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Design and Implementation of Simple Robot Graphical Model

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Abstract: *Graphical modeling and simulation to analyze and visualize geometry and dynamic processes can improve construction and maintenance in many ways. This paper presents the usefulness of graphical modeling and simulation for the development of construction/maintenance equipment that requires extensive geometry analysis for machine design and remote-operation for control purpose. The development of a tele-operated clinker clearing robot for the maintenance of lignite-fired power facilities is described. The geometric and kinematic design of the robot was performed based on graphical modeling and simulation through interference analysis and visualization. The use of this graphics technique was further extended to the control of the robot from a remote distance because of the hazardous work environment condition. Graphical representation of the equipment and the work environment enhanced equipment control by providing better spatial perception to the operator. Real-time simulation with graphical models also ensured safe and reliable operation of equipment. It is believed that the workflow and the techniques discussed in this paper can also be successfully employed for the development of new equipment that needs to deal with geometrically complex and hazardous work environments.*

Keywords: Graphical simulation, Geometric modelling, Graphical control interface, Tele-operation, Robot design

I. INTRODUCTION

The Three-dimensional graphical modeling and simulation technique is a valuable tool to improve construction and maintenance processes. Graphical simulation can be achieved by changing position, orientation, and geometry of graphical models and by changing viewing or zooming patterns. Graphical simulation in the context of construction is defined as, "The use of high-powered computer graphics to visualize geometry and animate motion in order to simulate a dynamic process" [1]. With the increased computing power of the personal computers and the decreased expenses for graphics hardware and software platforms, the technique is now used in AEC industry in many ways. Firstly, it enhances the communication between different project participants with the intuitive visualization capability. Design and construction details can be dynamically visualized with walkthrough functionality. Collisions are checked and eliminated for dynamic elements of the project to improve constructability and maintainability by simulating the construction and maintenance process within the graphically generated virtual world [3], [19]. In addition, construction schedules can be developed and reviewed by visualizing activity sequences [12]. Construction equipment selection can also be optimized based on the performance check with the models [1], [8].

The use of this graphics technique is further extended to design and control of construction and maintenance equipment and/or robot. Graphical modeling and simulation in this sense in comparison with the above described construction applications would mean 3-D modeling of equipment and work environment followed by simulation and/or visualization of equipment operation with the purpose of geometric and kinematic design as well as remote-control of equipment.

The benefits of using graphical modeling and simulation for design of equipment/machinery are clearly evidenced by the extensive use of this technique in the industrial sector and the academia which was supported by the commercial software platforms of this purpose [8], [16]. The geometric design of new equipment can be developed and optimized with graphical models, and the spatial performance of a new equipment/robot for construction can be analyzed and improved based on the results of simulation [18]. The simulation of equipment operation also improves the development process with far better understanding and/or communication of equipment design ideas to eventually perform the construction/maintenance operation in consideration successfully.

The graphical modeling and simulation technique for the purpose of the control of construction or maintenance equipment is also emerging. In space applications or hazardous operations such as nuclear waste remediation, control techniques based on dynamic graphical feedback updated in real-time have been employed for safe and remote control of equipment [2], [6]. This technique, often referred as graphical control, graphical control interface or graphical programming, however, depends on the ability to generate accurate work environment model.

Despite the difficult technical issue, dynamically updated graphical models have been successfully employed to control several types of construction and maintenance equipment. One good example would be the joint effort between Caterpillar and Trimble that developed a 3-D graphical model based earthmoving equipment control systems [4], [17]. Other examples are the graphical model-based real-time operator interfaces for excavators, and compactors [7], [10], [11]. Further examples can be found from a survey on graphical control interfaces for construction and maintenance equipment [15]. Other benefits of using the simulated or animated graphics technique include the operator training capability in a simulated environment.

This paper presents an exemplary practice on using the 3-D graphical modeling and simulation technique for design and control of equipment in hazardous, large-scale, and unstructured environments with complex geometry. The equipment discussed in this paper is a robot developed to break and clear “clinkers” in fossil power plant as an automated maintenance effort. As other construction and maintenance operation, clinker clearing is a very labor intensive, dirty, requiring heavy forces and, most of all, very dangerous. This paper describes the development process of this robot, which was based on the 3-D graphical modeling and simulation technique. The focus of this paper is on the 3-D graphics technique in relation to the development of geometric design and the control system of the robot. The mechanical system design of the robot along with the test results of the robots mechanical performance such as the robots clinker breaking capability is discussed in Saidi et al. [14]. It is believed that the development of new equipment that needs to be tele-operated in hazardous, unstructured and complex environment can benefit from the tools and procedures presented in this paper.

II. SIMPLE ROBOTIC ARM MECHANISM & MODELLING ANALYSIS

Like the human arm, a robotic arm mechanism consists of arms (links) and joints (steering gears). The modeling and kinematics analysis of the manipulator structure studies the mapping relationship between the end position of the arm and the output of every joint. Generally speaking, it can be divided into two different sub-problems: the as the output of all□forward and the reverse problem. If we take vector joints in an arm, p as the pose of arm end, then the forward problem can be . Given the output of each joint, it solves the pose of□ f () □expressed as p the arm in three-dimensional space. However the inverse problem solves the f () p , that is, when the pose of the arm□ □problem of end is known, the output angle of each joint should reversely be solved. Obviously, the reverse problem is more complicated but more practical, in this section we will take a simple three-axis robotic arm as an example to introduce its kinematic and geometric modeling methods.

