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Robotic Food Applications Example: Ice Cream Portioning

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Abstract

This paper presents the research findings and describes the commercial application of a development in robotic food processing: ice cream portioning. The challenges for robotics in handling and processing of food items are the high degree of product variability, the fragile and perishable characteristics and the hygiene and sterilisation requirements. Information on item variability is acquired employing smart sensing combined with *a priori* knowledge. This product information is then processed by adapting the generic operation instructions and by correcting any deviations using feedback information from the process. Fundamental issues in robotic food processing are discussed briefly, followed by specific issues on portioning of ice cream for vending purposes. Implementation details and test results are presented with an attempt to critically review the lessons learned. An international patent has been approved and commercial developments are progressing in New Zealand with sales in Europe.

1 Introduction

1.1 Common factors in robotic food processing

Automation of processes with high variation requires specialised robotic developments incorporating advanced sensing and processing capabilities. Additional challenges are faced when small batch sizes of variable product items must be processed. Product variations in mixed batch production or processing of naturally varying objects such as in food automation require processing of acquired information combined with *a priori* knowledge and pre-programmed actions based expectations. The challenge in processing of variable objects such as fruit, fish and meat lies in the capability to adapt each process operation to each individual object. Variable objects have similar generic characteristics but are intrinsically different in, for example, dimension, shape, texture and hardness. A successful system must therefore be able to accommodate this variability in objects by individually tailoring the process operation to each object.

This can be accomplished by the use of sensory information concerning characteristics of each object to be processed, and by modifying a generic task and / or path plan. The close integration of sensing with actuation is an important element for robotic processes in variable product processing. The inherent variability of the product items often places high demands on the sensing capability of automated equipment.

Industrial Research Ltd has been involved in robotic food processing for some years, including the processing of fish fillets [Malone *et al*., 1994], a sensory gripping system for variable products [Friedrich & Nicholls, 2000] and commercial developments in robotic meat processing [Templer *et al*., 1999].

This paper presents research findings and describes commercial application of a development in robotic food processing: ice cream portioning. Soft ice cream is generally processed by machine but dispensed manually. Ice cream portions delivered manually can vary greatly between subsequent deliveries. Significant savings in material and operating costs can be made by consistent portion delivery. Robotic technology has been developed that automates the delivery and management of soft serve from machines that previously required trained personnel to operate.

Medium changes under temperature, pressure and air content are major factors determining the ice cream consistency. These factors are controlled in commercially available soft serve ice cream machines. Consequently, the size of the portion depends mainly on the opening time of the spigot and the length of time the spigot is open. Additionally, the portion size depends on the distance of the cone from the outlet valve obstructing more or less the free flow of the medium. The combination of valve setting and cone distance controls the flow rate of the ice cream in its given status and consistency. These settings are responsible for the final shape of the serving.. In other words, the position (and velocity) of the cone needs to be carefully controlled and suitably synchronised to the opening position of the spigot and its closing profile. Both of these actuations are servo-controlled with a closed loop feedback during delivery. In this case we are sensing indirectly the ice cream flow, modifying the pre-defined motion path and synchronisation for the spigot opening profile to the cone movement. Controlling ice cream portions has significant similarities to food automation in other areas.

Together with an industry partner we developed a suitable control architecture consisting of three major control modules, a sensing and perception module, a control module and an actuation module (Figure 1). This architecture is not limited to food pressing, but can be applied to a wide range of robotic problems, ie. when machines have to interact with a partly unknown environment, where actual measured parameters differ significantly from expectations (pre-programmed *a priori* knowledge).

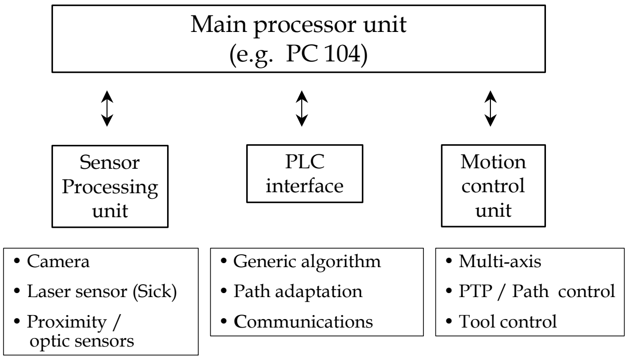

Figure 1: Typical control architecture for variable product processing.

