An Efficient Control Configuration Development for a High-speed Robotic Palletizing System

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Abstract—**This article presents a newly developed robotized palletizer control configuration consisting of a graphical application running on a human-machine interface (HMI) touch screens, a PLC program, and a servo system that executes palletizer reconfiguration and makes high-speed robotic palletizing possible. The servo system of the palletizer allows the PLC to reconfigure the palletizer automatically, based on the configuration data, and to control the product feed to the robots that execute the palletizing function. This allows the robots to handle several boxes at a time and therefore achieve high-speed palletizing.**

Significant downtime reduction during batch changes is achieved due to simplification of operator tasks, which makes the configuration and control method ideally suitable for production environments with frequent batch changes.

Packaging and materials handling industries may be financially benefited using this configuration and control method. These include low palletizer downtime, high palletizer throughput, low training costs, no rework due to configuration errors and wider availability of potential operators.

Keywords—**palletizing, packaging, materials handling, robotized palletizing, PLCs.**

I. INTRODUCTION

Palletizers are designed to automatically load cartons onto pallets and shrink-wrap plastic film around them for shipping or storing in warehouses in manufacturing industries. Pallets are normally wooden-made flat type containers are used for loading and packaging. Pallet boxes and tote boxes are also used for packaging and handling purposes. Pallets are also used for bulk storage of stock in an open plan floor area. Productivity of a palletizer system is assessed by system throughput which is defined by the hourly rate of transactions that the palletizer can perform.

This paper presents an industrial project with an objective to develop a control strategy that would make high-speed robotic palletizing possible. Until recently robots used in palletizing tasks could only be used for low to medium speed palletizing. This was due to several factors including:

- Long cycle times between consecutive pick/place actions;

- The need to decrease manipulation speed due to inertia which makes product retention in the gripper difficult during acceleration/deceleration;

- The need to stop and collate the boxes before the robot can pick them up.

The project developed has overcome these limitations through a combination of HMI (human-machine interaction) design, PLC software design, robot in-feed control design, robot gripper design and use of servomotors to perform fast and accurate automatic machine configuration on the fly.

The robot in-feed controller allows the PLC to send groups of boxes to the robot in the sequence determined by the pattern data downloaded from the HMI to the PLC. The robot gripper adjusts to the correct size on the fly as soon as it receives the group size information (the user selects the groups during layer pattern configuration). This strategy makes it possible to manipulate several boxes as a group while they move on a collating conveyor, without stopping the boxes.

As a result, the newly designed and built robotic palletizer [1] has achieved palletizing speeds comparable to dedicated mechanical palletizers, while maintaining high flexibility, short set-up times and ease of use.

The control strategy requires supporting software applications that would:

- Allow fast and accurate box pattern generation;

- Allow the new robotic palletizer to perform self-configuration based on the required pattern;

- Control the number of boxes that are presented to the robots at any time, as demanded by the required pattern and allowed by the robot gripper capacity;

- Allow multiple robots to work concurrently without interfering with each other.

The primary performance requirements of palletizers are based on basic economics: production equipment has to be cost-effective. Therefore, palletizers must offer high-throughput capacity, flexibility, minimum downtime losses, simple in operation, accuracy and reliability. High throughput capacity is the main contributor to the financial performance. Simplicity of operation is an important factor, as it determines

the level of training necessary to operate and maintain the equipment.

II. TYPES OF PALLETIZERS

In the manufacturing industries, stacking finished products on pallets as they are manufactured is a means of automatically making up a load for removal to the next stage of processes or to the shipping bay or warehouse. There are special purpose palletizing machines available for stylized roles such as the packaging of candles, canned beer and soft drinks. Two major types of palletizers [2] are available in the market:

- Mechanical palletizers, and

- Robotic palletizers

The key performance criteria by which a palletizer is judged are its palletizing throughput, operational flexibility, cost of ownership, and level of training required to operate and maintain the palletizer.

