the system described above was found to surprisingly useful as an interactive stand-alone image processing system. In this form the system became known as UCIPS for the University of Canterbury Image Processing System. UCIPS was one of <u>the</u> first microcomputer-based interactive image processing systems to be described and probably the first in the southern hemisphere! The system and its software are comprehensively reported in [5] [6]. The UCIPS system proved to be reliable and useful. The 10K image size was a good match to the 64k byte RAM space allowing two processed images to be toggled on the display for comparison between original and processed images.

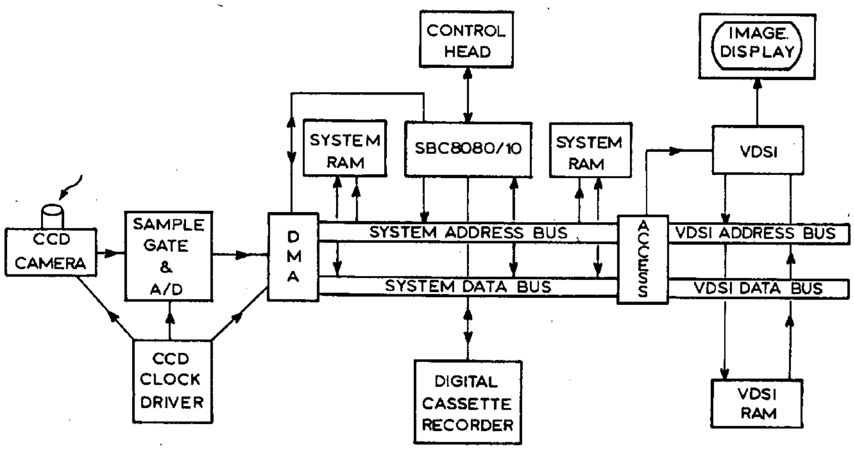

Figure 1: FADS – Fast Area Digitising Scanner

The system was used in a number of pioneering studies including the following; the use of spatial filtering algorithms for the reliable early, *in vivo,* detection of multiple pregnancies in sheep by radiography, optical bench simulations of astronomical, speckle interferometry [7], the measurements of leaf areas, stem discs in forestry studies and finally, the development of algorithms for fruit and produce inspection. The algorithm developed for kiwifruit inspection will be briefly demonstrated at the conference. The strategy used was to process the original image to yield an image of the same fruit as if perfect and then to compare it with the actual [8].

Discussion

Image capture involves the transduction and quantization of images, processes that are often poorly understood especially when digital images are merely considered to be pictures. The complete design of a system for a particular application involves specialist disciplines including; optics and image formation, solid-state sensor physics, analogue to digital conversion, algorithm development, computer hardware specification, information display and sometimes, mechanical control. Many system design parameters interact to a troublesome degree. The early projects briefly described here involved using a solid-state array camera to make scientific measurements and demanded that we thoroughly understood the transduction and quantization processes. This background was very helpful in later projects. The remote sensing project and flight trials also established the viability of operating a two dimensional array in the glimpse mode. In a manner analogous to the use of conventional camera, the solid state array was used to rapidly, in say 10 ms, capture images at relatively longer intervals, say 10 s.

Special Purpose Systems for Tree Scanning

The second case study reported here concerns the development of specialist scanning technology for the measurement of critical features of large growing, plantation pine trees for pre-harvest assessment. Assessing the potential yield of a stand of trees is one of the basic concerns of commercial forestry. The TreeScan project [9] had as its aim the design and construction of a proof-of-concept prototype system. This was to be capable of capturing images of trees and transferring them to a portable computer for analysis at the rate of at least ten per hour. The system was to be capable of operation under the normal forest conditions including a low and variable level of natural lighting, rugged terrain, a large variation in possible tree sizes and the presence of undergrowth. The accuracy was required to be plus or minus 0.5 m in height estimates and plus or minus 0.5 cm in stem diameter estimates. This directly translates to an image resolution of 8000 by 200 for a 40m tree. In addition to stem sweep (curvature) determination, the estimation of branch diameter and location was to be desirable, as was the capability to capture pairs of calibrated orthogonal images. We soon eliminated all possibilities other than a line scan camera viewing the "world" via a scanned mirror. The scanning mirror subsystem consisted of a shaft carrying the mirror and a worm-wheel drive with a 728:1 ratio and a minimal backlash. The precision rotation mechanism must produce accurate and repeatable mirror positioning with minimal gear backlash. The mirror rotation per line for a 40 m tree and 8000 pixels led to a mirror rotation per line requirement of 0.005 degrees and a shaft alignment repeatable to 0.01 degrees. An investigation of the lighting conditions in the forest and a series of conventional photographic studies of typical trees also led us to realise a need to adjust both the integration time and focus at regular intervals during the scanning of a tree. The final system captured images in blocks of 50 lines, scanned from bottom to top and adjusted focus and integration time after each block. The system finally gave consistent images of a high quality and no mechanical failures have been experienced.

