

Optimization Methods for Portable Automation Equipment Utilizing Motion Tracking Technology

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ABSTRACT

The use of portable automated equipment has increased in recent years with the introduction of flex track, crawling robots, and other innovative machine configurations. Portable automation technologies such as these lower infrastructure costs by minimizing factory floor space requirements and foundation expenses. Portable automation permits a higher density of automated equipment to be used adjacent to aircraft during assembly. This equipment also allows concurrent work in close proximity to automated processes, promotes flexibility for changes in rate, build plan, and floor space requirements throughout the life of an airplane program.

This flexibility presents challenges that were not encountered with traditional fixed machine drilling centers. The work zone surrounding portable machines is relatively small, requiring additional setup time to relocate and position machines near the airframe. Moveable equipment also allows more opportunities for human error, such as loading parts and programs out of sequence, leading to operational inefficiencies and rework. A well executed manufacturing plan is needed to determine machine loading strategy to efficiently position and operate the machines. This paper will examine methods to improve efficiency and reduce errors for portable automation by integrating various portable automation equipment using a centralized cell controller (CCC), an optical motion tracking system, and simple handling equipment.

INTRODUCTION

Traditionally, large machine tools have been successfully used for many large-scale aircraft assemblies. While these conventional machines provide increased quality, accuracy, and improved ergonomics, there remain several drawbacks. This type of equipment carries a high investment cost, requires long lead times, and is inflexible to changes in rate or manufacturing build plans. In more recent years, robotic systems with multifunction end effectors have been developed [1]. This is in part because of improvements in industrial robots and advances in end effector design. These systems have many of the benefits realized with traditional machine tools, with the advantage of lower cost positioning systems and high reliability. Large airplane structures such as fuselages and wing assemblies require an additional machine axis to extend their working area. This often requires machine beds anchored into the floor and stay-out zones for safety that impact system flexibility.

One new method is to use smaller part-applied tools that reference to local and accurate part features. Part-applied drilling systems using flexible rail technology recently have begun to be implemented in production [2, 3, 4, 5]. Further advances in technology also have led to the possibility of freely moving or crawler based automation systems, allowing even more flexibility [6]. These systems are advantageous because of lower machine cost, little-to-no infrastructure or construction cost, and the ability to allow many machines to work simultaneously. This enables increased throughput, accommodates manufacturing flexibility by allowing changes in rate and build plans, and allows concurrent work in close proximity.

Flexibility also presents some new challenges that were not encountered with traditional drilling solutions. The work zone of portable machines is relatively small, requiring additional setup cycles to frequently relocate and position machines onto the airframe. This higher number of setups increases chances for error. Loading the equipment in the incorrect location is possible. This possibility is enhanced in the beginning phase of assembly because there are then a limited number of reference features on exterior airplane surfaces to help operators locate the equipment correctly. Another source of error is the possibility of loading incorrect part programs for the respective area the machine is placed in. In certain circumstances the machine may be loaded correctly but the operator could acquire the incorrect index locations for a given part program. Management and delivery of numerical control (NC) part programs, drill usage data, process data, and machine specific information is increasingly difficult as the number of machines increases. A well executed manufacturing plan is needed to efficiently position the machines, and experienced operators are necessary to maximize the process. In addition, these portable systems cannot have the same level of autonomy as larger systems because of increased tool changes and setups which usually require a single operator per machine. All of these issues can lead to operational inefficiencies and rework if not handled carefully.

The purpose of this research program was to take the benefits inherent to large monument tools and robotic solutions and incorporate them into a system of portable equipment to gain the benefits of both. In order to realize this vision, the difficulties in portable automation previously described had to be addressed. A new system architecture was demonstrated to manufacturing to influence future investments in automation.

The proposed multi-spindle system comprises the following components, which are illustrated generically in [Figures 1](#) and [2](#):

- Handling systems capable of quickly loading and unloading equipment from assembly cell.
- Central computing software linking, controlling, and managing all work cell controller (CC) software components.
- An array of automated tools such as flex track drilling systems. In addition, there are hand operated tools such as drill motors, hole inspection equipment, torque tools, and others.
- A motion-capture system providing periodic measurements of the position and orientation of all tracked objects using motion-capture features on tools and the work piece.

