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Development of 2-DOF haptic devices working with magnetorheological fluids

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Development of 2-DOF Haptic Devices Working with Magnetorheological Fluids

A thesis submitted in fulfilment of the requirements
for the award of the degree of

Master of Engineering – Research

by

Bin Liu

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from

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CERTIFICATION

I, Bin Liu, declare that this thesis, submitted in partial fulfilment of the requirements for the award of Master of Engineering – research, in the School of Mechanical, Materials and Mechatronic, Faculty of Engineering, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Bin Liu

5th March 2006

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To my parents and all the people I love

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τ	shear stress of the MR fluids
τ_y	yield stress of the MR fluids
B	magnetic induction intensity
H	intensity of magnetic field
$\dot{\gamma}$	shear strain rate
η_0	field-independent plastic viscosity of MR fluids
η_{app}	apparent viscosity of MR fluids
K	consistency index in apparent viscosity model of MR fluids
F	shear force in the shear mode
$F\eta$	shear force without applied magnetic field in the shear mode
$F\tau$	shear force related to applied magnetic field in the shear mode
A	area of the working surface
L	length of the working surface
W	width of the working surface
g	gap between the two working surfaces
ΔP	pressure drop in the flow mode
ΔP_η	pressure drop without applied magnetic field in the flow mode
ΔP_τ	pressure drop related to applied magnetic field in the flow mode
Q	volumetric flow rate in the flow mode
c	function of the flow velocity
ω	angular velocity of the rotary disc
h	MR fluid gap in the disc-shaped actuator

r	position on the rotary disc surface
r_{inner}	inner radius of the rotary disc
r_{outer}	outer radius of the rotary disc
T	resistant torque
N	number of the turns of the coil
I	current in the coil
H_f	magnetic intensity in the MR fluid gap
H_s	magnetic intensity in the steel
L_g	width of the MR fluid gap
L_s	length of the steel path
μ_o	permeability of free space
μ_r	relative permeability of MR fluids
Φ	value of magnetic flux
Da	radius of MR actuator
Dc	thickness of the casing
Dd	thickness of the disc
Df	thickness of MR fluids gap
Dp	thickness of the plate
T_0	initial resistant torque in the sub-hysteresis model
I_s	constant electric current difference in the sub-hysteresis model
S_1, S_2	two constant slopes of T in the sub-hysteresis model
I_t, I_b	two vertexes of sub-hysteresis loop
θ	degree of the longitude of the spherical coordinates
ϕ	degree of the latitude of the spherical coordinates

α_x , α_y	rotation degree of the two MR actuators
M_φ	resistant torque along latitude direction of the spherical coordinates
M_θ	resistant torque along longitude direction of the spherical coordinates
M_x	resistant torque along X direction of the rectangular coordinates
M_y	resistant torque along Y direction of the rectangular coordinates
R	value of the resistance
C	value of the capacitance
f_c	cut-off frequency of the filter
U_i	input voltage
U_o	output voltage
T1, T2, T3, T4	transistors

ABSTRACT

The thesis presents the design and development of a 2-DOF (degree of freedom) magnetorheological (MR) fluid based haptic joystick and studies its applications in virtual reality. MR fluids are controllable fluids that can generate adaptable resistance forces when subjected to a magnetic field. This feature is capable of realizing novel haptic devices.

The developed system consists of three main parts: MR joystick, control and display hardware, and software. The MR joystick is constructed of two disc-shaped MR actuators positioned perpendicularly with a gimbal structure, which transfers the movement of the joystick handle into two actuator rotary movements. Therefore, operators can feel the resisting force generated by the two actuators. The dimensions of the actuators have been optimized using finite element analysis, and the steady-state performance of the actuators has been measured and analyzed. The kinetics of the joystick in terms of working space and resistance will be discussed. In the thesis, a subhysteresis model and a torque converting method will be employed to enhance the accuracy of the force control.

The applications of the MR joystick in virtual reality will be demonstrated by using six typical interface examples designed in LabVIEW. These demonstrations show that the MR haptic devices have a huge application potential in entertainment, medical, and general industry fields.