APPLICATION OF THE MODULAR AUTOMATED RECONFIGURABLE ASSEMBLY SYSTEM (MARAS) CONCEPT TO ADAPTABLE VISION GAUGING AND PARTS FEEDING

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Abstract

This paper presents the first phase results of a collaborative effort between university researchers and a flexible assembly systems integrator to implement a comprehensive modular approach to flexible assembly automation. This approach, named MARAS (Modular Automated Reconfigurable Assembly System), has been structured to support multiple levels of modularity in terms of both physical components and system control functions.

The initial focus of the MARAS development has been on parts gauging and feeding operations for cylinder lock assembly. This phase is nearing completion and has resulted in the development of a highly configurable system for vision gauging functions on a wide range of small components (2 mm to 100 mm in size). The reconfigurable concepts implemented in this adaptive Vision Gauging Module (VGM) are now being extended to applicable aspects of the singulating, selecting, and orienting functions required for the flexible feeding of similar mechanical components and assemblies.

1.0 Contemporary Flexible Assembly Technology

Andreasen, Kahler, and Lund[1] have defined assembly processes as composed of three main stages: handling, composing and checking. These three stages can in turn be subdivided into storage, transport, and positioning functions. Another view of the assembly process is to define it in terms of operations related to workpart gauging, feeding, gripping, and fixturing.

Independent of the classification approach used for assembly processes, workparts must generally be properly gauged or tested, fed, oriented, and held for the assembly function to be a success. Many researchers have attempted to provide suitable analytical approaches to model this processing of workparts, often by looking at one function (such as trajectory or motion planning, collision avoidance, parts insertion, etc.) in high detail. Others have noted the commonality between many of these functions and attempted to leverage this to define the separate problems in a common context.

For example, Natarajan[2] observed the duality between the motion planning problem and the problem of designing a feeder for orienting a workpart from some arbitrary initial orientation I to a final orientation G. In principle, an algorithm that would facilitate automatic design of parts feeders based on CAD/CAM representations of workparts should also be able to benefit from previous developments in workpart grasp modelling. Similar techniques should also be applicable to the problems of flexible fixturing system synthesis and gauging function definition and design.

Unfortunately, the practical industrial technologies and tools for making these support operations adaptable from process to process (or part type to part type) are currently very limited. Typical so-called flexible assembly systems (FAS) in use today are often fairly flexible in terms of potential workpart trajectories, yet relatively primitive in terms of easily or automatically adapting to the various aligning, gripping, and fixturing needs of different workparts or processes. These flexible assembly systems are often little more than a robot surrounded by a set of fixed tooling that is programmed once and left to run for several months or years until new production needs dictate system retooling. The potential advantages of flexible automation are thus hardly realized in this scenario.

Machine vision subsystems, quick change tooling modules, and various advances in off-line programming/simulation systems[3,4] have been suggested as the essential breakthroughs that will pave the way for a proliferation of cost effective and truly flexible (agile) assembly systems. However, most automated assembly systems being implemented today still employ primarily fixed tooling for the actual grippers, fixturing, vision gauging system components (optics, lighting, mountings, etc.), and parts feeding/orienting/guiding functionality. Machine vision systems have become easier to setup and program yet the required support equipment for parts presentation and illumination still entails significant custom design and fabrication. Quick change tooling modules are typically used to simply swap one fixed piece of end of arm tooling for another.

Off-line programming/planning/simulation systems can improve the efficiency of designing and programming automated assembly systems. Alternative system approaches and assembly task strategies can be quickly evaluated and compared prior to the fabrication of a proposed system. However, the resulting assembly system designs are not necessarily more flexible. Further, assembly system programming changes or adaptations are still done off-line and not local to the actual assembly

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system controller. This minimizes the ability for the assembly system to automatically reconfigure itself under local control. Thus, the resulting assembly system is not able to as easily and quickly adapt itself to required changes in production schedules or capacity balance. The ability for such dynamic reconfiguration is likely to be an increasingly important feature as assembly systems become more flexible.

2.0 Application of Analytical Tools to Industry Practice

Although significant, most of the leading edge analytical advances in flexible assembly over the last several years have yet to be applied to solve practical real-world manufacturing requirements. This is not entirely surprising since leading edge analytical developments, by definition, are not directly amenable to industry application. Another potentially significant factor is the relatively limited practical collaboration between researchers in the academic community and system integrators and end users in industry.

