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A TUTORIAL ON ERGONOMIC AND PROCESS MODELING USING QUEST AND IGRIP

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ABSTRACT

This paper will discuss the benefits of sharing data between discrete event process simulation and ergonomic workplace assessment using software developed by Deneb Robotics Inc. A modeling exercise has been developed to illustrate the integration of ergonomic and discrete event process modeling. This paper will provide an overview of ergonomic and process modeling, a summary of features and functions of ergonomic and process modeling, and a demonstration of model creation, analysis, and data sharing. The advantages of integrating these simulations into a combined analysis will be demonstrated.

1 WHY INTEGRATED ANALYSIS?

Digital Manufacturing is becoming an indispensable tool in streamlining the design to implementation process. Engineers are creating "Virtual" factories, true 3-dimensional (3D) environments that allow visualization of the production process much earlier in the product's life cycle. The quality and quantity of data is continuously increasing, with many companies standardizing on 3D solid modeling of both components and manufacturing hardware. With the implementation of MRP and ERP systems, this data is becoming available throughout the enterprises. The widening availability of digital data has provided greater opportunities for experimentation during the design phase by using highly accurate simulations.

Within this virtual environment, the present challenge focuses on developing methods to maximize the benefits from possessing this digital data. In many cases, the same data is passed through several analytical tools in the digital manufacturing process to minimize build risk. How do you effectively and easily pass this relevant, shared information between software packages that have distinct analytical purposes? Combining information from different packages to provide more accurate analytical results would be better still, since in many occasions the results obtained from performing one analysis may affect the results of another.

This methodology challenge exists within the manufacturing simulation field, where the same geometry, timing, and process data are examined from several different perspectives. Simulation model accuracy and integrity are essential items for ensuring that digital analysis can be used to predict actual production system behavior. Sharing data and combining the results of different simulation tools, such as ergonomic workplace assessment and discrete event process simulation, can assist in creating a highly realistic picture during the analytical phase of the design process.

This tutorial addresses the benefits of combining ergonomics and process simulation, by providing a technique to share digital data and results between two specific software packages developed by Deneb Robotics, Inc. Each package's basic functionality will be discussed, and an integration approach will be introduced. Finally, suggestions on applying this procedure will be reviewed.

2 LABOR ANALYSIS SHARES DATA

Ergonomic workplace assessment and discrete event process simulation are both used in analyzing labor requirements. The analyses, however, yield results that achieve different objectives. Ergonomic workplace assessment addresses an operator's work assignment from the perspective of whether that operator is physically capable of performing the assigned tasks, possibly within a specified time. Discrete event process simulation examines labor at a macro level, including the number of operators a task requires, the availability of operators to perform tasks, and the operators' impact on production. Thus, ergonomists and industrial engineers simulate labor activities from different perspectives.

Both types of labor analysis are essential for ensuring that the actual real-world process will work as designed. A task's workplace may be designed ergonomically for operators of any size, yet without applying process variability with discrete event simulation, that task can be the bottleneck for the entire production scheme. Conversely, a one-operator task may meet cycle requirements through a discrete event simulation, but a workplace assessment analysis utilizing digital humans would reveal that the task requires two operators and a layout redesign. Integrating these two analytical activities provides a more realistic environment in which to assess labor requirements.

Deneb Robotics, Inc. has developed simulation tools that assist in integrating these analyses:

- IGRIP or ENVISION with the Ergonomics option, used for ergonomic assessment analysis (referred to in this tutorial as ERGO)

- QUEST, used for discrete event process simulation of material flow systems, such as in manufacturing or warehousing

In addition to sharing common input data and results, a unique feature of this software combination is they can share the true 3D, physics-based workplace environment. QUEST and ERGO provide the solution of efficiently combining process and ergonomic simulation, both numerically and visually.

3 QUEST – A PROCESS SIMULATION APPROACH TO LABOR ANALYSIS

Labor analysis from a discrete event process simulation perspective will be discussed in this section.

