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AN EXPERIMENTAL SYSTEM FOR MEASURING ROBOT PATH

Anezio Alves de Oliveira Júnior
e-mail: anezio_junior@yahoo.com.br

Rodrigo Câmara Werlang
e-mail: rwerlang@mecanica.ufu.br

Clinton Haisen Hatayama

João Carlos Mendes Carvalho
e-mail: jcmendes@mecanica.ufu.br
Universidade Federal de Uberlândia, Faculdade de Engenharia Mecânica
38400-902 Uberlândia – MG

Abstract. *In the last decade parallel robotic structures have addressed great attention from both theoretical and practical viewpoint. Several prototypes have been conceived and built together with the development of theoretical investigations on kinematics and dynamics. The interesting for this architecture are the characteristics of the parallel structures such as high stiffness and load capacity and, moreover they are highly accurate due to non-cumulative joint errors. Based on capabilities of parallel structures we propose an electro-mechanical system to verify a spatial robot path, named as Kinematic Calibrator. The system is based on Stewart Platform. In particular we propose a system to determine the end-effector position and orientation, with respect to the base, of a spatial manipulator by using the forward kinematic model of the kinematic calibrator. This is possible by substituting the Stewart Platform legs by micro cables with linear transducers. The Kinematic Calibrator is described and initial experiments are reported to prove the feasibility of such system as a measuring system of robot path.*

Keywords: *Kinematic calibration, Stewart platform, Parallel robot, Robotics.*

1. INTRODUCTION

In the last decade parallel robotic structures have addressed great attention from both theoretical and practical viewpoint. Several prototypes have been conceived and built together with the development of theoretical investigations on kinematics and dynamics.

Parallel architectures are articulated mechanisms having one or more closed loops. They are composed basically by a fixed base and a mobile platform connected by “legs”. On the mobile platform one can fix tools, cabines, etc. In many types of parallel structures the actuators can be installed on the base turning them lighter. The interesting for this architecture is due to parallel structures present characteristics such as high stiffness and load capacity and, moreover they are highly accurate due to non-cumulative joint errors.

Many parallel architectures have been proposed and studied as those presented by Stewart (1965), Clavel (1988), Pierrot et al. (1991), Merlet e Gosselin (1991), Jacquet et al. (1992), Romiti e Sorli (1992), Byun e Cho (1997) e Lallemand et al. (1997). The attention are focused to a number of possible industrial applications such as manipulation, packing, assembly and disassembly processes, motion simulation, milling machines, toys and sensors.

Based on capabilities of parallel structures we propose an electro-mechanical system to verify a spatial robot path, both position and orientation of its end-effector, named as Kinematic Calibrator. The system is based on 3-3 Stewart Platform.

In this paper we present the experimental system that uses 3-3 Stewart Platform as a Kinematic Calibrator to verify the path described by spatial manipulators.

In particular we propose a system to determine the end-effector position and orientation, with respect to the base, of a spatial manipulator by using its kinematic model and the leg length of the kinematic calibrator. This is possible by substituting the 3-3 Stewart Platform legs by micro cables with linear transducers. The Kinematic Calibrator is described and initial experiments are reported to prove the feasibility of such system as a measuring system of robot path.

2. STEWART PLATFORM

A Stewart Platform, also named as Stewart-Gough Platform, is a fully parallel non-redundant architecture with six degrees of freedom that consists of six variable-length legs connected at one end to a fixed base by universal-joints and at the end to a mobile platform by ball-joints (Stewart, 1965). The Stewart Platform can be classified as *m-n type* where *m* represents the number of articulated points on the base and *n* those of the mobile plate. Then, there are the symmetric types: 6-6 type, 6-3 type and 3-3 type and the non-symmetric types: 4-4 type, 6-5 type, 6-4 type, 5-5 type and 5-4 type. A spherical Stewart Platform was proposed by Wohlhart (1994).

Stewart Platform presents the same characteristics of other parallel architectures. As a result of its characteristics the Stewart Platform is one of the most studied parallel structures, being used as flight simulators, manipulators, wrists, milling machines, load cells and toys.

Figure 1 presents the type 3-3 Stewart Platform used to develop the Kinematic Calibrator proposed in this paper. It can be observed the mobile plate and the base composed by equilateral triangular plates and the six prismatic legs. Each two legs are connected at one vertex of the triangles.