Academic research tends to focus on issues that are more abstract and provide long term benefit to the state of the art. Innovators in industry tend to focus on more near term and precise objectives such as delivering a working assembly system next quarter that will operate with 99.5% up-time and support N variations on a set family of workparts with setup changeover not to exceed M hours. This difference in objectives and motivations can tend to preclude meaningful collaboration.

There are, however, significant potential advantages to such collaborations. The difference in approach by academics and industry can provide new perspectives to each group. It is generally recognized that collaborative teams composed of individuals with diverse backgrounds can act to improve both the effectiveness and rate of innovation[5,6]. There are two essential ingredients to achieving this potential in practice:

1. An appropriate framework of project objectives that emphasizes goals and results which are clear to all contributors.

2. A suitable means of monitoring and managing the progress of the team towards these objectives.

It is not the intent of this paper to investigate or pursue the validity of these observations at length. This subject has been and continues to be the focus of substantial research and study by others. However, we will use these as a guide in defining a framework for the development of an integrated approach to support the essential assembly process functions in a truly flexible assembly system.

3.0 The MARAS Concept

From the above, the new approach to flexible automated assembly development should foster effective collaboration and synergy between contributors in both academia and industry. It is also important that it facilitate the adaptation and extension of appropriate analytical tools to real world applications. Towards these ends, Table 1 defines primary characteristics of the new approach, named MARAS (Modular Automated Reconfigurable Assembly System).

Table 1
Primary MARAS Concept Features
1. Use building block approach for mechanical modules and subelements.
2. Employ unified analytical models, scalable from basic to advanced capability.
3. Use object-oriented representations of physical elements (including actuators, passive components, and sensors) as well as software control functions.
4. Use building block elements for modelling and control functions.
5. Initial emphasis on a specific range of parts that is small enough to be practical yet with enough general features so as not to be trivial.

MARAS has some similarity to other contemporary reconfigurable system concepts in that it emphasizes a modular or building block approach to implementing flexible assembly systems. However, MARAS is structured to emphasize multi-level modularity for both system physical components and related system control software.

At the physical level, MARAS extends some of the modular concepts for flexible fixturing defined by Asada and By[7,8] and borrows from other modular approaches such as the RobotWorld modular robotic station base concept of Scheinman[9] and the Carnegie Mellon Reconfigurable Modular Manipulator[10]. The MARAS concept extends the approach of flexible fixture system synthesis based on combining appropriate fixturing subelements (fixels) to combine similar families of physical elements to support the other fundamental functions required in assembly:

1. Gaugels (physical elements that are combined together to form Vision Gauging Modules or VGMs).

2. Feedels (physical elements that are combined together to form Adaptable Feeding Modules or AFMs).

3. Grippels (physical elements that are combined together to form Generalized Gripper Modules or GGMs).

MARAS specifies that these building block elements will be represented in an object-oriented fashion to facilitate the development of a unified set of analytical tools. Further, the use of object-oriented representations for these mechanical elements can potentially act as an integrating common reference frame for machine element designers, analysis model developers, and software systems engineers. Machine designers can create a database of mechanical element definitions that can be matched and integrated as needed to meet the requirements of different workparts and assembly support functions.

Analytical modelers will initially apply group technology to classify these building block elements. This includes extended definition parameters to categorize and describe the elements in terms of how they can be controlled or used in conjunction with other elements to support specific functions and/or specific types of workparts. These categorizations will form the basic of applied modelling tools to be developed for prediction of the performance of the initial set of elements and associated design derivatives or improvements.

Software system engineers will utilize the element representations to support the development of efficient software modules or objects for the monitoring and control of the MARAS assembly system modules. This will aid in the translation of analytical modelling tools from theory to practice. Both will be based on the same data object representations. Control and sequencing functions to be performed will also be defined as generalized objects and methods to further assist in the development of a unified modelling and control system.

The use of a common building block definition system for machine designers, analytical modelers, and software developers will improve understanding between the various contributors. It should also lead to more focused innovation. The common representation will allow advances or improvements in one area, such as modelling tools development, to be more readily applicable to other aspects of the concept as it evolves. Developments in each area can start at a basic level and be gradually scaled with time to be more sophisticated in scope and robustness.