A. Mechanical Palletizers

Mechanical palletizers offer high speed palletizing and low initial costs. However, because, these machines are designed for a specific range of products and a limited number of patterns they offer low flexibility. Manual system reconfiguration is required during product changeover, resulting in long product changeover downtime and significant productivity losses, especially when production batch sizes become smaller. Frequent set-up errors add to the total downtime and in extreme situations can cause costly product and machine damage.

B. Robotic Palletizers

Typical robotic palletizers offer high flexibility in palletizing and shorter product changeover downtime. However, they can only achieve low to medium speed palletizing and have a higher initial cost than the mechanical types.

During product changeover there are still some mechanisms that need manual adjustments, which frequently results in set-up errors that add to the total downtime, and can cause significant losses due to potential product and machine damage in industries.

III. CURRENT RESEARCH IN AREAS OF PALLETIZING

One area of research in palletizing is related to the development of optimization algorithms for pallet loading, where the objective is to maximize the pallet area utilization [3]. These algorithms are designed to maximize the use of a pallet's area by determining a pallet loading strategy that would result in an optimum pattern configuration, and therefore the best possible use of the available storage space on the pallet. Although intuitively this seems like a simple task, it is easier said than done. The main reasons for this are the variations in products / boxes and pallet sizes, and loading requirements.

Another area of research is aimed at the creation of pallet-loading algorithms that are rule and constraint based [2]. This stem from the need to respect certain constraints in a pallet-loading configuration, such as gaps between boxes that allow air to flow for the purpose of even product temperature maintenance while pallets are stored in cool rooms or transported in refrigerated vehicles.

The most challenging palletizing requirements for research are in "Order picking" applications where the main challenges are the palletizing of non-uniform and mixed-size items [4, 5]. There has not yet been any successful implementation of a high-speed robotic palletizing application that can successfully palletize non-uniform and mixed-size items, firstly because it is practically impossible to stack non-uniform items to any useful depth and secondly because mixed size packages require continuous rearrangement and multiple handling of the products being palletized. Even more challenging are the products that are both non-uniform and mixed size. One method used in the industry is to place non-uniform items in rectangular containers that can be staked on a pallet. This, however, results in a non-optimum pallet space usage.

The remaining challenge in this project is to generate and convey the predetermined pattern configuration and pallet loading information to the palletizer in the most efficient and accurate way possible.

IV. A NEW ROBOTIC PALLETIZER

A new robotic palletizer (Figure 1) has been designed and built [1] to meet the stated needs of the industry. High throughput capacity is achieved by handling several boxes together as a group on the fly. The necessary information regarding the number and position of boxes to be handled simultaneously is generated by the graphical configuration application and sent to the robots by the PLCs.
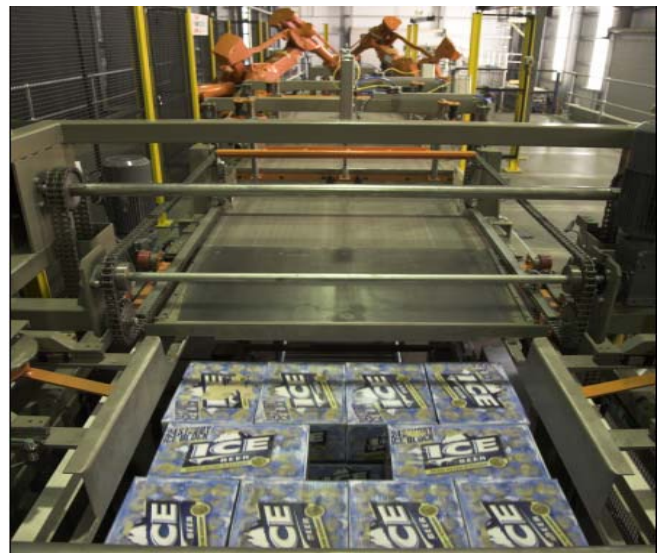

Figure 1. A robotic palletizer with graphical configuration

Minimum changeover downtime has been achieved through automatic palletizer re-configuration. This in turn is achieved using servomotors to execute all necessary adjustments based on the downloaded configuration data. The fast configuration retrieval and download to PLC further reduces the changeover

downtime. This is achieved by using an efficient information retrieval and download method provided by the graphical configuration application.