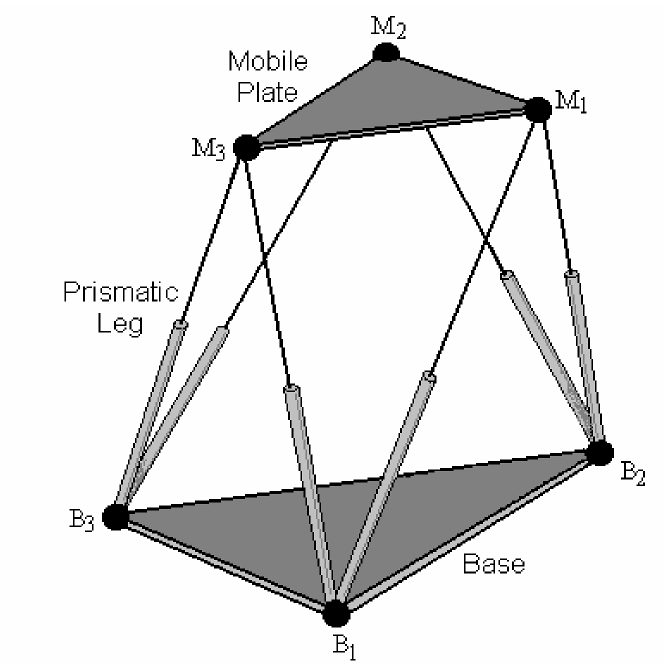

Figure 1. Scheme of 3-3 Stewart Platform

The forward kinematic model analysis has the aim of finding the position and orientation of the mobile plate, related to a reference frame fixed on the base, when the leg lengths are known. Many studies have been made and published with this model like those proposed by Nanua, Waldron and Murthy (1990), Innocenti and Parenti-Castelli (1990), Dasgupta and Mruthyunjaya (1994), Husty (1996) and Lee and Shim (2001).

The forward kinematic model used in this paper was described by Griffis and Duffy (1989) and Sousa (1997). In this method a spherical articulated mechanism is associated to each vertex of the base. Analytical methods can provide all configurations in a closed form. Solving the system we have sixteen solutions for the location of mobile plate (position and orientation) for a input set of leg length. These solutions can be real, complex, repeated or out of the workspace of the structure. A methodology is proposed to find a unique solution as described on item 4.

3. KINEMATIC CALIBRATOR BASED ON STEWART PLATFORM

The Kinematic Calibrator for robot path is a system based on 3-3 Stewart Platform which its six SPS segments are substituted by steel micro cables connected to linear transducers. The mobile plate of the Stewart Platform is attached on the end effector of the robot. By imposing a movement for the robot, the lengths of SPS segments (micro cables) vary. These lengths variations are measured by the six linear transducers, which are used as input of the Stewart Platform kinematic model to obtain the position and orientation of Kinematic Calibrator mobile plate. Then, refering to the same inertial reference frame, it can be compared both trajectories: the commanded trajectory of the robot and the obtained trajectory by Kinematic Calibrator. A scheme of the system is presented in Fig. 2.

