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Vision-based control of a flying Spherical Inverted Pendulum on a Quadrotor

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A spherical inverted pendulum represents an example of a nonlinear and unstable dynamical system. It has the property of the impossibility of measurement at the ball joint. It must be noted here the absence of sensors that can measure states at the ball joints. The spherical inverted pendulum is also called an under-actuated system because it has a greater number of joints than the number of actuators. The control of under-actuated systems is currently a field of research that is very active due to their vast applications in robotics, aerospace and marine vehicles. Furthermore, the interest of the scientific community to the theme of controlling the spherical Inverted Pendulum has continued to increase, especially because it is more reasonable to model many applications of the inverted pendulum, like the Segway [1] that can lean to the left or right or a humanoid robot [2] as a spherical inverted pendulum than a simple one. Most of researchers have developed control strategies to control the spherical inverted pendulum by applying two planar forces f_x and f_y along the x-axis and y-axis respectively. However, they were all discussed in terms of decoupled techniques which means that they have considered the Spherical Inverted Pendulum as two simple inverted pendulums which has made the region of stability limited [3], [4] and [5]. From an application point of view, such limitations will be removed by enlarging the region of stability by adding a vertical force f_z along the z-axis. In this way, the base will become capable of moving in the space in order to control the pendulum.

In order to achieve this goal, this paper proposes an inverted pendulum that is attached by a ball joint to a Quadrotor such that this last enables to control the Spherical Inverted Pendulum in its unstable equilibrium upright position. The thing that has already attracted many attentions [6-12]. However, most of these research were discussed either in terms of decoupling or they considered a simple inverted pendulum with different initial conditions of the angle and angular velocity of the pendulum. In other terms, in order to control an inverted pendulum in real life, the angular positions and angular speeds must be measured using an

encoder at the bearing. The thing that is impossible for the case of the spherical inverted pendulum.

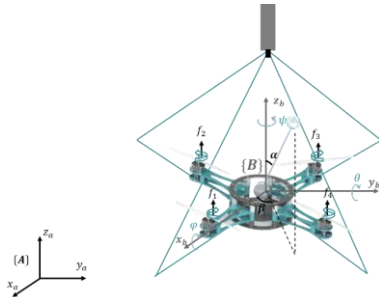


Figure 1. The Flying Spherical Inverted Pendulum

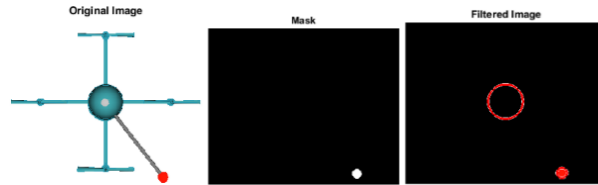


Figure 2. Resulting images after applying the algorithm.

In this paper, the visual servoing of a Spherical Inverted Pendulum on a Quadrotor Fig.1 is treated. This technique will control the spherical pendulum in the vertical position based on visual information from a camera placed over the Quadrotor. The camera records images from the environment and on the basis of certain characteristic points of the observed image, the current position of the pendulum will, therefore, be derived from the desired position Fig.2. This difference in image characteristics between the current location and the desired location is then used to generate a backstepping-based control which will cause the Quadrotor to move in order to adjust the position of the spherical pendulum in its equilibrium position unstable Fig.3, 4, 5 and 6.

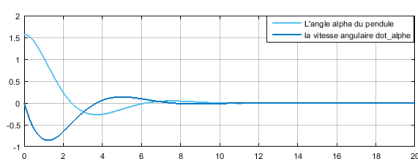


Figure 3. Simulation result for the angle α and its velocity of the Spherical Inverted Pendulum

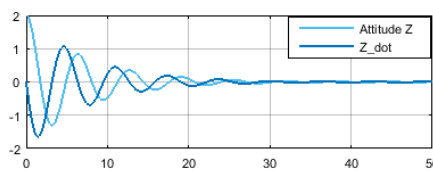


Figure 4. Simulation result for the altitude z of the Quadrotor

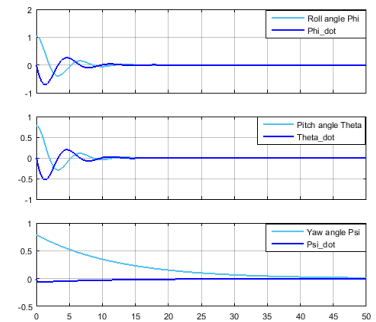


Figure 5. Simulation result for the rotational movement of the Quadrotor

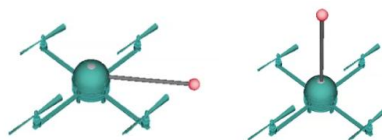


Figure 6. Screenshot of the virtual reality environment of the system in Simulink.

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