AC 2009-1927: A SMALL-SCALE AUTOMATED WAREHOUSE

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Flexible Robotic Manufacturing

Abstract

The following paper describes a hardware and software system used in modeling an automatic flexible manufacturing system. This system was designed, constructed and tested by students at the Oregon Institute of Technology to model an agile manufacturing system. The focus of this system is exploring processes to remove rigidity in automated processes. Modern automated processes deal with diversity in products by either installing a number of different manufacturing systems, or by producing large amounts of stock to be sent to inventory followed by modification of the manufacturing systems for new products. Rather than following these costly and time-intensive processes, the goal is to construct a single system that is able to flexibly switch between different manufacturing processes on demand and produce directly based upon demand. That is to say that rather than having a number of systems, or producing large amounts of stock to send to inventory, a localized system would be able to automatically produce to order. In this manner costs of large systems, changing out systems, and inventory are reduced while preserving the precision of automated systems.

The project described models a flexible manufacturing process from the aspect of servicing stationary work cells. The issue with flexibility from the standpoint of a manufacturing cell is not so much the ability of the cell to carry out a variety of tasks, but rather the issue is of receiving and locating different materials and tools necessary to these processes. As such this project covers supplying parts and materials to stationary robotic work cells in a manner that is fully automated and can be interpreted within the stationary work cells.

This project employs an autonomous intermediate robot used to transfer and receive parts and goods between stationary robotic work cells and a central supplying depot. Parts and goods are interfaced between the intermediate robot and stationary systems in preloaded modules to be placed inside the stationary work cell work space. The primary constraints are presenting parts and goods in space in a manner that can be found by both intermediate systems and stationary systems. That is, the part and goods within the modules must be fixed in space with appropriate tolerances such that automated systems within the stationary work cell can find them, and the modules themselves must be fixed in space with appropriate tolerances such that the intermediate robot can find them in space. Further, in exchanging modules, intermediate and stationary systems must communicate to some degree.

Introduction

The main purpose behind exploring flexible automated systems can be found within the principles of Lean Manufacturing. The primary goal of this project is the exploration of increasing product quality while decreasing both costs and time. This can be done by exploring the principles of the Seven Wastes in manufacturing processes, as proposed by

Taiichi Ono: specifically, Waiting, Defects, Overproduction, and Unnecessary Inventory are four of the Seven Wastes that relate to this project[4].

The first two wastes of Waiting and Defects are universally addressed by automated systems. After removal of the human element, automated processes are able to have high precision in that they can produce large numbers of goods homogenously both in quality and production time. As such, the issues of waiting on products due to inconsistencies in the amount of time to process, as well as the issues of defects caused by inconsistent manufacturing processes between workers, is removed. This principle, more than any other, has been in practice since even the earliest advances within the industrial revolution[2].

The second issues are those of Overproduction and Unnecessary Inventory. Although automated systems can carry out a single task very precisely, they are highly rigid and cannot switch between different processes easily. Commonly for new processes, either many different systems must be installed for different products, or systems must be shut down and refitted to carry out new processes. Due to the cost and time in doing this, it becomes economically impractical to shut these machines down or use them in production of only a few goods. As such, manufacturers often produce many of a given good to be stored in inventory for later sale or use. This storage in itself is highly inefficient due to base costs on storage such as inventory taxes, the value of stored goods with comparison to space value, and the uncertainty of the demand on the goods stored.

Due to these reasons, the value of a flexible automated manufacturing system becomes evident. Application of these systems within modern manufacturing processes thus becomes highly desirable. With modern advancements in the fields of robotics and computers, the tools needed to carry out such tasks have become more and more readily available and capable of carrying out these tasks. The result has been a continuing increase in the introduction of robotic systems into manufacturing processes globally. Similar systems to the one covered in this project, such as KIVA, have been successfully used in packaging warehouses to reduce inventory retrieval[5]. With the continued advances and application of robotic systems in manufacturing processes, the desire for more flexible means of automated manufacture have come to the fore. As such, the focus of this project is highly contemporary with the ever-changing face of industry.

