Development of a programmable aeration controller

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Abstract

This paper describes the development of a remotely accessible (via modem) PC-based system for the control and monitoring of aeration systems. The system comprises a PC and interfacing hardware, modem, weather station and sensors in the grain. This system offers more flexible and efficient control of aeration, reduced maintenance costs and more efficient supervision by regional offices of storage sites which are often difficult to access. As a research tool, the system has similar benefits. In particular, access to data and system status via the telephone network saves time and travel expenses, and reduces the dependence on local operators for collecting information. The programmability of the system ensures that it can be easily adapted to different control strategies and new applications as these are developed.

Information gathered in the first two years of trials of the system will be used to improve control algorithms and to verify mathematical models of heat and mass transfer in grain stores under aeration. These trials have already demonstrated the feasibility and usefulness of such remotely controlled systems.

Introduction

There has been little recent work on aeration controllers in Australia. Existing systems have only a single mode of operation, whereas microprocessor technology offers greater flexibility and improved performance.

The PMCAM (programmable microprocessor control and monitoring system), also known in the control industry as a SCADA (supervisory control and data acquisition) system, is a multipurpose computer-based data control system which can be programmed to control aeration systems, log system information and allow remote control and monitoring and remote collection of data.

The failure of unattended systems is not always apparent on casual inspection. With a microprocessor controller we can avoid this problem by checking for system faults, looking for conflicting behaviour, using numerical models of aeration in bulks to control aeration for maximum cooling, automatically switching aeration off at the optimum time, and even aerating without cooling when some ventilation is desirable.

By avoiding the need to travel to remote sites to collect data we can save considerable time and money. With control and supervision from a central location, we reduce the need for training operators at each site and can instead concentrate on training regional operators in more detail. We also have greater flexibility since we can modify the control program at any time and download it over the telephone network.

Hardware

Figure 1 gives the layout of the PMCAM hardware. The components inside a standard mini-tower computer case are: 80386SX motherboard with 1MB RAM, low capacity hard disc (40 or 80MB), 3.5" floppy disc drive, video card, serial card, HDD and FDD controller card and an analog-to-digital and digital I/O card. Components mounted inside the main PMCAM enclosure, but outside the PC case are: the external modem connected to the serial port, interfacing and multiplexing board with built in watchdog timer, and one analog input card for each set of 16 channels of analog input, connected to the interface card.

Nominally the motherboard should be at least an 80286 with 1 Mb RAM. A serial I/O and disc controller card controls the floppy disc and hard disc drives, and provides the interface for serial communication. For this application we need a low-cost modem, and this usually means medium speed. Both 1200 and 2400 baud must be available as some country phone systems are very noisy and should not be run faster than 1200 baud. Low cost is essential because of the risk of lightning strikes and the need to reduce overall costs.

We are currently using a 12 bit analog-to-digital converter card with 16 analog input, 2 analog output, 16 digital input and 16 digital output channels. The analog interface card was designed simply to allow easy connection of sensor wires to the analog input cable. The multiplexer (MUX) card is used to expand the number of analog channels available from 16 to a maximum of 1216. A watchdog timer card reboots the computer if the control software fails to send a signal at regular intervals. This provides more reliable operation.

The components outside the PMCAM enclosure are a weather station and the grain temperature and perhaps moisture sensors. The weather station normally contains two dry-bulb temperature sensors and one relative humidity sensor. It can also house a rain sensor. Typically, the relative humidity sensor will be a dual temperature/r.h. sensor.

The first system constructed, installed at a large site in South Australia, used existing thermocouple sensor cables and a requirement for RTD (resistance thermometer device) sensors in the duct. We currently use semiconductor temperature sensors rather than thermocouples or RTDs for their simple interfacing requirements, and lower overall cost. Thermocouple cable is approximately five times the cost of copper wire. Instrumenting a 20 m high silo with thermcouple wire would incur a considerable wiring cost.

The phone connection may be either a mobile phone with modem interface or a direct connection to a fixed line into the site. The 1993 season was the first time we used mobile phones, and they were a mixed blessing. Although cheaper than a permanent phone line in particular sites where the telephone line is far from the silos, reception is not always good.

