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PARAMETRIC DESIGN USING IGRIP

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Parametric Design Using IGRIP

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Abstract

PNL has, with the assistance of Deneb robotics employees, developed a means of using the IGRIP code to perform parametric design of mechanical systems. This method requires no modifications to the IGRIP code, and all design data are stored in the IGRIP workcell. The method is presented in the context of development of a passive articulated mechanism that is used to deliver down-arm services to a gantry robot. The method is completely general, however, and could be used to design a fully articulated manipulator. Briefly, the method involves using IGCALC expressions to control manipulator joint angles, and IGCALC variables to allow user control of link lengths and offsets. This paper presents the method in detail, with examples drawn from PNL's experience with the gantry robot service-providing mechanism.

Introduction

Waste Storage Tank Problem

The Department of Energy's (DOE) Hanford site near Richland, Washington is being cleaned up after 50 years of nuclear materials production. One of the most serious problems at the site is the waste stored in single-shell underground storage tanks. There are 149 of these tanks containing the spent fuel residue remaining after the fuel is dissolved in acid and the desired materials (primarily plutonium and uranium) are separated out. The tanks are upright cylinders 75 ft. in diameter with domed tops. They are made of reinforced concrete, have steel liners, and each tank is buried under 7-12 ft. of overburden. The tanks are up to 40-ft. high, and have capacities of 500,000, 750,000, or 1,000,000 gallons of waste. As many as one-third of these tanks are known or suspected to leak. The waste form contained in the tanks varies in consistency from liquid supernatant to peanut-butter-like gels and sludges to hard salt cake (perhaps as hard as low-grade concrete).

The current waste retrieval plan is to insert a large long-reach manipulator through a hole cut in the top of the tank, and use a variety of end-effectors to mobilize the waste and remove it from the tank. PNL is currently developing and testing end-effector designs using a PaR XR4320 manipulator to carry the end-effectors over a bed of waste simulant. This paper describes the use of parametric design within IGRIP to support the design of fixtures for this effort.

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Off-Line Programming

Off-line programming and simulation codes such as IGRIP are often used to develop designs for workcell tooling, fixtures, and manipulators. For many of these design tasks, use of parametric design techniques is very valuable. While IGRIP is not designed for this purpose, parametric design can be done entirely within IGRIP. The example that follows illustrates this method for a passive articulated mechanism that delivers services to the toolplate of a gantry robot. The method can easily be used for other types of mechanical systems (including complete manipulator mechanical units).

Example Problem

PNL is currently involved in the development of manipulators and end-effectors for use in the clean-up of the Hanford underground waste storage tanks. As part of the end-effector development effort, a PaR XR4320 gantry manipulator (Fig. 1) has been procured and installed in PNL's 337 high-bay facility. This manipulator will be used to evaluate the performance of waste removal end-effectors.

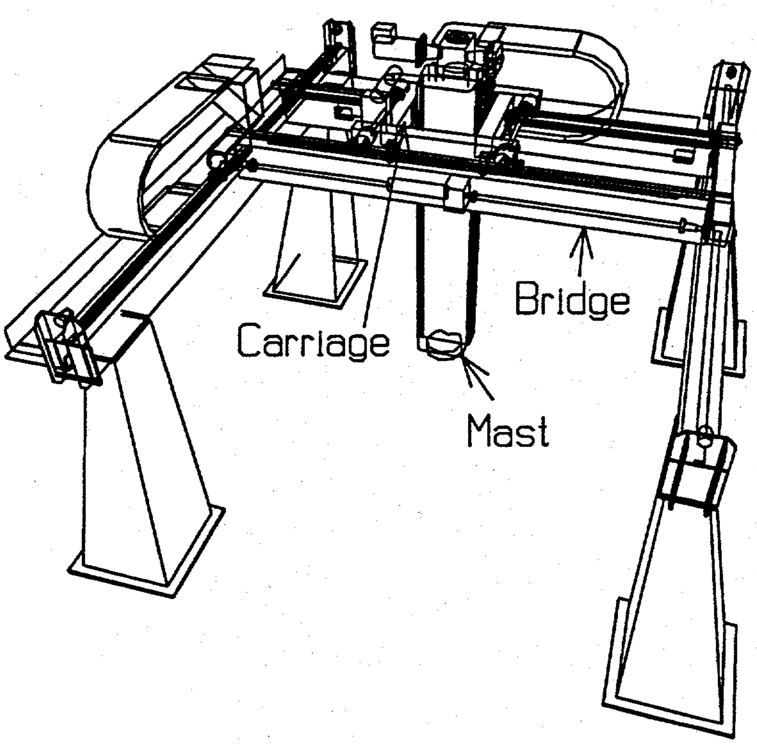

FIGURE 1. PaR XR4320 Gantry Manipulator

End-effector Description

Several different end-effectors designs will be used to remove the variety of waste forms described above. The basic design of interest here consists of a hemispherical shell with the open end facing the waste surface. High-pressure water jets will spray down inside the shell to mobilize the waste, which will be drawn off in the center of the end-effector by a high-velocity vacuum system. An example of this end-effector is shown in Fig. 2. The high-velocity vacuum system uses a 6- to 10-in.-diameter heavy-duty, wire-reinforced conveyance hose to carry the waste away from the end-effector. In the field-deployed system using a long-reach manipulator to remove waste from a tank, the conveyance hose will be routed along the manipulator arm. In the test system, the conveyance hose cannot be routed along the manipulator as the hose cannot be bent around a tight radius required to follow the cable routing on the XR4320. Also, routing the hose in this way is not prototypical - a hose routed along the long-reach manipulator deployed in tank would be mostly straight, with relatively few bends that are relatively gentle.

