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A STEP-compliant Industrial Robot Data Model for robot off-line programming systems

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ABSTRACT

Recently, various robot off-line programming systems have promoted their own robot data models, resulting in a plethora of robot representation methods and unchangeable data files among CAx and robot off-line programming systems. The current paper represents a STEP-compliant Industrial Robot Data Model (IRDM) for data exchange between CAx systems and robot off-line programming systems. Using this novel representation method, most resources involved in a robot manufacturing system can be represented. The geometric and mathematic aspects of industrial robots have been defined in IRDM, so that the robot off-line programming system could have abundant information to represent robots' kinematic and dynamic behaviors. In order to validate the proposed models and approaches, a prototype robot off-line programming system with 3D virtual environment is presented. The functionalities of IRDM not only have significant meaning for providing a unified data platform for robot simulation systems, but also have the potential capability to represent robot language using the object-oriented concept.

1. Introduction

Modern industries have been more and more heavily dependent on industrial robots [1]. In the early applications of robots (such as material transfer, precision assembly, welding and painting), the path planning tasks are usually very simple. Hence, the online teach in and playback mode can handle with most robot programming tasks. However, the increasing demands of 3D path planning in traditional and new emerging applications like machining have gradually revealed the necessity of robot off-line programming systems [2]. Therefore, many academic and commercial activities have been conducted into this field in the latest several years, and many software solutions have been released, such as V-Rep, Robotmaster and Robotworks. Besides, even some traditional machine tool related manufacturing software developers, such as Delcam, VeriCUT and ST-Machine, have also incorporated their own off-line robot programming capabilities [3].

For the robot off-line programming systems, the representation of robot data model is vital for exchanging data between different CAx and robot off-line programming systems. The data model of a robot usually consists of geometric aspect and mathematic (kinematic and dynamic) aspect, whereas most CAD systems can only provide geometric information. There are numerous geometric resource models reported in literatures together with a range of commercial CAD systems for representing geometric models. But there is so far even no standardized information model available for exchanging data of both aspects for a robot. Subsequently, most robot off-line programming developers have to promote their own kinematic models individually in their systems. Until recently, almost all the robot models of current software systems are private and unchangeable, which results in a plethora of robot representation methods and contemporary non-interoperable robot off-line programming systems.

In recent years, the data model of manufacturing resources has been included in the STEP standard (ISO 10303). STEP-NC, as an extension of STEP in the CNC field, is being developed as the data model for a new breed of CNC machine tools [4], and has successfully verified the functionality and competence of the STEP model to describe the machining process data and machine tool data [5,6]. Therefore, the STEP standard is regarded as the most suitable format to describe the robot data model. In recent years, many researches have been undertaken on modeling the manufacturing resources or CNC resources regarding to the STEP standard [7–9], since the representation of CNC resources has been considered vital for making efficient and economic manufacturing decisions [10,11]. For example, the modeling phase (data collection and model design) was about 60% of the total time spent on a simulation project [12]. In this regard, machine tools have been modeled to form a contribution to management of information and knowledge in manufacturing [13]. Industrial robot is

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considered as one of the elements of the CNC manufacturing system, thus is also conducted in the modeling work. However, most mathematic data models of previous researches are not able to exactly meet the demand of robot off-line programming systems, except for a few exploratory researches [14].

This paper proposes a generic information model for representing the data mode of an industrial robot, namely Industrial Robot Data Model (IRDM). In order to make it STEP-compliant, IRDM is accordingly defined in an EXPRESS file (as requested in the STEP standard ISO 10303-11) and expressed as EXPRESS-G diagrams. In the data models of IRDM, the data contents for a robot are categorized into product models, process models, resource models and mathematic models, and depicted in Section 2. The concept of model categorization is firstly proposed by Vichare et al. [15], whereas IRDM reveals that the mathematic model can also be covered and can be together with other models integrated into a neutral data file. Based on this concept, the related models in a robot off-line programming system are proposed in Sections 3, 4 and 5, which include robot resource data, kinematic and dynamic data and manufacturing process data, respectively. In Section 6, a prototype system STEP-VM is developed to validate the feasibility of integrating IRDM into the robot off-line programming process. The paper concludes and discusses that IRDM not only is beneficial to the robot off-line programming system but also has potential meaning to define the future robot language in robot controllers.