3.1 An Overview of QUEST

QUEST is a discrete event simulation software package, used to simulate the flow of material, transactions, documents or other discrete flow processes. Using 3D CAD geometry, QUEST analyzes the performance of existing or proposed manufacturing facilities by simulating the process behavior over a specified time. QUEST combines a graphical user interface with material flow logic grouped in modules for: labor, conveyors, automated guided vehicles (AGVs), kinematics, power and free conveyors, and automated storage and retrieval systems (AS/RS). A Value-Added Costing module assists in implementation of Activity Based Costing during the simulation analysis. Statistical results can be viewed with graphical and numerical analysis capabilities.

Features that assist in creating a “3D Virtual Factory” environment include:

- QUEST imports and exports 3D or 2D CAD geometry from a variety of CAD formats, and allows custom geometry to be created internally. Model graphics and animation output are also available in several formats.

- QUEST imports and exports data, such as scheduling and routing information, to and from external systems, enabling direct communication with spreadsheets, project planners, ERP, and MRP systems.

- A graphical user interface is provided along with a powerful programming language for additional capabilities, such as external model creation and control, and exceptions to standard routing and scheduling selections.

- QUEST serves as an integrated solution by importing detailed workcell models generated from various Deneb software products. The detailed analysis software is also instantly accessible from within QUEST via this integration.

- QUEST also provides a Virtual Collaborative Engineering (VCE) environment, where individuals in remote locations can simultaneously view and interact with the same model over a secure link.

- QUEST integrates Virtual Reality (VR) devices, such as head-mounted displays, stereo glasses, and cybergloves, to immerse the user within the factory floor simulation.

3.2 Labor Analysis Using Process Simulation

Discrete event simulation is used to examine how scheduling and routing variations affect the overall system performance. Using QUEST, labor variations to a task's sequences can be introduced and analyzed for optimum performance. In the real world, the operator may not complete the task as designed for quantifiable reasons. For example, the task may typically be modified or interrupted due to machine failure, the presence of a higher priority task, or product mix variations.

With an event-driven model, an operator also experiences delays due to machine cycle, traffic congestion, and part starvation. In alternate scenarios, the operators may not have standard sequences to perform, but tasks broken into small segments that can be varied throughout the day. Through the QUEST simulation, these variations can be included to maximize factory throughput.

The stochastic nature of discrete event simulation addresses these differences, and assists in providing a realistic labor analysis. In this process simulation, however, the initial assumption is made that an operator is physically capable of performing the task as designed, and within the allotted time constraints. An ergonomic simulation is necessary to validate the task’s sequence of events, workplace design, and cycle time.

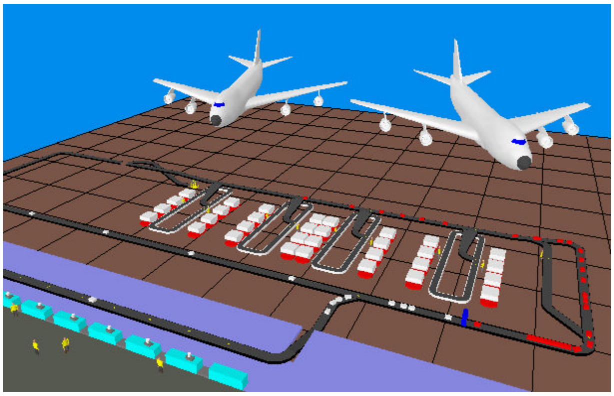

Figure 1: QUEST Examines Labor Impact on the Overall System

4 ERGONOMIC LABOR ASSESSMENT USING ERGO

Labor analysis from an ergonomic simulation perspective will be discussed in this section.

4.1 An Overview of ERGO

ERGO is a simulation environment for ergonomic assessment and task analysis. It provides a programming interface for rapid prototyping of human motion within a work area. Embedded within the IGRIP or ENVISION environment, the human model within the workcell can interact with other moving devices to accomplish specified tasks. ERGO provides 3D, anthropometrically correct, digital humans in 5th, 50th, and 95th percentile male and female models, with the flexibility for individual customization.