4.0 Phase I MARAS Focus

A specific set of small parts, cylinder lock components, was selected for the first phase of MARAS system development. These components range in size from approximately 1 mm to 25 mm in length. Some of the parts are mostly planar while others are cylindrical or more complex in shape. This provides a reasonable variety of shapes, aspect ratios, and details such that the part family includes a number of aspects found in other small parts.

Two fundamental functions of the assembly process were selected for this initial phase: vision gauging and parts feeding/orienting. The definition of an initial basic set of modular elements and corresponding modular control approaches for these functions was the primary objective. The development of corresponding analytical tools for

these elements is currently in progress but is not part of the scope of this paper.

This initial focus has resulted in the development of a working version of one subsystem of a practical MARAS system: the Vision Gauging Module (VGM). Preliminary physical building block element definitions for another important subsystem, the Adaptable Feeding Module (AFM), have also been completed.

The VGM is a reconfigurable subsystem for vision inspection of small (1 mm to 100 mm) mechanical components. Fixturing, illumination, optics, and other required physical elements of the VGM (gaugels) have been designed to address different part family applications with little or no mechanical setup change. A corresponding set of software modules has been defined and developed to support automated execution of system changeover to support new part family inspection operations with object-oriented definition of system operations. Here, the VGM can be reconfigured on-line to perform entirely new gauging functions based on a device configuration database downloaded to the VGM controller by a supervisory controller with links to parametric CAD representations of the parts to be gauged.

The AFM is a similar subsystem and approach for adaptable parts feeding and orienting. Geometric analysis of parts to be supported by the system will define guiding checking/inspection elements (called feedels) from a generalized family. The active control of the AFM will also be driven by the geometric representations. As with the VGM, the AFM will be reconfigured on-line to perform entirely new feeding functions based on a device configuration database downloaded to the AFM controller.

5.0 Phase I Parts Description

Figure 1 provides a simple side view of the primary components to be assembled to produce a typical cylinder lock. The plug is a rotating cylindrical component that is turned by the key within the cylindrical base of the body. The driver, attached to the plug by the cap, is the component that activates the lock latching mechanism. The plug will only rotate if the key's notches match the heights of the corresponding base pins installed in the cylinder lock assembly.
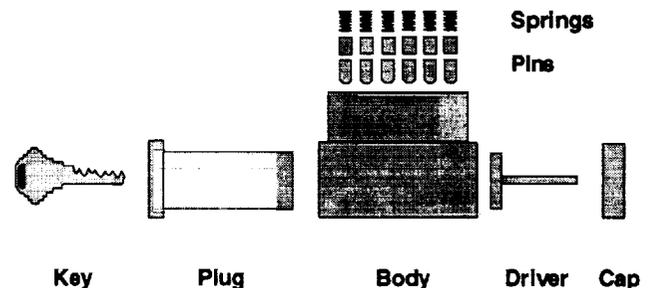

Figure 1 - Cylinder Assembly Components

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The key, plug, and body are each approximately 25 mm (1 inch) in length. Other part dimensions are roughly to scale as shown in Figure 1. The part variations and gauging requirements are extensive, as indicated in Table 2. Each of 30 key types employs a unique key blade cross section with different sets of dimensions and tolerances for each type. Further, each key type is available in either 5 or 6 pin variations. The key blade cross section variations also apply to the plugs, since the keys are inserted into the plugs to operate the cylinder.

Table 2		
Part Variations		
Part	**Variations**	**Gauging Requirements**
Keys	30 types, 2 lengths	8 dimensions
Plugs	30 types, 2 lengths	25 dimensions
Bodies	2 types, 2 lengths	25 dimensions
Pins	2 types, 13 lengths	5 dimensions
Springs	2 types	3 dimensions
Drivers	8 types	3 dimensions
Caps	2 types	3 dimensions

5.1 Parts Handling, Orienting, and Gauging Requirements

Both the plugs and bodies include a high number of dimensions to be checked. This includes pin hole locations and alignment plus face and tail details such as key slot alignment, concentricity, and body "tang" alignment. The tang of the body is the vertical block that holds the top pins and springs. Two lengths of bodies and plugs are required, to support both 5 and 6 pin variations.