Simple Robotic Arm Mechanism

A typical tandem robotic arm consists of a set of links (rigid bodies) that meet end to end through joints. Each joint in the.

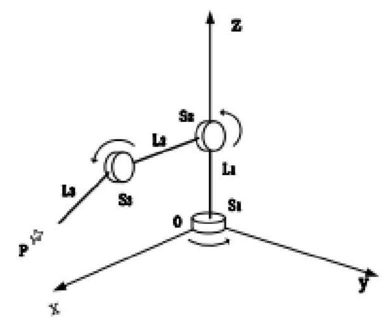

FIGURE I. A 3-AXIS ROBOT ARM

robotic arm provides a rotational or translational freedom to the arm, and their output changes the relative position and orientation between adjacent two links. Therefore, as long as the robotic arm has enough degrees of freedom, it is possible to control the end of the arm to reach any position in the threedimensional space just by adjusting the output angle of each joint. Take the simple robotic arm in figure I for example. The robot arm is composed of three joints S1, S2 and S3, three links L1, L2 and L3. Joint S1 is fixed on the ground, and its output axis (L1) coincides with the z-axis and is fixed to joint S2. Joint S2 and S3 are in the same vertical plane as the whole robot arm, and their output axes are all parallel to the horizontal plane, so that they can cooperate with each other to adjust the angle between L1 and L2, as well as L2 and L3, thereby driving the end of the arm move in a vertical plane.

Kinematic Principals

The kinematics is to study the mapping relationship between the motion of the multi-link (rigid body) structure and the output of the arm without considering the mass of the manipulator and the magnitude of the force and moment. Its analytical methods are mainly divided into two categories: analytical method and graphical method. The analytical method, also named D-H parameter method, is a method proposed by Denavit and Hartenberg in 1955 to describe the geometric relationship between the links and joints in a tandem robot arm. It uses the link length aj and the torsion angle αj to represent the j-th link, link offset dj and the joint angle θj to represent the j-th joint, so the transformation relationship between the adjacent two joints could be determined by these four parameters. In the process of solving the inverse problem, it is necessary to carry out the inverse motion decomposition of Euler transform or RPY (roll, pitch and yaw) transform frequently. The kinematics equation is very complicated, and the computer operation precision and speed are mutually restricted, so it is not friendly to beginners. The graphical method is to simplify the system into simple geometric figures and use mathematical theorem such as Pythagorean theorem to solve the position and orientation relationships between the mechanical links. This method is intuitive and easy to understand, but it is strictly limited to some simple arm structures in practical applications. However, for the simple three-axis robotic arm shown in figure I, the graphical method can complete the kinematic analysis of it easily, and the modeling process of the robotic arm will be elaborated below.

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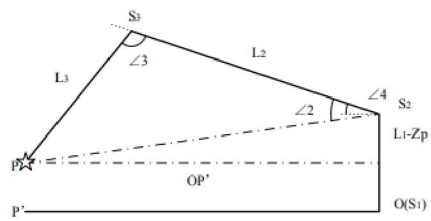

Fig 2: Schematic Diagram of Vertical Plane

Geometric Modelling Method

To explain the mapping relationship between the position of the arm end and the output of each joint, we take point P in 3- dimensional space as the target point. In order to make the arm reach the point P, joint S1 is first driven to keep point P in the same vertical plane as the robot arm, then joint S2 and S3 will help the arm end move freely in the vertical plane until it reaches the target point. The output angle of the three joints are calculated as follows: • With the projection point of point P on plane oxy, it is easy to figure out the required output of joint S1. • Then joint S2, S3, and point P are in the same vertical plane, and the schematic diagram of the plane is shown in figure II, where P' is the xp ,, yz□projection of P in the horizontal plane. With the coordinates of P , the Euclidean distance from the target point P to joint□0,0, L1 □ and S2 □pp PS□S2 can be easily obtained. Then, the lengths of the three sides of triangle 3 with cosine theorem as is shown□2 and □S23 are known, so it is easy to solve in (1) (2).

$$\angle 2 = \arccos \frac{PS_2^{\ 2} + L_2^{\ 2} - L_3^{\ 2}}{2 \times PS_2 \times L_2}. \qquad (1)$$

$$\angle 3 = \arccos \frac{L_2^{\ 2} + L_3^{\ 2} - PS_2^{\ 2}}{2 \times L_2 \times L_3}. \qquad (2)$$

In the geometric sense, we have established a mathematical model of the system, however, in order to control the end of the arm to a certain position, the real output of steering gears is related with the practical installation. For joint S2 whose output range is -150° to 150°, if its median position (output angle with none input) is parallel to the horizontal plane, then its output actually should be the angular difference between median position and the target position, that is, ∠4. Thus, given the position of the arm end, the output of all joints in the arm could be solved by the graphical method discussed above. On the contrary, if we know the angles of each pair of links, the position of arm end could also be figured out exactly. Furthermore, if the three attitude angles of the arm end are required, more joints have to be introduced into the arm to improve the degree of freedom, which is beyond the scope of this article.