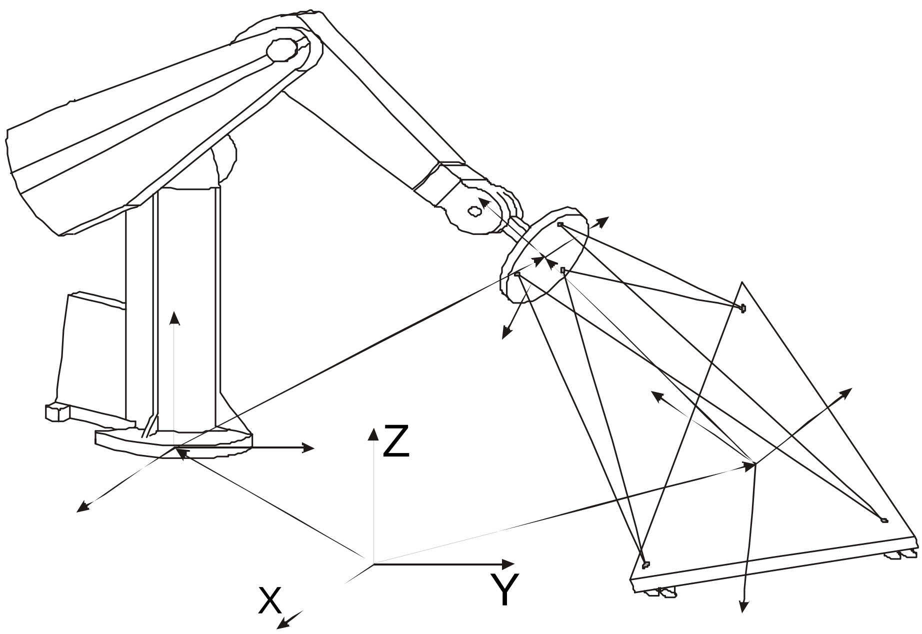

Figure 2. Schematic structure and use of Kinematic Calibrator for robot path

Figure 3 presents a complete scheme of the Kinematic Calibrator system. It can be identify in this figure the six linear transducers corresponding to each leg. The leg length variation produces a changing in the voltage V_i (i=1 a 6). These voltage are acquired by using an AD/DA Acquisition Card (PD2-MFS-8-500M/14 – UEI) which is converted in equivalent leg length r_i (i=1 a 6). Then, these leg lengths are used as input of the forward kinematic model of Stewart Platform to obtain the center position of mobile platform given by coordinates X, Y and Z and its orientation given by rotations θ_X, θ_Y e θ_Z around the X, Y e Z axis respectively. Finally the controlled trajectory of the robot, both position and orientation, can be plotted to analyze them.

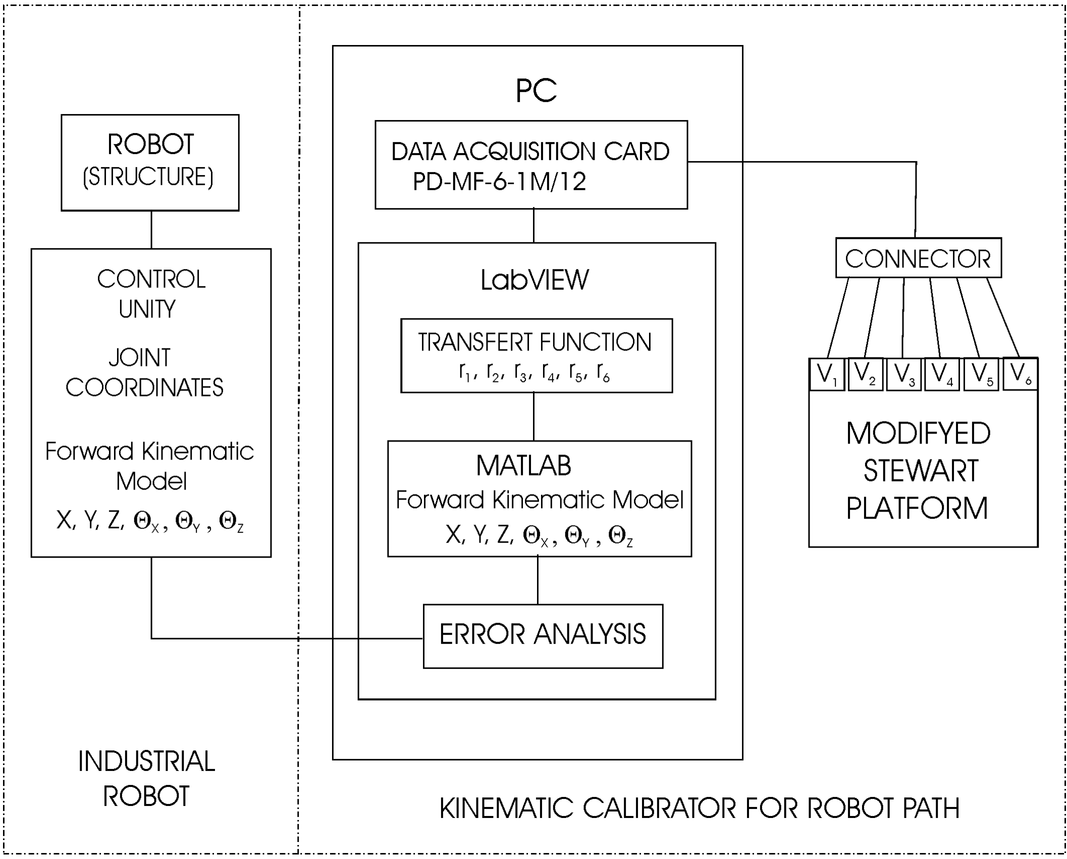

Figure 3. The experimental scheme for Kinematic Calibrator for robot path

4. AN EXPERIMENTAL SYSTEM FOR KINEMATIC CALIBRATOR

An experimental system has been designed and settled up at the Laboratory of Automation and Robotics in Uberlândia with the basic idea by using commercial components. Thus, we noticed the advantage of using virtual instruments with LabVIEW - **Lab**oratory **V**irtual **I**nstrument **E**ngineering **W**orkbench software (National Instruments, 1998) with an acquisition card (United Electronics Industries, 1998). By using a PC and virtual instruments we have a graphic man-machine interface that facilitates the tasks for programming, acquiring, modulation, recording and management of acquired data.