Two types of pins (bottom pins and top pins) must be supported. Bottom pins alone have 10 unique lengths. Radius of nose curvature for each end of the base pins is different, since the leading (bottom) edge of the pin must be very narrow to mate effectively with the key notches and the top of the top of the pin must be relatively flat.

Table 3		
Part Orienting Requirements		
Part	**Source**	**Orienting Requirements**
Keys	Bulk	Vertical
Plugs	Bulk	Vertical
Bodies	Pre-oriented	Vertical
Pins	Bulk	Lead edge down
Springs	Bulk	Vertical
Drivers	Bulk	Vertical, tail up
Caps	Bulk	Threads down

Variations for caps and springs are fairly minor (one or two different dimensions) but drivers come in a wide range of styles to support different types of latching mechanisms.

Table 3 summarizes the source of the parts to be supported plus the final orientation requirements for use by the robotic flexible assembly stations. Excluding cylinder bodies, all parts are originally without any orientation and are located in bulk bins. Many parts are also fabricated both in-plant and externally.

The source of the incoming parts is one of many additional issues to be considered in defining and implementing a gauging and feeding system approach. These issues also include:

1. Parts may need to be assembled both in plant and externally.

2. Gauging is required between fabrication operations or steps for some parts.

3. The production rate approximates 1 part/second.

4. Low capital is available for project implementation.

5. The required implementation schedule is short.

6.0 The Modular Inspection/Palletization Cell

In applying MARAS to the cylinder lock parts gauging and orienting application, the following system design constraints were defined:

1. Gauged and oriented parts will be loaded to pallets (to address both in-plant assembly and external assembly). This feature will not be required for applications where the oriented parts are to be presented directly to assembly stations; the approaches defined for this application are not restricted to palletized parts only.

2. Individual inspection/palletizing cells will be used for each part group, with some combining of part groups if practical. However, a uniform system architecture will be supported across all inspection/palletizing cells to maximize interchangeability, simplify maintenance, and minimize development effort.

3. Generalized singulating, selection, and orienting approaches will be used where applicable (to support system modularity, reconfigurability, and minimal implementation cost).

4. 100% inspection will be provided for only first level features (due to high number of details for full inspection plus the high production rate).

5. Partial sampling with integral automated SPC for the full set of part dimensions will be supported by a reconfigurable Vision Gauging Module.

6. The inspection/palletizing cell will be controllable either manually (through a touch screen Man-Machine Interface) or automatically (via the robot/vision controller).

7. The VGM (and to a lesser degree, the orienting station) will utilize uniform mechanical components, electrical components, optics, and software across all inspection/palletizing cells.

Figure 2 presents an overview schematic of the Modular Inspection/Palletization Cell approach. As shown, the Vision Gauging Module can be sited directly adjacent to the Orienting/Palletizing station, where it can be loaded/unloaded and controlled by the orienting/palletizing robot. The VGM can also be sited remotely from the Orienting/Palletizing station where it can be loaded/unloaded and controlled manually. This is required for gauging parts at various upstream points in the fabrication process and also for gauging parts supplied from outside the plant.
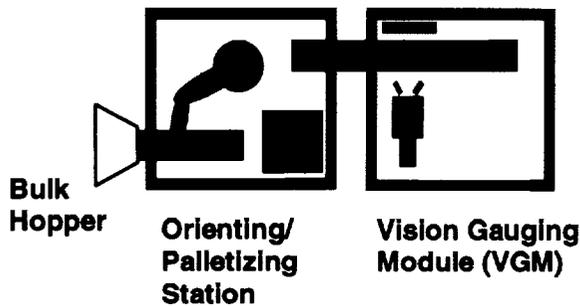

Figure 2 - The Modular Inspection/Palletization Cell Concept

7.0 The Prototype Vision Gauging Module

The Vision Gauging Module incorporates a number of the MARAS attributes noted above. Since the VGM is further developed than the Adapatable Feeding Module or AFM, it will be used to further illustrate these concepts.

Consistent with the core MARAS concept, the following features were included as part of the prototype VGM design:

1. Modular building block elements (camera mounts, light source mounts, calibration targets, electrical components, etc.).

