Simplified Analytical Dynamic Model for a Parallel Prosthetic Elbow

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Abstract. A three degree of freedom elbow prosthesis impelled by linear actuators disposed in parallel is modeled by the Lagrange-Euler method. The method proposes to replace a parallel mechanism with an equivalent serial topology with the purpose of calculating the Laplacian, however the parallel topology is used for the calculus of forces and torques. The result is a simplification in the mathematical analysis without an important loss in precision.

1 Introduction

Meanwhile important efforts have been done for analyzing mechanical serial systems, little has been done for analyzing parallel mechanisms. The Stewart-Gough platform with six legs and six actuators is described very well in literature [1][6][9], but a more complete description of orientation platforms with three actuators is needed. Moreover, it is still difficult to find an analytical model for a simple pendulum hanging in a spherical joint.

In previous works, an elbow prosthesis with three degrees of freedom for transhumeral amputation replacement is proposed [3]. The motorized movements of this prosthesis are: humeral rotation, elbow flexion and pronation-supination. This prosthetic elbow is considered a complete elbow since it includes a motorized humeral rotation, which, in a natural way, cannot be transmitted through the stump to the prosthesis.

Figure 1 depicts the mechanism to be analyzed. It can be seen that there are three actuated links and one fixed link. It can be noted by simple inspection that, in order to perform a single movement, at least two actuators must be energized. For example, if actuators 1 and 2 are contracted at the same velocity, a flexion of the elbow is produced, but if the same actuators are moved in opposite directions then a pronation or supination is produced. Contracting actuators 2 and 3 produces the equivalent to internal humeral rotation.

The forearm of the prosthesis is equivalent to a parallel four legs orientation platform, but the methods proposed in the state of the art to model these structures require that the mechanisms have a symmetrical geometry [12].

2. Methodology.

If we want to develop the exact dynamic model for the mechanism in Fig 1, we should consider that the center of masses and the rotational inertia of each actuator changes as a function of its length. In order to solve the three mechanical closed loops we should have a methodology like the one proposed by Nakamura [6][7], Cheng [4], and analyzed in [9]. However, some considerations can be done before solving the dynamics of the elbow.

First consideration. As an effort to reduce the load and torques in the stump, and in order to increase the payload at the prosthetic hand, each linear actuator has 80% of its mass in its proximal end [2], and this end does not change its length. As a result, the change of position of the center of mass can be ignores; also, changes in rotational inertia in each actuator are very small.

Second consideration. The prosthesis should fit the dimensions of a natural arm. Although, only at elbow flexion of 110º, the actuators are completely parallel to each other, they are almost parallel in every position. This implies that actuators rotate almost at the same velocity in every movement.

Figure 1. Schematics of a three degree of freedom parallel elbow. This elbow performs flexion, humeral rotation and prono-supination.

After the two considerations above, we are allowed to propose that the four parallel links can be considered as only one, located at the center of the four actuators. This unique link should rotate in a spherical joint located at the center of the proximal end of the four links. In addition, this bar will have constant length (ending where the hand lies) and it will have a constant center of mass and rotational inertia. This transformation is depicted in fig. 2.

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