DEVELOPMENT OF A SENSING STRATEGY FOR AN ASSISTIVE DEVICE USING AN ISOTROPY GENERATOR

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Abstract

This paper presents a sensing strategy to detect and measure forces acting on a collaborative robot member in a way that satisfies isotropy conditions. The described sensing strategy has the advantage of allowing the simplification of the equations and minimizing sensitivity to measurement errors. This solution was designed through the use of an isotropy generator, a mathematical tool that was originally developed for the design of isotropic parallel manipulators. The main issues to be addressed are first presented, followed by the explanation of the concept of isotropy generator. Details on the development of the sensing strategy itself are finally given.

Keywords: robotics, assistive device, sensors, isotropy

DÉVELOPPEMENT D'UNE STRATÉGIE DE MESURE DES FORCES AGISSANT SUR UN ROBOT ASSISTANT BASÉE SUR UN GÉNÉRATEUR D'ISOTROPIE

Résumé

Ce document présente une configuration particulière de capteurs permettant la détection et la mesure des forces agissant sur un robot assistant tout en respectant les conditions d'isotropie. Cette configuration a ainsi l'avantage de mener à des équations simplifiées et à une sensibilité aux erreurs de mesures minimale. Cette solution a été développée à l'aide d'un générateur d'isotropie, un outil créé à l'origine pour la conception de manipulateurs parallèles isotropes. La problématique ayant menée au développement de cette solution est d'abord présentée, suivie de l'explication du concept de générateur d'isotropie. Des détails sur la configuration de capteurs ainsi obtenue sont finalement donnés.

Mots clé: robotique, robot assistant, capteurs, isotropie

1 INTRODUCTION

Since they share a common environment with humans, collaborative robots and assistive devices require safe and optimal interaction features. One could desire to physically guide the robot by direct contact on its members for example. This involves the use of sensors and more intuitive human/robot interfaces than usual joysticks or keypads. Different solutions to this problem already exist in the literature, e.g., 6-DOF force/torque sensors mounted at robot joints or a tactile skin mounted on the surface of the robot members. However, it may be relevant to develop a sensing strategy that would satisfy the isotropy conditions, in order to minimize measurement errors and simplify the related equations. For the solution presented in this paper, this has been achieved through the use of an isotropy generator [1], which consists of six straight lines represented by six unit screws satisfying the isotropy conditions.

2 GENERAL PROBLEM

In order to allow guidance of the assisitive device through direct physical contact and to detect collisions, there is a need to measure the resultant force and torque acting on the member, in magnitude and in direction. The developed sensing strategy must be resistant to possible collisions and show good precision in force measurement. These requirements led to the development of a solution consisting of an assembly of six tension/compression load cells inserted between the robot member and a protective shell, placed in a way that allows the measurement of all desired forces and torques. In order to minimize sensitivity in forces measurement errors and to facilitate the treatment of the related equations, particular attention has been given to the sensor localization in order to respect isotropy conditions.

3 ISOTROPY GENERATOR

Tsai and Huang [1] developed a method of designing isotropic 6-DOF manipulators using an isotropy generator, which consists of six unit vectors derived from the system of nonlinear equations that can be developed from the isotropy conditions. An isotropy generator can be easily obtained by assigning a value to each of the three free parameters of the algebraic solutions they have developed. Since these parameters will influence both the dimension and shape of the created generator, many different generators can be obtained from these equations, which makes this method quite interesting for the studied case.

Figure 1 shows two examples of isotropy generators that can be obtained with this method. The six unit screws are represented by vectors $\mathbf{e}_i$, whose position about the reference point O is determined by corresponding perpendicular vector $\mathbf{r}_i$. These vectors could be compared to six force vector and their respective moment arm about the reference frame. Length $\|\mathbf{r}_i\|$, which directly influences the size of the generator, is actually one of the three chosen parameters, and must remain constant for all six offset vectors in order to satisfy the isotropy conditions. A Jacobian matrix associated with each isotropy generator can be obtained from the algebraic solutions developed by Tsai and Huang [1], where variables x_i, y_i, z_i and u_{ij} are functions of the three chosen parameters.

