TOLERANCE ANALYSIS OF RPRPR PARALLEL MANIPULATOR

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Abstract—Registering the maximal stance mistake given an upper bound on display parameters vulnerabilities, called irritations in this paper, is trying for parallel robots, for the most part in light of the fact that the direct kinematic issue has a few arrangements, which end up plainly flimsy in the region of parallel singularities. In this paper, a neighbourhood uniqueness theory that permits securely registering posture mistake upper limits utilizing nonlinear improvement is proposed. This speculation, together with a relating maximal permitted bother space and a certified rough posture mistake upper bound substantial over the entire workspace, will be demonstrated numerically utilizing a parametric variant of Kantorovich hypothesis and certified Nonlinear worldwide enhancement. At that point approximate linearization’s are used in order to determine approximated tolerances reaching an endorsed maximal stance blunder over a given workspace. Those resistances are finally verified utilizing ideal posture mistake upper limits, which are registered utilizing worldwide improvement systems. Two illustrative cases are considered keeping in mind the end goal to feature the commitments of the paper.

Keywords—Tolerance, mechanisms, manipulator, perturbed, Kantorovich.

I. INTRODUCTION

For two decades, parallel manipulators have pulled in the consideration of an ever-increasing number of analysts who think about them as important elective plan for mechanical systems. Parallel Kinematics Machines (PKM) offer fundamental favourable circumstances over their serial partners, for example, bring down moving masses, higher firmness and payload-to-weight proportion, higher normal frequencies and better unique execution. In any case, PKM are not really more exact than their serial partners. Without a doubt, regardless of whether the dimensional varieties can be repaid with PKM, they can likewise be amplified opposite with their serial partners. Wangetal. [1] considered the impact of assembling resiliencies on the exactness of a Stewart stage. Kim et al. [2] utilized a forward mistake bound examination to find the blunder bound of the end-effector of a Stewart stage when the blunder limits of the joints are given, and a backwards mistake bound investigation to decide those of the joints for the given mistake bound of the end-effector. KimandTsai [3] considered the impact of misalignment of direct actuators of a three Degree-of-Freedom (DOF) translational parallel controller on the movement of its moving stage. Han et al. [4] utilized a kinematic affectability examination strategy to clarify the gross movements of a 3-UPU parallel system, and demonstrated that it is exceptionally touchy to certain moment clearances. Fan et al. [5] broke down the affectability of the 3PRS parallel kinematic shaft stage of a serial-parallel machine instrument. Verner et al. [6] introduced another technique for ideal alignment of PKM in light of the abuse of the minimum blunder touchy districts in their workspace and geometric parameters space. Truly, they utilized a Monte Carlo recreation to decide and delineate sensitivities to geometric parameters. Besides, Caro et al. [7] built up a resistance amalgamation strategy for instruments in view of a strong plan approach. Ryu et al. determined a volumetric blunder show and an aggregate mistake change grid from a differential backwards kinematic condition, which incorporates all kinematic mistake sources [8]. Liu et al. detailed an approach of geometric mistake demonstrating for bring down portability manipulators by expressly isolating the compensable and uncompensable blunder sources influencing the stance precision [9].
Briot and Bonev proposed a straightforward technique in light of a point by point mistake investigation of 3-DOF planar parallel robots that brings significant comprehension of the issue of blunder amplification [10]. Rolland utilized logarithmic instruments with a specific end goal to process an upper bound of the moving stage posture mistake for a Gough-Stewart stage while considering geometric and numerical errors [11-13]. Merlet and Daney utilized a first arrange guess of the stance blunder to survey the stance blunder in a workspace and play out a dimensional blend of the controller [14]. Patel and Ehmann investigated the volumetric blunder of a Gough-Stewart stage excessively [15]. Amid the early outline procedure of building frameworks, the examination of the execution affectability to vulnerabilities is a vital undertaking. High affectability to parameters that are characteristically uproarious can prompt poor, or surprising execution. Thus, it is imperative to break down the sensitivity of their execution to varieties in their geometric parameters and to decide the ideal dimensional resistances. To this end, some lists, for example, the finesses and the manipulability have been utilized to assess the sensitivity of robots execution to varieties in their incited joints. Be that as it may, they are not reasonable for the assessment of this sensitivity to different kinds of vulnerability, for example, varieties in geometric parameters. Two files were proposed in to assess the sensitivity of the end-effector posture (position + introduction) of the Orthoglide 3-pivot, a 3-DOF translational PKM, to varieties in its outline parameters. In a similar vein, four 3-RPR planar parallel controllers (PPMs) were looked at in view of the sensitivity of their execution to varieties in their geometric parameters. In, an interim linearization strategy is utilized for the sensitivity examination of some parallel controllers. In any case, the previous research works don't manage the resistance amalgamation of parallel controllers, which is a basic issue. In the present paper, we defeat two needs in the writing: First, a completely thorough technique is proposed to process a certified upper destined for the posture mistake because of limited vulnerabilities in the model parameters of a PKM all through its workspace. Second, a strategy is proposed for the resistance amalgamation of PKM, going for incorporating the biggest resiliencies while keeping the stance blunder of the moving-stage underneath a given point of confinement. The proposed resilience combination technique is made out of three stages:

