Intelligent Actuators for a High Speed Grading System

Ken A Mercer[1], Donald G Bailey[1], Colin Plaw[1], Ralph Ball[2], Harvey Barraclough[2]

[1]Institute of Information Sciences and Technology
[2]Institute of Technology and Engineering
Massey University, Palmerston North, NEW ZEALAND
E-mail: K.A.Mercer@massey.ac.nz

Abstract: It is desirable with some types of produce to form it into bundles which meet strict weight and visual requirements using a grading machine. The produce is normally singulated into cups on a conveyer system and must be processed at 10 – 30 each second. A system of actuators is required to remove the produce from the conveyer and drop it down a particular chute to form a bundle.

This paper describes a system which controls actuators on a grading machine. Dedicated micro-controllers are under the control of a PC in a master / slave RS485 network. An daisy chain scheme is used to automatically assign addresses. Each actuator includes a sensor for synchronisation with the conveyer.

**Keywords:** microcontroller, embedded system, produce grading

1. INTRODUCTION

Grading and packing systems are used to improve the appearance and value of produce. To counter natural variability similar sized items are grouped together while inferior items may be trimmed or rejected. Generally produce is sold by weight so an important role of the grading system is to ensure bundles are slightly heavier than the specified weight. Economic considerations dictate that the specified weight is not significantly exceeded; effectively giving away produce.

When each item is a small fraction of the total bundle weight, this criterion can be achieved by sorting the produce into each grade. However, when the bundle weight is small, so each bundle only contains a few items, the variability in bundle weight can be significant.

Produce is normally singulated into cups on a conveyer system and the weight measured or estimated. It is then directed to particular chutes to build bundles. A large number of chutes may be needed to meet both the appearance and weight requirements. When the appropriate quantity has been collected by a chute it is released as a bundle to be packaged for sale.

This particular system consists of a PC, running under the windows operating system, which uses image processing to estimate the weight [1] and evaluate several attributes of the produce on a conveyer (Figure 1). It also runs a sorting algorithm to determine which, of as many as 60 chutes, is the destination. A further function is to release completed bundles.
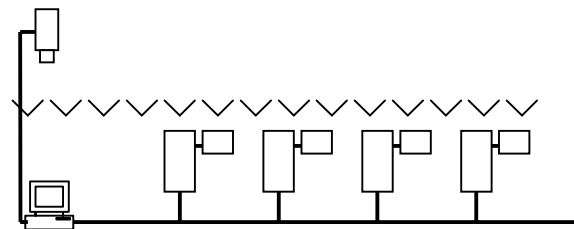
1.1. Conveyer Description

This conveyer system has a plastic chain running in a shallow tray. The chain carries V shaped cups which are unbalanced so they can tip to empty their contents for bundling. They are retained in a horizontal position by a trigger system with a protruding tag (which has a soft iron armature) for activation by a solenoid. (Figure 2)
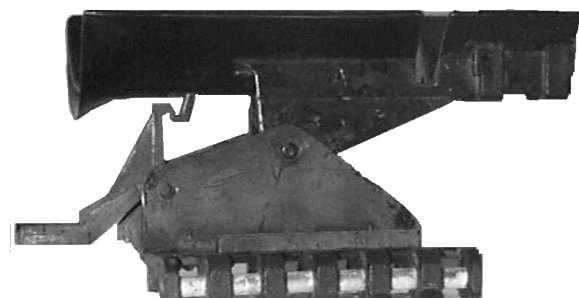

Figure 2: Produce Cup mounted on Chain

The conveyer moves at a constant speed which can be adjusted from zero to 30 cups/s. The normal speed is 10 cups/s.

2. ACTUATOR REQUIRMENTS

Each actuator must perform a number of tasks. These include identifying a particular cup containing the produce destined for its chute, activating the trigger on the cup to tip the produce down the chute, and releasing the bundle when complete.

2.1. Cup Identification

Cups can be identified by counting them as they pass a point on the conveyer. In the past this has been done by the sensor which triggers the camera. By knowing the distance between the sensor and a particular actuator an algorithm can determine when to trip the cups.

This dead reckoning approach would be economical and feasible with a short, rigid conveyer. However, with a longer conveyer, errors due to elasticity, thermal expansion and wear render it unsatisfactory. In the past this has required periodically adjusting each solenoid position through trial and error to give reliable triggering.

An improvement is obtained by grouping actuators into clusters with a sensor for each. Pitch errors caused by mixing sections of worn and new conveyer chain would still make adjustment critical. The system remains complex because the actuators are each at different distances from the sensors.

