The commercialization of a low-cost, high-speed pick-and-place casepacker

S. DICKERSON[1]*, S. COLEMAN[1], G.V. MCMURRAY[2], W. HOLCOMBE[2] and J. PRINCE[3]

[1]CAMotion, Inc. 75 Fifth Street, Suite 216, Atlanta, GA 30308, USA
[2]Georgia Tech, Georgia Tech Research Institute, 505 Tech Way, Atlanta, GA 30318-0823, USA
[3]Cargill Meat Solutions, Cargill, 33 Dart Road, Newnan, GA, 30265, USA
***Steve.Dickerson@CAMotion.com**

Keywords: robotics; material handling; high speed; meat packing

Summary

This paper describes the automation of case-packing at the back end of a food processing plant. Such automation is motivated by the availability and cost of labour (including wages, insurance, floor space, and training), welfare of workers, reduction of risks and worker injuries, the availability of suitable labour, and the ability to meet OSHA safety requirements.

A team consisting of a university research group, a commercial high-tech robotic motion control company, and a pork processing plant has developed and demonstrated a high-speed, low-cost robotic casepacker that addresses the needs of food processing companies. As designed, the robotic casepacker is able to meet the minimum packing needs (58 trays/min at one tray per move) of the package operations. The team has also developed and installed the peripheral equipment required to bring the empty totes into the work cell and to release the full totes onto a conveyor.

Overview

The food processing industry has been a labour-intensive industry since its inception. The nature of the product as well as the production volume and variety has dictated the use of manual labour to perform many operations in processing plants. Typical tasks, such as packing individual product in a tray pack or arranging the trays in a shipping case, have been considered appropriate as manual operations in the past. Reasons for this include product variety, speed, lack of exact product specifications, difficulty in product handling, and the need for grading and inspection.

Motivations to automate tasks in the back end of food processing plants include increased throughput, the availability and cost of labour (including wages, insurance, floor space, and training), welfare of workers, reduction of risks and worker injuries, the availability of suitable labour, and the ability to meet OSHA safety requirements. Most of the workers are in a nearly freezing temperature environment. Interest in automating these tasks has been increasing in recent years due to these issues. However, technology has not yet been able to provide cost-effective solutions to these tasks. A casepacking robot has been under development at Georgia Tech since 1992 in an attempt to satisfy this unmet need.

Georgia Tech, working with its commercial partner, CAMotion, has developed a high-speed, low-cost robotic casepacker that addresses the needs of food processing companies. As designed, the robotic casepacker is able to meet the minimum packing needs (58 trays/min at one tray per move) of the package operations in a food processing plant. The team has also developed and installed the peripheral equipment required to bring the empty totes into the work cell and to release the full totes onto a conveyor. FoodPAC funding supported the development of the tote-handling equipment and the field test of the system at a red meat, case-ready packing plant. Excel Case Ready, now Cargill Meat Solutions, hosted the 6-month field test. The system was installed at the plant on December 7, 2003, and Georgia Tech and CAMotion personnel beginning on December 19 conducted the first trial operations of the system. Over the 6-month field test period, operation and maintenance of the casepacker were gradually transferred to the Excel plant operation staff. Beginning in January 2004, plant personnel were provided a training class taught by CAMotion employees on how to operate the casepacker. Since then, nearly all production on that line has been packed by the new casepacker.

Another important aspect to this project was the addition of a vision system to inspect for labels on the trays. CAMotion undertook this task. CAMotion employees used a DVT colour camera to identify the tray and the location of the label in less than 0.25 second. If the label was correctly placed, the tray was allowed to proceed to the casepacker, but if it was incorrectly placed, the system kicked the tray off the conveyor by using a pneumatic kick-off device. The vision system is correctly working and is nearly 100% accurate.

During the field test, the casepacker packed nearly 1,000,000 trays. The average packing rate was 1.27 seconds per tray, but the fastest packing rate was 1.13 seconds for the #10S tray of boneless pork. The end-effector successfully grasped 99.64% of the trays.

Cell description

This cell is for the purpose of taking weigh-price-labelled, wrapped pork products in Styrofoam trays and placing them in a tote. The pattern of placement varies widely and is changed several times a day. The process has been entirely manual as is typical in the industry. The operators doing the task have as a secondary function the inspection of the wrapping and label placement. The machine was retrofitted into an existing manual line where trays with meat come down a conveyor toward a dual conveyor system for the totes. In manual operation the totes are removed from the top conveyor, filled to the level and pattern desired, and placed on the bottom conveyor. The bottom conveyor is powered so that the full totes move automatically to the shipping area. The incoming totes are placed on the top conveyor by a person de-nesting totes from a pallet and pushing the totes down the conveyor to the workstations.

