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Multibody Mechatronic Systems

Proceedings of the MUSME Conference held in Huatulco, Mexico, October 21–24, 2014

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Preface

The MUSME 2014, IFToMM-FeIbIM–International Symposium on Multibody Systems and Mechatronics is the fifth event of a series that was started in 2002 as a conference activity mainly for promoting these topics in South American community. The first event was held at Universidad Panamericana de la Ciudad de México, Mexico in May 2002, the second was held at Federal University of Uberlandia, Brazil in March 2005, the third was hosted at Universidad Nacional de San Juan, Argentina, in April 2008, and the fourth was celebrated at Universidad Politecnica deValencia, Spain, in October 2011. This year the MUSME event has come to SUNEO (Sistema de Universidades Estatales de Oaxaca) at UMAR Campus Huatulco, Oaxaca, under the auspices of Instituto Politecnico Nacional (IPN) and Universidad Autonoma de Queretaro, Mexico.

The MUSME aim was decided at the funding meeting in 2002 as: a conference stimulating integration between Mechatronics and Multibody Systems Dynamics disciplines; a forum for facilitating contacts among research people and students; and a match conference for communities from IFToMM (International Federation for the Promotion of Mechanism and Machine Science) and FeIbIM (Federación Iberoamericana de Ingeniería Mecánica). In addition, since the beginning it has been considered preferable to have the MUSME Symposium in a location within South America, but without neglecting the possibility to bring MUSME in other parts of the world, since it is supported both by IFToMM and FeIbIM.

The aim of the MUSME Symposium is to bring together researchers, industry professionals, and students from a broad ranges of disciplines referring to Mechatronics and Multibody Systems, in an intimate, collegial, and stimulating environment. Again, in the 2014 MUSME event we received a significant attention to the initiative, as can be seen by the fact that this Proceedings volume contains contributions by authors from all over the world.

The Proceedings volume of the MUSME Symposium is published within the Springer series on MMS (Mechanism and Machine Science) and contains 53 papers that have been selected from 63 submitted papers after peer review for oral presentation. The accepted papers cover several aspects of the wide field of Multibody Systems and Mechatronics. Special attention has been given to organizing student sessions with good works from young researchers, who are still in the formation process.

This is the first time that the Proceedings is published by Springer whereas the previous proceedings were published as CD proceedings that nevertheless are available at the hosting institutions.

We would like to express grateful thanks to the members of the International Scientific Committee for MUSME Symposium for cooperating enthusiastically for the success of the MUSME 2014 event:

Prof. Marco Ceccarelli (Chair), Italy
Prof. Mario Acevedo, Mexico
Prof. Jorge A.C. Ambrósio, Portugal
Prof. Alberto Cardona, Argentina
Prof. Osvaldo H. Penisi, Argentina
Prof. João Carlos M. Carvalho, Brazil
Prof. Javier Cuadrado, Spain
Mario Fernandez Fernandez, Chile
Prof. Manfred Husty, Austria
Prof. Tatu Leinonen, Finland
Prof. Vicente Mata, Spain
Prof. Carlos Munares, Perù
Prof. Pietro Fanghella, Italy

We thank the authors who have contributed with interesting papers in several subjects, covering many fields of Multibody Systems and Mechatronics and, additionally, for their cooperation in revising papers in a short time in agreement with the reviewers' comments. We are grateful to the reviewers for the time and effort they spent in evaluating the papers with a very tight schedule that has permitted the publication of this Proceedings volume in time for the symposium event.

We thank Rector Modesto Seara Vazquez for accepting to host the MUSME 2014 event at SUNEO. We thank our colleagues for their help at the LARM Laboratory of Robotics and Mechatronics of University of Cassino and at the ESIME Ticoman del Instituto Politecnico Nacional. We thank the Director of ESIME Ticoman, Javier Roch Soto. We thank COFAA-IPN for its economic support for some activities of the MUSME event.

We also thank the auspices of IFToMM (International Federation for the Promotion of Mechanism and Machine Science) and FeIbIM (Federación Iberoamericana de Ingenieria Mecánica).

We thank the publisher and Editorial staff of Springer for accepting and helping the publication of this Proceedings volume, since the early step in 2012.

We are grateful to our families since without their patience and comprehension it would not have been possible for us to organize MUSME 2014, IFToMM-FeIbIM–International Symposium on Multibody Systems and Mechatronics and this Proceedings volume.

June 2014

Marco Ceccarelli
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Contents

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Kinematic and Workspace-Based Synthesis of a 2-DOF Mechanism for Haptic Applications

R. Roberts and E. Rodriguez-Leal

Abstract This paper presents the development of a mechanism aimed to haptic applications. The basic design proposed in this work is intended to interact with a finger without the use of a fixture attached to the body. This work investigates the theoretical workspace of a human index finger and proposes a two degree-of-freedom 7-bar linkage mechanism that is synthesized based on such workspace. The paper determines the closed-form solutions to the forward and inverse position, and presents a prototype that is built and tested as a proof of concept of the novel device. The workspace of the constructed mechanism is compared with theoretical models in order to assess their similarity and the viability of accelerometers as position sensing instruments is also tested.