The structure of Kinematic Calibrator is composed by an equilateral triangular base, whose sides can be adjusted from 350mm to 2050mm; six linear transducers fixed, two by two, on each vertex of the base, an equilateral triangular mobile plate with side of 115mm, and the six legs composed by steel micro cable. A barrel composes the linear transducers, where the micro cables can roll on and/or roll out, coupled with a high resolution potentiometer. The distance between the base and mobile plate can be adjusted from 200mm to 1000mm. The micro cables are kept stressed by a spring inner the linear transducer. One can be use different sides for the mobile plate by changing it. With these dimensions the constructed Kinematic Calibrator can be used for most industrial robots.

Figure 4 presents the structure of Kinematic Calibrator and Fig. 5 one vertex with two linear transducers where can be seem the B_i point of the base, Fig. 1.

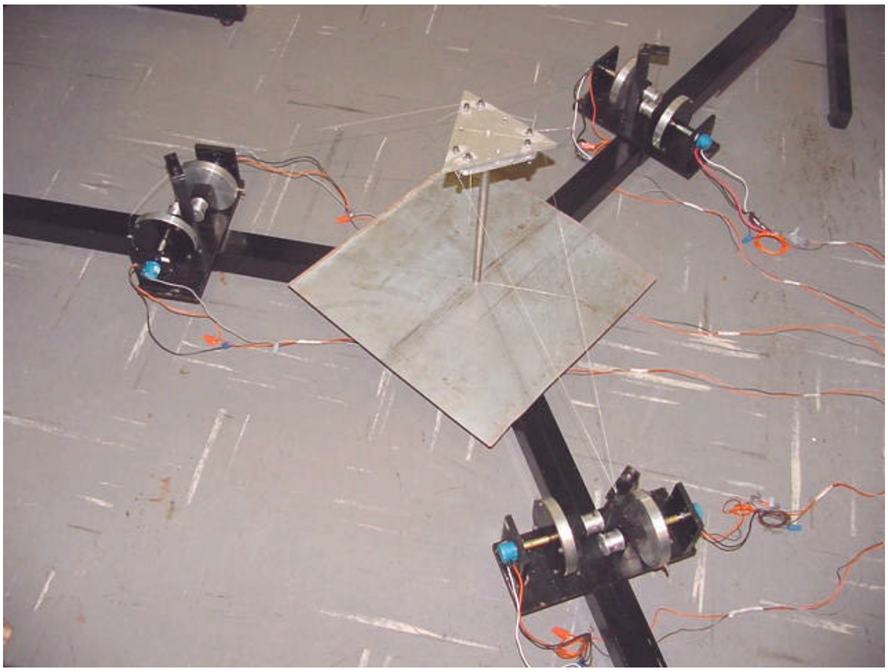

Figure 4. Kinematic Calibrator prototype

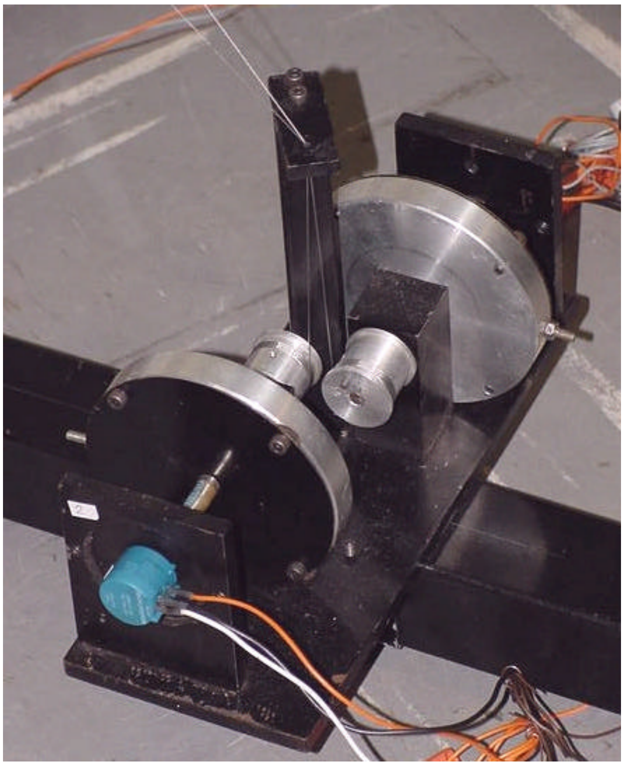

Figure 5. Linear transducers on a vertex of the base of Kinematic Calibrator

Figure 6 presents a layout of virtual instruments in LabVIEW frame for Kinematic Calibrator tests. The virtual instruments are composed by sensors and suitable boxes, which perform several tasks for acquisition, modulation and recording measures. The waves of data are acquired at each channel in a specific scan rate and acquisition time by an “AI Multi PT” box. The Butterworth Filter box is a suitable filter used to reduce noise in the signals. The triangle boxes are used to convert the potentiometer signal (measured in V) into the leg length (given in m).