The most accurate approach, which eliminates any problems with pitch errors, is to incorporate a sensor with each actuator. This has the disadvantage of cost as many more sensors are needed. However it simplifies mounting because only the distance between sensors and their associated solenoid is critical and this is easy to reproduce. Also, all the actuators are now identical.

2.2. Cup Release

The actuators are required to trip particular cups as they arrive at their destination chute. The cup is tipped by pulsing the solenoid which operates the trigger. To minimize power consumption, it is desirable to make the pulse as short as possible, while giving reliable triggering. At full speed the cups pass the solenoid at 30 ms intervals. Thus the width of the solenoid and trigger effectively limit the useable pulse length to 20 ms. For reliable triggering, the timing of the pulse must be accurate to within about 5ms.

The solenoids operate from a 48 V supply and require a current of 4 A while activated. This is quite a high peak power requirement of almost 200 W per actuator.

2.3. Bundle Release

Off-the-shelf 24 V pneumatic valves are used to operate pneumatic cylinders which release completed bundles. The cylinder toggles with each bundle so on average each valve is energized half the time.

2.4. Buffering

There is considerable latency between the time that the produce is graded, and energizing the solenoid. This requires that the data be buffered somewhere in the system. The need to trigger multiple actuators simultaneously suggests that such buffering is best done at the destination.

3. IMPLEMTATION OPTIONS

3.1. Direct Digital I/O

Initial investigations considered using digital I/O cards mounted in the controlling PC. Typically cards have 16 or 32 I/O channels available so several would be needed. Also this approach is not straight forward because the operating system cannot time to the precision required.

However cards are available with buffered output which can be preloaded and automatically clocked out. Unfortunately they are very expensive. In addition, this approach would require switching hardware and sensors mounted remotely from the PC. The resulting long lines would be susceptible to noise pickup. It would also be necessary to use individually mounted solid state relays to handle the voltage and current requirements.

3.2. Programmable Logic Controller

A PLC is designed to perform a function in response to attached sensors. Modern PLCs can be networked so can, in principle, receive instructions from a host PC. They also have sufficient memory to buffer the data. The fastest scan times are as low as 1 ms [2] giving a 2 ms timing uncertainty which is satisfactory for this application. To handle the current and voltage requirements it would be necessary to use externally mounted solid state relays.

3.3. Intelligent Actuator

This is an approach which considers the hardware associated with each chute as a single entity requiring connection to a power supply and a communication line. Internally, components can be selected to match this application.

The major component is a microcontroller which need not be complex. Such devices can time accurately and have on chip serial communications which can interface to an appropriate line driver. There are also ample I/O pins available for sensing the conveyer and, using power MOSFETs, the required actuation. A microcontroller also has available memory which can be used to buffer cups data.

The disadvantage of constructing an intelligent actuator is that it is not an off the shelf approach which increases development time and risk. However this is offset by the advantages of increased flexibility.

It appears wasteful to use one microcontroller for each chute when it has the capacity to simultaneously control several. However, this approach is more modular and simplifies the software significantly.

4. ACTUATOR IMPLEMTATION

4.1. Cup Sensing And Identification

It is important that cups moving past an actuator are reliably sensed and identified. As the trigger tag protrudes over the actuator it is an obvious target for detection. Individual cups can then be identified by counting.

As the tag contains the solenoid armature magnetic sensing would appear an obvious choice. However, although robust, available sensors are expensive and bulky.

The approach used is a reflective optical system based on a Sharp IS471. This is an integrated synchronous IR modulator and detector which is inherently immune to stray illumination. The modulator output directly drives a LD274 emitter. The detector provides a digital output indicating a reflection. Both face upwards through a thin window in the actuator enclosure with the emitter inclined by 20° so they focus on the same spot. To avoid a false reflection from the internal window a vertical baffle is mounted in between the emitter and the IS471 as shown in Figure 3.

The sensing system has been proven very reliable with a 5 to 10 mm gap. Also, because the emitter is angled, objects further than 20 mm are not detected.
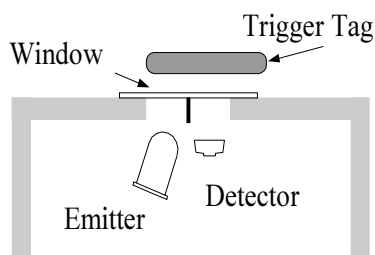
4.2. Reference Sensing

It is necessary to identify an reference cup to synchronize all the actuators. The cup counters can then be reset each time the reference goes past.