Thus, a pivotal subject in modern manufacturing, this topic is of high interest to all industrial fields. The design, integration, and operation of such systems affect a wide range of engineering professions. The ability of Engineers to be able to understand, design, and integrate with these systems is of great importance. This project is highly valuable in that it covers a topic that is of increasing concern. Further, because of the nature of automated systems, this subject crosses multiple fields: Mechanical, Manufacturing, Electrical, Software, and Hardware Engineering. As such this project allows for exposure to many subjects and practices over and above one's direct field of study. Further, because of the requirement for multiple field cooperation, the project is reflective of industry and requires technical communication and integration across fields.

Application of these principles within an academic environment is thus evident. Due to the ever growing relevance of robotic systems in industry, this project grants students exposure to not only principles of robotic design and programming, but also into aspects of the final application of robotics in streamlining manufacturing processes. This project specifically focuses on the manners in which these processes can be improved upon by increasing the level automation while maintaining production flexibility.

Through design and construction of systems such as these students are granted experience not only with the mechanics, hardware, and software but also with integration. Because systems such as these cross many different fields (Software, Hardware, Mechanical, Electrical, and Manufacturing) students must integrate with systems outside their fields. As such students are granted experience in technical communication and project management associated with a cross-discipline project.

After completion the system is an invaluable academic tool in demonstrating the processes of automated manufacture. Principles of Lean Manufacture and methods of improving the overall efficiency of manufacturing systems can be explored. Further, this specific system allows students to analyze and improve upon principles of flexible automation. Because of the increasing roles of robotic systems in manufacturing processes, this experience is highly valuable to students entering into the professional field.

Design

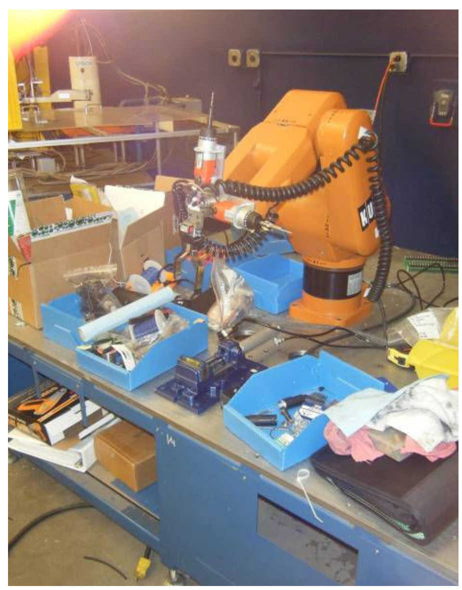

Fig 1 Stationary Robotic Assembly

The method by which this project will be carried out is through the use of an autonomous robotic shuttle to transport modules between stationary work cells. Parts, goods, and tools to be delivered to said work cells will be affixed in space through the use of preloaded modules. These modules will be retrieved from a central storage depot, transported across the workshop floor, and loaded into the stationary cells. Spent modules will be removed and returned to the storage depot.

The robotic system is ground based and runs on a differential drive system. In this manner, control of the robot across the workspace can be carried out as a function of the right and left motors. This method of conveyance is very efficient from a design and production standpoint because it is very simple and easy to manufacture. Again, because controlling a differential drive system is simply a function of right and left motor control, the mechanical design, hardware design, and software design become rather simple. Further, as opposed to three- or four-point drive systems, a differential drive system is highly efficient in drag associated with turning.

This drag, caused by dragging wheels perpendicular to their direction of motion for multi, rigid wheeled systems, becomes especially taxing upon the system. In robotic systems, this drag is of serious concern when related to available torque. Because available torque coming from a DC motor of fixed voltage is limited, the drag associated with drive and turning function becomes a function of payload. As such, by utilizing a differential drive system, the payload of the robot nearly doubles per motor.

Fig 2 iRobot Create with BAM Module

Interface between this ground-based shuttle and the stationary work cells is carried out through a fork lift mechanism. A custom fork lift head is attached to an electrical vertical linear slide. In this manner the lifting head, or end effecter, can slide beneath parallel grooves on the part modules and lift the modules by vertically translating the end effecter. Thus all interface between the autonomous shuttle and part modules is locked in rotation about the x and y axis, and locating the part modules and end effectors becomes a function of the translation and rotation of the differential drive system and vertical translation of the linear slide only. This same practice occurs in modern warehouses with manually operated forklifts.

The part modules are designed as a means of locking tools, parts, and products in space while still allowing for a universal interface with the transportation shuttle. Although the tools, parts, and products may differ in size, location, and quantity depending upon the process to be carried out by the stationary work cell, the module that they will be placed in will always be of a standard geometry easily fixed in space and found by both stationary and mobile systems alike.