III. THE DESIGN OF JOINTS

Just like the joints of an arm, steering gears are the actuator that drives the movement of the manipulator. It is essentially a closed-loop position (angle) servo system consisting of a DC (Direct Current) motor, and suitable for conditions where the angle is changing constantly and can be maintained if needed. According to the input signal, the steering gears are mainly divided into analog steering gears and digital steering gears. The input signal required by the analog servo steering gear is PWM(Pulse Width Modulation) signals, and it occupies a PWM port of the controller. If there are multiple steering gears, the controller needs to have enough output ports for PWM signals. However, digital steering gears can receive digital signals, and they are usually connected through a bus. Compared with the analog steering gear, the it has high control precision and adaptability, more importantly, it does not occupy the PWM

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interface of the controller, so it is more suitable for the control of robot arm that contains multiple actuators. Distributed system connects the main controller with many digital steering gears through a bus. In actual working process, the controller issues control commands of output angle and speed, then the data is transmitted through the bus after being encoded. After receiving the data, steering gears could decode the data and respond to the command corresponding to its serial number. In this structure, the controller can easily control any actuator on the bus and it is very convenient for the system to add or delete a steering gear if needed. Therefore, the distributed architecture was also applied in this research to achieve the control of a robotic arm.

A. Principles of Steering Gears

A steering gear is essentially a closed-loop position (angle) servo system, composed of a controller unit, a motor driver module, a DC motor, a gear reducer, position sensors, circuit protection module, and so on. As is shown in figure III, the steering gear control unit accepts the control command from the main controller and controls the DC motor to drive the motion of links. In this process, the position sensor such as potentiometer detects the actual output angle of the steering gear in real time, and then their output is converted into a digital signal and fed back to the control unit. After comparing the feedback signal with the desired output, the control algorithm in the controller would adjust the output in real time according to the error, thereby the output of the system is controlled at the specified position.

B. Control Strategy of Steering Gears

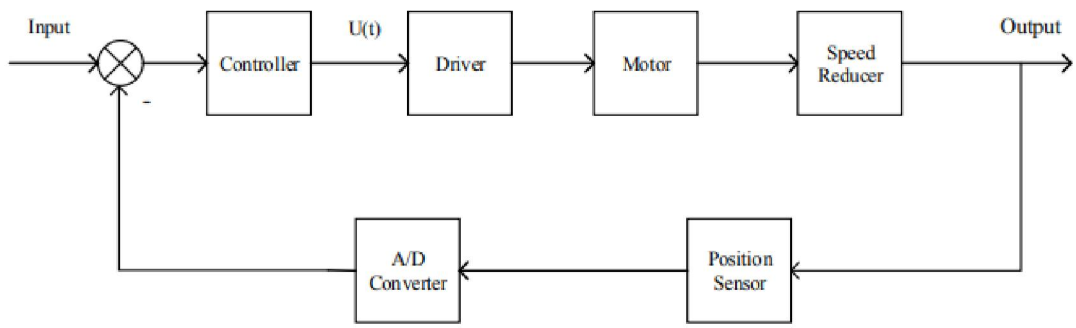

Fig 2: Woking Process

The control algorithm is the core of the closed-loop position servo system. Its function is to adjust the input value of the controlled object in real time according to the difference between actual output and target output. PID (Proportion, Integration, and Derivation) control strategy is one of the earliest developed control strategies, and because of its simplicity, good robustness, and high reliability, it is widely used in industrial environments, especially for deterministic control systems that can establish accurate mathematical models. PID defines the difference between the feedback c(t) and the desired output r(t) as the system error e(t), and linearly combines e(t) with proportion, integration, and differentiation to obtain the input signal of controlled objects, its control laws can be expressed as:

$$u(t) = K_P[e(t) + \frac{1}{T_I}\int_0^t e(t)dt + \frac{T_D de(t)}{dt}]. \qquad (3)$$

Kp is the proportionality coefficient, Ti and Td are the integration time and the derivative time respectively. The proportional element of the PID controller can reduce the deviation e(t) proportionally in real time, while the integral element is mainly used to eliminate the static error and improve the system type. The differential part can reflect the change trend of the deviation signal, thereby speeding up the system's response and diminishing the setting time.

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IV. CONCLUSION

In order to help beginners learn the design method of robot arms, this paper introduced the mechanism composition and kinematics of simple robotic arms, and expounded the method of modelling by geometric method. On this basis, the basic principles of steering gears, especially the designing method of control algorithm was described in detail and verified by simulation. This paper also has built a robot arm that can complete the function of playing an electronic organ. The performance of the control algorithm were verified by experiments, and the motion analysis of the system was also carried out, so readers can determine the input of every actuator just by referring to the table. The design methods and the example of this paper are feasible and practical, so it may help readers, especially beginners, to explore and practice the process of constructing robot arms independently.

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