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Discretization and fitting of nominal data for autonomous robots

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ABSTRACT

This paper presents methodologies to discretize nominal robot paths extracted from 3-D CAD drawings. Behind robot path discretization is the ability to have a robot adjusting the traversed paths so that the contact between robot tool and work-piece is properly maintained. In addition, a hybrid force/motion control system based on Fuzzy-PI control is proposed to adjust robot paths with external sensory feedback. All these capabilities allow to facilitate the robot programming process and to increase the robot's autonomy.

1. Introduction and motivation

The process of robot off-line programming (OLP) has become increasingly popular in recent time, mainly inside Small and Medium-Sized Enterprises (SMEs). To this effect has contributed the required knowledge in robot programming which has been replaced by high widespread knowledge within enterprises. One way to use OLP is recurring to CAD drawings of the robotic cell in study (Chen & Sheng, 2011; Kim, 2004; Liu, Bu, & Tan, 2010; Vosniakos & Chronopoulos, 2008). When CAD drawings are used to program a robot, the programming task can become easier, more intuitive and less monotonous. In addition, the knowledge required is high disseminated within enterprises structure because SMEs generally use CAD packages to design and develop their products. Moreover, while a robot is in the production phase the following working setup can be prepared off-line, thereby the setup time is reduced and the management of workers becomes easier.

A series of studies have been conducted using CAD as interface between robots and operators, for example, a review on CAD-based robot path planning for spray painting is presented by Chen, Fuhlbrigge, and Li (2009). Nagata, Kusumoto, Fujimoto, and Watanabe (2007) propose a robotic sanding platform where the robot paths are generated by CAD/CAM software. An example of a novel process that benefits from the robots and CAD versatility is the so-called incremental forming process of metal sheets (Schaefer & Schraft, 2005). The robot paths are achieved from a CAD model on the basis of specific material models. Prototype panels or customized car panels can be economically produced using this method. Feng-yun and Tian-sheng (2005) present a robot path generator for the polishing process, where cutter location data are generated from the postprocessor of a CAD system. A CAD-based robot programming system where is referred the use of a sequence of virtual robot tool models to define the robot paths is presented by Neto, Mendes, Araújo, Pires, and Moreira (2012). Nevertheless, the CAD-based robot programming systems have found some adversities. The major of them is calibration, i.e., the differences in alignment between the real environment and the virtual environment (CAD). These differences always exist and are almost impossible to determine because their origin is unpredictable. In order to deal with the uncertainty and inaccuracy of the robot working environment, the introduction of sensory-feedback in robotic systems has been studied and implemented (Mendes, Neto, Pires, & Moreira, 2010; Neto, Mendes, Pires, & Moreira, 2010). However, many of the robots are not able to easily incorporate sensory-feedback and some special care needs to be taken to ensure proper running of the system. One of the possible approaches is to discretize the path in small paths (Nagata, Kusumoto, et al., 2007). After that, some appropriate adjustments should be done on these small paths while the robot is performing them (Pires, Afonso, & Estrela, 2007). Several studies about robot path discretization have been proposed, such as Nagata, Hase, Haga, Omoto, and Watanabe (2007), which presents a CAD/CAM-based position/force controller. This study addresses a calculation method of robot orientation from cutter location data. Some algorithms for robot path discretization have been proposed to smooth robot paths (position and orientation) (Feng-yun & Tian-sheng, 2005; Neto, Mendes, et al., 2012). Nielson (2004) proposes an algorithm for nonlinear smoothly interpolating orientation, which showed excellent results when used in Spline curves. Sheng, Xi, Song, and Chen (2001) present a method for robot path planning where nominal data are extracted from a CAD surface. A methodology for robot path planning from 3-D CAD models by means of the linear and circular discretization is presented by Berger and May (2005). Kuffner (2004) addresses some implementation issues and techniques in rigid body path planning using the

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Lei group SE(3). Nagata (2005) presents a completely local algorithm for surface discretization. The main idea is the discretization of a curve segment supporting itself on the position and normal vectors at endpoints.