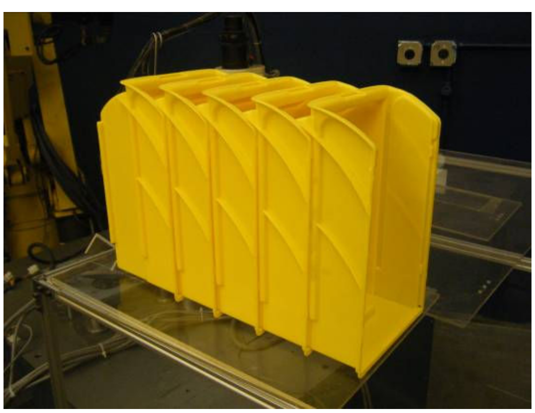
Fig 3 Standard Parts Bins for Bin Modules

For this project specifically, a secondary step is taken to allow for ease of interface between projects. The primary focus of this project is in the transportation and delivery of parts and goods in a manner that a secondary stationary work cell can receive. As such, the processes of manufacture, the parts required, and the exact spatial location of these parts are outside the focus of this project. Rather, the part modules are designed to be easy to affix and locate by both projects but are left empty. Instead, the modules are designed to carry an array of standardized bins. With this design, it is possible to fully design the part modules as they interfaced with both the shuttle and the stationary cells without a defined part selection or orientation but rather with a constant workspace and weight limitation for part placement.

Constraining of the modules within space is carried out by a series of inclined planar structures to lock the modules in all six axes due to the force of gravity. At both the storage depot and the stationary work cells, the modules are designed to sit atop a series of footholds. Both the storage facility and the stationary cells are fitted with four male truncated pyramidal footholds at each module docking location. Each module is fitted with a corresponding set of female structures across its base. As the module is lowered onto the footholds, the interaction between the male and female fixtures orients and fixes the module in all six axes with a known position to both mobile and stationary systems. Similar geometry is found on the fork lift end effecter. Here, the forks of the end effecter are slanted at both sides. Each module again has a corresponding female geometry that constrains the module in the mobile robot's tool space. The main difference between this geometry and that of the footholds, though, is that this geometry is constant along the direction of the forks. As such, the modules are fixed in only 5 axes, allowing for slide along the fork under substantial force to break static friction.

Navigation and orientation for the autonomous shuttle are carried out predominantly by an overhead machine vision system. Across the workspace floor, position and orientation of the mobile shuttle is monitored through a standard machine vision program. These data are used to continually update the status of the robot and plan its path to reach its final destination. Aspects of navigation, including obstacle avoidance, are managed locally through the use of ultrasonic sensors on board the mobile robot. Control of the mobile robot is carried out remotely on a centralized server where all local data from the robot and external data from the overhead camera can be unified into the governing program.

Electrical Controls

All controls and electrical components for this project are based around the use of the iRobot Create as a central control board. This robot's versatility and its ability to communicate with a number of computer softwares help to make it the best choice. Also, as an academic model, information regarding controls, programming, and precedent applications are highly abundant. Further as regards our specific project, the iRobot Create controls itself through a differential drive system. These properties make it an ideal system to control the mobile shuttle.

Although the control system and the versatility of the Create to communicate with a number of devices are more than adequate, the physical properties of the Create are not. Based upon the iRobot Roomba, a robotic vacuum cleaner, the maximum payload of the Create itself was no more than roughly 10 pounds. Further, the size of the chassis made it inadequate in carrying large objects or reaching any reasonable heights. As such, a new chassis was designed to be controlled by the Create board.

Fig 4 DC Motors and Drive Trains

Of primary concern are the drive motors. Due to the increased requirement of the final weight on the drive motors, the small 5VDC drive motors of the Create had to be replaced with large 0.5 hp 24VDC drive trains. As such, the mosfets of the Create had to be replaced to allow larger current across the Motor wires from a secondary power supply. This was the only major alteration that had to be done directly to the Create board. After removing the 5VDC motors from the Create drive trains, the original Create drive encoders could be used directly. By mechanically mounting the original Create drive wheels to the wheels of the new drive train, it became possible to use the data from the velocity encoders without either mechanical or computational correction.

