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The time optimal trajectory planning with limitation of operating task for the Tokamak inspecting manipulator

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ABSTRACT

In this paper, a new optimization model of time optimal trajectory planning with limitation of operating task for the Tokamak inspecting manipulator is designed. The task of this manipulator is to inspect the components of Tokamak, the inspecting velocity of manipulator must be limited in the operating space in order to get the clear pictures. With the limitation of joint velocity, acceleration and jerk, this optimization model can not only get the minimum working time along a specific path, but also ensure the imaging quality of camera through the constraint of inspecting velocity. The upper bound of the scanning speed is not a constant but changes according to the observation distance of camera in real time. The relation between scanning velocity and observation distance is estimated by curve-fitting. Experiment has been carried out to verify the feasibility of optimization model, moreover, the Laplace image sharpness evaluation method is adopted to evaluate the quality of images obtained by the proposed method.

1. Introduction

The trajectory planning is a fundamental and crucial problem for all kinds of robots. It can be divided into two stages to complete operating task along the specified path for a robot: firstly, designing a path in the operation space according to the operating task and getting some via-points, then obtaining the joints value through the inverse kinematics of manipulator, finally, generating the joints trajectory by the corresponding interpolation function. In order to maximize the productivity of robot, the time optimal trajectory planning is a key issue. Lots of works have been done to obtain the minimum time. As early as 1985, Bobrow JE and Shin KG define the basic idea of this algorithms that is to write the dynamic equation of manipulator using the curvilinear abscissa of the path in the position-velocity phase [1,2]. Then, the optimal control will be found by using the different search algorithm like indirect methods [1,3], dynamic programming [4], direct transcription methods [5,6] and so on. To get a globally optimal solution, the time-optimal path tracking problem was transformed into a convex optimal control problem in [7,8]. Because of the uncertainty of dynamic parameters, the kinematic trajectory planning algorithm was proposed as described in [9]. This algorithm is subject to the kinematic constraints on joint velocity, acceleration and jerk. Wang CH uses the cubic B-splines to interpolate the via-points [10]. A technique for time-jerk optimal planning robot trajectory has been stated and used in the actual experiment latter in [11–13]. The same method is used in [14] to ensure an efficiency tracking performance with fluent motion. However, these efforts only consider the joint torque, torque rate, velocity, acceleration and jerk, they neglect the constraints in the task space. Although Verscheure D introduces a limit expansion about the operation space velocity and acceleration, the threshold value is a constant [7].

As for the detection task for ITER, famous AIA robot has performed its first deployment in Tore Supra Tokamak vessel under real vacuum and temperature conditions in 2008 [15], and Gargiulo L describes the robot capabilities with the present operations conducted on Tore Supra [16]. But the images obtained by the AIA is not clear because of the resolution of the camera, moreover, the trajectory of this robot has not been optimized, which leads to the imaging quality of camera can't be ensured and the execution time is not fast. To meet these requirements, Villedieu E decides to upgrade the AIA prototype [17], but in this paper, the method of ensuring fast detection and clear imaging has been proposed. In order to complete the inspection task for the Tokamak vessel, a specified path is designed for the Tokamak inspecting manipulator [18–20]. The trajectory optimization model with limitation of operating velocity is proposed to meet the inspection requirements. Here, the maximum scanning velocity will change according to the

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0920-3796/

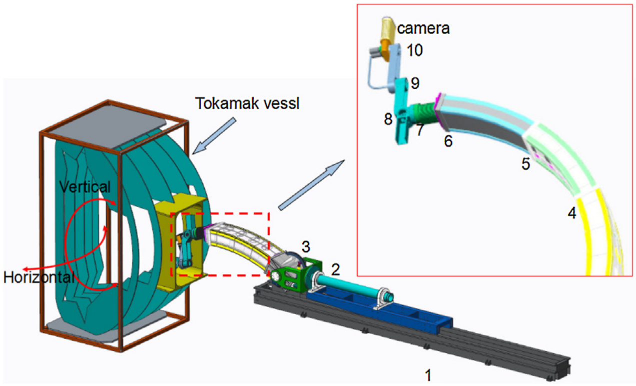

Fig. 1. The operation task system.

observation distance of camera in real time to obtain the minimum time. The relation between scanning velocity and observation distance of camera is crucial, which can be got by the curve-fitting. To verify the feasibility of this method, the Laplace image sharpness evaluation method is adopted to evaluate whether the images have been improved.

The rest of this paper is organized as follows. Section 2 describes the inspecting manipulator and operating environment. Then, Section 3 details the optimization model of time optimal trajectory planning with limitation of operating velocity. The method of solving the optimal value will be introduced in section 4. Section 5 conducts some experiments to demonstrate the efficiency and feasibility of this method. Finally, section 6 summarizes the paper and puts forward the future work.