Calibration Evaluation and Testing

Evaluation of an instrument such as the TreeScan typically involves iterative testing cycles. As the capability of the system becomes fully understood, any limitations are identified and modifications are made. First both the hardware and the software must be characterised and calibrated. Then the system has to be tested in a controlled environment and finally tests carried out in a typical forestry environment. Height estimates were typically correct to ±10 cm at a height of 30 m and ±25 cm at a height of 40 m. Size estimates of, for example branch widths, were correct to within ±1 cm up the full length of the tree for a typical 14 cm diameter branch. Test results also showed that sweep could be accurately determined to ±2 cm which relates to a typical sweep classification of one tenth of a stem diameter. The field trials of the TreeScan system established that the system could be reliably operated in the plantation forests and that the data generated was accurate and consistent.

TreeScan V

The original system served as a "proof of concept" and as a scientific instrument provides a benchmark against which alternatives can be compared. A major shortcoming of the system was its slow image capture rate of up to five minutes per image. This rate was a function of the light level in the forest. It also needed technically sophisticated operators. This made it unsuitable for routine measurements. See also the next section for further discussion of this matter. As a custom design incorporating precision engineered components the original TreeScan system was also expensive to replicate. The second-generation system was called TreeScanV: the "V" indicating the use of a video camera/recorder. The new design mainly used off the shelf components and a commercial camcorder rather than an industrial line scan camera and specially made precision mechanics. This made the new system easier to replicate and reduced manufacturing cost of the field unit to a third of the original cost. The TreeScanV system uses a scanning platform and a small video camcorder to capture a series of images along the stem of the tree. The images are collected with a small degree of overlap to construct a composite high aspect ratio image. The sub-images are registered and combined together using a spatial frequency domain correlation technique [10].

The field equipment is used to record images of the trees and associated data onto video tape so that both the data and images can be automatically extracted by a personal computer. The functional block diagram of the scanning platform is shown in figure 2

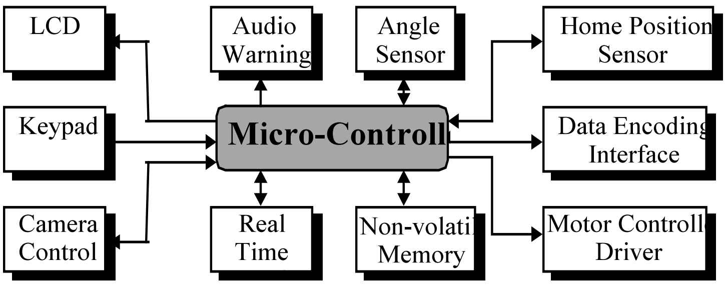

Figure 2: Scanning Platform System

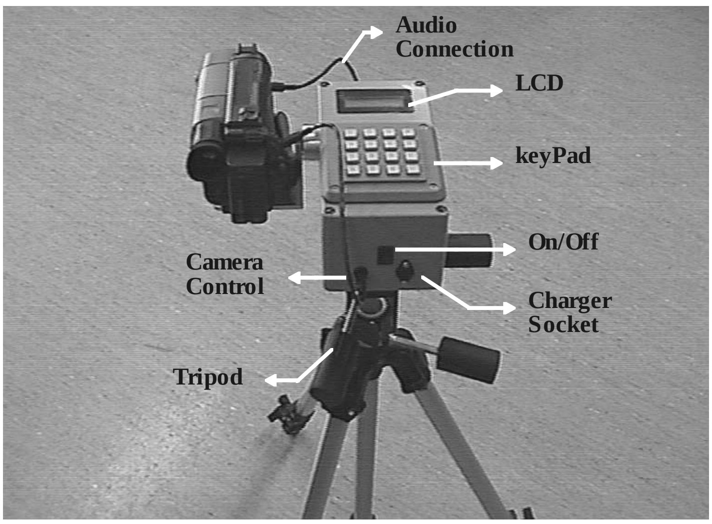

Figure 3: Field equipment, from Nourozi (1997)

The base computer is a PowerPC Macintosh with 604c processor and 64MB of RAM and internal video digitizer. It is used as the controller and processing unit of the system. A Sony Hi8 video player with S-Video output is used to play back the recorded tapes. The video player is equipped with the LANC interface and its operation is controlled by the computer through a specially developed interface unit. The images produced by the system each occupy to 8 MB depending on the distance of the camera from the tree at the time of recording. A CD-ROM writer unit is used to archive images. Limited field trials were performed on TreeScanV but unfortunately the project has become an indirect casualty of the economic downturn in 1999.