Simplicity of operation is achieved by implementing a graphical configuration application that provides an intuitive user interface, and is simple to learn and use. To execute a product changeover the operator stops the machine, selects a new product from a list, downloads the configuration to the PLC, and then presses the machine Start button to restart the machine. Palletizer reconfiguration is executed automatically and almost instantaneously.

Accuracy and reliability is achieved by producing accurate pattern and pallet configurations using the graphical configuration application. The servomotors execute an accurate palletizer re-configuration based on the data received from the graphical configuration application. The robots and servo-controlled mechanisms also execute accurately and reliably the palletizing task based on the data received from the graphical configuration application.

V. CONFIGURATION APPLICATION DESIGN

It was intended that the configuration application would be a prototype application. The following GUI screens were developed first, followed by algorithm and code development.

A. The splash screen

This screen appears when the application starts. It displays a Robomatrix Wizard and company logos, the application version and a copyright warning. The Splash screen closes automatically when the display time (six second) expires, and the Pack and Pallet set-up screen is loaded and displayed in its place.

B. Pack and Pallet Set-up screen

This screen is used for setting up the desired box in-feed direction, box size, pallet size and Squarer (pattern squaring mechanism) size using the following parameters:

The Pack Orientation which has two options:

Short edge leading - the boxes are feeding with the shorter edge first into the Robomatrix palletizer.

Long Edge Leading - the boxes are feeding with the longer edge first into the Robomatrix palletizer.

The graphical representation of the box changes orientation according to selection.

Pack Dimensions (mm): The Pack Dimensions data entry allows the user to enter the dimensions (maximum 500mm) of the box.

Pallet Size (mm): The Pallet Size data entry allows the user to enter the dimensions of the pallet that will be used for palletizing.

Layout screen navigation button allows navigation to the next screen (Layout screen), and the Exit button allows the user to close and exit the Robowizard application. The software will ask for confirmation.

C. Layer configuration screen

This screen allows boxes to be placed on the pallet. The box and pallet sizes are as previously selected on the Pack and Pallet Set-up screen. The pallet is represented by the dark-grey rectangle. The box (pack) is represented by the white rectangles. The picture (Figure 2) below shows a pattern of nine boxes on the pallet. The layer configuration screen performs the following applications as described below.
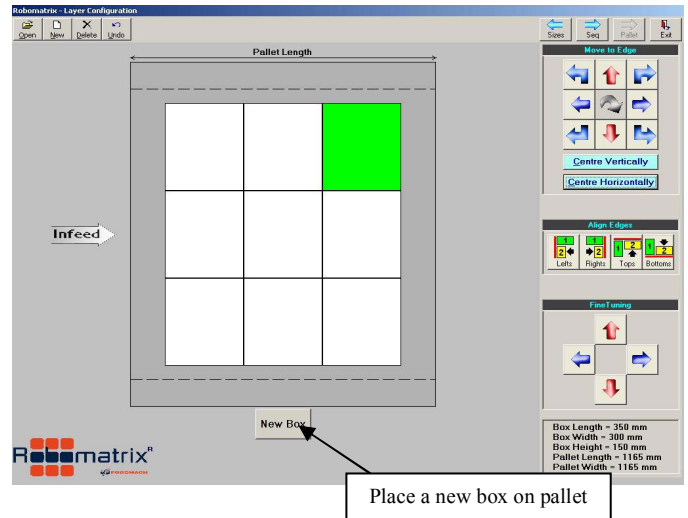

Figure 2. A layer configuration screen

New Box button: this button is used to place a new box (pack) on the pallet. User can drag the box close to the desired position and then use placement arrows to place the box accurately in the desired position.