2. The industrial robot data model (IRDM)

In this paper, the proposed IRDM provides representations of available industrial robots for robot off-line programming systems. In an industrial robot off-line programming system, a 3D simulation interface is a necessity, since many complex conditions have to be inspected, such as collision, joint over limit, workspace detection, path review, etc. [16] In order to realize above 3D detections, the simulation system must have a CAD core, and the IRDM should provide normal exchangeable geometric definitions of a robot. In the STEP standard, there have two sub-parts (called Application Protocol in the STEP standard) providing the geometric definitions, AP203 and AP214. Nevertheless, due to the absence of robot's resource and mathematic models (generally include kinematic and dynamic models), the current STEP models with only geometric definitions cannot completely describe all the properties of an industrial robot. Thus, the proposed IRDM provides robot definitions, so that it can represent the remaining manufacturing resources such as kinematic configurations of robots, end effectors, auxiliary devices, and kinematic and dynamic notations. In addition, using the object-oriented concept of STEP-NC, the conventional robot manufacturing tasks are redefined as projects, work plans and working steps. The various types of models are categorized into product models, process models, resource models and mathematic models, as illustrated in Fig. 1.

In order to save the amount of modeling work, the IRDM integrates entities from several previous established STEP schemata, including ISO 10303-105, Unified Manufacturing Resource Model (UMRM, proposed by Vichare et al.), and ISO 14649 (Fig. 2).

Firstly, the development of a human-comprehensive and mathematically complete kinematic model needs a lot of knowledge and work. Fortunately, such kinematic model is provided by the ISO 10303-105 standard (usually known as IR 105, where IR stands for Integrated Resource). IR 105 specifies an information model for the kinematic aspects of a mechanical product as required for the communication between CAD systems and kinematic analysis systems, and among dissimilar kinematic analysis systems [17]. It describes a variety of entities such as kinematic joints, kinematic links and kinematic pairs, so that the kinematic structure of a mechanism can be determined. The models defined in IR 105 support tree kinematic structures and close loop kinematic structures, so it is compatible with most current industrial robots. However, IR 105 does not provide enough robotics definitions, e.g. the definition of the D–H notation (Denavit–Hartenberg notation) [18], which is the most essential data for describing the kinematics of a robot.

Secondly, the process modeling work is introduced from ISO 14649, since the machining task has been successfully described using STEP-NC in the last decade. ISO 14649 is a new model of data transfer between CAD/CAM systems and CNC machines, which replaces ISO 6983 (G and M code). It remedies the shortcomings of ISO 6983 by specifying machining processes rather than machine tool motion, using the object-oriented concept [6]. The object-oriented concept that can be extended to other manufacturing tasks for an industrial robot is defined as a multipurpose manipulator [19]. Therefore, the corresponding workingstep and technology entities have to be redefined for different operations and technologies.

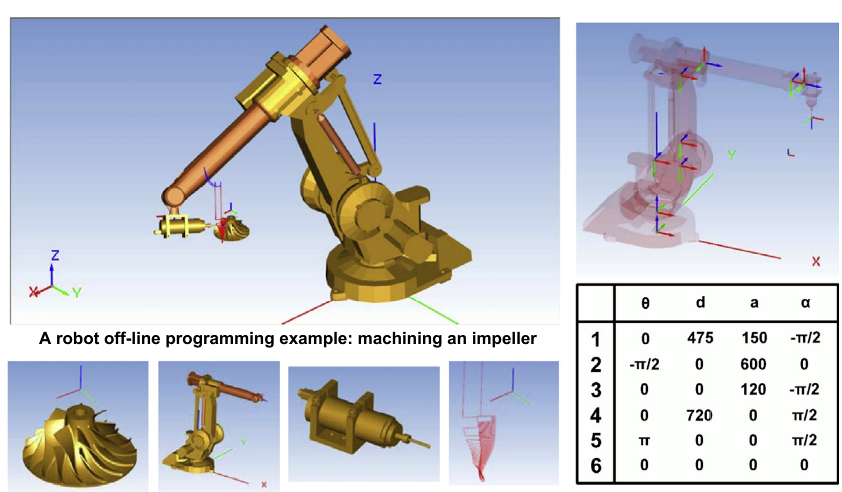
Thirdly, a robot manufacturing system generally consists of various manufacturing resources such as robots, end-effectors, fixtures and other auxiliary devices. The representation of manufacturing resources is essential for creating an integrated, exchangeable and interactive

Product model
- Workpiece
- Manufacturing feature
- Planar face
- Surface
...

Process model
- Toolpath
- Workingstep
- Operation
- Technology
...

Resource model
- Machine tool
- Robot
- End-effector
- Auxiliary device
...

Mathematic model
- Coordinate frame
- Kinematic notation
- Dynamic notation
- Algorithm
...



	θ	d	a	α
1	0	475	150	-π/2
2	-π/2	0	600	0
3	0	0	120	-π/2
4	0	720	0	π/2
5	π	0	0	π/2
6	0	0	0	0

Fig. 1. Model categorizations of the IRDM and a instance of robot off-line programming.