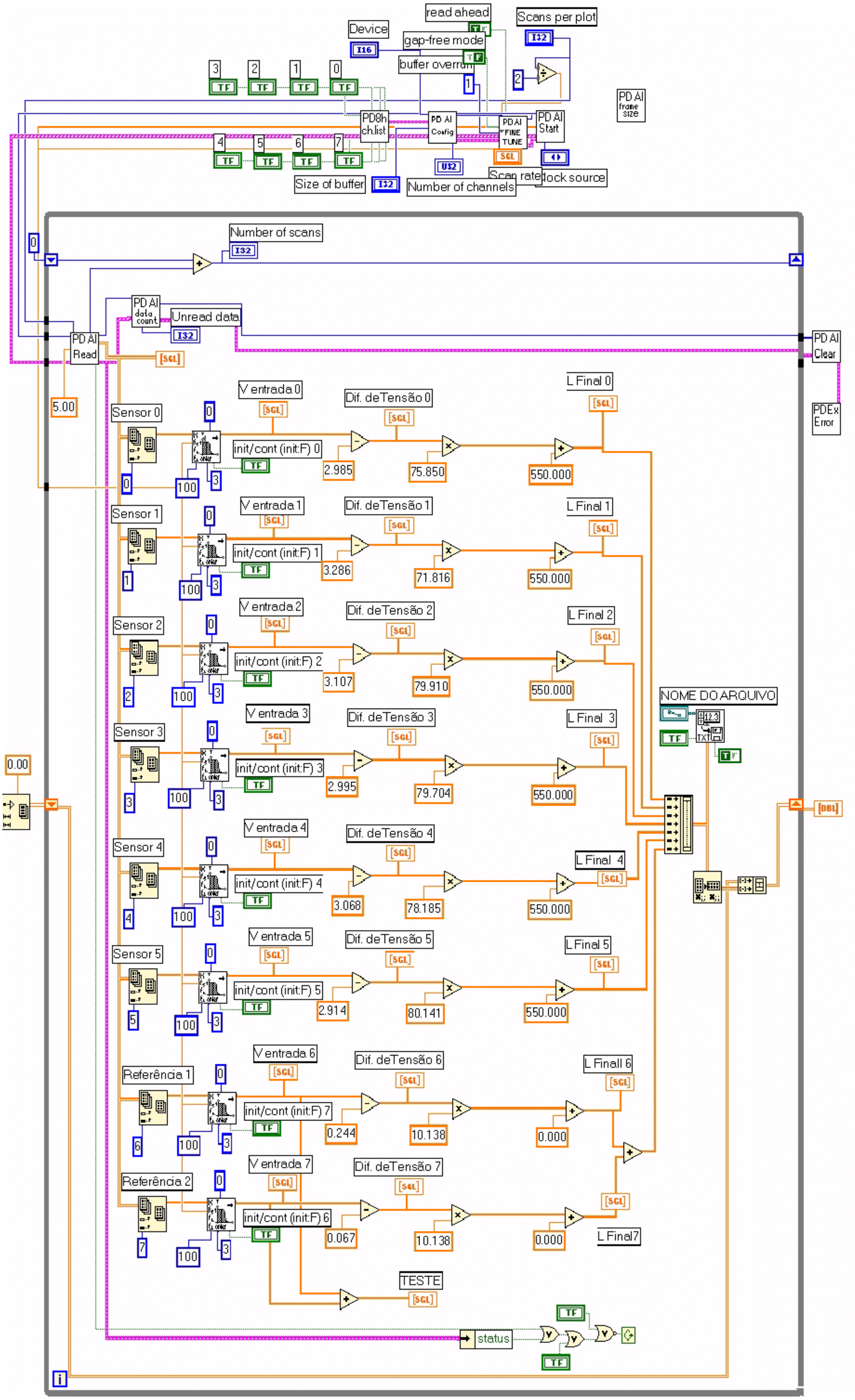

Figure 6. Lay-out of virtual instruments in LabVIEW frame for Kinematic Calibrator

The forward kinematic model of 3-3 Stewart Platform gives sixteen solutions for a leg length set input data. Among these results we can obtain complex and real coordinates, repeated results and results out of the structure workspace. To prevent this problem and find a unique solution, we have proposed a systematic approach: the mobile platform starts its movement from an initial position which all legs have the same length, i.e. X=0, Y=0, Z=H, $\theta_X=0$, $\theta_Y=0$ and $\theta_Z=0$; the position of the platform center must be above the base (coordinate z is positive); the complex results are eliminated (they do not have practical meaning); the order of the mobile platform vertex (points M_1, M_2, M_3, M_1), defined in a counterclockwise, must be unchanged in the projection view of the mobile plate on the base plane. If that order changes it means that the mechanism has passed through a singular point – the movable platform was turned. As each new position is closed to initial point (the acquisition rate is 15001samples/sec for 8 channels), the forward kinematic model considers as solution the position that is more closed with the initial position. At each iteration, the new calculated position is saved as the initial position.

5. EXPERIMENTAL RESULTS

To verify the validity of the proposed system, the initial tests have been made with the mobile platform describing a vertical linear displacement.

The displacements have been measured using a linear transducer attached at the center of the mobile plate. Several tests have been made and examples of results are presented in Figs. 7 and 8. Figures show the historic behavior in time of both measured and numeric displacements.