Stage 1 A thorough parametric posture blunder upper bound 4(p) is figured, which relies upon the estimation of the bother p, together with an annoyance space P where this upper bound is substantial. Both are processed utilizing Kantorovich hypothesis, where Kantorovich constants are assessed over the full controller workspace utilizing certified nonlinear worldwide enhancement.

Stage 2 Since the past upper bound is negative, its use for resilience blend may prompt some finished plan (i.e., too little resistances are planned prompting a superior exactness than the required one). Along these lines, a non-thorough linearization of the most extreme stance blunder in the workspace is proposed and utilized for combining inexact resistances.

Stage 3 A thorough sharp posture blunder upper bound is finally figured for the resilience orchestrated at Step 2 utilizing certified nonlinear worldwide advancement. The cruder upper bound figured at Step 1 is important to make this issue provably predictable.

Stage 2 is really discretionary: A precise direct estimation can be acquired by building a straight model utilizing the sharp blunder upper bound registered at Step 3 for various resistances. In any case, the issue to be unraveled at Step 3 is more difficult than ones to be tackled at Step 2, along these lines beginning with the straight estimation gave by Step 2 can end up being more efficient.

The paper is sorted out as takes after. Stage 3 persuades the need of Step 1, and is in this manner first nitty gritty in Section 3. A uniqueness theory is acquainted all together with process a certified sharp stance blunder upper bound over a given workspace by taking care of a nonlinear improvement issue. Stage 1 is the focal commitment of the paper, and is tended to in Section 4: A parametric rendition of Kantorovich hypothesis is proposed, which gives both a maximal bother space for which this uniqueness theory holds, and a rough certified posture blunder upper bound legitimate inside this irritation area and in addition in the controller workspace. Stage 2 is finally created in Section 5: A surmised linearization of the maximal stance blunder of the moving-stage in the workspace is proposed, which permits playing out some rough resilience combination. These estimated resiliencies can finally be redressed utilizing the outcomes got in Section 3. Two illustrative
cases are given in Section 6 keeping in mind the end goal to feature the potential and breaking points of the approach. The two illustrations manage the resistance combination of a RPRPR parallel controller and a 3– RPR parallel controller with a fixed introduction of this moving-stage, individually.