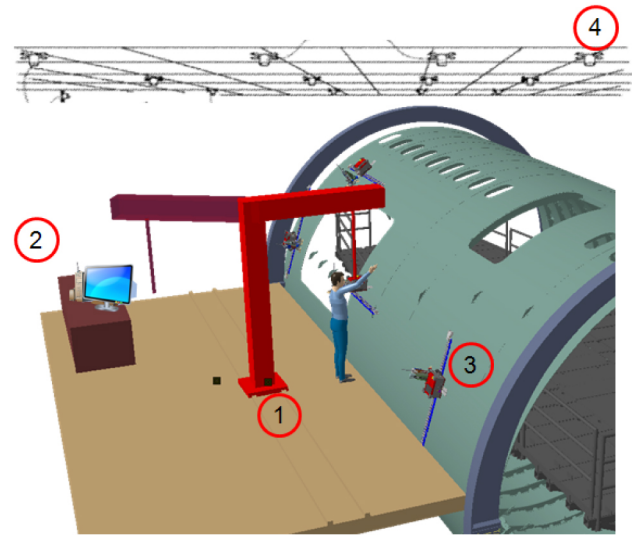


Figure 1. Conceptual assembly cell for fuselage assembly

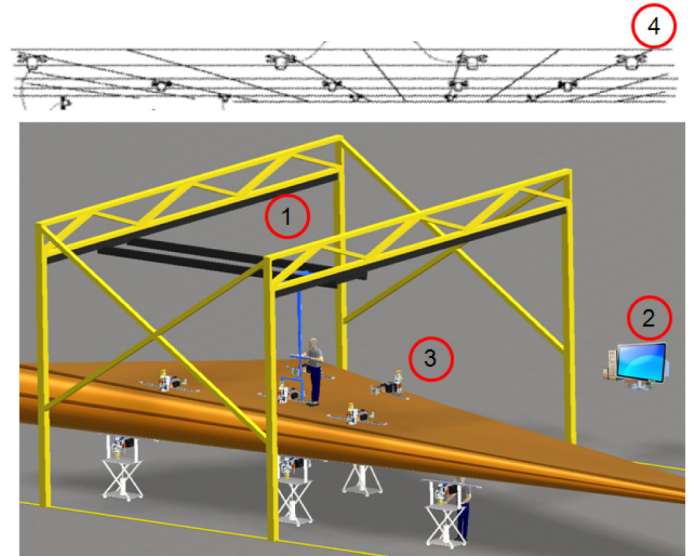


Figure 2. Conceptual assembly cell for wing assembly

HANDLING SYSTEMS

One seemingly trivial but important component is the handling equipment used for loading and unloading the automated systems. The manipulation of the machines must be quick and easy for the operator. Several machine handling systems were tested and evaluated as shown in [Figure 3](#). For fuselages, a simple lifting system was found to be effective for machine loading and extending the area a person could load the machine along the length of a barrel to a height of several meters. For wing assembly, a single picking point lift was found to be the simplest solution.



Figure 3. Handling system loading machine on fuselage assembly

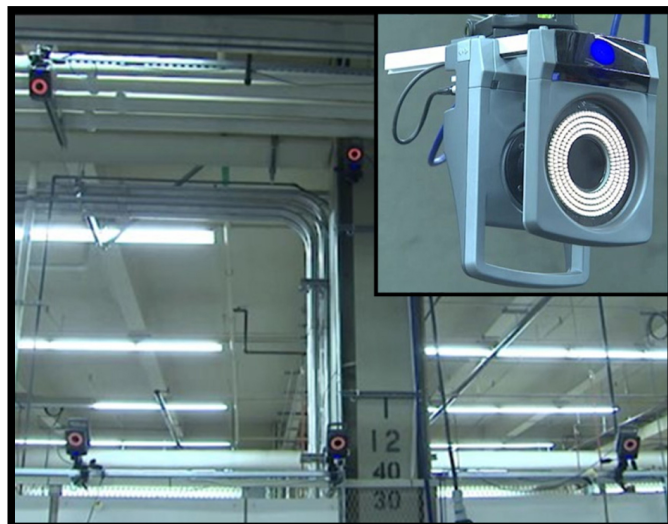


Figure 4. Picture of motion capture camera

MOTION CAPTURE

Knowing the precise location of parts, tools, and automated machines in the assembly cell was a vital piece of the system demonstration. The position measurement system needed to simultaneously track multiple objects at a time, operate in a large measurement environment, have high refresh rates as well as low lag times, be robust enough to function in a manufacturing environment, and be cost effective. Many metrology options were considered for application, including radio frequency and ultrawideband, laser tracker, laser radar, photogrammetry, radio frequency identification (RFID), electromagnetic, and other vision system solutions. Based on cost and capabilities, a 3D motion capture system was chosen.

The motion capture system uses multiple cameras arranged in a pattern around the assembly cell. Each charged-coupled device (CCD) camera has a light-emitting diode (LED) array mounted concentrically around the lens. The camera measures the travel time of the LED light that is reflected by spherical retroreflective markers mounted on all objects being tracked. The motion capture software combines each camera's data to then triangulate the position of all objects in the assembly cell. Unique patterns of three or more retroreflective markers are used to define each specific item to be tracked. These unique patterns are recognized by the motion capture system, and the position and orientation information for each tracked item are output by Ethernet.

PORTABLE AUTOMATION EQUIPMENT

Several forms of automation equipment were used in the demonstration. The mini flex track drilling system (Figure 5) was used to demonstrate automated drilling. The system was enhanced from previous versions of the two NC axes semiautomated mini flex tracks [4]. Four additional NC axes were added to increase the machine autonomy, while still maintaining its relatively small size and simple user interface. The onboard control system and Ethernet connectivity made it a good choice for the demonstration.



Figure 5. Several flex track machines on test part