2. Use of a generalized nest block to hold parts in various orientations before optics.

3. Design for loading by hand, robot, or fixed automation.

4. Reconfigurable software (via setup file and downloaded set points and recipes).

7.1 The VGM Station Base

Figure 3 presents the general purpose nature of the station base employed for the VGM. Extruded aluminum profile sections were used to fabricate the frame and table base for mounting the optics, electronics, traversing slide, and other components. The table base is formed from adjacent 160 mm x 40 mm extruded sections, providing a mounting base very similar to the T-slot type of base often employed for machining fixture mounting. A 0.75 meter (30 inch) servo-controlled traversing rail slide is mounted to the top of the table base to index parts to be gauged before the appropriate optics.

The VGM station table base can support mounting of up to three to four cameras or mechanical gauging subsystems plus required illumination sources (front lighting, back lighting, structured lighting, etc.). A family of general purpose mounts has been developed to address quick and flexible placement of these gauging elements or "gaugels" on the VGM table base. This facilitates efficient setup or changeover if entirely new lighting approaches and/or lens characteristics are required for a new gauging application

The NEMA 12 enclosure mounted to the lower side of the table base provides a sealed and air-conditioned housing for the supervisory control computer, network interfaces, illumination sources, power supplies, and input/output subsystems. Sliding opaque door panels (not shown) are installed between the frame sections above the table base. These are to minimize dust infiltration and background lighting disturbances in the gauging area. The touch screen operator interface panel is installed to the top of the VGM station base frame on a swivel base. The screen centerline is at 1.7 meters above floor level for optimum ergonometrics.
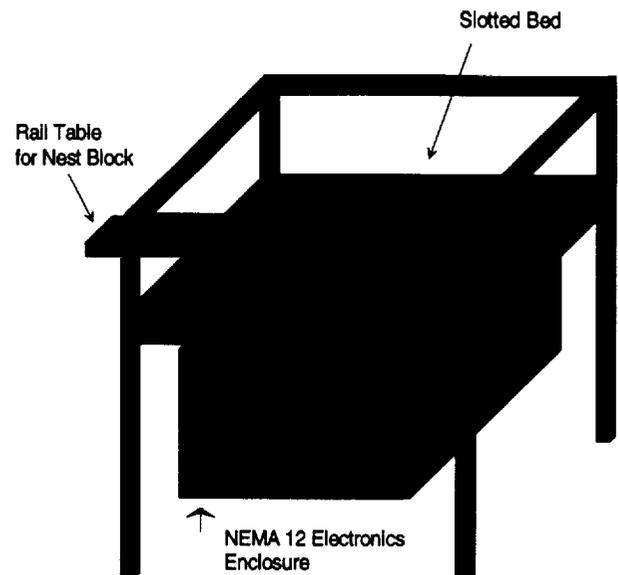

Figure 3 - Vision Gauging Module Station Base

7.2 The VGM Generalized Nest Block Approach

The VGM must be able to support easily reconfigurable fixturing or gripping approaches to facilitate a wide range of part geometries and gauging functions in an adaptable manner. A generalized nest block fixture design is employed for this purpose, as shown schematically in Figure 4. Here, the nest block base is a CNC-produced fixture block that includes aligning nests for holding parts in the orientations required for vision gauging all the required dimensions and features. Parts are placed approximately in the nest from above by hand or by automated means. Next, a mating CNC-produced clamping "plate" is actuated by either operator or automatic command to provide final and deterministic positioning of the parts in the nest block. Although the vision system can compensate for positional inaccuracies perpendicular to the view axis, accurate and repeatable alignment is especially important in the direction along the view axis to maintain focus integrity when the field of view (and thus, depth of field) is small.

Proximity sensors mounted to the nest block are used to verify clamp bar activation and deactivation. An integral calibration target is incorporated into the nest block for ease of optics alignment and calibration.
Although simple geometries are shown in Figure 4, a typical nest block and clamp bar include numerous details to provide the required aligning/orienting functions plus optical paths to view the required part sections. Using advanced CAD systems and CNC greatly streamlines the design and fabrication of the nest block and clamp bar for any required part.
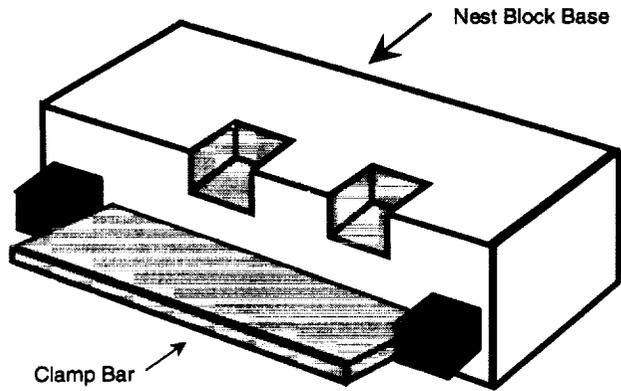

