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# A New Decoupled Parallel Manipulator with Four Degrees of Freedom

V. Arakelian S. Briot

Département de Génie Mécanique et Automatique, L.G.C.G.M. / EA3913  
Institut National des Sciences Appliquées (I.N.S.A.)  
20, Avenues des buttes de Coësmes, CS 14315, 35043 Rennes Cedex, France

vigen.arakelyan@insa-rennes.fr  
sebastien.briot@ens.insa-rennes.fr

**Abstract.** A new 4-DOF parallel manipulator, called the PAMINSA<sup>1</sup>, is presented in this paper. The invented parallel structure consists of two (or three) legs, each one of which is a pantograph mechanism. The architecture of the PAMINSA is such that the platform displacements in the horizontal plane are independent of the translation along the vertical axis. The advantages of this architecture are the simplification of the vertical control based on the linear input-output equation and the improvement of positioning accuracy in the horizontal plane.

**Keywords:** Parallel manipulator, decoupled motion, SCARA motion

## 1. Introduction

A typical parallel manipulator consists of a moving platform connected to a fixed base by means of several kinematic chains, called legs. Such a coupled architecture allows the improvement of their stiffness and as a result the withstanding of higher payloads with lighter links. Thus parallel manipulators show better positioning accuracy and load-carrying capacity than serial manipulators. However they have nonlinear coupled kinematics and dynamics, which is a drawback for the industrial applications. It is obvious that the parallel structure with linear input-output equations is more appealing than the nonlinear one. In recent years, this problem has attracted researchers' attention and different structures have been proposed [1,2].

## 2. Description of the PAMINSA

The concept of the suggested manipulator is based on the following consideration. An energy analysis shows that the work of the gravitational forces of the manipulated object displaced in the horizontal plane is zero because the gravitational forces are always perpendicular to the displacements. However, the work of the same forces in the case of the vertical displacements is not zero (the gravitational forces are parallel to the displacements). This phenomenon is used in the design of hand-operated balanced manipulators [3,4], in which horizontal displacements of the manipulated object are carried out manually without much effort

and vertical displacements are driven. These properties are used in the suggested novel manipulator architecture. The schematic representation of the PAMINSA with two legs is shown in Fig.1, in which the each leg of the manipulator is realized by a pantograph mechanism (Fig.2) with two input points  $A_i$  and  $B_i$ , and the output point  $C_i$  ( $i = 1,2$ ).

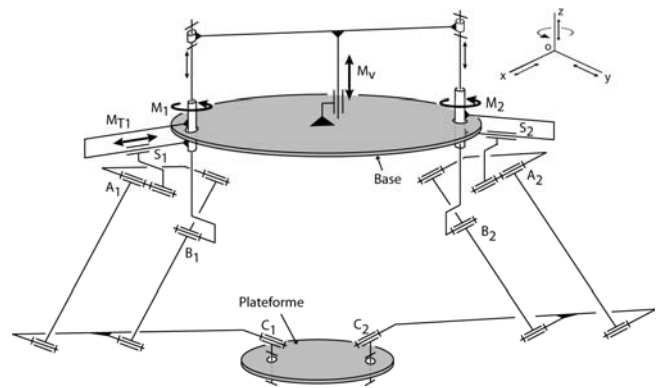


Fig. 1. Schematics of the PAMINSA with two legs.

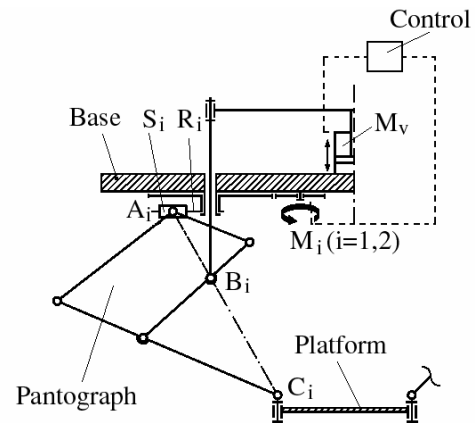


Fig. 2. Kinematic chain of each leg.

The input points  $A_i$  are connected with the rotating drivers  $M_i$  by means of the prismatic guides  $S_i$  mounted on the rotating links  $R_i$ . One of the prismatic guides  $S_i$  is driven ( $M_{T1}$ ). This type of manipulator architecture allows the generation of motion in the horizontal plane by the drivers  $M_1, M_2, M_{T1}$  and the vertical displacements by the driver  $M_v$ . In Fig. 3, the projection of the manipulator mechanism in the horizontal plane is presented.