Keywords Haptics · Workspace analysis · Kinematics · Human–machine interaction · Prototype

1 Introduction

The enhancement of the user-experience in virtual environments has been a highly studied topic in recent years [1, 2]. Audiovisual devices are capable to provide engaging interactive experiences to users, and can be classified as one-way or two-way communication systems, e.g. watching TV or playing videogames respectively. One of the most challenging issues in two-way communications is the saturation of the communication channels that result in the loss of information. To overcome this issue, a haptic device could be used as an alternative communication channel. For several decades, haptic devices have been commercially available for

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different applications, e.g. using vibrotactile actuators in cell phones and pagers [3], or guiding tools that are designed to help soldiers to navigate in battlefields [4]. Moreover, the gaming industry is a niche for haptic devices, enhancing the multimedia experiences of players and providing a new sense of realism [5]. Furthermore, force feedback haptic devices have received a special interest from the medical community including applications such as palpation, needle insertion, laparoscopy, endoscopy, endovascular procedures or arthroscopy [6].

Several of the commercial single-point force feedback devices are designed to be manipulated using an entire hand, displaying three translational degrees-of-freedom (DOF), and can be provided with three additional rotational DOF [6, 7]. Some of the benefits of this type of devices include a workspace in which comfortable movement is allowed, and a mechanism design that is low weight while is capable to provide reliable force feedback. Some of the drawbacks that are encountered in single-point force feedback devices include accuracy limitations in multiple-object simulation, which is essential for object recognition in haptics [8, 9].

This paper describes the development and synthesis of the novel haptic device and is organized as follows: Sect. 2 presents a description of the desired characteristics and features of this mechanism. Section 3 performs a thorough mathematical analysis of the mechanism. A practical approach for conducting the synthesis of the mechanism is discussed in Sect. 4, where the workspace of a human finger is used to determine the dimensional parameters of the mechanism. Section 5 discusses the prototype and validates the theoretical workspace with experimental data. Finally, the paper presents conclusions and suggestions for further work.

2 Mechanism Description

The new haptic mechanism proposed in this paper considers the following features: (i) compact size suitable for finger movement, (ii) non-collapsibility, (iii) low mechanical impedance. A compact apparatus is desirable since a long term goal of this project is to build a multi-point haptic device. Hence, it is important to reproduce this mechanism five times within the workspace of a hand. A non-collapsible mechanism eliminates the inclusion of components that force contact with the finger. This feature is required in cases in which movement flexibility is desired. Finally, reducing inertia and friction in the device is desired to achieve a realistic haptic experience.

Figure 1a shows the proposed seven-link and six-joint mechanism, which can be thought as two four-bar mechanisms that share a common bar. The base is connected to link 2 with links 1 and 3 with the use of joints, while the platform is connected to link 2, with links 4 and 5. Note that all the axes of the joints are parallel to each other and to the Z axis. Consider that links 1, 3, 4 and 5 have a length l while link 2, the base and the platform have a length that is equal for the three elements, although the particular value of this parameter is irrelevant as the following equations will show. The abovementioned dimensional considerations

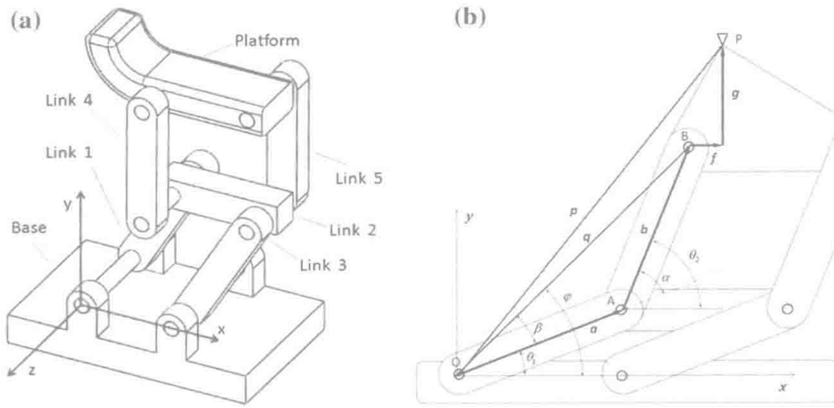

Fig. 1 **a** CAD model and **b** vector representation of the seven bar linkage

guarantee that the mechanisms comply with the Grashof condition [10]; they also assure that the base, platform, and link 2 remain parallel for all positions of the mechanism. Note that the joint connecting links 2 and 5 is active, meaning that a motor applies torque to this kinematic pair; this is also the case for the joint connecting the base and link 1. The following section includes the kinematics analysis that determines the closed-form solutions to the position, velocity and acceleration of the seven-bar mechanism.

3 Mechanism Kinematics

The forward *kinematics* consists in determining the position vector p of an arbitrary point P of the platform. See Fig. 1b for a vector representation of the mechanism. Note that for analysis convenience, all vectors lie on the XY plane and is possible to determine p as follows:

$$\boldsymbol{p} = [\,lc\theta_1 + lc\theta_2 + f, \quad ls\theta_1 + ls\theta_2 + g\,]^T \tag{1}$$

where f and g are the magnitudes of vectors f and g. θ_1 and θ_2 denote the angular position of the active joints connected to links 1, and 4, respectively. Note that links 1 and 3 are parallel, the same is true for links 4 and 5.

The *inverse kinematics* consists in finding the magnitude of the angular positions of the active joints for a given position of the platform. Consider from Fig. 1 that vector q describes the position of point B and can be expressed as:

$$\boldsymbol{q} = [\,lc\theta_1 + lc\theta_2, \quad ls\theta_1 + ls\theta_2\,]^T \tag{2}$$

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