A Novel Wearable Assistive Device for Jaw Motion Disability Rehabilitation

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Abstract

Temporomandibular disorder (TMD) is a group of dysfunctions in the masticatory system that cause muscle stiffness and weakened masticatory ability. TMD is commonly suffered by a considerate percentage of the population, impairs oral hygiene and brings inconveniences to a great number of patients. The therapeutic exercise with significant efficacy is widely advised among patients in the treatment of the mandibular hypomobility to reduce pain and increase the inter-incisal opening of the mouth. This thesis proposes a novel wearable device to passively assist to deliver the mandibular movement.

The mandible, attached to the skull via masticatory muscles and pivoted at the condyles at the temporomandibular joint (TMJ), can be simplified as moving in the two-dimensional sagittal plane. A planar four-bar linkage was synthesized to reproduce the specified normal jaw motion in terms of incisor and condyle trajectory on the coupler point to meet the kinematic specification. Adjustable lengths of the links were used to achieve a group of trajectories of any possibility. The prototype of the linkage has been fabricated, integrated with the sensory units and electronic hardware into a Mechatronic system.

The dynamics of the entire system was analyzed, along with the model thoroughly built up in Simulink, to facilitate further controller design. A closed-loop control scheme based on the device was proposed, and it is able to achieve the accurate position control to the crank to ensure the position of the jaw to be notified. A series of experiments with the device has been carried to evaluate the performance of the controller, with the control algorithm implemented into a micro-controller based board.

The exoskeleton was then evaluated in terms of the kinematic and dynamic interaction in the hybrid human-machine system, in which the condyle movement was recorded by AG500 tracking machine. Simulation and experimental methods were respectively developed to investigate the joint force which is in-vivo inaccessible. Simulation was conducted by adding the dynamic model of the mandible into the linkage model with controller. A test-rig was designed to mount the skull and the jaw replicas which simulated the counterparts in human body. Experiments were carried to evaluate the joint force and the performance of the controller; results obtained from both simulations and experiments have indicated the force level inside the TMJ is rather small compared with the one in the circumstance where maximum chewing force is applied.

Acknowledgement

At the moment of approaching to the completion of the PhD study, looking over what's been going through in the past four years, memories during the whole doctoral journey all crowded into my mind, full of best and worst scenes. From losing direction at the beginning, to the struggling whilst getting in the research till the persistence to the last moment, they showed up in silence to me every time when I came across difficulty. It would likely not finish the thesis without the help and support from people around me, to some of whom it is only possible to mention here.

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Declaration

The author declares that this is her own work except where due acknowledgement has been given. It is being submitted for the PhD in Engineering to Massey University, New Zealand.

This thesis describes the research carried out by the author at School of Engineering and Advanced Technology, Massey University, New Zealand from February 2009 to November 2013, supervised by Prof. Peter Xu, A/Prof. Johan Potgieter and Prof. Olaf Diegel.

List of Publications

Wang, X., Xu, W., Potgieter, J., & Diegel, O. (2010). "A jaw exoskeleton for jaw motion disability rehabilitation: System conceiving and mechanism synthesis," in Proceedings of the 25th International Conference on CAD/CAM, Robotics and Factories of the Future (CARs&FOF), 2010. (pp. 1 - 12).

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X. Wang, P. Xu, J. Potgieter, and O. Diegel, "Review of the biomechanics of TMJ," in Mechatronics and Machine Vision in Practice (M2VIP), 2012 19th International Conference, 2012, pp. 381-386.

X. Y. Wang, J. Potgieter, W. L. Xu, and O. Diegel, " Development of Jaw Exoskeleton for Rehabilitation of Temporomandibular Disorders " in Robot Intelligence Technology and Applications, The 2nd International Conference on, 2013.

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Definitions and Abbreviations

2D	two-dimensional	HMI	human-machine interaction
3D	three-dimensional	HMS	human-machine system
ADC	analog-digital converter	ICR	instantaneous center of rotation
AG	articulograph	IDE	integrated development environment
CMP	continuous passive motion	IP	incisor point
CNS	central nervous system	KC	kinematic center
CP	condylar point	LSB	least significant bit
CPG	central pattern generator	LSQ	least square
CS	coordinate system	MCU	microcontroller unit
CSA	cross-sectional area	MDA	multi-body dynamic analysis
CVA	cerebrovascular accident	MRI	magnetic resonance image
DAC	digital-analog converter	PCSA	physiological cross-sectional areas
DAQ	data acquistion	ROM	range of motion
DLC	dimeric link chain	STD	standard deviation
DOF	degree of freedom	TMD	temporomandibular joint disorders
EMG	electromyography	TMJ	temporomandibular joint
FEA	finite element analysis	UI	user interface
FHA	Finite helical axis	VR	virtual reality
GUI	graphic user interface	WAD	wearable assistive device