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Identification of Joint Clearances in Parallel Robots by Using Embedded Sensors

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Abstract

DELTA robots are the most famous parallel robots and usually used as a high speed pick-and-place machines with purely translational degrees-of-freedom. In parallel robots, most of the joints are generally passive joints. A DELTA robot contains three identical kinematic chains. Each chain exhibits a spatial parallelogram with four passive spherical joints (Fig. 1). Manufacturing errors and with it wear cause excessive magnitude of clearance in the spherical joints, which results in non-ideal behavior. The resulting positioning inaccuracy of the end-effector can be reduced by a proper compensation of actuators' input trajectories. Therefore, it is important to achieve an accurate estimation of the joint clearances. The status of passive joints is difficult to monitor. However, it is known that when the joint elements collide, actuation torques are affected by the collision and thus vary depending on the state of motion [1]. Focusing on the collision of joints with clearance, this paper presents a method to judge, which joint in the robot has effective clearance by measurements of the actuation torques. A major challenge in this context is the selection of a suitable trajectory that allows for such identification. More specifically, a trajectory is considered suitable when solely one of the twelve passive joints collides and eventually the effects on the actuation torques are induced by the collision at only one single joint.

During the motion, the behaviors of joints with clearance in a parallel robot can be classified into two cases, in which the joint elements are constraint (sliding) or constraint-free (collision). The corresponding virtual link model (model b) and the constraint-free model (model c) are applied to assess on the occurrence of collisions in joints with clearance (Fig. 2). In contrast to ideal joints (no clearance, model a), in the virtual link model, the centers of joint elements are assumed to be connected by a link. The length of the virtual link then corresponds to the magnitude of the joint clearance. The condition, that forms the virtual link model, is that a tensile force occurs. In the constraint-free model, the joint is not constraint, i.e., no reaction force will be exerted. The condition, that forms the constraint-free model, is that the joint elements are separated. The flowchart of the analysis to determine, which joint elements collide is shown in Fig. 3. Accordingly, the aforementioned conditions are evaluated based on the dynamic modeling of the overall system performing a set of randomly selected

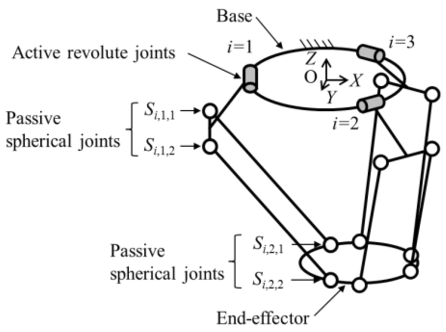

Fig. 1 The DELTA parallel robot used in the simulation and the experiment.

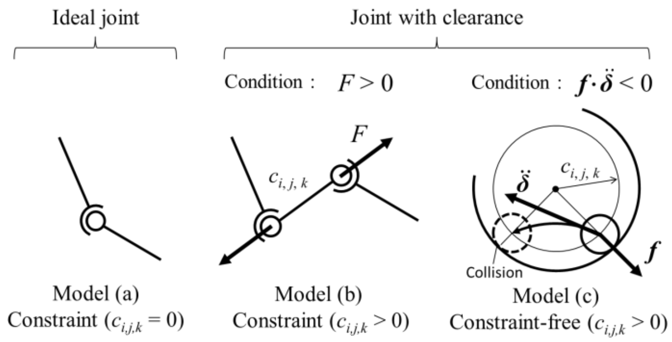

Fig. 2 Joint models. F and f stand for joint reactions in driving and stationary states. $\ddot{\delta}_{i,j,k}$ stands for relative acceleration of the joint.

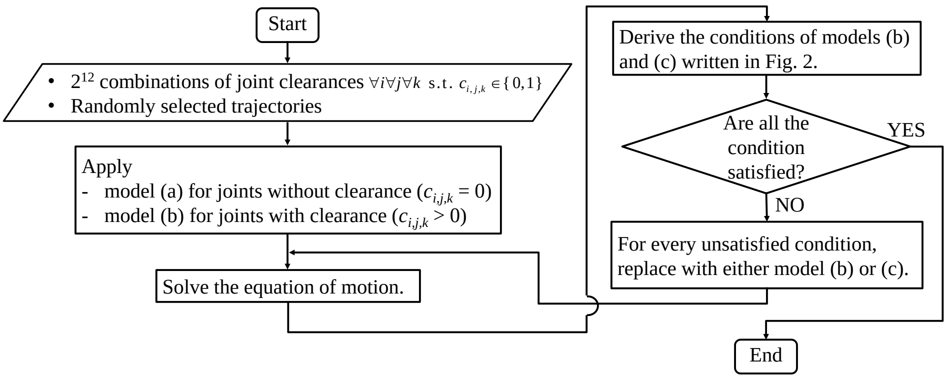

Fig. 3 The flowchart of the analysis to determine which joint elements collide.

trajectories. Therefore, in a first step, the equations of motion are derived for the ideal model (a) and the constraint model (b). Then, the conditions for models (b) and (c) are evaluated and adapted accordingly.