<sup>1</sup> Parallel Manipulator of the I.N.S.A.

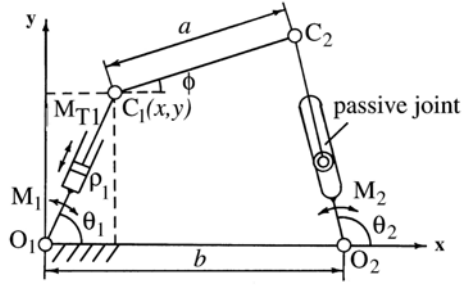


Fig.3. Schematics of the manipulator in the horizontal plane.

### 3. Kinematics and singularity

The kinematic relation between  $\mathbf{x} = (x, y, \phi, z)^T$  and  $\mathbf{q} = (\theta_1, \theta_2, \rho_1, Z)^T$  can be expressed as:

$$x = \rho_1 \cos \theta_1 \quad (1)$$

$$y = \rho_1 \sin \theta_1 \quad (2)$$

$$\phi = 2 \arctan \left( -\frac{1 \pm \sqrt{1 - AC}}{A} \right) \quad (3)$$

$$z = kZ, \quad (4)$$

where,

$$A = -\frac{-\rho_1 \sin \theta_1 + \tan \theta_2 (\rho_1 \cos \theta_1 - a - b)}{a} \quad (5)$$

$$C = -\frac{-\rho_1 \sin \theta_1 + \tan \theta_2 (\rho_1 \cos \theta_1 - b + a)}{a} \quad (6)$$

and  $k$  is the magnification factor of the pantograph. Thus we can note that the platform displacements in the horizontal plane are independent of the translation along the vertical axis  $z$ . The advantage of decoupling is a simplification of the kinematic computations. It is very helpful to obtain an easy formulation for direct and inverse displacement analysis, also for singularity analysis.

In the presented manipulator there are two kinds of singularities corresponding to the configurations of the pantograph when the input points  $A_i$  and  $B_i$  and the output point  $C_i$  are aligned [5] and to the configurations of the closed-loop kinematic chain shown in the Fig.3 [6]. So the singularity analysis does not present any difficulty.

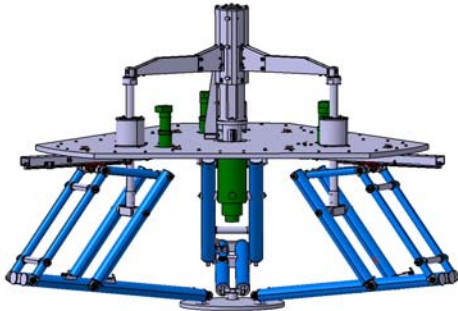


Fig. 4. A CAD model of the PAMINSA with three legs.

Similarly it is possible to create the same motions in the horizontal plane by one rotating actuator  $M_1$  and two linear actuators  $M_{T1}, M_{T2}$ . In this case the passive joint becomes the revolute joint  $O_2$  (see Fig.3).

It should be noted that the same concept can be realized by three legs. In this case the prismatic guide is not driven and the displacements in the horizontal plane are generated by the three drivers  $M_i$  ( $i=1,2,3$ ). In Fig. 4, a CAD model of the PAMINSA with three legs is presented.

### 4. Conclusions

The obvious advantages of the suggested manipulator architecture include:

- a simplification of the vertical control based on the linear input-output equation;
- the decoupling of the driver powers into two groups, which allows the lifting of heavy load to a given altitude with only one very powerful actuator and then, by using other less powerful actuators, its accurate positioning in the horizontal plane, i.e. it is possible to use two kinds of drivers;
- the improvement of positioning accuracy along the vertical axis because the mechanical locking of the structure does not allow the altitude variations during the displacements in the horizontal plane;
- the improvement of positioning accuracy in the horizontal plane because the loads on the drivers  $M_i$  due to the gravitational forces of the platform are canceled.

The authors believe that the proposed manipulator could be used in industrial applications for the manipulation of heavy equipment with great positioning accuracy. Various fields are possible depending on the type of the industrial application.

Finally, it should be noted that patent concerning of the PAMINSA is pending and a prototype is currently being developed.

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