ERGO's Human Modeling features provide the user with two different development environments for generating operator motion sequences. The sequences can be developed through the standard graphical user interface, or through real-time human motion capture using Virtual Reality (VR) instrumentation.

Ergonomics Analysis features include ergonomic posture, energy and lifting analyses. A typical ERGO user may generate motion sequences and then evaluate the sequences to assess potential risks associated with each activity. Analytical assessments include:

- Anthropometric analysis and human joint range of motion for reach, accessibility, and visual perspective
- Rapid Upper Limb Assessment (RULA) Posture risk assessment
- Energy Expenditure prediction analyzing body fatigue
- NIOSH lifting equation for two handed lifting assessment
- Motion time analysis for developing accurate cycle times based on standard time data (MTM-UAS)

4.2 Labor Analysis And Workplace Assessment

ERGO is used in labor assessment for designing a workplace that will accommodate humans of varying capabilities in performing assigned tasks within the specified time. Assembly line balancing can be performed by using an ergonomic analysis that quantifies operator cycle time and energy expenditure rates. The risk associated with designing a workplace for an unknown operator can be minimized by analyzing digital humans in the virtual environment prior to the workplace being built.

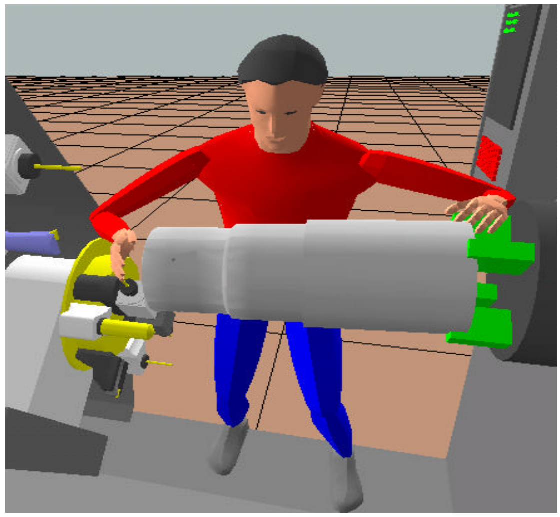

Figure 2: ERGO Addresses Whether the Operator Can Physically Perform the Task at All

Variation to the ergonomic simulation occurs by replacing the digital human with a different anthropometric model. An inherent problem, however, exists because the process itself is deterministic; workplace assessment addresses an operator's cycle time for a task, but is not concerned with throughput analysis. Discrete event process simulation is essential for ensuring that the labor assignments work to the benefit of the overall system.

5 USING ERGO AND QUEST TO ADDRESS LABOR REQUIREMENTS

Analyses from ERGO and QUEST can be combined to enhance the accuracy of labor assessment. ERGO verifies workplace assessment, increasing the confidence factor that an operator can physically perform the assigned tasks. To strengthen the analysis, QUEST introduces additional levels of variability into labor assessment. The example below provides a methodology for sharing data between ERGO and QUEST.

5.1 Designing A Workplace And Defining Tasks With ERGO

After defining a preliminary layout, operator work envelope, and process plan, the suggested starting point involves using ERGO to design an operator's workplace and tasks. Once the tasks have been articulated, the operator's behavior can be analyzed for design feasibility. Possible ergonomic analyses to perform at this level include:

- Anthropometric Analysis, to determine the workcell's flexibility for operators of different shapes and sizes
- Repetitive Motion Analysis, using RULA Posture Analysis and NIOSH Lifting Analysis, to determine the operator's physical capability for performing the task based on its required frequency
- Energy Expenditure Analysis, to assess the task's quality over time and ensure that the workload expectations placed on the operator are reasonable
- Motion Time Analysis, to validate that the preliminary design remains within the defined time envelope

Using the above analyses, the workplace can be validated for a specified task; however, the task is verified only for the defined deterministic set of behaviors. Additional variability over time can be introduced into the workplace by using QUEST, providing a stochastic analysis of energy expenditure and motion-time studies.