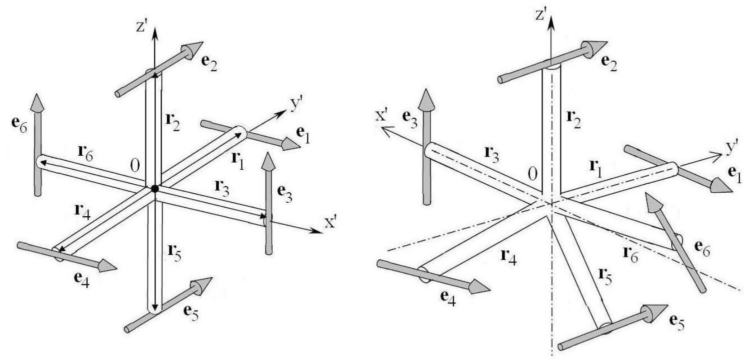

Figure 1: Examples of isotropy generators.

For the first generator shown in Fig. 1, we obtain the following Jacobian:

$$\mathbf{J} = \begin{bmatrix} 1 & 0 & 0 & u_{41} & u_{51} & u_{61} \\ 0 & 1 & 0 & u_{42} & u_{52} & u_{62} \\ 0 & 0 & 1 & u_{43} & u_{53} & u_{63} \\ 0 & x_2 & x_3 & x_4 & x_5 & x_6 \\ x_1 & 0 & y_3 & y_4 & y_5 & y_6 \\ y_1 & y_2 & 0 & z_4 & z_5 & z_6 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & r & 0 & 0 & -r & 0 \\ 0 & 0 & r & 0 & 0 & -r \\ r & 0 & 0 & -r & 0 & 0 \end{bmatrix} \tag{1}$$

The isotropy generator method can be used to find an isotropic configuration for the Gough-Stewart platform by intersecting the six straight lines with lower and upper surfaces of the platform in order to get its six prismatic actuators aligned with these lines, as shown in Fig. 2.

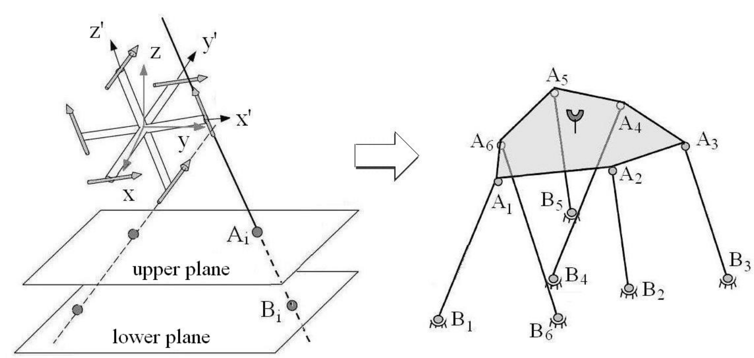

Figure 2: Design of an isotropic Gaugh-Stewart platform.

4 Application to Sensing

By placing the load cells in order to get their axis aligned with vectors $\mathbf{e}_i$, an isotropic sensor configuration could therefore be obtained. The simplest way to do so is to select an isotropy generator with orthogonal vectors $\mathbf{e}_i$ and $\mathbf{r}_i$, which would allow easy measurement of forces and torques along x, y and z axes, and to locate it inside the robot member in order to get both surfaces intersected, as shown in Fig. 3. Six tension/compression load cells can then be inserted between the robot member and the shell, their axis being aligned with vectors $\mathbf{e}_i$. By attaching the cells to the surfaces with spherical joints, force measurement becomes constrained to those acting along the sensor axis, without any torque transmitted. As it can be seen in Fig. 3, at least two forces

