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A Simulation Tool to Study the Kinematics and Control of 2RPR-PR Parallel Robots

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Abstract: This paper presents an educational simulation tool to analyze the kinematics and dynamic control of 2RPR-PR planar parallel robots. The tool, which is very intuitive, allows the robotics students to simulate the forward and inverse kinematic problems of these robots, visualizing the evolution of the solutions to the forward kinematics in the complex space. The tool also allows the students to study the relation between the singularities and the design of the robot, and analyze different methods to change between different assembly modes.

Keywords: Control, Dynamics, Kinematics, Parallel robots, Singularities, Virtual laboratory

1. INTRODUCTION

Parallel robots are robot manipulators in which the end-effector or mobile platform (the part of the robot that usually interacts with the environment) is controlled by two or more legs working in parallel. Due to their closed-chain structure, parallel robots are usually faster and more precise than classical serial robotic arms and have a higher payload-to-weight ratio. However, parallel robots also have smaller workspaces than serial robots, they can adopt singular configurations in which control issues occur, and are generally more difficult to analyze, which makes simulation tools essential to study parallel robots.

Currently, there are many simulation tools to study parallel robots. Petuya et al. (2014) present *GIM*, an educational tool to simulate the forward kinematics, statics and velocity problems of general architecture planar and spatial parallel robot manipulators, as well as to visualize their singularities and workspaces. Ben-Horin et al. (2008) present *SinguLab*, a graphical user interface to study the singularities of Gough-Stewart platforms using Grassmann-Cayley algebra. Other simulators like *DexTAR Sim*[1] and *RoboDK*[2] allow the user to simulate the kinematics and offline programming of 5R and Delta-like parallel robots, respectively. *The CUIK Suite* (Porta et al., 2014) allows the user to solve the kinematic problems of general structure manipulators and visualize their configuration spaces, workspaces and singularity sets. Similarly, the package *Bertini* (Bates et al., 2013) can also be used to solve the kinematic problems of parallel robots, obtaining both the real and imaginary solutions, which can be useful to analyze the kinematics of the robot, as shown in the present paper. Finally, general-purpose commercial programs such as ADAMS and MATLAB/Simulink can also be used to simulate the dynamics and control of parallel robots (Hajimirzaalian et al., 2010; Li and Xu, 2009).

This paper presents a new Java simulation tool to study the kinematics, the singularities, and the dynamic control of a 2-degrees-of-freedom (DOF) planar parallel robot called 2RPR-PR. The presented simulator is part of the web-based virtual and remote laboratory PaRoLa (Parallel Robotics Laboratory[3]).

PaRoLa (Peidró et al., 2016, 2015c) is an educational virtual and remote laboratory developed with Easy Java Simulations[4], designed to support and facilitate the study and analysis of parallel robots in robotics courses at undergraduate and master's levels. PaRoLa is composed of a set of Java applets that allow the students to simulate and study the kinematics, singularities, workspace, and dynamics of some parallel manipulators, such as the 5R, the 3RRR, and the Delta robots. Also, it allows the students to remotely control a real 5R parallel robot.

The simulator presented in this paper aims at expanding the collection of robots supported by PaRoLa, by allowing the students to simulate the 2RPR-PR robot, a 2-DOF parallel robot that can be used as a versatile joint. The presented tool can be used to simulate the forward and inverse kinematic problems of this robot, allowing the user to visualize the evolution of the (complex) solutions to the forward kinematics. Also, this tool can be used to study the relationship between the design of the robot, its singularities, and the ability of the robot to change between different assembly modes without crossing singularities. Finally, the simulator can also be used to simulate the dynamic control of the robot, to study the possibility of changing between different assembly modes by crossing singularities. The presented tool can be freely downloaded from `http://`

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[1] http://www.mecademic.com/
[2] http://www.robodk.com/
[3] http://arvc.umh.es/parola
[4] http://fem.um.es/Ejs/

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`arvc.umh.es/parola/2rpr_pr.html` (the latest version of Java may be required).

The remainder of this paper is organized as follows. First, Section 2 describes in detail the robot that can be simulated with the proposed tool. Next, Sections 3, 4, and 5 describe how the kinematics, singularities, and dynamic control of the robot can be studied with the presented simulator, respectively. Finally, Section 6 presents the conclusions and the future work.

