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Small Scale Mechatronics Devices as Educational and Research Engineering Tools

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Abstract: This paper presents several mechatronics equipments of low cost and small scale, employing components and technology applied to model building. All systems were developed and built by students with different levels of knowledge in Pontifical Catholic University of Rio de Janeiro to aid the teaching, learning and research in Engineering, particularly on the Control and Automation, Mechanical and Mechatronics fields.

Keywords: Teaching, Control Engineering, Embedded systems, Education Laboratory, Educational Aids

1. INTRODUCTION

The Control and Automation, Mechanical and Mechatronics Engineering arouse interest of a large number of students; one of its most interesting application is vehicles in general – aerial, ground and marine –, an interdisciplinary field in which theoretical and practical knowledge of modelling, simulation and control of dynamic systems are needed.

In order to further motivate the students and attract potential candidates to this area, the Mechatronic System Development Laboratory (*LDSM*, in portuguese) was created, a multidisciplinary environment where a series of equipment and components of ground vehicles are available for testing, evaluation and experiments. Every scale system and its components is properly instrumented; control techniques and electronic monitoring devices, such as transducers, microprocessors and computers, are widely used, all of which with technology marketed to model building.

The *LDSM* activities are geared exclusively to the academic field, being developed by undergraduate and graduate students as research or monograph topics. The devices are used in presentations and demonstrative classes for high school students, freshmen of the aforementioned engineering fields and undergraduates in more advanced disciplines related to the area. In the future, those projects will be remotely operated by students from other educational institutions.

2. MECHATRONIC SYSTEM DEVELOPMENT LABORATORY

The Mechatronic System Development Laboratory was created in 2007 with financial support from *FAPERJ* (Foundation for Research of Rio de Janeiro). The laboratory consists of a number of commonly used equipments in actual vehicles like dynamometers, motion simulators, scales for measuring the distribution of weight and moments of inertia, besides other daily mechatronics systems such as an automatic traction elevator and railroad, all on a small scale and using the same basic concepts and devices of its real equivalent systems. The main advantage of this kind of operation is, in addition to requiring small footprint, a relatively low cost, since most of its components can be found in the accessible model building market.

Every project in the *LDSM* was designed and built at Pontifical University Catholic of Rio de Janeiro, with the aid of a prototype development workshop, also implemented with funds provided by *FAPERJ,* which contains a three axis CNC milling machine, a 3D printer and a laser cutting machine, all exclusively to undergraduates and graduates involved with projects linked to the research group.

The main intention behind *LDSM*'s creation was to disclose for high school students and freshmen engineers what projects can be done in Mechanics, Control and Automation and Mechatronics Engineering, as this type of equipment and technology has appeal to young people. The laboratory has been a great advertisement for the mentioned courses.

All apparatuses, described in the following chapter, have been developed by students at different knowledge levels, from second year undergraduates to bachelor's thesis, master's theses and even doctoral dissertations. The main goal of this project is to help students practice the theoretical knowledge acquired in classroom by developing systems that will improve the training of future engineers.

3. PROJECTS

The *LDSM* is directly linked to scientific research and the development of knowledge and technology in System Dynamics. So far, three doctoral dissertations, several masters and bachelor's theses and numerous undergraduate research projects have been conducted on the laboratory. They are all aimed at the design, simulation, construction, testing and validation of the following apparatuses, presented in chronological order.

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3.1 Vertical motion simulator with three degrees of freedom

The equipment designed during a master's thesis by Llerena (2000) and shown on Figure 1, reproduces the vertical dynamics of a ground vehicle's under suspension, that is, the bounce, pitch and roll movements. At the time, this apparatus did not exist in the market and was considered a technological innovation.

The work consisted of a computational simulation of the project, in order to define its components and characteristic parameters; a study on the similarity of the dynamic scale models and their real equivalents, as to establish the relationship between the small scale and actual vehicle subjected to similar inputs; and fuzzy logic to control the highly nonlinear pneumatic actuation system.

When *LDSM* was implemented, undergraduate students built the simulator using an open loop actuation system, which reproduced, with restrictions, the typical base inputs suffered by tires in contact with the ground. Currently, this pioneering apparatus is disabled due to new equipment, which replaced it with great advantages, as the next sub item describes.