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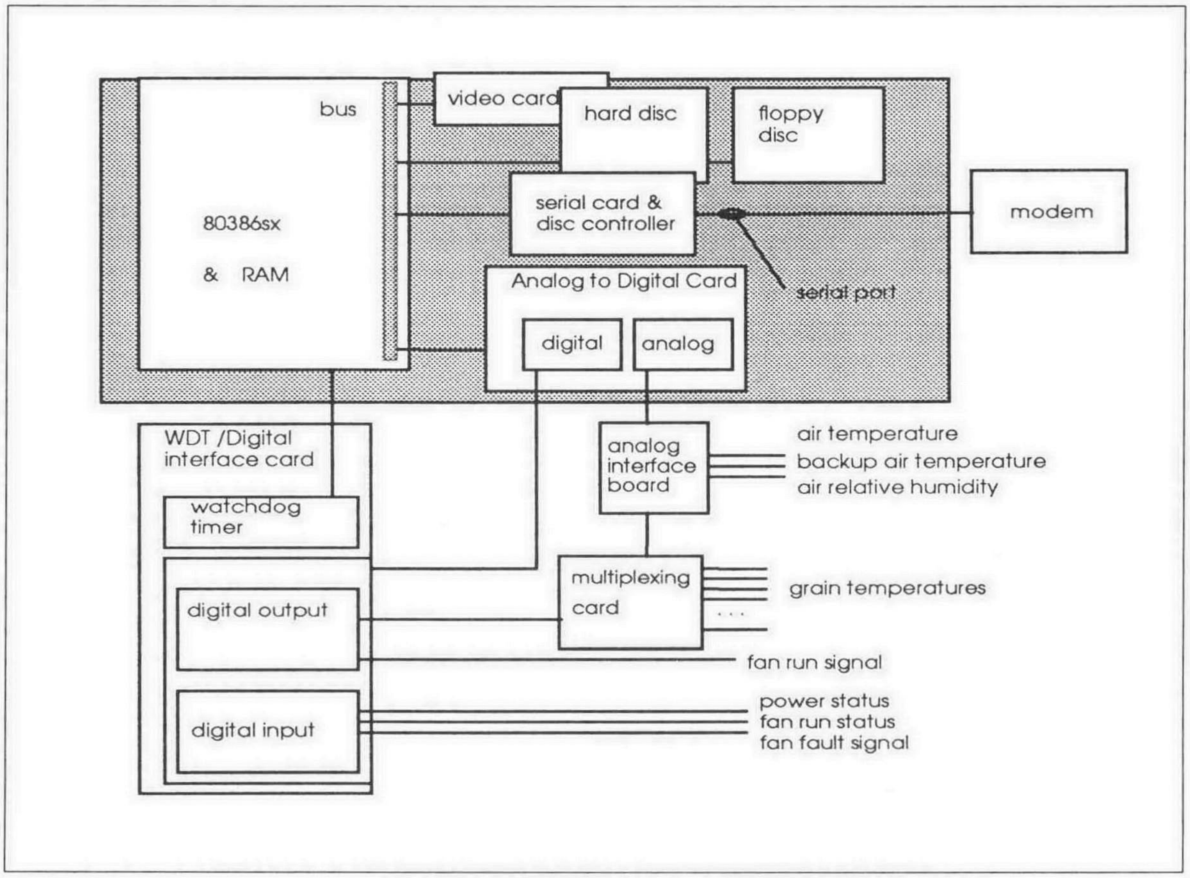

Fig. 1. PMCAM hardware configuration.