II. PERTURBED KINEMATIC MODELS

We consider a kinematic model $f(x,q,p)=0$ of a non-redundant parallel manipulator, where $f : \mathbb{R}^n \times \mathbb{R}^n \times \mathbb{R}^m \rightarrow \mathbb{R}^n$, $x$ being the pose, $q$ the actuated joint coordinates and $p$ a perturbation vector associated to some uncertain model parameters, so that the nominal model is $f(x,q,0)=0$. If $n>n'$ then the robot is over-actuated, which can be handled by the method proposed in this paper, although experiments presented in Section 6 are restricted to $n = n'$. We also denote this nominal model by $f(x,q) := f(x,q,0)$.

Example 1. The nominal model for a RPRPR, whose geometry is shown on the left-hand side diagram of Fig. 4, is

$$(x_1 + 1)^2 + x_2^2 - l_1^2 = 0$$
$$(x_1 - 1)^2 + x_2^2 - l_1^2 = 0$$

Considering perturbations $p_i$, $i \in \{1, ..., 4\}$, on the position of the fixed revolute joints, and $p_i$, $i \in \{5, 6\}$, on the lengths of the actuated prismatic joints gives rise to

$$(x_1 + 1 + p_1)^2 + (x_2 + p_2)^2 - (l_1 + p_1)^2 = 0$$
$$(x_1 - 1 + p_2)^2 + (x_2 + p_4)^2 - (l_2 + p_2)^2 = 0$$

We suppose that $f$ is differentiable and has locally Lipschitz continuous first derivatives with respect to pose and perturbation, e.g., $f$ is twice differentiable with respect to these variables. The Jacobian matrix of $f$ with respect to variables $x$ and $p$ are denoted respectively as $F_x(x,q,p)$, called the kinematic parallel Jacobian matrix, and $F_p(x,q,p)$, called the sensitivity Jacobian matrix. The nominal generalized workspace is defined by

$$\mathcal{G} := \{ (x,q) \in \mathbb{R}^n \times \mathbb{R}^n : f(x,q) = 0 \land g(x,q) \leq 0 \}$$

where $g$ is a set of inequalities that defines the generalized workspace of interest. We assume that $\mathcal{G}$ is bounded. We also require that $\mathcal{G}$ does not contain any parallel singularity, but this will be checked by the proposed method. In some situations, the kinematic model can be solved for the pose coordinates inside $\mathcal{G}$, giving rise to a direct model $d : \mathbb{R}^n \rightarrow \mathbb{R}^n$ that provides an explicit description of the nominal generalized workspace:

$$\mathcal{G} := \{ (x,q) \in \mathbb{R}^n \times \mathbb{R}^n : x = d(q) \land g(x,q) \leq 0 \} \quad (6)$$

When perturbations are to be taken into account, we expect to have a direct model that depends on perturbations: $x = d(q,p)$. Such a direct model is generally not correct for arbitrarily large perturbations, and therefore has to be associated to a perturbation domain $P$ for which it is valid (for simplicity, the perturbation domain $P$ is supposed to contain 0 and to be convex). Although such a direct model with explicit dependence on perturbations naturally arises in the context of serial robots, it is usually quite difficult to obtain for parallel robots, or even does not exists. The pose error is the error between the nominal pose and the perturbed pose for fixed actuated joint coordinates. When a direct kinematic model is available, this can be expressed as $e(d(q,0),d(q,p))$, where $e$ is either the norm of the positioning error or the norm of the orientation error, so

$$e(x,x') = \| \pi(x - x') \|$$

where $\pi$ is a projection on a subset of the coordinates of the pose.

When no direct model is available, the situation is more complex since it becomes difficult to associate perturbed poses to their nominal counterpart.

III. TOLERANCE SYNTHESIS

Let $P$ be the perturbation domain provided by Theorem 1. Our aim is to determine a vector of tolerances $\Delta = (\Delta_j)$ such that

$$S_\Delta = \{ p \in \mathbb{R}^m : \| p^{(i)} \| \leq \Delta_j \}$$

is contained inside $p$, and that the error $e(x,x')$ is less than a given threshold $e$ for all perturbations in $S_\Delta$.