All peripheral components are controlled through the use of a BAM (Bluetooth Adapter Module). This module is used as the means of wireless communication between the Create board and control server. The BAM module connects to the Create board through a standard serial port to communicate with all integrated systems; the BAM module also has the feature of a series of I/O ports to control peripheral devices. As such, the BAM module can be used to control all systems of the Create board and peripheral devices such as ultrasonic sensors and the linear slide.

Fig 5 Linear Slide and Analog Controls

Another limitation of the Create is its battery pack. Again, being modeled after the iRobot Roomba, the power supply is rather small and does not meet the demands of the new chassis and peripheral devices. The two most power-intensive devices of the system are the drive motors and the linear slide. Each drive motor is rated at 24VDC and the linear slide at ±24VDC (48VDC gradient). As such, a larger secondary power supply was selected and integrated into the system to control these devices, which split the power supply into two parts. Large power-consuming devices such as the drive motors and linear slide are controlled from the Create board but are powered by the secondary power supply. All low power systems and control power are powered off of the original Create rechargeable battery.

Software

The primary software used in controlling this project is Microsoft Robotics Studio 1.5 (MSRS). This is a new Visual Programming Language (VPL) program created by

Microsoft for multiplatform control programs. The programming language is designed to allow complex programming to a number of devices, with only rudimentary programming skills. Although the program itself is run in C#, the VPL interface allows users to construct complex programs as a conglomeration of individual tasks and subtasks[1].

The primary reason for selecting this software is predominantly due to the relative power to ease-of-use ratio of the software. The VPL interface within MSRS allows for complex coding to be written in C# without the need for extensive knowledge of C# programming[1]. Upon installation, MSRS automatically includes a number of services and tasks. These services and tasks exist as pre-coded C# modules represented by windows within the VPL interface. Communication between these modules is carried out by simply connecting lines between them within the VPL interface, linking the appropriate aspects of code together to construct a working program.

The manner in which these modules communicate also has a great advantage. Unlike standard programming languages which run code linearly through a series of steps, MSRS is able to carry out tasks asynchronously[1]. That is to say, rather than a given process within a code waiting for completion of other tasks above it, VPL runs processes independent of other processes within the program. Especially concerning the realm of robotics, this becomes highly useful. It becomes possible for multiple tasks to run simultaneously. Thus, tasks such as sensor data, motor control, positional data, etc. can be carried out individually as they become available rather than waiting upon other data to complete. Even multiple robotic systems can be controlled under the same program, in which each robot, although controlled within the same program, can run independently of the other. Especially when concerning the application seen in this project, where the governing program is located at a central server and not onboard the robot, issues arise with the speed of communication. With data acquisition being controlled by a non-local server, these speed issues grow as the length of the program increases. Utilizing MSRS removes many of these issues by allowing tasks to proceed independently of one another, creating a more continuous stream of information between server and robot.

The ability of MSRS to interpret many different tasks and data streams independently also makes the software package highly versatile. As stated before, MSRS comes with a number of preexisting services. These services allow for MSRS to carry out specialized tasks and communicate with peripheral devices. By using these services, it becomes possible to interface many different components of a robotic system directly into MSRS. Because these services run asynchronously, MSRS is able to interpret each system independently. This ability makes it possible to unify multiple systems through a central server regardless of whether the devices are mobile or stationary, and regardless of whether they are connected through one central hub, or through separate systems (Calsyn). Further, being constructed in C# makes it possible to create services needed to control devices not included in MSRS through direct C# programming or through the composition of other services and tasks found in MSRS[1].

Another important reason for selecting MSRS as the primary programming software is cost. MSRS is currently an open software free for public and academic download and application. For this reason, not only this project but other robotics projects at the Oregon Institute of Technology are run in this program. Due to this fact and that it will most likely be a continuing trend amongst future projects, the use of MSRS allows for ease of communication between projects.

Conclusion

This project integrates some commercially available hardware with low cost software to provide a simulation of a flexible material handling system. Through its design, construction and operation students were able to learn principles of robotic manufacturing processes and system design. Through application of this system in an academic environment, students are able to explore not only the methods of robotics (programming, spatial location, interfacing, etc.) but also explore the application of robotic systems on manufacturing processes.

As stated before, the principles of flexible robotic assembly is highly contemporary. Such principles are of high concern to modern manufacturing industries. It this manner projects such as these can aid students in gaining exposure to these systems in an academic environment before entering the professional field.

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