A small (1.1 x 2.5 x 5.1) neodium magnet was initially mounted under the reference tag in such a way that it did not interfere with the operation of the solenoids. An Allegro 3121 Hall effect sensor detected the magnetic field as this tag passed. Unfortunately the range was insufficient for this approach to be robust in the field.

An alternative approach uses the same optical sensor for normal cups to detect the reference cup. The reference tag has been widened by 50% over its normal 20 mm width. The leading edge is unchanged and is detected normally, however the if the tag transit time suddenly increases by >25% it is assumed that the reference tag is responsible.

This approach has proved to be reliable when the conveyer is running at uniform speed. However, when it is stopping it is likely that normal tags will be falsely recognised as the reference because they are travelling slower. This can be alleviated by ramping the speed down slowly but it is almost eliminated by only allowing a small cup count based window for reference detection. This window is used once the conveyer has completed two full revolutions. The conveyer can now be shutdown in an orderly fashion by simply ensuring the reference cup is outside the area of the actuators.

4.3. Buffering

Depending on the operating speed there is as little as 30 ms between each cup. In the worst case all the actuators could be required to trigger during the same 30 ms period. The mastering PC can also get distracted from its control function by another task (windows is not a real time operating system).

As a consequence it is necessary for the actuators to receive commands ahead of time and buffer them. The buffer could be quite small as it is rare for the PC to be unavailable for more than 100ms. If it was small the PC would have to be aware of the current count that each actuator was up to. The PC would internally buffer commands until particular cups had almost reached corresponding actuators. This could result in a communication overload if many cups were due to be triggered at once.

An alternative approach is to buffer the list of cups destined for each actuator at the actuator. The potential size of this buffer for is the number of cups between the camera and the actuator. As there are more than 256 cups on the chain two bytes are needed to identify each.

The chosen microcontroller has 256 bytes of auxiliary RAM available. It was all used so the buffer can hold trigger instructions for 128 cups. This is less than the number of cups between the camera and the furthest actuators so it could overflow. However, virtually all the produce would have to be directed to a single chute for this to happen which is extremely unlikely.

There is a time delay between a cup is arriving at its destined actuator and activating the associated solenoid. This is because the cup sensor is located ahead of the solenoid. A further delay is needed before turning it off. Similar delays are needed between triggering a cup which contains the last item in a bundle and activating the pneumatic cylinder valve. A second, much smaller, buffer located in internal RAM is used for these delays and other minor functions such as blinking indicating LEDs.

4.4. Outputs

The microcontroller is connected to two 15 A MTD15N06 MOSFETs which control the trigger solenoid and the pneumatic valve. The trigger solenoid is straight forward – it is switched on briefly as described above when a particular cup arrives.

Controlling the pneumatic valves is more complicated. Half of the valves can be expected to be on at any one time. The duty cycle ranges from several seconds upwards while a bundle is constructed. They each draw a current of 240 mA when powered from a 24 V supply.

If connected directly to the 48 V supply the valve would overheat. In addition, once closed, a lesser current is sufficient to hold it closed. Accordingly the microcontroller connects the valve directly to the 48 V supply for 8 ms, then modulates it with a 25% duty cycle. This halves the normal power consumption while the valve is activated.

5. RELATED ISSUES

5.1. Communication

A multi-drop half duplex RS485 network interconnects the intelligent actuators. MAX487 devices are used allowing a maximum of 128 actuators on the bus. The RS485 protocol is resistant to noise and DC offsets as it uses two balanced lines. This is important as there are momentary high currents in the power supply conductors. This results in the ground points of each actuator varying by several volts from one end of the chain to the other.

The controlling PC communicates to the intelligent actuators via a standard serial port and a converter at 115,200 bps. All communication is in packets of 5 bytes and follows this simple format:

Byte	Contents
1	Address
2	Command
3	Data1
4	Data2
5	Checksum

An address of zero is a broadcast to all actuators. 18 commands are defined – the most important is to send a spear to an actuator. In this case the data bytes hold the cup number of the spear. A number of query commands are also defined.

A command/response protocol is used so all commands are echoed back to the controlling PC to verify reception. Queries are echoed with appropriate data bytes. This protocol also means that the data direction on the bus is predictable which is necessary with a half duplex system.