Inter-process communication between the GUI Win32 and the RTSS processes is achieved through shared memory. The shared memory consists of two circular buffers, one to send data from the RTSS process to the GUI, and the second to send path information from the GUI to the real-time process. A third shared memory block is created for a matrix data structure that contains joint data calculated from the path points (or knots) provided by the path planning software. These points control the behaviour of the robot manipulator. The joint path generation program uses cubic spline interpolation between the points to generate real-time path demand coordinates for the joint control systems to track.

Additional issues in food processing are hygiene measures including easily cleanable surfaces, sterilisation and wash down requirements. Due to these requirements, food processing equipment is manufactured in many cases from stainless steel and our development is not an exception. All external and internal surfaces that may be in contact with ice cream have been produced in stainless steel.

The following section details the operation of automated ice cream portioning.

2 Automating Ice Cream Portioning

The development centres around a commercially available soft serve ice cream machine typically used in fast food outlets. The American machine is able to produce soft ice cream at a dispensing rate of approximately six portions per minute. The ice cream mixture is cooled, aerated, pressurised and then frozen via a flash freezer unit. The ice cream is maintained in a servable condition by a freezing cycle of approximately 10 min.

Soft ice cream is a complex compressible medium with non-linear flow characteristics where the relationship between weight and volume constantly changes. The consistency of the delivered ice cream portion depends on a large number of variable parameters such as temperature, pressure and air content. As consistency and

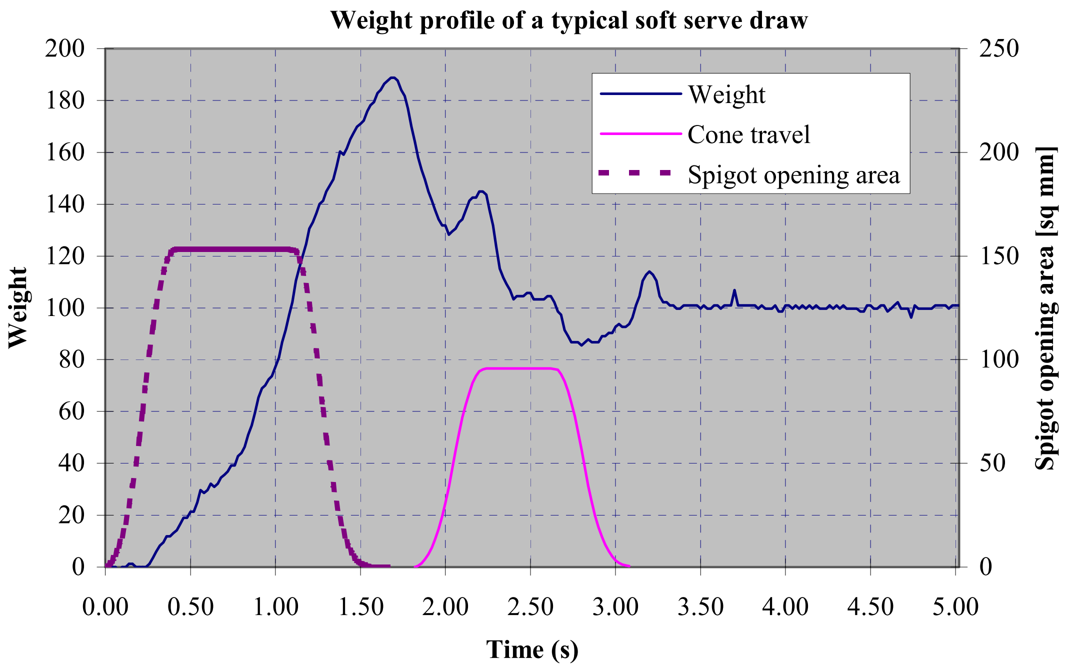

Figure 2:: Typical weight profile with spigot opening and cone travel superimposed.

texture changes over time, dispensing ice cream in a vending situation contributes to the challenge to deliver consistent portions.