Figure 4 - Vision Gauging Module Generalized Nest Block

7.3 Vision Gauging Module Elements Representation

A key component of the MARAS concept is the representation of the elemental building blocks. This includes physical elements as well as control definitions. The representation of an object typically includes geometric definitions plus extended parameters that describe other attributes such as ranges of control or actuation supported, discrete operating states, mating requirements for integration with other modules, etc.

For the prototype VGM systems, Table 4 provides a sample of typical element definitions:

Table 4 Sample Object Parameters or Properties	
Object	Sample Parameters
Back light module	Size of illumination area Light intensity range Available mounting elements Available illuminator elements
Laser line source	Range of focal lengths Ratio of line width to length Available mounting elements Available light intensities
Nest block	Focal centerline height Number of nests Number of actuators, sensors Actuator and sensor connects
Camera lens	Focal length range FOV range
Gauging shot	Illumination modules used Associated gauge functions Number of analysis steps Nest translation for shot Calibration set parameters

Although the examples presented in Table 4 are by no means a complete set of the object definitions used for the prototype VGM, it does illustrate the type of information contained within these definitions.

7.4 Inspecting/Palletizing Cell Control Architecture

Figure 5 provides a block diagram view of the major components employed for the Inspection/Palletizing cells. This includes an Intel 486 based supervisory computer running Microsoft Windows that functions as the supervisory controller, man-machine interface, SPC analyst, and production tracking system for each inspection/palletizing cell. These supervisory computers are also networked together via ethernet to support upload of summary information to higher level plant systems. Remote access to these systems is supported via modem communications for service diagnostic and maintenance purposes.

The software used to operate the supervisory computer is a next generation derivative of VAX/VMS and OS/2 based factory control software systems originally implemented for discrete parts assembly/test at facilities such as Chrysler, General Motors, and Caterpillar in the late 1980s. This software was entirely re-written and enhanced over the last year utilizing current object-oriented development tools and coding approaches.

Additional information regarding the supervisory computer software functions is presented in section 7.5 below.

Emulation of Modicon Modbus communications protocols is an important feature of this architecture. This provides the flexibility to communicate to a wide variety of robotic/vision controllers and other intelligent devices via relatively simple serial line connections. This communications link is used to collect operating status and process data from the robot/vision controller for the orienting/palletizing station and one or more VGM stations. Process setpoints, recipes, and status change commands (such as clamp station, start station, stop station, abort cycle, etc.) are also downloaded to the robot/vision controller via the emulated Modbus. In addition, the Modbus protocol was extended to support automated download of setup or configuration files to the robot/vision controller over the same line used for production data uploads and command/recipe downloads.
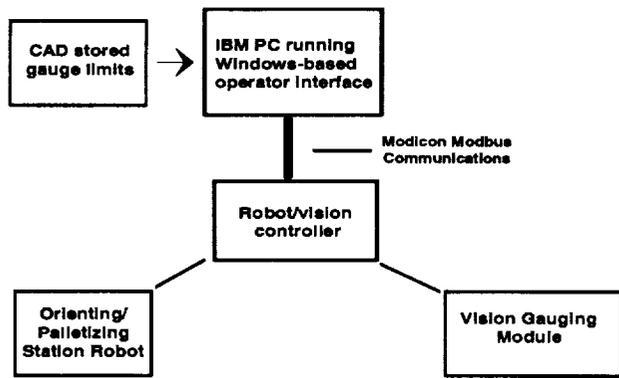

Figure 5 - Inspection/Palletization Cell Control Components Schematic

The software developed for the robot/vision controller is another vital component of the overall architecture. Based on commands, setpoints, and setup file information downloaded from the supervisory controller, the main software control program in the robot/vision controller performs the following functions:

1. Controls light source activation and nest block clamping activation (via Opto 22 Optomux network modules).
2. Senses states of nest block clamp (via proximity switches linked to Opto 22 Optomux network modules).
3. Commands traversing slide to index nest block to required positions.
4. Performs setup file defined vision gauging functions (frame acquisition, vision algorithm execution, numeric functions, data analysis functions).
5. Updates status block with most recent gauge results and process information for collection by the supervisory computer.