2. The operation task system

The Tokamak inspecting manipulator is a 10-DOFs redundant robot manipulator as shown in Fig. 1, and it can be regarded as the macro-micro structure. The macro part consists of the first six joint, and next four joints make up the micro part. The first joint is translational and the other joints are rotary. This macro-micro structure is very convenient to execute the inspecting task for the Tokamak. The macro part moves along the center line of the vessel in the horizontal plane, and is responsible for driving the micro part to the area which will be scanned, then the micro manipulator will inspect the vessel along the specified path in the vertical plane. Although the micro manipulator consists of the last four joints, the joint 8 only moves when the manipulator entering into the vessel, and then will keep zero, so the micro part is similar to the three-link planar arm [21]. In fact, the vessel is covered by the blankets and divertors as shown in Fig. 2, the purpose of this inspecting manipulator is to scan the vessel to check the situation of the blankets and divertors. So, if the velocity of the end-effector is too fast, the images of camera will be blurred and some disturbances will be caused during observation.

3. Time optimal trajectory planning

The basic time optimal trajectory planning based on the kinematic is described generally as follows:

$$min\ f = \mathrm{T} = \sum h_i (i = 1, 2, 3, \ldots, N-1)$$
$$subject\ to \begin{cases} |\dot{Q}_j(t)| \le sup(VC_j) \\ |\ddot{Q}_j(t)| \le sup(AC_j), j = 1, 2, 3, \ldots, M \\ |\dddot{Q}_j(t)| \le sup(JC_j) \end{cases} \quad (1)$$

The meaning of those symbols in (1) is described in Table 1.

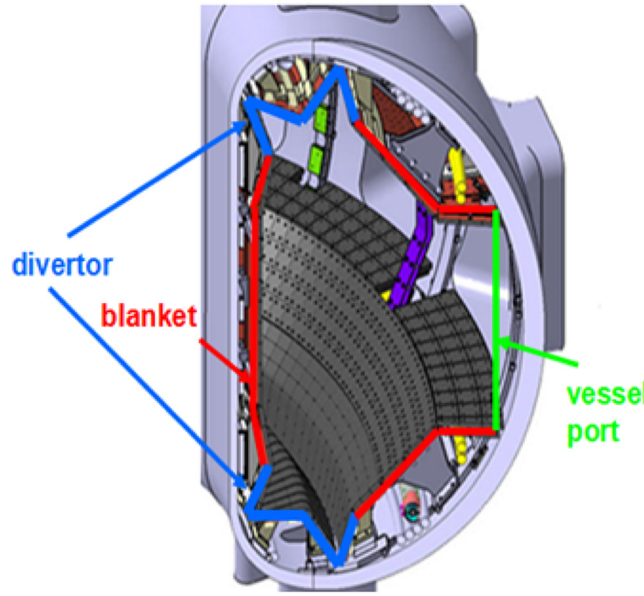

Fig. 2. The components of in-vessel.

Although the minimum time will be got by solving the optimization model (1), it will create the uncertain end-effector velocity and will influence the imaging quality of camera. So, it is necessary to limit the operating velocity.

As we all know, the different observation distance should be matched with different operating velocity, thus, the relation between the velocity v and observation distance d should be obtained as expression $v = f(d)$. Here, d is a variable, so the v will change in real time.

Finally, the new optimization model of time optimal trajectory planning can be expressed like follows:

$$min\ f = \mathrm{T} = \sum h_i (i = 1, 2, 3, \ldots, N-1)$$
$$subject\ to \begin{cases} |\dot{Q}_j(t)| \le sup(VC_j) \\ |\ddot{Q}_j(t)| \le sup(AC_j) \\ |\dddot{Q}_j(t)| \le sup(JC_j) \\ |v_i| \le f(d_i) \end{cases}, j = 1, 2, 3, \ldots, M \quad (2)$$

4. Solving the optimization model

4.1. Laplace image sharpness evaluation method

Firstly, we focus on how to get the relation $v = f(d)$ between operation velocity and observation distance of camera. Here, the imaging quality is evaluated by the Laplace image sharpness. In image processing, image gradient can be used for edge detection, whose value will be higher if the image focuses better, which means that the image is clearer. Laplace operator belongs to one of gradient

Table 1
The meaning of symbols.

h_i	Time interval between two via-points
N	The number of via-points
M	The number of manipulator joints
$\dot{Q}_j(t)$	The velocity of *j-th* joint
$\ddot{Q}_j(t)$	The acceleration of *j-th* joint
$\dddot{Q}_j(t)$	The jerk of *j-th* joint
VC_j	The max velocity of *j-th* joint
AC_j	The max acceleration of *j-th* joint
JC_j	The max jerk of *j-th* joint