This simulation is successfully applied to the well-known DELTA parallel robot as shown in Fig. 1. In this context, all of combinations of presence or absence of joint clearances (2^{12} combinations) and randomly selected initial conditions of a given number of pick-and-place trajectories are taken into account. In order to select trajectories, which can detect the clearance at one specific spherical joint, a score was introduced based on the simulation results. The results of the scoring are shown in Fig. 4. As a simple example, a high score means that a collision occurs at $S_{1,1,1}$ while at all other joints no collisions occur. In contrast, a (close to) zero score means that collision does not occur exclusively at $S_{1,1,1}$ but also at some other joints or solely at other joints but not $S_{1,1,1}$. For the sake of brevity, the scoring for more complex assessments is not presented in this abstract. Fig. 4 exemplarily shows the scores for $S_{1,1,1}$. Accordingly, for several trajectories (given as initial conditions), the high score (indicated in blue) is reached. The results clearly demonstrate that there exist trajectories, where a collision occurs only at specific joint. Using these results, a single trajectory was optimally selected for a successful detection of joint clearances at each spherical joint by the nearest point search.

Two experiments were conducted to validate the simulation results. In the first experiment, only ideal joints are taken into account. In the second experiment, joints with clearances in accordance with Fig. 5 (white bars) are deployed. Using the previously selected trajectories, the actuators' current values were measured. Then, the anomaly score [2] was defined with reference to the current value of the first experiment, in which all of the spherical joints are ideal. The score increases with the current value fluctuating from the value in case of using ideal joints (Fig. 5). As shown in the results, properly assuming the threshold of anomaly scores, three out of four joint clearances can be detected. While the predictability should be improved, experimental investigation showed that the presence of joint clearance can successfully be identified using the selected trajectories.

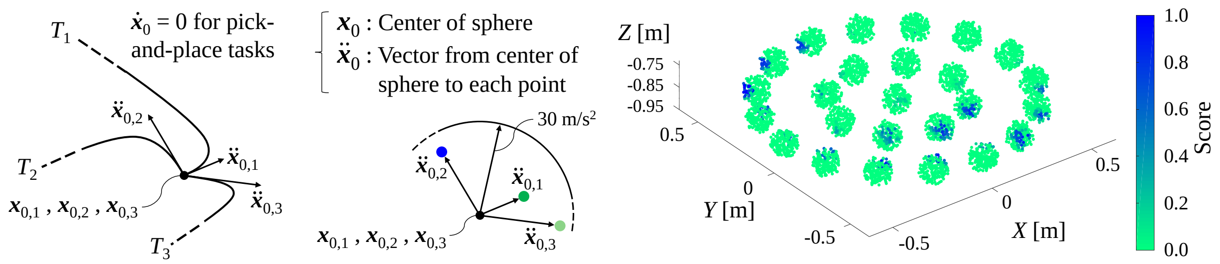

Fig. 4 Initial conditions of trajectories scored to detect the specific spherical joint clearance (here $S_{1,1,1}$). The acceleration space for each position is expressed in the position space at a dimensional scale of 0.003 m to 1 m/s^2.

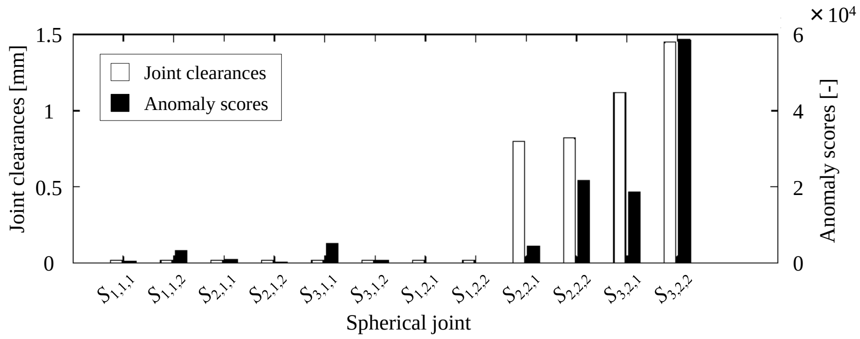

Fig. 5 The clearances of spherical joints used in the experiment and the anomaly scores on each trajectory calculated from the experimentally measured current value.

References

[1] P. Flores et al., A study on dynamics of mechanical systems including joints with clearance and lubrication, *Mechanism and Machine Theory* Vol.41 (2006), pp.247–261.

[2] V. Chandola, A. Banerjee, V.Kumar, "Anomaly detection: A survey," (2009), ACM Computing Surveys 41 (3): 1.

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