DESIGNING A ROBOT BASED ON PARALLEL MECHANISM TO REPRODUCE HUMAN CHEWING BEHAVIOUR

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Abstract

To quantitatively assess masticatory efficiency and/or food texture changes during chewing, the jaw movements and forces of human chewing behaviour need to be reproduced. We have proposed a robotic solution where a parallel mechanism with six degrees of freedom (DOF) is developed and based on the biological model of human mastication system. This paper presents such a robot and outlines the design requirements of its actuation system. Six double-acting actuators replace the main muscles of mastication (masseter, temporalis, and lateral pterygoid) according to the biological attachment points and orientation. Actuator strokes, velocities and accelerations are found by implementing human chewing trajectories as inverse kinematics. The actuator forces are calculated for static biting.

1. Introduction

The human masticatory system has been simulated mathematically and physically by various research groups. For example, van Essen et al. (2005) developed a computer model based on anatomical data and the visible human data set. This model of the human masticatory system includes the bones and all the major muscles of mastication. While such a model can be used to simulate the action of simple bites, or to calculate the stresses and forces on the teeth, they are rather inappropriate if one is interested in the assessment of masticatory efficiency with numerous variations in food properties, dentition, and physiological structure of jaws, or quantitative measurement of the dynamics of food texture.

To reproduce the masticatory process in a more objective way, Xu et al. (2004) proposed a robotic solution. This paper describes the latest progress and improvements in building the robot with a focus on the design of actuation systems.

2. Materials and Methods

2.1 Human Biomechanics

To align the physical model with its biological foundation, the literature on the human mastication apparatus was reviewed. The human masticatory system consists of a lower (mandible) and an upper jaw (maxilla). The mandible is connected to the skull by two very complex shaped incongruent jaw joints, the temporomandibular joints (TMJ) and guided by the contraction of the muscle of mastication. The jaw joints are more complex than other joint systems in our body, which typically just rotate around a fixed joint axis. When we open or close the jaw by more than 10 degrees, the mandible rotates and translates anteriorly with respect to the temporal bone (Scapino, 1997). This does not allow the movement to be restricted to a fixed joint axis. Furthermore, a soft tissue (articular disc) within the TMJ enables the mandible to move with six degrees of freedom.

The human muscular system, controlled by the central nervous system, consists of a large number of muscle that work as an ensemble (Scapino, 1997). Anatomically, the muscles of mastication are divided into elevators (masseter, temporalis, and medial pterygoid muscles) and depressors (geniohyoid, mylohyoid, and digastric muscles). The lateral pterygoid has two heads with different actions and cannot be regarded exclusively as elevator or depressor. Since the DOF of the TMJ are smaller than the number of muscles of mastication, the human chewing system is kinematically redundant (Koolstra, 2002). This means that the same movement can be achieved with an infinite number of different muscle contraction patterns. From a mechanical point of view, there are more muscle groups in the human masticatory system than apparently necessary to accomplish its tasks. This may be due to spatial requirements, such as the adjacent airway and alimentary tract (Koolstra, 2002). In our design, we choose the major jaw muscles (masseter, temporalis, and lateral pterygoid) to be replaced by our actuators (see Fig. 1).

2.2 Mechanical Design Concept

To ensure that all masticatory movements can be achieved, a parallel mechanism was chosen (Daumas et al., 2005). The mechanism consists of two platforms and six actuators, which are connected to each other via spherical joints. The movable platform represents the mandible and the fixed platform the human skull. The six actuators are used in place of the jaw-opening muscle groups (temporalis, masseter and lateral pterygoid) (Pap et al., 2005). Because of bi-directionality the actuators also replace the jaw-opening muscle groups (Fig. 2). The jaw included in the model was obtained from a human cadaver by computer tomography and is therefore an accurate replica of a human jaw.

Van Eijden et al. (1997) measured muscle length in the closed-mouth position and the three dimensional coordinates of the attachment points for each subdivision of the masticatory muscle groups in eight cadavers. By using the force-vector- analysis and the sub-muscle groups, the resultant muscle orientations have been calculated. Attachment points to the jaw and the length of the longest sub-muscle group in closed-mouth position have been chosen to specify the actuator properties. To analyse the actuator properties such as stroke, velocity, and acceleration, human chewing trajectories recorded while chewing sample foods were implemented as inverse kinematics using SolidWorks and COSMOS/Motion software.

4. Results and Discussion

The robotic model was found to be able to reproduce jaw movements and force applications of human chewing behaviour. It has been validated by extensive simulations in SolidWorks and COSMOS/Motion. The required actuator properties are approximately 5mm, 35mm/sec, 1000mm/sec (masseter), 25mm, 70mm/sec, 3000mm/sec (temporalis), and 18mm, 60mm/sec, 1500mm/sec (lateral pterygoid), for stroke, velocity, and acceleration, respectively. The static appliance of 260 N occlusal load requires actuation forces of 150N, 150N and 200N for masseter, temporalis and lateral pterygoid actuator, respectively.

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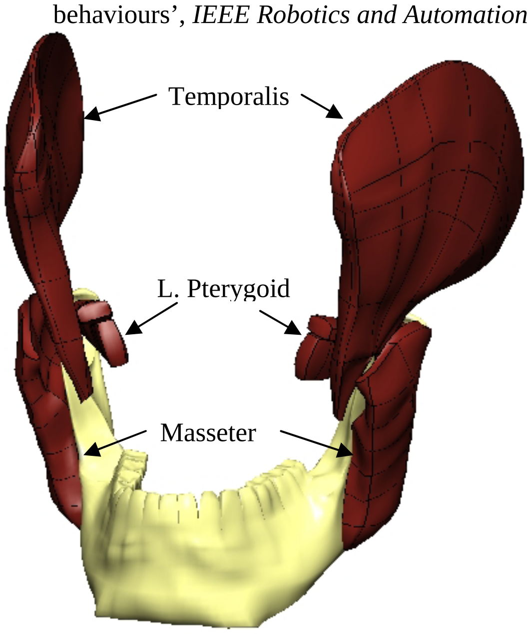

Figure 1. Anatomically based mathematical masticatory system

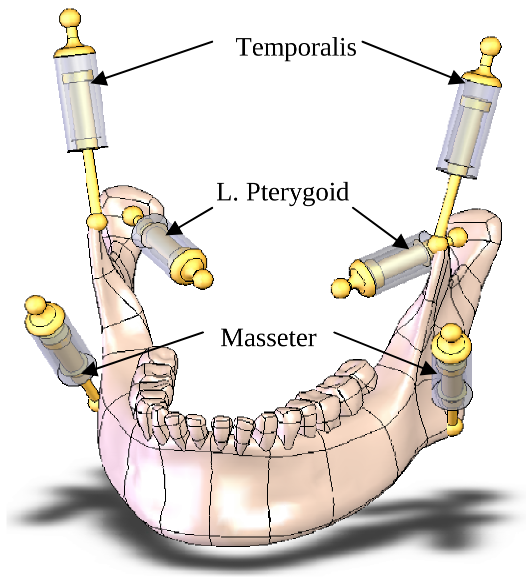

Figure 2. Physical robot of the mastication system