Move to Edge arrows: these arrows are used to move the box to the desired position. Dragging and dropping the box close to its final position are also allowed and then the arrows are used to position the box accurately. For a left-to-right in-feed machine the first box should be placed in the top right corner. For a Right-to-Left machine the first box should be placed in the top left corner. Boxes should be placed in a logical, sequential order that would allow boxes to travel to their final position in the pattern without interference.

Centre Vertical button: allows the pattern to be centered vertically on the screen (pallet).

Centre Horizontal button: allows the pattern to be centered horizontally on the screen (pallet).

Align Edges buttons: these buttons allow the user to select one box and align another box to one of its edges (left, right, top, bottom). To align to boxes first select the type of alignment that you wish to perform by pressing one of the four buttons (Lefts, Rights, Tops or Bottoms). Next, select the first box (reference box) and then select the second box that you want to align to the first box.

New button (on toolbar): this clears all of the boxes from the pallet and prepares the pallet for loading a previously saved

pattern or creating a new pattern from scratch by placing boxes on the pallet.

Sizes arrow (on toolbar): allows navigation to the Pack and Pallet Set-up screen. All unsaved pattern data will be lost if you proceed to the Pack and Pallet Set-up screen. To save pattern data navigate to the Pack Sequence screen by pressing the Sequence button on the toolbar.

Exit button: this button allows the user to close and exit the Robowizard application. The software will ask for confirmation.

D. Pack Sequence screen

This screen allows the user to select boxes into groups, test the group feed sequence and then save the pattern to a pattern file for later use. The pattern files are used to place layers of boxes on a pallet.

Pack sequence screen includes group number and pack adjustment functions, Align Edge buttons, Save button, Test button, layout and Exit buttons. Figure of the Pack Sequence screen and the functions, as described below, on this screen will be demonstrated during paper presentation.

Pack Adjustment: allows the user to create gaps between groups in the X direction (sideways on the pallet).

Align Edges buttons: these arrows allow the user to select one box and align another box to one of its edges (left, right, top, bottom). To align to boxes first select the type of alignment that you wish to perform by pressing one of the two buttons (Lefts, Rights). Next, select the first box (reference box) and then select the second box that you want to align to the first box.

Save As button (on toolbar): allows the pattern to be saved to a pattern file after the pattern was tested.

Test button (on toolbar): allows the pattern of boxes / packs to be tested as they would be in real life. If there is no interference and the sequence is logical, the test will finish successfully and will allow the pattern to be saved to a pattern file.

Layout button (on toolbar): this button allows navigation back to the Layout screen.

Pallet button (on toolbar): allows navigation to the Pallet Configuration screen.

E. Pallet Configuration screen

Pallet Configuration Screen allows the user to create a pallet configuration by selecting up to three types of layers (A, B or C) from the previously saved layers and then adding these layers to the pallet in a logical order. Layer A is added first and then layers B and C as needed. A typical pallet will only have layers of Type A and B. In some circumstances a third layer type is required. In this case a previously saved layer can be added to layer C type and included in the pallet configuration. The pallet configuration can then be saved and also downloaded to the PLC. A saved pallet configuration can be opened and downloaded to the PLC when needed.
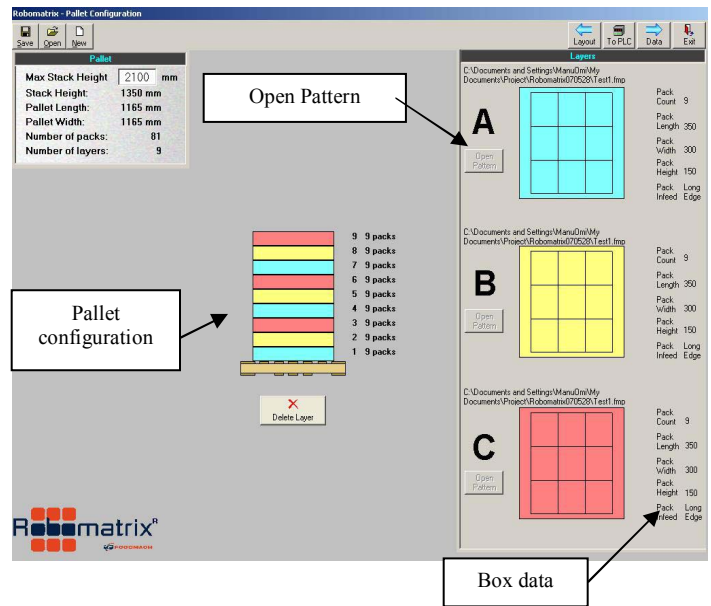

Figure 3. Applications on a pallet configuration screen

Using the pallet configuration screen the following functions may be performed.