As a tutorial example, Figure 3 shows an operator's workplace for picking up a widget from a robotic application and placing the widget in a machine tool. The task is simple, provided the machinery remains operational.

By dividing an operator's task into sub-tasks within ERGO, energy and time data can be gathered for each sub-task and exported to a table (see Table 1). In this example, data for operations 5 and 45 are collected to evaluate alternate scenarios due to various external events. For these operations, the delay time and labor requirements need to be considered, possibly revealing drastic variations in energy consumption and overall cycle time.

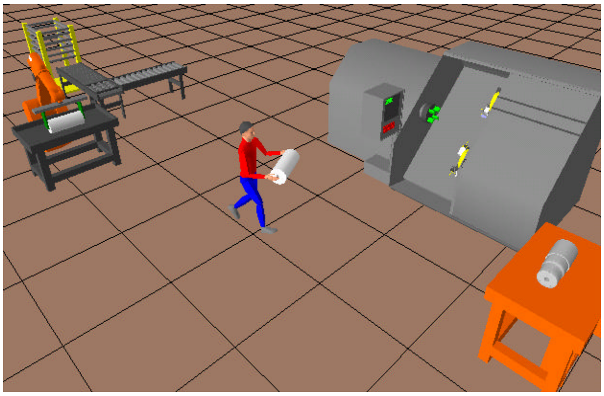

Figure 3: Import Results From ERGO into QUEST

5.2 Importing ERGO Results Into QUEST

The ERGO data can be shared with QUEST, both visually and numerically. An advantage to the graphics generated by ERGO is that any portion of the animation can be recorded and imported into QUEST. This function is demonstrated in Figure 3, containing an ERGO model visually integrated into a QUEST model. To minimize model building time, QUEST can maximize re-use of visual data.

Numerically, the energy expenditure and cycle times can be assigned to respective tasks within QUEST, and QUEST addresses the variability of these tasks, whether scheduled or unscheduled. Labor interruption assignments, such as downtime and higher priority routings, can then be introduced.

In addition to standard discrete event simulation throughput analysis, realistic human analysis can be performed. Labor analysis is enhanced to include parameters in addition to labor utilization and cycle time information. Energy expenditure data now includes the stochastic nature by adding external factors affecting an operator's task assignments. Based on these new results, modifications can be made to the ERGO model and re-analyzed within QUEST until an acceptable task list -- one that satisfies parameters developed for workplace assessment and also meets production requirements -- is defined

5.3 Experiment With Alternate Sequences

Once the initial model has been created within ERGO and QUEST, alternate sequences can be tested. For example, an alternate sequence may be required in the event of machine downtime, or based on product scheduling requirements. To expand on the above example, an operator is required to perform an alternate task during robotic downtime as illustrated in Figure 4.

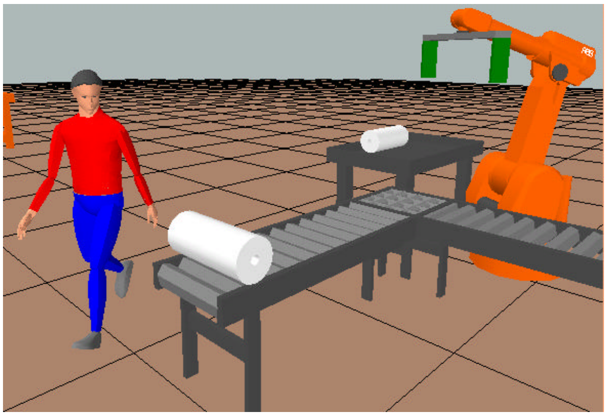

Figure 4: QUEST Handles Alternate Task Scenarios

The same ergonomic modeling is performed with ERGO for the exception sequence, which replaces operations 10A – 40A in Table 1 with operations 10B – 40B in Table 2. Only during this downtime event will the operator perform this alternate sequence. Again, the generated data can be shared with the discrete event process simulation modeled in QUEST.