The present automatic cell has a powered section of the upper conveyor to move the totes into the pneumatically powered tote handler. The tote handler moves the totes into the robotic load position. After completion of loading trays into a tote, the tote is lowered and then pushed onto the lower conveyor.

Because the weigh-price-labelled trays of meat are presented at a lower level for manual operation than needed by the robotic machine, an inclined conveyor is used to bring the trays up to the load position. During this transition a machine vision system is used to verify the correctness of the label and that no wrapping material is protruding over the edge of the tray. If either is incorrect, the tray is pushed into a tote used for that purpose. Sometimes the tray problem can be corrected and the trays can be inserted back into the incoming stream manually.

The overall objective is to reduce the manning of the line to about 0.5 people from the usual 1.5 people. The extra labour is used to maintain and operate the wrapping and weigh-price-label machines. Because this latter causes the trays to be presented in a spaced manner, no auxiliary tray spacing equipment is provided for the robot. However, a few trays, up to 3 depending on tray size, can back up at the conveyor feeding the robotic pick head and the machine continue to operate properly. The back up is limited by the need to keep the vision head and push-off area clear.

In the **Figure 1** below, the direction Y of the robot is aligned with the incoming tray conveyor. The direction X is perpendicular to this direction and horizontal. The Z axis is vertical.

Technology of the robot

This is a gantry machine with travel limitations of approximately 0.3 m, 0.8 m, 0.25 m in X, Y, and Z directions respectively. The motions necessary are a sequence of short up motions to clear the conveyor end stop, a horizontal motion to over the tote, a vertical down motion into the tote, and return via a similar trajectory. In every case the motions are rounded at the corners and the rounding varies in a manner to avoid hitting edges. All motions are limited in acceleration, velocity, and jerk. Jerk being the time derivative of acceleration. The typical full speed limits are 2.5, 4, and 7 Gs in X, Y, and Z and approximately 3 m/sec in Z and Y and 2 m/sec in X. Usually the next tray is not available for a fraction of a second before pickup so a delay is implemented just above the pickup point until such time as the tray is sensed. Similarly, the motion with a tray is delayed above the tote position if it the tote is not available.

The pattern of motion varies with the product being packed, where the product is taken as the combination of tray size, tray weight, tray height, and packing pattern to be used in the tote. Hundreds of patterns are possible and stored in the machines controller. Currently the operator to enter the desired product uses a touch screen. There is a delay between products, as the upstream processes also need to be adjusted.