Pallet information: provides some basic data about the pallet. It also allows the user to limit the maximum height of the pallet by entering a desired Max Pallet Height. The default maximum pallet height is 2100 mm.

Open Pattern buttons: allow the user to open a pattern file for each pattern type (A, B or C) that will be used to create a pallet configuration. When pressed, the Open Pattern button opens a pattern file selection window.

Pattern type A, B and C images: Once a pattern file was opened for say pattern type A, you can stack that pattern on the pallet by clicking the pattern image.

There are also Delete Layer, Save, Open, New, Layout buttons and Exit buttons available on the Pallet Configuration screen for individual operations. To PLC button (on toolbar) allows a pallet configuration to be downloaded to the PLC. The configuration data includes default values for palletizer set-up.

F. Output Data screen

The Output Data screen (Figure 4) is designed for initial palletizer set-up during the commissioning stage. This screen is password protected.

The following palletizer configuration data as for example pattern position and sizes of group of boxes, robot working envelop data, robot delay before pick up, manipulator grasping points, robot release and accumulation offsets, manipulating velocities, and other required parameters can be accessed from this screen.
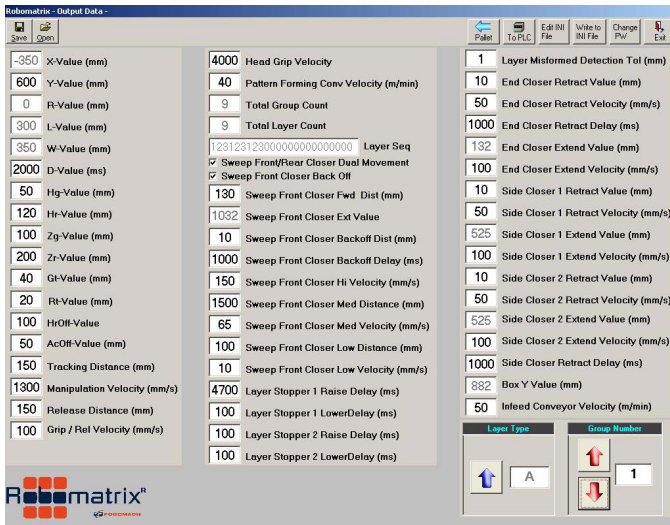
Figure 4. Features on the output data screen

VI.   PROGRAMMING USING VB6

Once the layouts of the screens were finalized, application structures (algorithms) were created and the code was written to achieve functionality that would perform the desired actions.

The control configuration was programmed using VB6 because of the wide availability of programmers and in-house knowledge of the VB6 programming language. A secondary reason was that the application could be developed a lot faster in VB6 than in other languages. At this stage, a prototype-level application that could be used to test the effectiveness of the graphical pattern generation, pallet configuration and palletizer configuration was acceptable. If the application were as effective as anticipated then the software would be rewritten in Java (as a separate project) to make it platform independent. The following flowcharts show basic algorithm information for the functions on the pack and pallet setup screen. Due to the space limitation algorithms for the rest of the screen applications developed were not possible to display in this article.