During the discrete event simulation, the effects of downtime will be enhanced by the presence of alternate ergonomic scenarios. These alternatives establish a refined labor analysis model, since external factors that could affect the operator's performance are taken into account. Due to the enhanced capabilities of the process, labor risk is reduced and overall model confidence is increased.

6 SUGGESTIONS FOR APPLYING ERGO AND QUEST INTEGRATION

A combined labor analysis involving ergonomic workplace assessment and discrete event process simulation can be applied in activities such as:

- balancing assembly lines, where many operators must be coordinated across a variety of operations
- scheduling jobshop activities and product mix variation
- routing alternate activities due to equipment failure and task priority management

Data can be shared between QUEST and ERGO with minimal effort, allowing efficient and easy integration for a combined analytical process. There are additional advantages to this process, such as:

Table 1: Time and Energy Results From ERGO

Kcal Log for Worker	Operator #1
Weight	98.07 kg
Sex	MALE

Op#	Movement Description	Move Kcals	Move Time (sec)	Average Kcal Rate (Kcal/min)
5	Near Table, Wait for Widget to be Available (posture 1_1 to 1_2)	0.0001	0.0200	2.3537
10A	Walk to Table, Position Arms to Prepare Widget (posture 1_2 to 1_9)	0.1483	2.5089	3.5461
20A	Prepare Widget (posture 1_9 to 1_10)	0.3923	10.0010	2.3538
30A	Lift Widget (posture 1_10 to 1_11)	0.13856	0.5705	14.5726
40A	Walk Near NC Machine (posture 1_11 to 1_30)	0.6247	5.0332	7.4474
45	Wait for NC Machine to be Available (posture 1_30 to 1_31)	0.0001	0.0010	2.9737
50	Walk to NC Machine (posture 1_31 to 1_43)	0.1959	1.2678	9.2679
60	Load Widget in NC Machine (posture 1_43 to 1_51)	0.1930	3.2226	3.5937
70	Move To Machine Controls (posture 1_51 to 1_61)	0.0646	0.9010	4.3044
80	Depress Machine Control Button (posture 1_61 to 1_67)	0.0459	0.9020	3.0537
90	Move Away From NC Machine (posture 1_67 to 1_73)	0.0607	0.9000	4.04729
TTL	**Kcal Summary**	**1.8641**	**25.3100**	**4.4191**

Table 2: Alternate Task Results From ERGO

Kcal Log for Worker	Operator #1
Weight	98.07 kg
Sex	MALE

Op#	Movement Description	Move Kcals	Move Time (sec)	Average Kcal Rate (Kcal/min)
10B	Walk to Conveyor, Position Arms to Prepare Widget (posture 2_1 to 2_25)	0.9865	7.2010	8.2200
20B	Prepare Widget (posture 2_25 to 2_26)	0.5885	15.0010	2.3538
30B	Lift Widget (posture 2_26 to 2_28)	0.2578	4.5010	3.4364
40B	Walk Near NC Machine (posture 2_28 to 2_52)	1.1805	8.1010	8.7434
TTL	**Kcal Summary**	**3.0133**	**34.8040**	**5.1948**

- Enhanced ergonomic assessment is accomplished, such as in analysis of energy expenditure, by introducing a stochastic process environment.

- Visualization of digital humans in the process simulation environment provides a more efficient method for communicating and understanding the effects that operator sequencing has on material flow.

- Risk reduction is attained by providing an analytical method of validating that the operator can work within established guidelines and meet production requirements.

- Refined labor cost justifications can be established, by introducing feasible alternatives within the labor utilization study.

Increased accuracy and model integrity are a byproduct of integrating the analyses with shared digital data. These benefits assist in ensuring that digital analysis can be used to predict actual production system behavior much earlier in the design process.

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