This paper aims to promote the OLP of industrial robots, in which nominal data (obtained for example from CAD drawings) are adapted to robot motion for industrial processes such as Friction Stir Welding (FSW) (Cook, Crawford, Clark, & Strauss, 2004; Fleming, Hendricks, Wilkes, Cook, & Strauss, 2009; Soron & Kalaykov, 2006). The idea is to provide to users, with basic skills in CAD and robot programming, the tools to off-line generate reliable robot programs. However, as there are usually discrepancies between the virtual and real environment, the robot should be able to ensure recognition of their work environment and make appropriate adjustments (on-line) in the pre-programmed paths. In this way, we propose the use of sensory-feedback through the implementation of a hybrid force/motion control system. The function of this control system is to keep the contact between robot tool and work-piece. Nevertheless, even though not all commercial robots are ready to incorporate sensory-feedback in an easy way, most are prepared to make adjustments in the pre-programmed path, when the robot programs are being executed. Having this capability in mind, we propose the discretization of the nominal robot path in small sections and then make the adjustments that are desirable in these small sections (path adjustment). In this paper, some techniques of path discretization are presented, namely: linear paths, circular paths and curvilinear paths (Nagata patch). In addition, an interpolation technique is presented to interpolate end-effector orientation (Slerp). In order to perform the adjustments in the pre-programmed paths, a hybrid force/motion control system is presented, with special attention to the force control loop which is developed using Fuzzy reasoning and traditional Proportional Integrative control (PI).

The paper is further organized as followed. The second section focuses on the extraction of information from CAD. The third section presents some path discretization methods. The fourth section presents the hybrid force/motion control system used to produce adjustments in the pre-programmed path. The methods presented in the previews sections are evaluated through an experiment that is presented in section fifth. Finally, in the sixth section, conclusions are dawn and future work highlighted.

2. Acquisition and processing of nominal data from CAD

2.1. Case study

For this study, which is performed in the Cartesian space, nominal data are directly extracted from a commercial CAD package, Autodesk Inventor. Each CAD model consists in a robotic cell, points (representing robot paths also known as robot end-effector positions) and poses (representing orientations of the robot tool also known as robot end-effector orientations) (Fig. 1). The data extracted from a CAD model are transformation matrices, consisting in rotation matrices and coordinates of points, both in relation to the origin of the CAD model of the cell. The information needed to program the robot will be extracted from the CAD environment by using an application programming interface (API) provided by Autodesk. This API allows the data transfer between the Autodesk Inventor and a Software Interface (which is the application that manages the entire process). Later, the information extracted from CAD is converted into robot code. A diagram with the procedure to extract nominal data from a CAD model and their conversion into a robot program is presented in Fig. 2.

In order to extract information from a CAD model, all the components belonging to the model (robot, work-pieces, conveyors, etc.) must be drawn and assembled like in the real cell in their real dimensions and shapes. Furthermore, the points must define the beginning and the end of the robot path. Nevertheless, it is the user that defines the type of path (linear, circular or curvilinear). Fig. 3 represents schematically a robot path. The arrows represent the robot tool orientation in each discretized position and the *P*s represent robot positions.

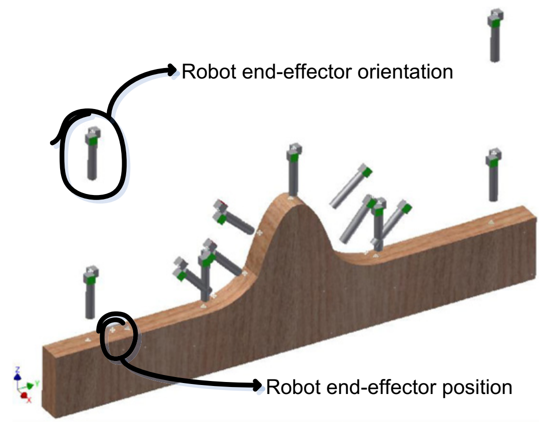

Fig. 1. A CAD model.

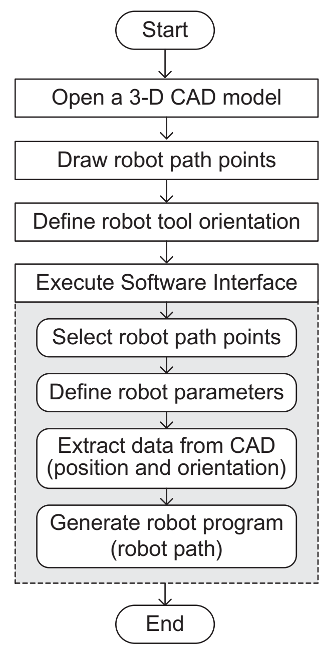

Fig. 2. Procedure to extract nominal data and generate robot programs from CAD.

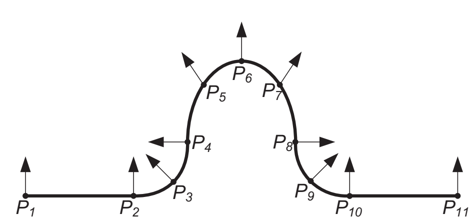

Fig. 3. Schematic representation of a 3D CAD path to extract nominal data.

2.2. Transformation between coordinate systems

In order to establish a match between the real environment and the virtual environment (CAD environment) some geometric