Supporting Document for Kinematics of the exoskeletons

Kinematic Modeling

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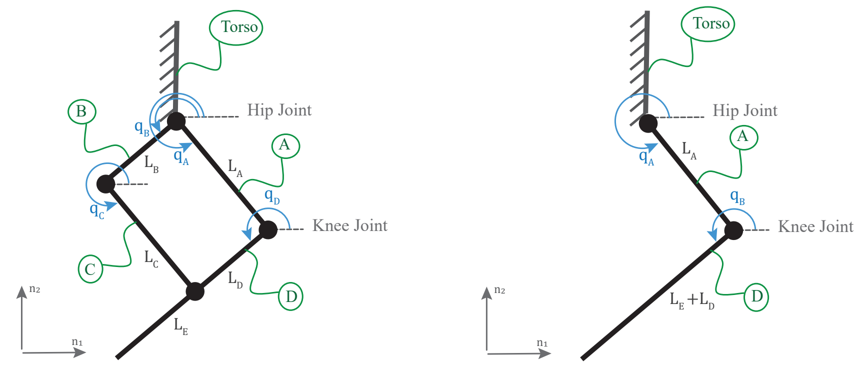
The biarticular exoskeleton was designed to assist hip and knee joints. The exoskeleton has been inspired by biarticular muscles and the aim of the design was keeping the weight in proximal joint (Hip) while delivering the required power to distal joint (Knee). The parallelogram mechanism has been purposed to accomplish this goal and take advantage of biarticular muscles biological features in the exoskeleton. The purposed exoskeleton was shown in figure A1(a). Where the hip joint will be assisted by applying



(a) biarticular device **(b)** monoarticular device

Fig A1. Assistive devices kinematics model. The parallelogram mechanism has been used to model the biarticular exoskeleton and the monoarticular exoskeleton modeled by two link serial manipulator.

directly the torque on the joint and second actuator torque will be applied to knee joint through the parallelogram mechanism.

$$x_{Bi} = l_A \cos(q_A) + (l_E + l_D) \cos(q_B) \tag{1}$$
$$y_{Bi} = l_A \sin(q_A) + (l_E + l_D) \sin(q_B) \tag{2}$$

Monoarticular Exoskeleton can be modeled as a two-link serial manipulator as shown in figure A1(b) where each joint is assisted by the directly joint actuator and the forward kinematics of monoarticular exoskeleton is:

$$x_{mono} = l_A \cos(q_A) + (l_E + l_D) \cos(q_A - q_B) \tag{3}$$
$$y_{mono} = l_A \sin(q_A) + (l_E + l_D) \sin(q_A - q_B) \tag{4}$$

For both of the exoskeletons configurations the kinematics in motion level also can be easily driven and resulted Jacobian of each configurations can be written as in Eq (5) and (6).

$$J_{Bi} = \begin{bmatrix} -l_A \sin q_A & -(l_E + l_D)\sin(q_B) \\ l_A \cos(q_A) & (l_E + l_D)\cos(q_B) \end{bmatrix} \tag{5}$$

$$\begin{split} J_{Mono} = \Bigg[& -l_A \sin q_A - (l_E + l_D)\sin(q_A - q_B) \\ & \;l_A \cos q_A + (l_E + l_D)\cos(q_A - q_B) \\ & \qquad (l_E + l_D)\sin(q_A - q_B) \\ & \quad - (l_E + l_D)\cos(q_A - q_B) \Bigg] \end{split} \tag{6}$$