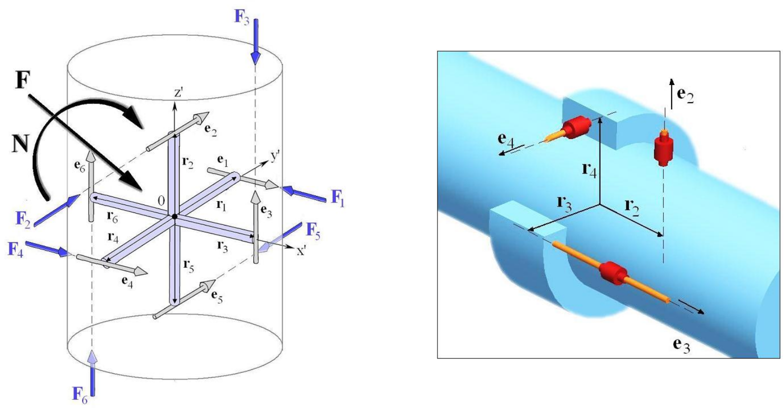

Figure 3: Location of sensors on the robot member based on an isotropy generator.

remain unaligned about each axis of the reference frame, which would allow a good measurement of both resultant force and torque acting on the robot member. Nevertheless, the configuration is also constrained by the length of vectors $\mathbf{r}_i$, which must remain constant as previoulsy mentioned. The distance $r = \|\mathbf{r}_i\|$ must be chosen in order to allow enough space for the load cells, that is $R_{robot} < r < R_{shell}$ with the assumption of a cylindrical robot member.

From the knowledge of the position of the sensors and the magnitude of the measured forces $\mathbf{F}_s$, the resultant torque $\mathbf{N}$ and resultant force $\mathbf{F}$ can be calculated :

$$\mathbf{W} = \begin{bmatrix} \mathbf{N} \\ \mathbf{F} \end{bmatrix} = \begin{bmatrix} rF_2 + rF_5 \\ rF_3 + rF_6 \\ rF_1 + rF_4 \\ F_4 - F_1 \\ F_5 - F_2 \\ F_6 - F_3 \end{bmatrix} = \mathbf{J}_s \mathbf{F}_s \tag{2}$$

Where a compression would result in a positive measured force and tension in a negative measured force. The Jacobian $\mathbf{J}_s$ of the system of equations is the following:

$$\mathbf{J}_s = \frac{\partial \mathbf{W}}{\partial \mathbf{F}_s} = \begin{bmatrix} 0 & r & 0 & 0 & r & 0 \\ 0 & 0 & r & 0 & 0 & r \\ r & 0 & 0 & r & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & 0 \\ 0 & -1 & 0 & 0 & 1 & 0 \\ 0 & 0 & -1 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

We recognize here the same Jacobian matrix as the one obtained in eq. (1), with vectors $\mathbf{N}$ and $\mathbf{F}$ inverted and with opposite signs due to direction inversion of forces along vectors $\mathbf{e}_1$ to $\mathbf{e}_3$ in order to get a positive force in the case of a compression. The same Jacobian could actually be derived from the 6R serial manipulator Jacobian form, which is:

$$\mathbf{J}_s = \begin{bmatrix} \mathbf{e}_1 \times \mathbf{r}_1 & \mathbf{e}_2 \times \mathbf{r}_2 & ... & \mathbf{e}_6 \times \mathbf{r}_6 \\ \mathbf{e}_1 & \mathbf{e}_2 & ... & \mathbf{e}_6 \end{bmatrix} \quad (4)$$

It appears clearly that the obtained system of equations is simple, each equation involving only two forces. The Jacobian matrix also satisfies spatial isotropy conditions as proposed by Klein and Miklos [2], since both the bump submatrix $\mathbf{J}_p$ (first three rows of matrix $\mathbf{J}_s$) and the twist submatrix $\mathbf{J}_o$ (last three rows) are isotropic, and $\mathbf{J}_p\mathbf{J}_o^T = \mathbf{0}$. A known condition for isotropy for manipulators is in fact that the singular values of its Jacobian are all identical, which requires matrix $\mathbf{J}\mathbf{J}^T$ to be a diagonal matrix with equal elements, which is clearly the case here and is readily verified from eq. (1). The corresponding Jacobian matrix being isotropic, the resulting sensor configuration would therefore satisfy the isoptropy condition, allowing the simplification of the equations and minimal sensitivity to force measurement errors.

REFERENCES

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