5.2. Actuator Addressing

A daisy chained self addressing approach is used to avoid manual configuration. Each actuator has a TTL level input and output pin defined. They are referred to as select in and out (SI and SO). The SO of one actuator connects to SI of the next. At startup all actuators have an address of zero and they pull their SOs low. The only device with a high SI is the first in the chain – it is assigned address 1. Accordingly it releases its SO and the next actuator accepts an address of 2.

Each actuator echos its SET_ADDRESS command back to the controlling PC which continues setting addresses until no further replies are received.

5.3. In-Circuit Programming

The micro-controller used is a Winbond W78E516B. This is a flash programmable 8051 variant with 256 bytes of auxiliary RAM. In addition to 64k EEPROM it has another 4k boot loader EEPROM so it can be reprogrammed in circuit.

Normally it runs from the 64 kB ROM. When the LOAD_NEW_PROGRAM command is received it switches to the 4 kB boot loader, erases the main program and waits to receive new code via the serial communication line. An individual actuator can have its code updated in this way, or the whole chain can be reprogrammed at once.

5.4. Solenoid Considerations

The solenoids which activate the triggers have been used in the industry for a number of years. They are wound on a transformer E core as shown in Figure 3. The maximum area available for the windings is 25 x 10. The standard coil has a resistance of 12.3 Ω and an inductance of 135 mH.
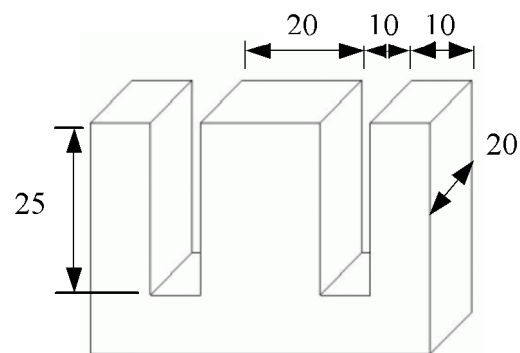

Figure 4: Trigger Activating Solenoid Core

Given these dimensions the question arises whether and how to redesign the coil to maximise the magnetic field strength H in the gaps, and hence the force exerted on the armature in the trigger tag. For a current I, number of turns N, and magnetic circuit length l [3]

$$H = \frac{IN}{l} \qquad (1)$$

If the area available for winding the wire is w x h and the wire has a diameter d the number of turns can be approximated by

$$N = \frac{w}{d} \times \frac{h}{d} = \frac{wh}{d^2} \qquad (2)$$

substituting (2) into (1) gives the magnetic field strength in terms of current and physical dimensions.

$$H = Iwh/ld^2 \qquad (3)$$

If the average length of each turn is a and the resistivity of the wire ρ the resistance of the solenoid will be

$$R = 4\rho lNa/\pi d^2 \qquad (4)$$

If a supply voltage V is available to drive the solenoid then Ohm's law gives the resulting current.

$$I = V\pi d^2/4\rho lNa \qquad (5)$$

Substituting (5) into (3) now gives the magnetic field strength

$$H = Vwh/4\rho lNa \qquad (6)$$

Given a core of a particular size the magnetic field strength can only be increased by using a higher supply voltage. Changing the wire size has no effect on the steady state magnetic field.

However, (5) indicates the current will be higher with thicker wire. Also, from a dynamic perspective [4]

$$L \propto N^2 \qquad (7)$$

So rise times will be slower with more turns.

To maximise the magnetic filed while compiling with the definition of "Extra Low Voltage" [5] 48 V was used for the power supply giving a peak current of about 4 A. It was decoupled locally with a 1000 µF capacitor which stores sufficient energy to charge the coil.

The observed rise time was about 10 ms. For higher speeds a coil with less inductance would be an advantage. However with the present specifications there is little advantage in redesigning the coil.

5.5. Logic Power Supply

The 5 V logic level requires about 60 mA. Using a linear regulator running from the 48 V supply would dissipate almost 3 W per controller which is excessive. A LM2594HV switch-mode regulator was therefore used to efficiently transform the supply.

6. CONCLUSIONS

Using intelligent actuators results in a system with an object oriented structure. The actuator has become a blob with defined functionality and the design is modular and expandable. The large number of identical units facilitates control from a higher level, aids debugging, and simplifies manufacture.

The system as described has been implemented and installed both on a test machine and now on a commercial grading machine with 42 chutes. It triggers reliably at 25 cups/s although product handling considerations currently limit the speed to 10 cups/s.

7. ACKNOWLEDGMENTS

8. REFERENCES

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