In Subsection 5.1, we propose a non-rigorous linear approximation of the maximal error in the workspace. In Subsection 5.2, we formulate the Tolerance synthesis as a multi-objective optimization.
problem, aiming to maximize the different tolerances $\Delta_i$. Finally, a certified upper bound for the pose error corresponding to the tolerances synthesized by this process is computed by solving the optimization problem described Section 3.

3.1. Approximate linearization of the pose error

Theorem 1 involves several overestimations, which leads to an overestimated error upper bound for the considered perturbation domain. We make the assumption that a linear approximation is going to be accurate within the perturbation domain provided by Theorem 1:

$$x - x' \approx F_x^*(x, q, 0)^{-1} F_p(x, q, 0)p$$

We obtain an approximate workspace worst case error $e(\Delta)$ in the following way:

$$\max_{(x, q) \subseteq \Delta} \| \pi(x - x') \| \approx \max_{(x, q) \subseteq \Delta} \| \pi F_x^*(x, q, 0)^{-1} F_p(x, q, 0)p \|

3.2. Approximate tolerance synthesis

In order to be able to compute a rigorous pose error upper bound using, we need to choose $\Delta_i$ using under the additional constraint that $S_\Delta$ is a subset of P. Therefore, admissible tolerances $\Delta_i$ satisfy

$$\sum_i y_i^\Delta \Delta_i \leq \epsilon$$

$$\sum_i y_i^\Delta \Delta_i + \mu \| \Delta \|^2 \leq \frac{1}{\lambda X}$$

As mentioned earlier, the domain is convex, and so is the set of admissible tolerances defined by. Finally, we want to select tolerances satisfying that maximizes each $\Delta_i$ in a multiobjective sense, i.e., that are Pareto optimal for these objectives. Since objectives and constraints are convex and almost linear, this multi-objective optimization problem can be easily solved using, e.g., weighted-sum or 4-constraint methods.

3.3. Rigorous validation of the approximate tolerance synthesis

Finally, solving the optimization problem provides a rigorous upper bound for the pose error over the workspace for the synthesized tolerances. Two cases arise: Either the rigorous upper bound is close enough to the approximate one so that the synthesized tolerances can be used, or the process can be repeated for neighbour tolerances in order to achieve better tolerances.

IV. CONCLUSIONS

The three-stage approach proposed in this paper was effectively connected to a 2-DOF and a 3-DOF parallel robot. Hypothesis 1 could register safe areas of irritations at Step 1, whose size is a couple of percent of the length of the longest connection on account of the 2-DOF robot, and a couple of per thousand of the length of the longest connection on account of the 3-DOF robot, which are sensible to synthesize resistances. The rough linearization registered at Step 2 gave exact approximations, which have been confirmed by the sharp upper bound figured at Step 3. Despite their evident exactness, they experience the ill effects of the way that one doesn't have any data on their
legitimacy for a given irritations. The proposed approach provides such a legitimacy area, and additionally thorough posture mistake upper limits.

Be that as it may, these preparatory trials likewise unmistakably demonstrate that the more unpredictable the robot, the littler the protected area of annoyance figured by Theorem 1 and the more extended calculation time. In this manner, those two issues ought to be unraveled for the strategy to be pertinent to robots with more DOF. To start with, bigger safe areas of bothers could be gotten by enhancing the declarations of issues (14), (15), and (16), where there is lost connection because of the way that worldwide most extreme might be come to at various postures in the workspace, and in addition by exploring the utilization of different standards that can broaden the joining space gave by Kantorovich hypothesis. Second, enhancing calculation timings for more perplexing robots involves tuning and practicing the optimization programming IBEX, and additionally taking care of numerically the backwards Jacobian, which is as of now formally upset.

At last, the proposed structure applies when the posture and the impelled joint directions are formally traded. For this situation, for a given workspace one can watch that impelled joint directions can be made up for achieving any stance or direction. This can likewise end up being helpful in the outline procedure

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