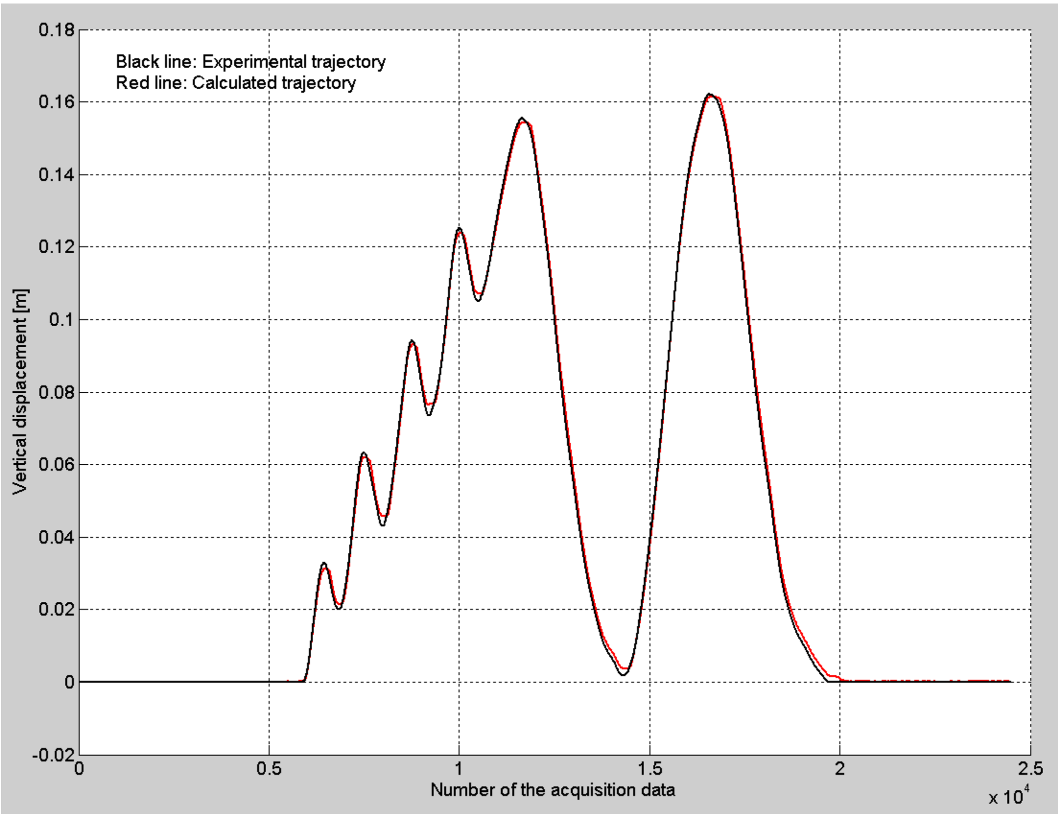

Figure 7. Example one - An experimental validation of Kinematic Calibrator by using the prototype during a vertical motion of the mobile plate.

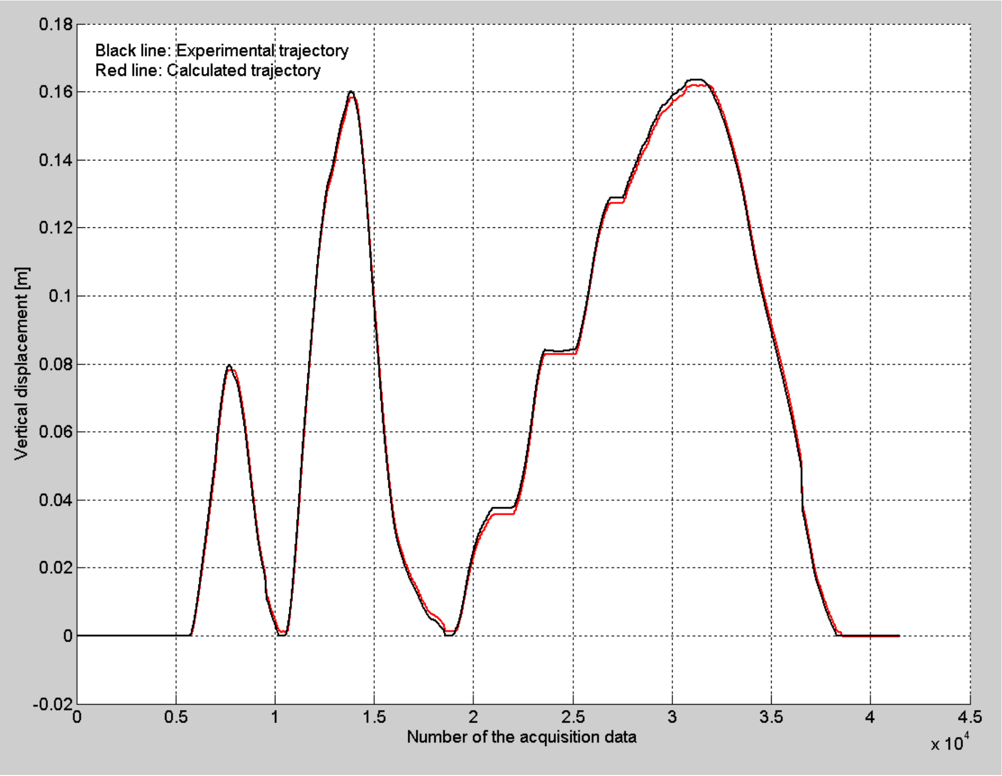

Figure 8. Example two - An experimental validation of Kinematic Calibrator by using the prototype during a vertical motion of the mobile plate.

These first experiments with a vertical linear transducer have given a first experimental validation of the Kinematic Calibrator since they have shown that the kinematic calibrator mobile platform can be moved easily with suitable precise path verifying the robot path.

Experimental activities are still undergoing at the Laboratory of Automation and Robotics in Uberlândia to obtain results for practical applications by using an industrial robot and to verify the origin of the errors at the top and at the lower points of the trajectory. One of the reasons for the differences that can be visualized in Fig. 7 and 8 can be due to flexibility of the experimental apparatus used to accomplish the vertical movement.

6. CONCLUSIONS

In this paper we have presented a suitable experimental system named as Kinematic Calibrator, for verify robot path, based on Stewart Platform.

First experimental tests show the practical feasibility of the proposed system. Further experimental activity is scheduled by using an industrial robot to evaluate experimentally the Kinematic Calibrator for robot path.

Analysis of the forward kinematic model are necessary to apply it for measuring robot path in a real time.

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