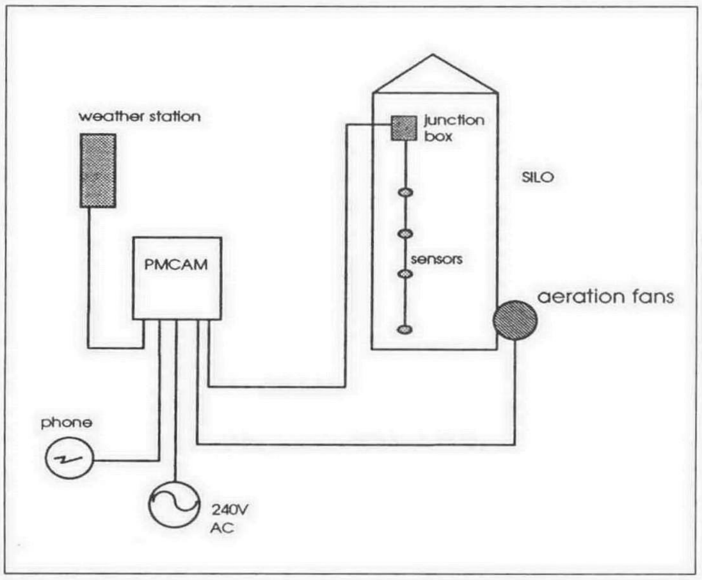

Fig. 2. Connection diagram for the PMCAM.

Discussion

Initial field trials were undertaken at three sites around south-eastern Australia.

Currently, we have 17 PMCAMs installed in 5 States from Western Australia to Queensland, aerating or monitoring the storage of grain in silos ranging from 100 to 15000 t capacity.

We have tested about four different hardware configurations for the PMCAMs. One important finding, although based on only four machines, was that the reliability of the expensive industrial grade motherboards was not as good as expected for the price. Of three initial industrial grade motherboards with battery backed RAM discs, one failed in the first year. For the second season of trials we installed an additional PMCAM with a standard commercial grade motherboard and hard disc drive at less than half the price and had satisfactory performance. We currently use standard rather than industrial grade equipment. Of the 17 systems installed to date we have had motherboard failures in only two of the standard machines.

Our field experience has shown us that a backup air temperature sensor should be used with each PMCAM so the PMCAM can function in the event of the main dry-bulb temperature sensor in the weather station failing.

The most serious problem we have had with the systems is the reliability of relative humidity sensors, a critical factor if we are to use wet-bulb temperature control. The cost of commercially available wet-bulb sensors is of the order of $1400. This is excessive considering that it will almost double the cost of the system. Three different makes of relative humidity sensors used in the field from 1990 to 1992 were unreliable. Indeed, one of the temperature sensors was also unreliable, and prompted us to install a backup, simple, temperature sensor in each site as a fail-safe device.

In late 1993 we tested two each of three other relative humidity sensors. The best performance, based on accuracy and repeatability, was given by the Vaisala combined temperature and relative humidity sensor at a cost of approximately $700. Although this was twice the previous price for relative humidity sensors, we have installed them in the bulk of our new sites and to date have had good, reliable performance.

Trials at one site in South Australia with 10 cells (5 fans) under aeration have allowed us to run four different aeration control algorithms at the same time at one site. The strategies were dry- and wet-bulb set point, and dry- and wet-bulb time proportioning control strategies [see Desmarchelier and Wilson (1994) for an explanation of these strategies]. The use of the PMCAM has firstly made it possible to have the one control system running all four of these algorithms (a very significant leap forward in flexibility) and secondly to monitor the conditions in the grain.

At this site each cell is fitted with a platinum resistance thermometer in the aeration duct. Since the system uses suction, this sensor gives an indication of the grain temperature in the bin. Trials over two years have shown that this duct air temperature gives a good indication of the time of passage of the first cooling front through the grain (Fig. 3).

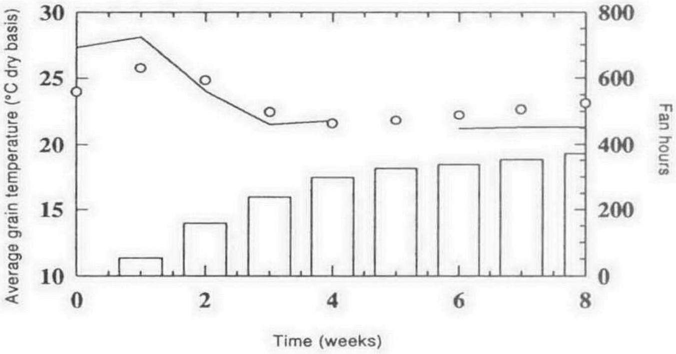

Fig. 3. Duct temperature as a rough guide to the time at which the first cooling front has passed. The open circles represent average grain temperature, while the lines are the duct temperature and the bar chart shows the fan hours.