2.1 Prediction of Portion Size

In order to dispense an accurate amount of ice cream, the duration and size of spigot opening must be controlled for each pour. Control of these process variables in general, could be defined by the process model. However, the reliability of the system would depend largely on the accuracy of the mathematical model. In a series of tests, the main contributing parameters were measured to identify prime relationships between portion weight_and the temperature of the delivered mix, the internal barrel pressure, the air content and the mix viscosity (measured indirectly via the motor current of the beater motor). Analysis of the data showed that the system is time variant and non-linear with dependent states. Therefore, an accurate model which would include complex dynamic relationships is difficult to develop and a simplified model would not be adequate for a realistic, consistent and reliable implementation.

2.2 Portion Control

Instead predicting a portion size by measuring variables, a rules-based system was employed. This system determines ice cream flow rates and corrects both servo-control settings, the opening of the spigot and the distance of the cone from the outlet valve.

The laboratory set-up for the portion control consists of

- a low-budget PLC to provide control for arm and spigot motor,
- an electronic weighing system with analogue output
- data-acquisition system LabView

The Programmable Logic Controller (PLC) controls the motors directly. As the motor load in both cases is approximately constant simple electronic braking was employed to achieve accurate positioning for the spigot opening and cone positioning (Figure 3).

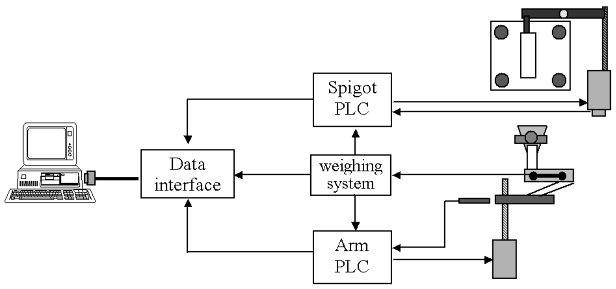

Figure 3: Portion control – laboratory set-up.

The dispensing cycle is initiated via push button to activate LabView and PLC cycles. The transporter arm moves up to the dispensing position triggered by an inductive sensor and the spigot cycle is started. The second motor opens the spigot and moves to the initial fill position. This position is monitored by encoder reading. The spigot close command is triggered by a timing signal from LabView. The spigot closes and LabView records the timing and final weight. The arm then lowers the cone with the portion depending on selected portion size. The timing for the next portion is calculated and will be adjusted after certain times to compensate for media changes and re-adjusted after each freezing cycle allowing it to follow a drift of ice cream parameter. This can be caused by consistency changes i.e. by a size variation of fat particles within the ice cream mix for instance after a long period of time without a draw or after heat treatment. The modified settings can cope with a high viscosity and considerably increased flow rate.

Figure 2 shows a typical weight profile of a portion delivery over time. Superimposed on the graph are spigot movement as well as the cone travel. The cone travel is carefully adjusted to optimise the shape of the portion. In the commercial realisation, the electronics development resulted in an embedded control system. With these adjustments a consistent portion delivery has been achieved. Further technical details are commercially sensitive and can therefore not be published.

2.3 Overall Operation

Vending of ice cream is accomplished by the following sequence. After initialisation that includes simple checks on ice cream presence and readiness, the machine is placed in a ready status and accepts coins from the customer. Upon receiving the right coin value in the electronically controlled cash box, a fresh cone will be dispensed from the cone storage. A motorised holder for cones or cups is positioned under the draw valve. The portioning system is realised with two servo-controlled axes, the cone positioning and the spigot opening. Smart software ensures that the combination of their movement produces the correct amount and characteristic shape of the ice cream portion. The details of the algorithms employed are commercially sensitive and are covered under international patent.