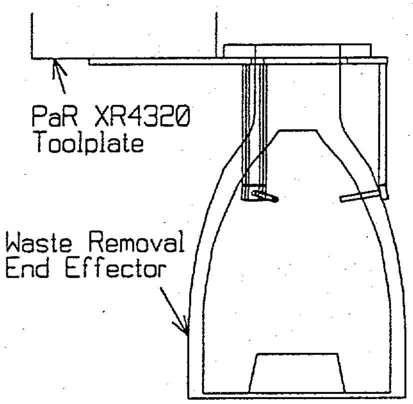

FIGURE 2. Typical Waste Removal End-Effector

XR4320 Gantry Description

The XR4320 gantry robot is a four-degree-of-freedom manipulator manufactured by PaR Systems, Inc. (Shoreview, MN). The four degrees of freedom consist of an X translation (provided by motion of the bridge), a Y translation (provided by motion of the carriage), a Z translation (provided by the mast), and a Z rotate (provided by a rotating toolplate at the distal end of the mast). Rated payload is 2225 N (500 lb) and maximum TCP speed is 91.4 cm/sec (36 in/sec).

CLMS Design

Because routing the conveyance line along the XR4320 was deemed undesirable, an alternative conveyance-line management system (CLMS) was required. A preliminary design consisting of a pylon mounted on the floor near the XR4320 supporting three serial passive links reaching to the gantry carriage was developed. This design is illustrated in Fig. 3. Because the three-link design is kinematically redundant, a constraint forcing the second and third joint angles to be the same was added. At this point, the design problem became one of determining the lengths of the three links and the location of the support pylon. Ideally, one would create a model of the XR4320 and the CLMS working together and be able to easily change the characteristics of the CLMS and test the new design. This would allow the designer to rapidly converge on a design minimizing the overall space occupied by the combined system (a constraint in our busy laboratory). Also, joint angle changes during operation could be minimized (to minimize hose flexing).

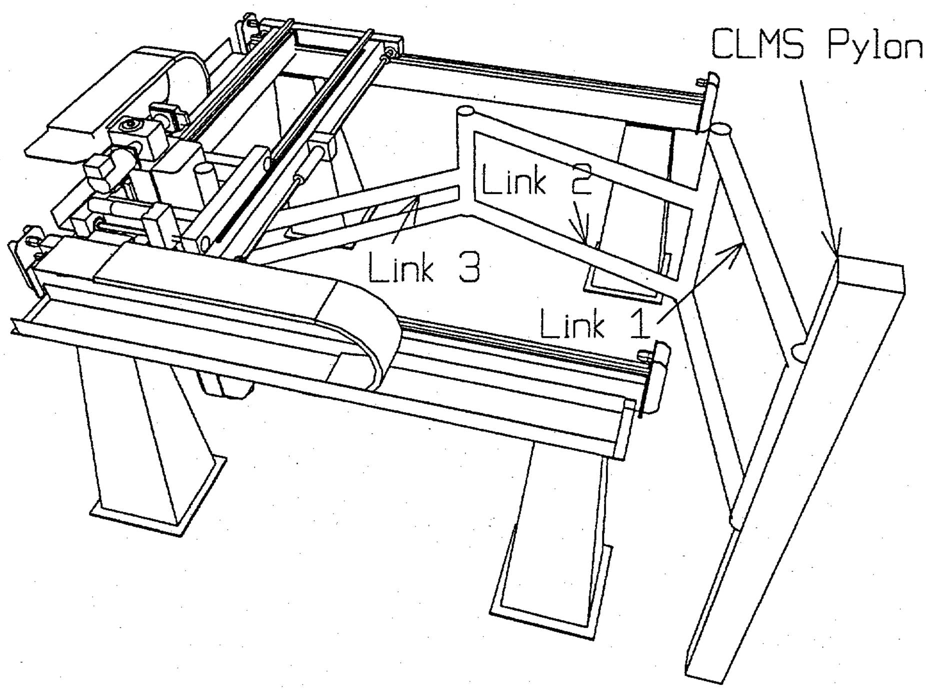

FIGURE 3. PaR XR4320 Gantry Manipulator With CLMS

Implementation Details

In essence, parametric design in IGRIP is implemented by writing the inverse kinematics of the design device as IGCALC expressions. The design variables (link lengths, etc.) are left as IGCALC variables, and scale and translate degrees of freedom are used to properly locate and scale the parts of each link of the device.