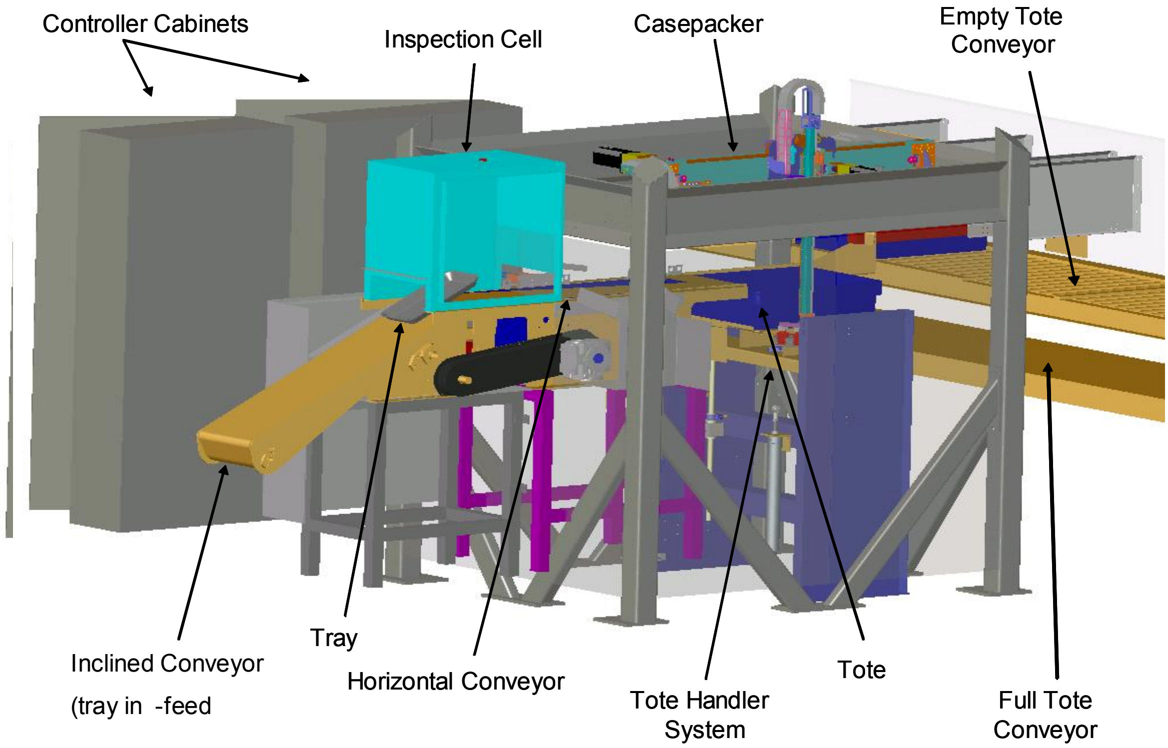


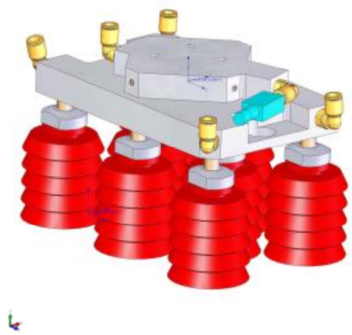
Figure 1 Casepacker Work Cell

All drives are timing belt driven. Motors are geared permanent-magnet brushless motors. The standard for high performance servo motors.

The controller implements a patented algorithm that prevents any significant vibrations of the mechanism. This algorithm takes into account the natural frequencies of the mechanism including the feedback control and causes the commanded motions at the motors to be slightly modified to prevent structural oscillations. This is sometime called "Command Shaping". This algorithm is particularly important for lightweight machines such as this and allows motions at nearly twice the speed that would otherwise be practical. The lightweight also permits smaller motors, amplifiers, bearings and drive belts.

Technology of the vacuum gripper

The vacuum gripper is remarkable robust in the sense of being able to handle a variety of shapes and weights of the trays. It has eight very flexible suction cups as shown in **Figure 2.** Four independent vacuum sources are used so that any combination of two grippers is adequate to pick up a package. However, as a rule all eight do sustain the vacuum. A range sensor is incorporated into the vacuum gripper to verify that a package has been and remains successfully gripped.



In operation, the vacuum is applied just before contact with the package on pickup and the cups are lowered to be compressed against the package. When approaching the drop-off point the vacuum is released and a blow off flow is initiated. This was found necessary for quick release. The gripper tore no packages and experiments showed that hundreds of cycles could be successfully completed with properly wrapped packages.

Figure 2 Vaccuum Gripper

Technology of the vision system

The vision system is a DVT model 630, a colour system. Although, in principle, a black and white system could be used to locate the bar code on the label to verify presence and perhaps placement, the variation in labels for various customers and over time is such that a very robust method was needed. It was found that because the colours used in the labels is more constant than other features, particularly in light of the fact that the meat itself is in view with various colours; a colour vision system was needed. In effect the vision system verifies that a sufficient area of label is in view within a pre-programmed window. The window is located with respect to the leading edge of the package. A photo sensor indicating that the package is in view triggers image acquisition. As with the placement pattern, hundreds of pre-programmed vision procedures can be programmed and requested by Ethernet communication with the robot controller. Although in practice very few are used as the labels are very consistent in shape, colour distribution, and desired placement relative to the leading edge of the package.

In addition, the vision system checks to be sure that little if any wrapping film is over the edge of the tray. The film in this case is automatically wrapped up stream but upon occasion errors are made that causes the material to protrude beyond the edge of the tray. In order to find such transparent overhanging material, the vision system searches for any specular (mirror like) reflections in zones just beyond the edge of the tray.

The tote handler

The objective of the tote handler is to be able to change totes in slightly over 1 second. Such a fast change means that no auxiliary control is needed on the tray feeding. That is, the change out time is so fast, just a little over one second, that the flow of incoming trays need not be slowed or managed by a separate piece of equipment. The weigh-price-label machine just upstream has a special mechanism to cause the trays to be spaced on the conveyor and no other flow control is required if the totes are handled properly. If for some reason a tote is not available, the conveyor feeding the weigh-price-label machine and the robot is stopped and manual intervention may be required because of a back up of trays into the vision system/ kick-off area.