All of these functions are definable by the setup file downloaded from the supervisory controller. The setup

file contains sets of parameters which completely define the required functions of the VGM. This provides the capability of downloading a setup change "on-the-fly" without the need to halt non-affected operations. The setup file is much more compact than downloading new programs to the robot/vision controller. Thus, the time required to implement a given VGM setup change is short. A set of setup files can be maintained on the supervisory computer in a protected directory that can only be accessed by authorized plant personnel. Currently, the files are maintained manually by used of a text editor.

The setup files define such parameters and selectable features as:

1. Number of cameras defined for the VGM.
2. Illumination sources to be used.
3. Nest block positions for each vision frame (camera shot) to be acquired.
4. The specific vision and numerical algorithms to be employed (including sequencing and execution parameters) for each camera shot.
5. Number of gauge variables to be tested, including process limits.
6. Association of gauging functions with processing stations or operations (for SPC purposes).
7. Reject condition codes.
8. Auto detection of optics failure.
9. Required clamping confirmation input identification (if any).
10. Error handling functions.

Setup file definitions can also be model (part type) specific. That is to say, a set of parameters defined in the setup file can be associated with a particular "model" or part variation. The setup file can thus define the operation of the VGM to be unique for different part variations. With appropriate definition of the setup file, the VGM will automatically adapt itself to process different parts via simple download of a new model code from the supervisory computer.

7.5 The VGM Supervisory Control Computer Software

The supervisory computer software must be very intuitive and easy to use for effective operation by plant floor personnel. Appropriate use of graphical user interface elements has thus been used towards this end in implementing the software.

A menu bar at the top of the screen has been kept purposefully simple for ease of use when performing common operations. Toolbar command button icons have also been employed to provide quick access to the most frequent functions, such as:

1. Starting and stopping the system monitoring functions (password protected).
2. Display of communications status.
3. Station selection for additional detail
4. Display of station control panel..
5. Display of station alarm/fault and production counts summary status.
6. Display of defined CAD images.

7. Display of raw process data from monitored stations.
8. Access to historical production trend displays.
9. Access to historical alarm/fault trend displays.
10. Access to SPC tracking displays, logs, and charts.
11. Access to the on-line help system.

8.0 Orienting and Singulating Concepts for Flat Parts

This section presents some of the basic general feeding approaches we have been pursuing as part of our preliminary definitions of an Adaptable Feeding Module (AFM). We are using these plus more complex approaches to orienting using both manipulators and passive handlers (using the terminology of Boothroyd, Poli, and Murch[11]) to define our first set of "feedel" elements plus corresponding parameter set definitions and control software objects.

Given the wider range of potential future applicability to other part families, we have first concentrated on flat parts to define candidate generalized singulating approaches. Singulation is the process of separating parts into a single vertical layer with only one or possibly two orientations ("top" up or "top" down).

For flat parts singulation, the following attributes are common:

1. Parts are originally in a bulk bin or hopper that dumps into a vibratory hopper (not bowl feeder) that dispenses a steady stream of parts onto a conveyor.

2. All parts don't need to be oriented. Allowing for de-selection of some parts to recirculate can make for a more robust and practical system design that also naturally supports part purging for changeover.

3. Generalized end-of-arm-tooling should be used where applicable (such as vacuum cups for flat parts).

4. Use generalized and/or modular singulating elements or bars.

5. Use vision where aligning/orienting is not possible or practical by geometric means only.

6. Use common mechanical components and control software for each part type.

By definition, we refer to a flat part as one where the thickness of one dominating geometric surface or plane of the part to be fed or oriented is much less the height and width of the surface. Examples include parts stamped from sheet metal where the resulting flat feature surface dimensions are large compared to the thickness of the part. For the target application of cylinder lock assembly, the keys fall nicely into this category. Some members of the driver part family may also apply. Given the ratio of the cap height to cap diameter of approximately 0.3, this should apply to caps as well.