A. Pack & Pallet Setup screen algorithms
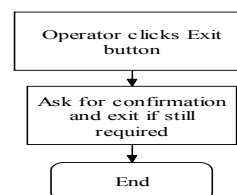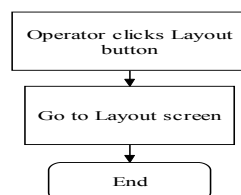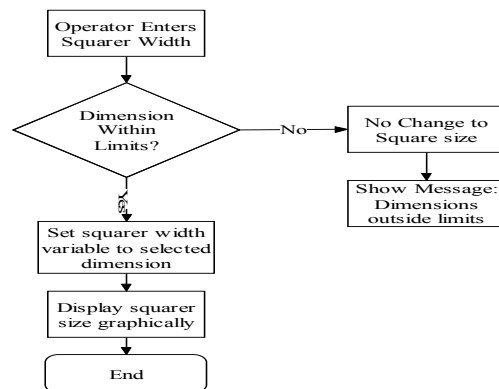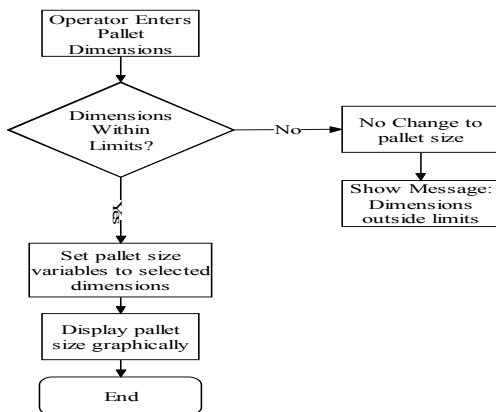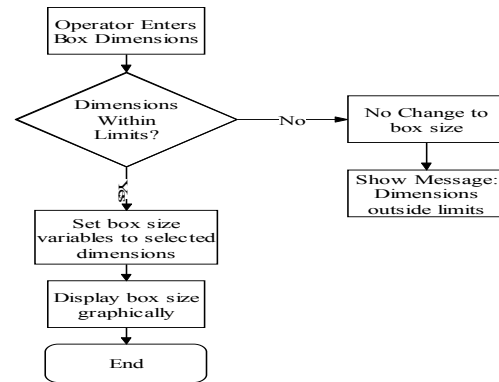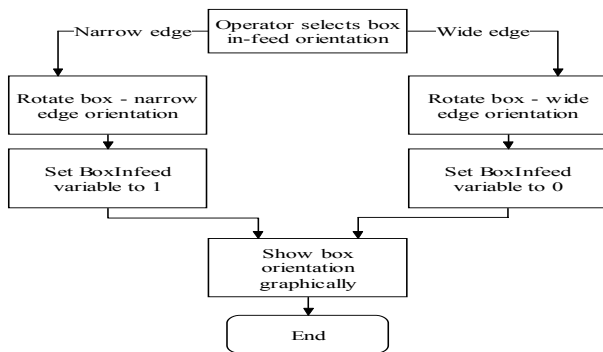
VII. CONCLUSION AND FUTURE WORK

The control strategy and the new palletizer design have together significantly increased robotic palletizing speed while maintaining high flexibility, and are in demand in locally and overseas.

The control configuration application was successfully developed, tested and commissioned. It is currently being used at two major sites of two different large soft drink manufacturers. It has attracted a substantial demand in different countries.

Choosing VB6 as the development language proved to be a good decision. It is a fast prototyping tool and allows good programming flexibility.

Further work could be done to modify the graphical configuration application such that it would automatically generate patterns and pallet loading configurations based on a desired output.

Optimized pallet loading algorithms have been developed by researchers, but those algorithms are not be used in this project, as they would not contribute to the intended outcome of the project. However, these algorithms are available and could be adapted to extend the capabilities of the graphical configuration application by allowing it to generate optimum patterns and pallet loading configurations automatically based on a desired output.

Choosing to develop the control software at prototype level proved to be a good decision. It allowed fast development and testing of various control strategies without the complexities of full-blown applications. The "bells-and-whistles" were added after the control strategy was operating successfully. However, it was preferred that the application be rewritten and optimized to achieve higher speed and reliability, portability and lower memory usage. Some functions and structures could be optimized to improve execution speed and memory usage.

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