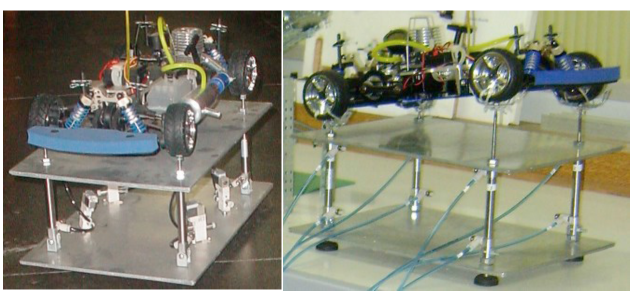

Figure 1. Vertical motion simulator with three degrees of freedom

3.2 Stewart Platform motion simulator with six degrees of freedom

The Stewart platform is a known closed kinetic chain mechanism. Vianna (2002) virtually simulated the device, shown in Figure 2; in 2008, Albuquerque designed and built a first version as a research topic and, in the following year the machine was redesigned to its current form. As a master's thesis object of study (Albuquerque, 2012), the system was modelled, analysed and improved. This work obtained the semi-analytical equations of the platform, using power flow concepts and bond graphs. The study also evaluated its movement's control through acceleration and angular velocity feedback.

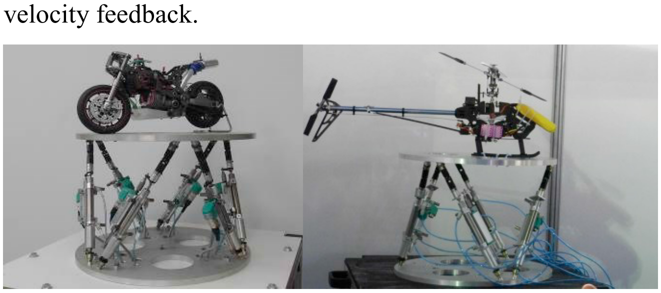

Figure 2. Stewart platform motion simulator with six degrees of freedom

As shown in Figure 3, this mechanism consists of six limbs (with variable lengths d_1, d_2, d_3, d_4, d_5 and d_6) that are connected to a fixed base by six spherical joints (A_1, A_2, A_3, A_4, A_5 and A_6) and to a moving platform by six universal joints (B_1, B_2, B_3, B_4, B_5 and B_6). The position and the orientation of the moving platform are given by x, y, z, φ, θ and ψ.

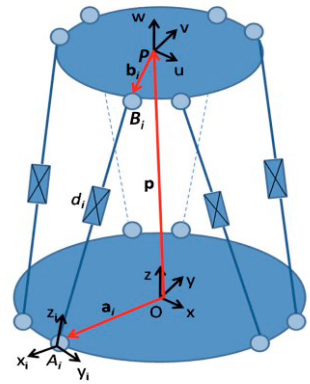

Figure 3. Geometric scheme of a Stewart platform

The inverse geometry could be obtained by the vector sum shown in (1) with $i = 1, \ldots, 6$, where $\boldsymbol{R}_B^A$ is the transformation matrix between the fixed frame $A(x, y, z)$ and the moving frame $B(u, v, w)$ (Tsai, 1999).

$$\overline{A_iB_i} = \overline{OP} + \overline{PB_i} - \overline{OA_i} \therefore \boldsymbol{d}_i = \boldsymbol{p} + \boldsymbol{R}_B^A\, \boldsymbol{b}_i^{\,B} - \boldsymbol{a}_i \quad (1)$$

Equation (2) is obtained applying the time derivative in (1). $\mathbf{s}_i$ is the unit vector on the direction of the segment $\overline{A_iB_i}$. $\mathbf{v}_P$ and $\boldsymbol{\omega}_P$ are the linear and angular speed of the moving platform, respectively, and they form the vector $\dot{\mathbf{x}}$, which describes the kinematic state of this platform (3). $\dot{d}_i$, with $i = 1, \ldots, 6$, are the actuator's linear velocities from the mechanism and they form the vector $\dot{\mathbf{q}}$.

$$\dot{d}_i = \boldsymbol{s}_i \cdot \boldsymbol{v}_P + (\boldsymbol{b}_i \times \boldsymbol{s}_i) \cdot \boldsymbol{\omega}_P \quad (2)$$

$$\dot{\boldsymbol{x}} = \begin{bmatrix} \boldsymbol{v}_P \\ \boldsymbol{\omega}_P \end{bmatrix} = \begin{bmatrix} (\dot{x} & \dot{y} & \dot{z})^T \\ (\dot{\phi} & \dot{\theta} & \dot{\psi})^T \end{bmatrix} \quad (3)$$

The inverse jacobian matrix relates the linear and angular speed of the moving platform ($\dot{\mathbf{x}}$) to the linear velocity of the actuators ($\dot{\mathbf{q}}$), Separating the variables related to the limbs from the variables related to the moving platform in (2), the inverse jacobian of the mechanism can be written. More details about this procedure can be found in Albuquerque (2012) and in Albuquerque *et al* (2013).

To solve the problem of the control based on the acceleration of the moving platform, the differential of the jacobian has to be obtained in order to achieve the relation between the velocities and accelerations of the limbs and the linear and angular accelerations of the moving platform as shown in (4).

$$\ddot{\mathbf{x}} = \dot{J}\dot{\mathbf{q}} + J\ddot{\mathbf{q}} \quad (4)$$