The tote handling mechanism is shown if **Figure 3**. It is entirely pneumatic in its operation. The sequence of events based on starting with a filled tote is as follows:

1. A set of rails holding the tote by the edges is retracted allowing the tote to rest on an elevator platform at essentially the same level.
2. The elevator holding the tote is lowered
3. When the elevator is detected to be low enough, and a tote is detected to be present on the empty tote conveyor a ram is actuated to push the next tote onto the waiting rails. These rails have been returned to the holding position simultaneously or earlier.
4. The robot is signalled to begin packing the empty tote.
5. When the elevator is completely down and space is verified on the full tote conveyor, a ram is actuated to push the full tote on the output conveyor
6. When this ram returns the elevator is returned to the up position ready to receive the next full tote.

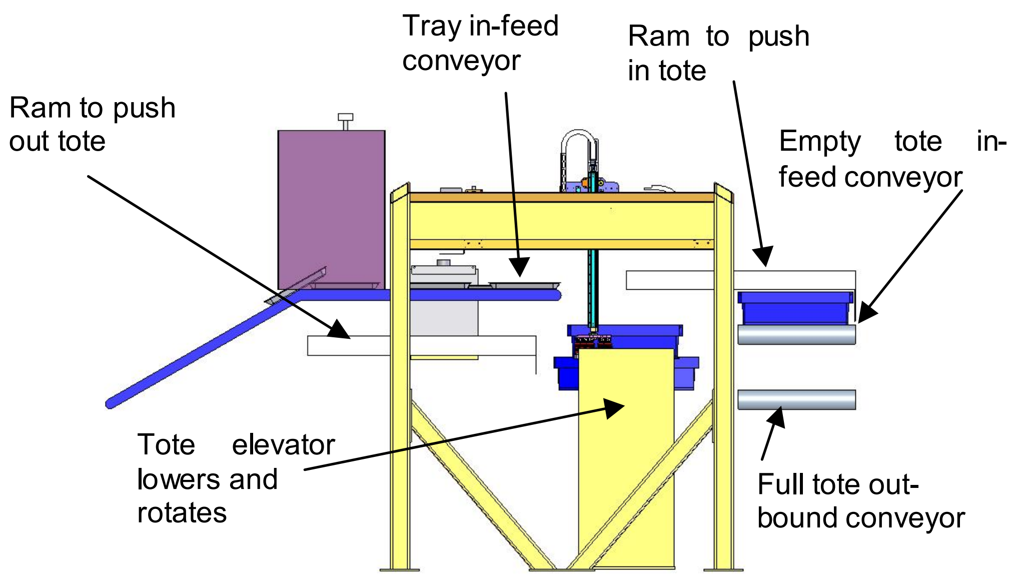


Figure 3 Tote Handling System

Production statistics

On high volume days, the line was packing over 10,000 trays per day. Two particularly high days were 10/1/2004 when 13,537 trays were packed and 7/29/2004 when 13,951 trays were packed. It is important to realize that production has a good deal of start and stop for the purpose of changing products and resolving difficulties with upstream operations. It is also true that most days are less than 8 hours of production on this line.

During a period from 5/25/04 to 8/4/04 a total of 28,229 totes were automatically packed with 275,248 trays. A total of 31 different products were handled of which 6 accounted for 90% of production on this line. On the most popular product, a relatively small tray, the average cycle time for placement was 1.13 seconds. This excludes any waiting for product. Most cycles include some waiting, as the robot is ready before the product is available. In fact, the average cycle time for this product, including waiting, was 2.67 seconds.

Lessons learned

While the test was very successful in demonstrating the technology, including the ability to fabricate a capable machine inexpensively using the advanced technology some improvements needed include:

1. Improved line control. If the machine must stop temporarily because of tote starvation, or other malfunction, it is desirable to be able to stop the flow of trays without causing a backup in the robotic machine. No such mechanism was provided here.
2. More reliable and flexible tote handling. The current machine was installed without significant modification of the conveyors feeding and removing the totes. The result of this was a rather ad hoc tote-handling machine that required an elevator to lower and rotate completed totes from the level of the top conveyor to that of the bottom. A more robust design is needed, however, the use of the elevator does minimize floor space required by both the conveyors and the overall machine.
3. Greater electrical reliability. Because of the short test relatively little attention was paid to the robustness of the wiring and housing of the computer and PLC used. In future version is expected that much more compact housings could be used and placed on or much nearer the work cell itself.

4. For some applications greater ability to inspect packages. This is an ongoing research project at the university.

Summary

An excellent demonstration of the practicality of cost-effective automation of tote packing has been completed. A similar demonstration of box packing is about to start at another plant. Even at the relatively low labour rates in the food processing industry, it is clear that automation of the process will have approximately one-year payback for two shift operations.