A CHEWING ROBOT BASED ON PARALLEL MECHANISM – ANALYSIS AND DESIGN

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József-Sebastian Pap

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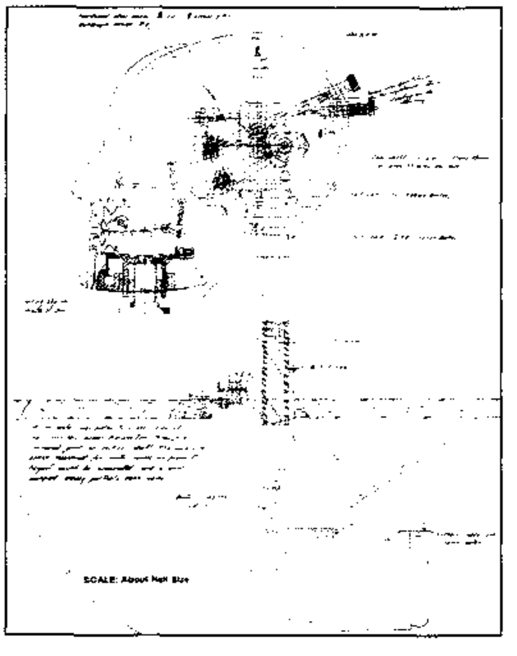

A copy of an original drawing of the "Dental Prosthetic Demonstrator" invented by the dentist George Burtenshaw and manufactured by the engineer Mel Harris from Taumarunui, New Zealand, dated in January 1938 (Cooke 1982).

ABSTRACT

Masticatory efficiency, dependent on number and condition of the teeth, length of time spent in chewing a bolus and the force exerted when chewing, influences an individual with the selection of food and therefore nutritionally diet. A characterisation of the masticatory efficiency could be possible with a chewing robot that simulates human chewing behaviours in a mechanically controllable way (Pap *et al.* 2005; Xu *et al.* 2005).

This thesis describes such a chewing robot, developed from a biological basis in terms of jaw structure and muscles of mastication according to published articles. A six degrees of freedom parallel mechanism is proposed with the mandible as a moving platform, the skull as a fixed platform, and six actuators representing the main masticatory muscle groups, temporalis, masseter, and lateral pterygoid on the left and right side. Extensive simulations of inverse kinematics (i.e., generating muscular actuations with implementing recorded human trajectories) were conducted in SolidWorks and COSMOS/Motion to validate two mathematical models of the robot and to analyse kinematic properties.

The research showed that selection of appropriate actuation systems, to achieve mandible movement space, velocity, acceleration, and chewing force, was the key challenge in successfully developing a chewing robot. Two custom designed actuation systems, for the six actuators, were developed and built.

In the first approach, the muscle groups were presented as linear actuators, positioned so as to reproduce the resultant lines of action of the human muscles. However, with this design concept the spatial requirements specified from the human masticatory system made the physical building of the model impossible.

The second approach used a crank mechanism based actuator. This concept did not allow a perfectly linear actuator movement that copied the muscle line of action. However, it was possible to fulfil the spatial requirements set by the human system and to allow reproduction of human chewing behaviours in relation to kinematic requirements and chewing force.

The design, manufacture and testing of the entire chewing robot with crank actuators was then carried out. This included the implementation of realistic denture morphology, a mechanical jaw and the framework design for the whole system.

In conclusion, this thesis research has developed successfully a mathematical and a physical robotic model. Future work on the control and sensing of the robot and design of a food retention system are required in order to fully functionalise the device.

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Cheers to Fly My Pretties for their Live at Bats.

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For those about to read this thesis, I hope you can grind your way through and digest all the relevant ideas.

Palmerston North, 21st of March 2006.

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GLOSSARY

All definitions of anatomic orientation terms are obtained from MedicineNet (2005).

Anterior – The front, as opposed to the posterior.

Anteroposterior – From front to back.

Horizontal – Parallel to the floor, a plane passing through the standing body parallel to the floor.

Inferior – Below, as opposed to superior.

Lateral – Toward the left or the right side of a body, as opposed to medial.

Mandible – lower jaw.

Mastication – chewing or grinding or crushing.

Maxilla – upper jaw.

Medial – In the middle or inside, as opposed to lateral.

Posterior – The back or behind, as opposed to anterior.

Sagittal – A vertical plane passing through the standing body from front to back.

Superior – Above, as opposed to inferior.

Superoinferior – From above to below.

Vertical – Upright, as opposed to horizontal.

ABBREVIATIONS AND ACRONYMS

DOF – Degrees of freedom.

FEM – Finite Element Method.

PCS – Physiological cross-sectional area.

TMJ – Temporomandibular joint.

a	Distance	$[m]$
a	Linear acceleration	$[m/s^2]$
A	Cross-sectional area	$[mm^2]$
b	Distance	$[m]$
B	Resolution	[-]
c	Distance	$[m]$
c	Permissible load	$[N]$
d	Diameter	$[mm]$
d	Distance	$[m]$
e	Distance	$[m]$
E	Young's modulus	$[N/mm^2]$
f	Distance	$[m]$
f	Factor	[-]
f	Accuracy	$[mm]$
F	Force	$[N]$
g	Gravitational constant	$[m/s^2]$
i	Gear reduction	[-]
I	Geometrical Moment of Inertia	$[mm^4]$
l	Length	$[mm]$
L	Vector length	$[m]$
m	Mass	$[kg]$

m	Module	[-]
n	Rotational speed	[min^{-1}]
r	Radius	[mm]
R	Lead	[m]
s	Displacement	[m]
s	Stroke	[mm]
t	Number of teeth	[-]
T	Torque	[Nm]
v	Velocity	[m/s]
x	Factor	[mm/s]
α	Angular acceleration	[s^{-2}]
α	Angle	[°]
β	Angle	[°]
γ	Angle	[°]
γ	Density	[kg/mm^2]
δ	Angle	[°]
δ	Tensile-compressive stress	[N/mm^2]
Δ	Difference	[-]
λ	Mounting coefficient	[-]
ζ	Angle	[°]
ϕ	Angle	[°]
μ	Efficiency	[-]
ω	Angular velocity	[s^{-1}]

Indices

0	Point of origin
0a	Static
1	First factor
2	Second factor
3	Third factor
a	Actual factor
acc	Under acceleration
axial	Axial
b	Buckling
BC	Ball centre
c	Cylinder
c	Constant
cs	Crank shaft
cs	Critical speed
dec	Under deceleration

DN	DN value
driven	Driven gear
driving	Driving gear
e	Entire
e	Extended
f	Folded
F	Force
GB	Gearbox
k	Minimum Thread
L	Load
M	Motor
Mass	Masseter muscle group
M.Ptery	Medial pterygoid muscle group
max	Maximum value
Occ	Occlusion
Ptery	Lateral pterygoid muscle group
Spindle	Spindle
tc	Tensile-compressive
Temp	Temporalis muscle group
u	Unsupported
x	Direction
y	Direction
z	Direction
α	Throughout acceleration