Costs

Hardware costs are currently just under $2000 per system excluding weather station, sensors, sensor wiring, and the installation cost to connect to power and telephone. Our current weather station configuration costs approximately $1200. Temperature sensors and other wiring add another $1000 to $2000. Table 1 shows the trend of PMCAM cost over the duration of the project. Currently, the capital cost of storage capacity for just the PMCAM on its own without sensors and installation, etc., is 14 cents/t for a 15000 t horizontal store and 96 cents/t for a 2000 t vertical store. If more than one vertical cell is controlled then the capital cost is reduced.

In 1992 we achieved energy consumption rates of between 0.5 and 0.8 kWh/t (at 14 cents/kWh this is equivalent to 7 cents/t and 11.2 cents/t, respectively), for final average grain dry-bulb temperatures of between 21 and 23°C from initial temperatures in the 28 to 30°C range.

In 1993 we achieved a final average grain dry-bulb temperature of close to 14°C from around the same starting temperature. This final temperature is slightly lower than the 15°C dry-bulb temperature limit recommended in order to ensure that later fumigation is effective (Australian recommendations for PH_3). Energy consumptions for the most aerated cell in South Australia, and the shed in New South Wales were 1.7 and 1.5 kWh/t (23.8 cents/t and 21.0 cents/t), respectively. The lower temperatures reached in 1993 naturally resulted in an increased energy cost compared with the 1992 trials. Nevertheless, these energy costs are less than expected for aeration systems. For example, costs of 50–100 cents/t are often attributed to aeration. We over-aerated slightly in the horizontal shed in 1993 and yet we still obtained energy costs less than half that of this value.

The observed energy consumption figures are in line with those of Navarro and Calderon 1982, but less than old Australian reports of 2.5–4.0 kWh/t (Sutherland 1968). Further reductions in energy consumption of at least 10% should be possible by careful tuning of the control algorithm, and by incorporating models to predict the time of passage of the cooling front, thereby allowing the fans to be switched off before excessive aeration occurs. These modifications are made possible because the PMCAM control program can be rewritten very easily.

The usefulness of the PMCAM for research purposes can be demonstrated by the use of temperature data collected by the system in a 15000 t capacity horizontal store. Contour plots of the data show the passage of the cooling fronts on a half-hourly basis, and provide a very detailed picture of the progress of the aeration. These data are also being used in conjunction with moisture measurements to map the distribution of moisture around the aeration ducts.

For the future one would not expect the present form of PMCAM to be used in medium to large sites because PLC (industrial programmable logic control) systems are more rugged, more likely to be in place for controlling other aspects of the existing machinery, and because the software becomes so complicated that it should be left for the experts in industrial control systems. The use of PMCAMs at smaller sites will affect the way larger sites are controlled. The results derived from operating smaller sites with the PMCAMs and optimising the control strategies can be incorporated into the software controlling the larger sites.

The PMCAM has shown itself to be a useful tool for the control and monitoring of aeration. Such systems will be of great value in the control and or monitoring of many other processes.

Using the PMCAM we have demonstrated that aeration is a much cheaper option than previously believed in Australia.

Table 1. Capital cost of PMCAMs over the term of the project ($Aust). The cost of sensors is not included, since the requirements depend on the site layout and number of sensors for the particular research involved. The cost of software is also not included.

PMCAM number	Year	Cells	Tonnes per cell	Capital cost ($)	Capital cost per tonne of capacity ($/t)
1	1990	10	1400	8410	0.60
2	1991	1	2200	4030	1.83
3	1991	1	2200	3375	1.53
4	1992	1	15000	2110	0.14
5	1993	1	2000	1920	0.96
6	1993	1	14000	1920	0.14

The flexibility and cost saving nature of PMCAMs makes them an excellent research tool, and, in its more appropriate forms linked into PLC systems, will prove to be an excellent way of controlling larger-scale processes.

Acknowledgments

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