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A SIMULATION MODELING APPROACH FOR ANALYZING ROBOTIC ASSEMBLY CELLS

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ABSTRACT

This paper outlines an approach for modeling the work cycle of robotized assembly cells. The approach incorporates an enhanced version of GERT network logic and the computational techniques of a discrete-event simulation program to yield a flexible, resource-based model of cell operations. A hypothetical robotic assembly cell is used to illustrate the model as an aid in cell design. Pre-determined cell performance measures can be used to evaluate a variety of design issues ranging from tooling modifications to different task sequences. To improve the efficiency of the simulation program, the Antithetic Variates variance reduction technique is applied to increase the precision in estimates of performance. For an in-depth description of the modeling approach, its application as an aid in cell design, and the improved precision achieved by the variance reduction technique, see Cash and Wilhelm (1986).

1. INTRODUCTION

Assembly is perhaps the most labor intensive process in manufacturing. The cell structure has become a predominant configuration for organizing assembly operations. This is because the majority of assembly is performed in small lots, or batches, and the cell offers the flexibility to process a variety of different products. Robots have been introduced to automate the assembly process and to increase flexibility of the cell structure. Robotic automation, however, tends to be difficult to envision, complicated to design, and expensive to build. Thus, it is essential that a methodology be developed to evaluate the effectiveness of robotic installations. The purpose of this paper is to present a simulation modeling approach which can be used as an engineering aid in designing robotic assembly cells.

A robotic assembly process may consist of a complex set of activities which are interrelated by precedence restrictions, limited tooling, and coordination between resources in the cell. In most applications the set of activities may involve hundreds of tasks; thus, analysis by hand is most often impractical. Even though assembly operations are preprogrammed, the durations of these activities, and hence, the entire assembly cycle is considered probabilistic rather than deterministic. This is because many random events may occur affecting completion times of tasks. A robot may require an uncertain number of attempts to grasp a part or position it correctly. A vision system may require different angles of view to identify specific parts. Tooling used in the process may wear, causing variations in task times. Therefore, probabilistic modeling using simulation techniques seems appropriate as an analysis tool.

2. MODEL DEVELOPMENT

In order to analyze an assembly cell, it is necessary to specify the fundamental activities of the process. Once specified, these activities can be used to develop a model of the cell. To accomplish this step, GERT network logic [Moore and Clayton (1976) and Whitehouse (1973)] is used to structure these activities into a network form that represents the assembly process.

GERT is a combination of network theory and probability theory that yields a readily applicable modern management tool for system analysis. The benefits of utilizing GERT network logic are that graphically illustrated networks provide a clear and concise description of what activities can take place and in what sequence. However, in order to model the complex activities in a robotic cell, the capabilities of GERT logic is extended in three areas: resource association, ROUTINE task, and task sequencing.

The first enhancement of GERT logic is resource association by which each task in the network is labeled with the resources needed to perform it. Thus, in addition to the network precedence constraints, a task is limited by resource availability since it can be processed only when all the required resources are available. If the resources are not available, the task is placed in a file of candidates and waits for processing until all required resources are made available.

The second extension to GERT logic is the addition of a ROUTINE task. ROUTINE task refers to a set of activities which are performed repetitively and require specific logic to be processed. A ROUTINE task is illustrated as a single activity in an extended-GERT network; yet, it actually refers to a subnetwork of individual tasks. In this modeling approach, such a ROUTINE is used to model the intricate interactions between a robot and a sensor which occur during the process of identifying parts and locating them in position. Thus, unique logic is enacted for each ROUTINE task, simplifying data preparation by the user.

The third area in which GERT logic is enhanced is task sequencing. This additional logic imposes a priority for processing tasks and allows tasks to be performed in different sequences. Since GERT logic only allows precedence relationships amongst tasks and probabilistic branching within a network, it is not capable of representing alternative sequencing rules. The logic for imposing different task priorities is incorporated in the simulation program.