2. THE 2RPR-PR ROBOT

Figure 1 shows the 2RPR-PR parallel robot. This robot is a 2-DOF closed-chain planar mechanism composed of a platform connected to a fixed base through one passive slider and two linear actuators (l_1 and l_2) placed in parallel. Due to the passive slider, the platform can only translate along the Y axis (translation y) and rotate in the XY plane (rotation φ). The translation y and rotation φ of the platform can be controlled by means of the linear actuators l_1 and l_2. The geometric design parameters of this robot are $\{a_1, a_2, b_1, b_2\}$. The parameters $\{a_1, a_2\}$ (with $a_1 \neq a_2$) are the positions of the attachment points of the linear actuators to the base along the X axis, whereas the parameters $\{b_1, b_2\}$ (with $b_1, b_2 > 0$) define the size of the platform as shown in Fig. 1.

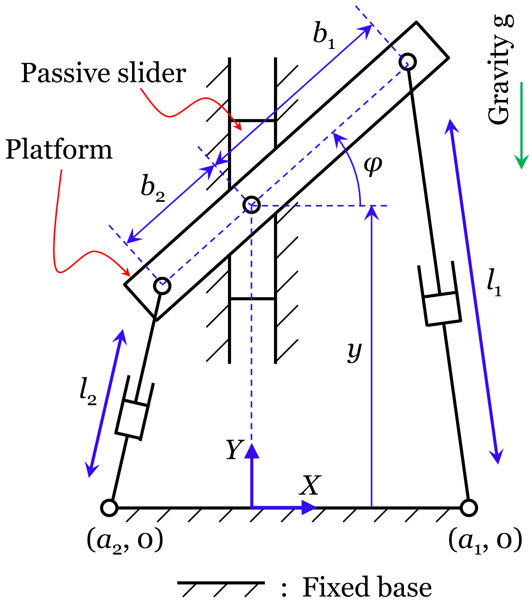

Fig. 1. The 2RPR-PR parallel robot.

This parallel mechanism has been studied by some authors. First, this mechanism was proposed by Ridgeway et al. (1996) as a high-stiffness joint for an articulated snake-like robot to explore nuclear facilities. Later, Kong and Gosselin (2002) analyzed the number of different solutions to its forward kinematic problem. Recently, it has been shown that this mechanism can change between different solutions of the forward kinematic problem without crossing singularities (Peidró et al., 2015b). Finally, this mechanism has also been used in a serial-parallel robot for climbing 3D truss structures (Peidro et al., 2015a).

One of the most interesting features of this mechanism is the possibility of using it as a high-stiffness versatile joint, as an alternative to less rigid classical serial joints. Indeed, depending on the pattern of actuation of the actuators l_1 and l_2, the motion of the platform can be a pure translation y, a pure rotation φ, or a combination of them. Thus, used as a joint, this parallel mechanism can behave as a purely prismatic (translational) joint, as a purely revolute (rotational) joint, or as something in between.

In this paper, we present a simulation tool to simulate and study some kinematic and dynamic aspects of this parallel mechanism. The simulation tool, shown in Fig. 2, has six panels p_i $(i = 1, \ldots, 6)$:

- p_1: represents the robot in its current configuration, similar to Fig. 1.
- p_2: represents the joint space, i.e. the space of the joint coordinates. The joint coordinates of this robot are the lengths of the linear actuators: l_1 and l_2 (which are represented in the horizontal and vertical axes of the panel p_2, respectively).
- p_3: a control panel in which the user can modify some parameters of the simulation.
- p_4: represents the space of translations y and rotations φ of the platform. The angle φ is represented in the horizontal axis of this panel, whereas the translation y is represented in the vertical axis.
- p_5: represents the complex solutions of the rotation φ, in cylindrical coordinates.
- p_6: represents the complex solutions of the translation y, in rectangular coordinates.

These panels will be described in detail in the next sections, together with the capabilities of the presented tool.

3. SIMULATION OF THE KINEMATICS

This section describes how the forward and inverse kinematic problems of the 2RPR-PR robot can be studied with the presented tool.

The forward kinematic problem consists of calculating the position y and orientation φ of the platform in terms of the lengths (l_1, l_2) of the linear actuators. It can be shown that this problem consists of solving a cubic equation and a quadratic equation in sequence, which yields $3 \times 2 = 6$ solutions. However, it has been shown that at most four of these solutions can be real (Kong and Gosselin, 2002), i.e. there can be at most four different real pairs (y, φ) for given lengths (l_1, l_2) (the remaining two solutions are always complex).

To simulate the forward kinematic problem, the user must specify the joint coordinates l_1 and l_2. This can be done using the corresponding boxes and sliders in the "Kinematics" tab of the control panel p_3. Alternatively, the user can click and drag the joint coordinates in the joint space in panel p_2, in which case both joint coordinates can be varied simultaneously (see Fig. 3a). When modifying the value of the joint coordinates, the simulator solves the forward kinematic problem, obtaining the six solutions (y_i, φ_i) $(i = 1, \ldots, 6)$, and represents the robot in the configuration associated to one of these six solutions in the panel p_1. The user can select which one