Figure 6 provides a simple overview of one approach to flat parts singulation. Here, the vibrating hopper feeds a conveyor that indexes parts towards an area where a machine vision camera is used to verify part position and orientation for acquisition by a robotic gripper. Wiper blades over the conveyor are used to achieve a single layer of parts. Narrowing blocks over the conveyor confine the parts to a specific region for the first level vision inspection and robotic acquisition for final orienting. This method is quite effective and can supply a steady stream of singulated parts. However, parts sometimes jam. This makes the approach unreliable. The use of a rotating wiper or brush can potentially alleviate this problem.
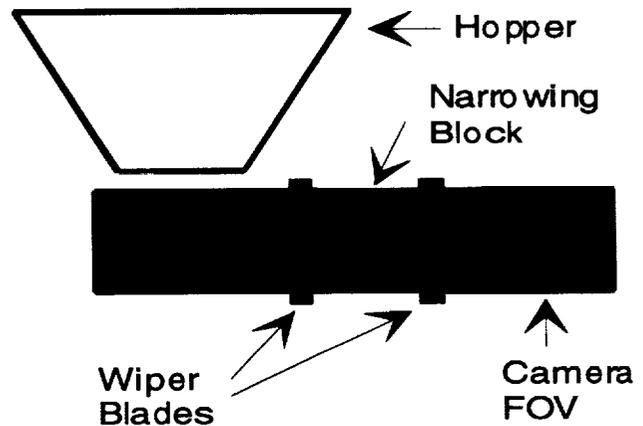

Figure 6 - Singulation of Flat Parts with Wiper Blades and Narrowing Blocks

Figure 7 presents another potential approach for flat parts singulation. Here, the hopper feeds a singulating ramp with shelves that deposit a single layer of parts on the conveyor. The ramp is sloped down towards the camera FOV and also away from the hopper. The lip height of each shelf is equal to the height of the flat part. Thus, parts will either slide off to the overflow area of the conveyor or fall into one of the shelves and slide down the shelf to the conveyor to be advanced to the camera FOV.
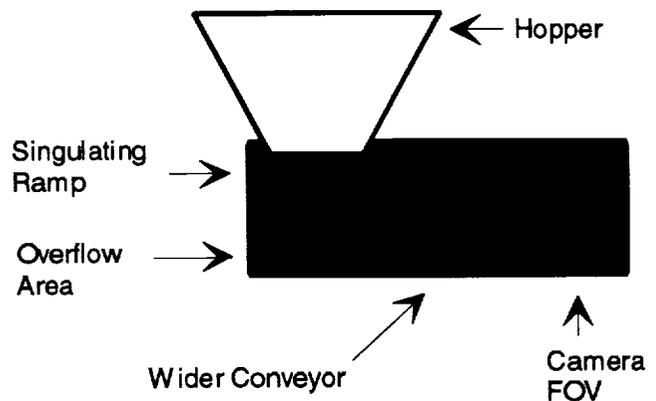

Figure 7 - Singulation of Flat Parts with a Singulating Ramp

Problems with this approach include a high ratio of overflow parts versus singulated parts and a less steady flow of singulated parts to the camera FOV.

9.0 Future Work

These two sample approaches are not intended to imply the full range of options available for singulating or orienting parts. However, they do serve to illustrate some fundamental principles worth considering in defining or implementing a generalized orienting system.

These and other approaches are being refined and verified for application to the cylinder lock application and other small mechanical part assemblies. Common to each of these approaches is the need for a modular and reconfigurable architecture in both the physical and software components. This applies to the guiding or aligning elements, vision systems, and the additional orienting functions performed by some sort of robotic gripper.

For the near term, the immediate goal is to complete installation of the first three inspection/palletization cells in the first quarter of 1994. Although these first installations will incorporate some of the reconfigurable features of the VGM for their feeding and orienting functions, it is expected that this will be even more so for the next two inspection/palletization cells to be completed later in 1994.

Application of these principles for adaptive gauging and feeding is now in progress for three other automated assembly projects to be completed towards the end of 1994. Additional integration of CAD modelling for automated or semi-automated synthesis of appropriate adaptable system configurations is planned.

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