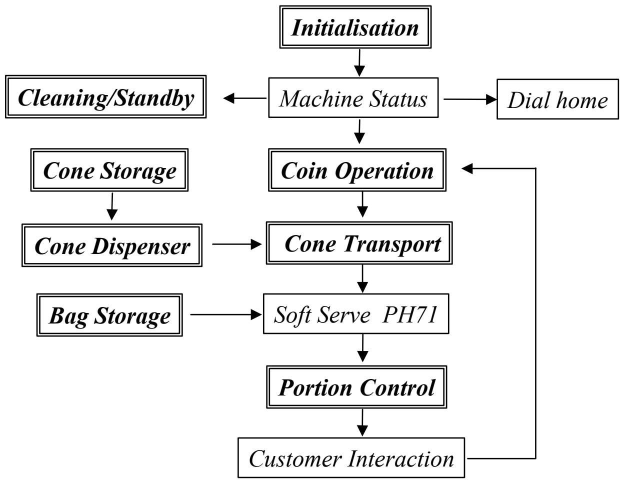

Figure 4: Ice cream vending operation.

The spigot is in view of the customer through a serving window. The customer can watch the filling process of the cone. The customer window opens after completion of the ice cream delivery. The machine is operational on a 24 hour basis without intervention except for an automatic sterilisation procedure during the night. There are various operation modes, including vending, ready, cleaning and

Figure 5: Finalised commercial prototype.

sterilisation modes. Any refills or error messages are requested and reported automatically via phone line. The machine can operate up to a fortnight without requiring manual cleaning provided the product is not sold out earlier. The following diagram shows the principle sequence of operation.

The result is a world first. The new vending machine pours a perfect cone, the right weight every time, sterilises itself every night, and can stay unattended for up to two weeks. As a result of its success, a separate clip-on portion control device for existing machines was developed. This device is an attachment that fastens to the front of the machine and operates the draw valve to dispense the product. This development is now commercially available (Figure 5).

3 Laboratory Test Results

The algorithm has been implemented in a prototype system. The actuations were essentially controlled by a PLC. For the control and logging of experimental data a LabView interface was implemented. An experimental run of over 500 portions has been completed over several weeks. Drawn at random intervals and different sizes a realistic vending situation was created. Approx 20% of these measurements were taken the following day after sterilisation. The diagram below shows the actual weight and the percentage variation. The samples were sorted into the three different portion sizes. Weight targets of 80, 100 and 120 g have been trialled and achieved results within +/-5% (Figure 6). Trials have been demonstrated to potential national and international clients.

4 Further Developments

The automated soft serve ice-cream vending machine has won the innovation award from the NZ Institute for Food Science and Technology (NZIFST) at the Foodtech'98 exhibition in Auckland, November 1998. The initial

Figure 6: Test results with weight variation (top line) and the percentage variation (bottom line).

Figure 7: Typical control architecture for variable product processing.

portioning system was developed for vending purposes. Since the development and implementation of the portioning method, a retrofit mechanism for automated ice cream delivery has been successfully developed (Figure 7). This unit has been further developed commercially with an embedded controller. Version 2 of this integrated electronic circuit is now complete and will be set up in Europe for a six-month trial period.

5 Conclusion

The commercial environment in New Zealand's prime industry presents many challenges for automated handling and processing. These challenges come from the fact that many applications require operations on product items that vary individually within a batch, often because the items were derived from nature rather than designed by man.

Our approach has been to develop systems that have strong sensory capability, and to integrate sensor data with versatile actuators, often in real time. We have demonstrated that knowledge-based systems can provide solutions in highly variable situations, for example in fish processing, ice cream portioning and in off-line programming. A large number of our research prospects have led to commercial systems, and we have been able to transfer our results to equipment manufacturers and end users via trial programmes in operating plants.

Our current portfolio of projects covers research into programming of human assisted and sensor-based machinery, intelligent end-effectors, semi-autonomous control for field applications, beef carcass processing, and two major systems for cutting and handling of lamb carcasses. All of these projects will have demanding sensory and control requirements, and will further develop the techniques described in this paper.

Acknowledgements

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