Device Inverse Kinematics

To properly model the design, it must first be understood. The CLMS is modeled as a four degree-of-freedom serial link planar manipulator. Physically, the four links correspond to CLMS links one through three and a fourth (nonexistent) link that adopts exactly the position and orientation of the gantry carriage. The four degrees of freedom are eliminated by four constraints: the fourth link must orient itself to the gantry carriage; the base of the fourth link must track the carriage position in the X and Y directions; and the second and third joint angles are constrained to be the same. The inverse kinematics of this device are developed using methods from Craig [1] to produce the CLMS joint angles as functions of the gantry X and Y positions, the pylon X and Y positions, and the lengths of the three gantry links.

IGRIP Modelling

While the inverse kinematics of the CLMS are developed as though it were a completely independent device, it is implemented in IGRIP as part of the gantry device. The CLMS joint angle expressions are implemented as IGCALC expressions dependant on the gantry joint angles; this forms the complete implementation of the CLMS inverse kinematics.

To implement the CLMS model, the XR4320 gantry robot was first modeled as an IGRIP device. Its inverse kinematics were assigned using the "generic" and "auto assign" features of IGRIP. The CLMS pylon was then attached to the gantry at the robot origin. The pylon was then assigned X and Y translation degrees of freedom that correspond to IGCALC variables. When those variables are assigned values, the pylon will move to the indicated location. At this point, the serial manipulator links can be attached to the pylon.

Each manipulator link consists of a rectangular open frame (see Fig. 3). Each frame is modelled as three parts: a vertical member located at the base of the link, a vertical member located at the distal end of the link, and a pair of horizontal members representing the span of the link. The horizontal members are created and saved as having a length of 1 mm. This simplifies the use of the scale degree of freedom. To add a link to the CLMS, a vertical member is attached to the pylon. The horizontal member pairs are attached to the vertical member and given a scale degree of freedom via an IGCALC variable dictating the length of the link. The distal vertical member is also attached to the basal vertical member. It's given a translate degree of freedom based on the same IGCALC variable as the horizontal member's scaling. If the distal vertical member is attached directly to the horizontal members (which are scaled for length), the vertical member will inherit its parent's scaling, resulting in undesirable distortion of the geometry. The basal vertical member is given a rotational degree of freedom using the appropriate inverse kinematics expression. This expression will make full use of the variables indicating pylon location and link lengths, allowing it to adapt automatically to any changes in these variables. Additional links can be attached in a serial or tree structure as long as attachments are made to non-scaled parts.

Modeling Pointers

In general, it is most convenient to implement each of the links that have parametric features as three separate parts. The first of these is attached to the parent part in the usual way. The second implements the parametric feature and is attached to the first. The third provides a non-scaled attachment point for subsequent links, and is attached to the first. It's given a translate degree of freedom to accommodate the motion engendered by the second (parametric) part.

In some applications, it may be useful to use link components that have no geometry. These can be created in the CAD world by using the "New Object" function, and then adding an auxiliary coordinate system to the part. The geometry-free part can then be saved and used in the same way as any other part.

To optimize performance, common calculations required in more than one joint angle expression may be stored in intermediate IGCALC variables. IGCALC variables are evaluated sequentially beginning at the base part of the manipulator and proceeding outward from there. Hence, if the intermediate expressions are evaluated as part of the joint angle calculation of the first link in the CLMS, they will be available for the other links.

Parametric Design

By following this procedure, the basic CLMS is created as part of the XR4320 gantry device. With appropriate variables set for each of the three link lengths and the pylon X and Y location, the CLMS end-point will track the gantry carriage. Since IGCALC variables can be accessed and set within GSL, a GSL raft popup program can be written to allow the designer to adjust the CLMS parameters and drive the XR4320 through a test path illustrating the behavior of the design. This allows the designer to test and evaluate many designs before settling on the most appropriate one.

Application to Manipulator Design

While the mechanism described here is quite specialized, the design method could be applied to any similar device, including an articulated manipulator. To apply the method to a manipulator, the general method outlined above would be used. In this case, the device would be given Cartesian style inverse kinematics by defining the first three joints as X, Y, and Z translations and the next three as X, Y, and Z rotations. The generic inverse kinematics and auto assign functions are used to set up these inverse kinematics. The six degrees of freedom would represent the location of the manipulator tool point, and the inverse kinematics would be worked out as above, with the design parameters included in the joint position expressions. This procedure would allow the parametric design of the kinematic properties of an entire manipulator mechanical unit. Designing for multiple manipulator poses (or configurations) would be made simpler by the inclusion of conditional logic in IGCALC expressions.

Conclusion

The use of parametric design methods is well accepted in the mechanical design industry. In the robotics industry, however, much design work is performed using off-line programming tools such as IGRIP. The technique presented here allows these design methods to merge; designers using IGRIP to develop robots, tooling, and fixtures can now use parametric methods as a design tool.

References

[1] Craig, John J., 1989, "Introduction to Robotics Mechanics and Control", Addison-Wesley, New York