3. MODEL IMPLEMENTATION

To efficiently use the network model in analyzing the cell, a discrete-event simulation program is developed to implement the modeling approach. The simulation approach was chosen because it is, perhaps, the most practical means of capturing the essential elements and interactions within this rather complex system. This type of analysis also allows for easy manipulation of model parameters allowing detailed study of alternative designs.

The corresponding real time horizon of the simulation is finite; a terminating event exists to end the process upon completion of the assembly. Due to the finite horizon and the nature of the system, the transient or time-dependent performance of the robotized cell is of primary interest. In order to derive estimates of performance for the cell, the simulation model is replicated a number of times. Point estimates and confidence intervals are derived by applying standard statistical procedures based on the assumption that task times are normal, mutually independent, and identically distributed. After carefully verifying the simulation program, the estimates of performance can be used to evaluate different design and operational procedures.

4. HYPOTHETICAL CELL

Evaluation of this modeling approach is demonstrated in the design of a comprehensive, but hypothetical robot assembly cell. The cell consists of two robots which assemble a variety of components onto a base plate. Each robot is provided a dedicated sensing system, which can operate independently of the robot. Tooling used in the assembly process consists of several end-of-arm effectors that are located in a centralized storage center. It is assumed the robots can interact to perform cooperative activities and that tasks are designed so that the robots will not collide.

Four categories of tasks used to model an assembly process were ROUTINE, DRILL, SCREW, and MANUAL. ROUTINE tasks modeled the positioning of a component temporarily on the base plate. Drilling modifications necessary for the part to be permanently attached were represented by DRILL tasks. SCREW tasks modeled the process of permanently attaching the part to the base plate. Manual tasks were used to represent assembly activities that are not automated, such as manual inspections. Each category consisted of a set of different tasks which could be used to represent a complicated assembly process.

Performance measures including resource utilizations, task starting times, and the expected cycle time (or makespan) were calculated to test alternative cell designs. Design issues addressed by the tests include methods employed, tool operating speeds, cell layouts, robot travel speeds, end-of-arm effectors, number of tools provided in the cell, and alternative sequencing of tasks. Collectively, these test cases demonstrate use of the simulation model as a decision aid that can be used by the cell designer.

5. VARIANCE REDUCTION TECHNIQUE

Since the evaluation of a cell design is based on estimates of performance generated from the simulation, it is essential that the sample variance of these estimates be as small as possible. With a small sample variance, the width of the confidence intervals for a point estimate will be smaller, thus increasing the precision of the estimate relative to the "true" value. In most simulations, the common approach to reduce sample variance is to increase the number of observations. However, this method is generally inefficient because the amount of variance reduction achieved is offset by the "cost" of generating additional observations. Therefore, an alternative variance reduction technique, Antithetic Variates [Bratley, et al. (1983), and Law and Kelton (1982)], is applied in the simulation program.

Antithetic Variates is a technique applied when the absolute performance of a system is being studied. The efficiency of implementing this approach has been illustrated by Rubinstein, et al. (1985) and Sullivan, et al. (1982). This method has been useful in practical applications and does not require the user to have additional knowledge of the system as do other variance reduction methods. The technique involves pairing consecutive observations and inducing negative correlation within the pairs but leaves the observations independent across pairs. In the modeling approach, the Antithetic Variate technique is applied to generate variates from the normal distributions that model task durations. The relative efficiency between applying Antithetic Variates and the "Crude" method is investigated.

6. CONCLUSION

Since robotic assembly equipment is becoming both more complex and costly to put in place, it is necessary to evaluate the effects of planned modifications on productivity before they are implemented. The simulation modeling approach described in this paper outlines a method which can be used to accomplish this evaluation. For a more detailed description along with numerical results, see Cash (1986) and Cash and Wilhelm (1986). This method demonstrates its usefulness as an analysis tool for the design of a hypothetical robotic cell. In addition, it illustrates the benefits of applying Antithetic Variates as a method for reducing sample variance.

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