Discussion: Technology Transfer and Technological Mastery

Towards the end of the development of the original TreeScan system we realised that for the system to be successfully adopted, a new technology would have to be transferred to our client. Capital goods can be transferred but they do not represent a technology only that part of the technology embodied in the hardware. The remainder consists of disembodied knowledge, which can be transferred, but the ability to use it effectively cannot. This ability can only be acquired through technological effort defined as "the use of technological knowledge together with other resources to assimilate or adapt existing technology, and/or create new technology". The combination of technological knowledge and technological effort leads to technological mastery defined as "operational command over technological knowledge, manifested in the ability to use this knowledge effectively and achieved by the application of technological effort". Dahlman and Westphal [11] also emphasise that mastery results from effort and not transfer. and range image filtering (as a processor for kiwifruit inspection images) [14] [15], a liquid nitrogen cooled linear diode array based readout system for an astronomical spectrometer, and more recently, the Kea project that has involved the development of a DSP and CCD array based image compressing and watermarking intelligent camera for security applications. The Kea project was carried out by a joint industry – university team with the university team providing critical technology transfer and image capture and signal processing skills. Technology transfer was facilitated by an industry funded graduate student who completed a PhD degree on aspects of the project then rejoined the company. This project has been reported in several papers [16] [17] and will be briefly described during the conference.

Image Analysis and Artificial Intelligence Projects

In addition to the hardware and software system projects mentioned above, the author has been

Technology is characterised by a considerable element of tacitness, difficulties in imitation and teaching, and uncertainties regarding what modifications will work and what will not. The key aspect of mastery is that it involves active involvement in the technology by generation, application or modification. Mastery is relative and cannot be fully quantified, see Hodgson [12] for a more complete account of the model summarised here.

The research and development program discussed here has led to the development of new systems and the mastery of a new specialised technology. That mastery continues to reside with the university group that developed it. It was realised that our client neither has technological mastery nor a wish to acquire it. The development of TreeScan V was an attempt to eliminate the need for our client to have technological mastery by the development of a device that is technically undemanding and simple to use. TreeScan V encapsulates a sophisticated technology in what could be described as a specialised appliance. In designing systems for industrial clients it is very important to determine both the specification for the systems and the level of technological mastery aspired to by the client. If there is a mismatch of expectations then successful technology transfer is unlikely to occur.

Further Hardware Systems Development Projects

In addition to the projects briefly described above the author has been involved in numerous hardware and system developments including; the development of further stand-alone image capture and interactive processing systems [13], a multiprocessor system based on the intel Multibus, a chip for real-time rank

involved in numerous image analysis projects and projects related to biologically inspired image processing [18] and artificial intelligence. Two unusual image analysis projects were the application of statistical texture analysis techniques to the monitoring and measurement of wear in wool carpets [19] and the application of texture and other measures to the characterization of the microstructure of the carbon anodes used in electrolytic aluminium smelters [20].

Biologically inspired image processing has been a life-long background interest, the best known and reported research work was an investigation of log polar mapping techniques in pattern recognition [21]. Over the past ten years research has been undertaken into the use of neural networks and fuzzy neural networks in learn-by-example image processing. The long-term aim of this work had been the development of image processing systems for domain experts who have a strong understanding of an application but little or no expertise in algorithm development. The essential aspect of our technology is to introduce existing problem knowledge into a neural network before training it. Good results have been reported [22] [23] [24] in applications including tree counting in aerial mapping images and the detection of calcifications in digital mammograms. This work continues.

The Future of Image Processing Systems Engineering

In the previous sections of this paper, I have, in effect presented my credentials as an image processing systems engineer. Early work on stand alone remote sensing and image processing systems involved learning the skills of a "pixel mechanic"; later projects in image analysis were essentially exercises in software development. The development of the Treescan systems and the intelligent security camera (Kea) were exercises in systems integration calling on skills from earlier projects. A characteristic of all of this early work was that the systems developed were very specialized and fragile to changes in operating conditions or system specification. My long standing interest in biologically inspired image processing together with our work on connectionist architectures have led me to the conclusion that a second era is about to dawn in digital image processing. It is my considered view that the three paradigms of evolutionary computing with genetic algorithms at its core, neural networks and fuzzy logic are rapidly leading towards flexible artificial intelligence which when approximately applied to image processing applications will result in adaptable and resilient image processing technology to service the needs of man for good or evil.

Conclusion

The case studies described range from remote sensing on a scale of 30m by 30m per pixel to investigations of microstructure at a scale of 40 pixels per mm and from the measurement of texture in carpets as they wear to shape and branch size measurements on 30m pine trees in the forest. It is concluded that the applications of digital image processing to measurement almost know no bounds.

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