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Static Accuracy Enhancement of Redundantly Actuated Parallel Kinematic Machine Tools

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Short summary

Redundantly actuated parallel kinematic machines are a new type of mechanism derived from classical parallel kinematic machines by adding one or more redundant links. In this dissertation, new calibration methods have been developed to improve the static positioning of such machines. These methods are based on geometrical and elasto-geometrical modeling. The latter takes into account the elements' elastic deformations due to the redundancy.

Keywords

Redundantly actuated parallel kinematic machines, static accuracy, calibration, elasto-geometrical modeling

Abstract

Redundant parallel kinematic machines are parallel mechanisms to which one or more kinematic branch is added in order to improve their mechanical properties, in particular, their stiffness. Redundant parallel kinematic machines have then more actuators than their degree of freedom.

New calibration methods are developed in this thesis in order to deal with the particularities related to the actuation redundancy. First, calibration methods using geometrical models are tested. Several measurement systems and control models are compared. A self-calibration is also carried out, where the redundant branches are switched to a passive mode. Thus, they play the role of the measurement system and the mechanism can be calibrated without the help of extra sensors.

Geometrical calibration methods, however, do not take into account the internal constraints due to the redundancy. Elastic deformations are neglected although they are shown to have an influence on the positioning accuracy after the calibration.

Modeling methods are then developed that take into account the geometry of the mechanism as well as the stiffness of its elements to improve the accuracy of the calibration. With such modeling methods, it is possible to determine the tool-center-point position for redundantly actuated parallel mechanisms from geometrical and stiffness parameters and given positions for all actuators. The modeling methods are first demonstrated on a simple mechanism. They are then tested on a real machine and used in calibration processes.

Résumé

Amélioration de la précision statique des machines-outils à cinématique parallèle redondante

Les mécanismes à cinématique parallèle redondante sont des mécanismes parallèles auxquels a été ajoutée une branche cinématique, ou plus, dans le but d'améliorer leurs propriétés mécaniques, en particulier, leur rigidité. Les mécanismes à cinématique parallèle redondante possèdent donc plus d'actionneurs que leur degré de liberté.

De nouvelles méthodes d'étalonnage sont développées dans cette thèse afin de prendre en compte les spécificités liées à la redondance d'actionnement. Les méthodes d'étalonnage utilisant des modèles géométriques sont d'abord testées. Plusieurs systèmes de mesure et plusieurs modèles de contrôle sont comparés. Un auto-étalonnage est aussi réalisé. Pour cette méthode d'étalonnage, les actionneurs redondants sont mis en mode passif et jouent le rôle de système de mesure. Le mécanisme peut être étalonné sans ajout de codeurs.

Cependant, les méthodes d'étalonnage géométriques ne prennent pas en compte les contraintes internes liées à la redondance. Les déformations élastiques sont négligées bien qu'il soit montré qu'elles ont une influence sur la précision de positionnement après étalonnage.

Des méthodes de modélisation qui prennent en compte la géométrie du mécanisme ainsi que la rigidité des éléments sont donc développées pour améliorer la précision de l'étalonnage. Avec de telles méthodes, il est possible de déterminer la position de l'outil des mécanismes à redondance d'actionnement à partir de paramètres géométriques et élastiques et de la position de tous les actionneurs. Les méthodes de modélisation sont d'abord appliquées sur un mécanisme simple. Elles sont ensuite testées sur une machine réelle et utilisées dans des processus d'étalonnage.

Zusammenfassung

Verbesserung der statischen Genauigkeit von Werkzeugmaschinen mit redundanter Parallelkinematik

Mechanismen mit redundanter Parallelkinematik sind Parallelmechanismen, denen eine oder mehrere kinematische Ketten zugefügt werden, um die mechanischen Eigenschaften, insbesondere die Steifigkeit, zu verbessern. Maschinen mit redundanter Parallelkinematik besitzen dann mehrere Antriebe als ihr Freiheitsgrad erfordern würde.

In dieser Dissertation werden neue Kalibrierungsmethoden entwickelt, um die mit der Antriebsredundanz verbundenen Besonderheiten zu betrachten. Zuerst werden Kalibrierungsmethoden basierend auf geometrischen Modellen getestet. Verschiedene Messmethoden und Messsysteme werden verglichen. Eine Selbstkalibrierung wird durchgeführt. Bei dieser Kalibrierungsmethode werden die redundanten Antriebe freigeschaltet und als Messsystem genutzt. Die Maschine kann dadurch ohne externes Messsystem kalibriert werden.

Dennoch betrachten geometrische Kalibrierungsmethode keine internen Verspannungen, die mit der Redundanz verbundenen sind. Die elastischen Verformungen werden vernachlässigt, obwohl gezeigt wird, dass sie einen Einfluss auf die Positioniergenauigkeit nach der Kalibrierung haben.

Es werden deshalb Modellierungsmethoden entwickelt, die sowohl die Geometrie des Mechanismus als auch die Elementsteifigkeit betrachten, um die Genauigkeit der Kalibrierung zu verbessern. Mit solchen Methoden ist es möglich, die Werkzeugposition redundanter Parallelkinematiken aus den Geometrie- und Steifigkeitsparametern und allen Antriebspositionen zu bestimmen. Die Modellierungsmethoden werden zuerst an einem einfachen Mechanismus angewandt. Sie werden danach an einer realen Maschine getestet und in einem Kalibrierungsprozess genutzt.

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