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# **Tree Pruning/Inspection Robot Climbing Mechanism Design, Kinematics Study and Intelligent Control**

A thesis presented in partial fulfilment of the requirements for the degree of

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## **Abstract**

Forestry plays an important role in New Zealand's economy as its third largest export earner. To achieve New Zealand Wood Council's export target of \$12 billion by 2022 in forest and improve the current situation that is the reduction of wood harvesting area, the unit value and volume of lumber must be increased.

Pruning is essential and critical for obtaining high-quality timber during plantation growing. Powerful tools and robotic systems have great potential for sustainable forest management. Up to now, only a few tree-pruning robotic systems are available on the market. Unlike normal robotic manipulators or mobile robots, tree pruning robot has its unique requirements and features. The challenges include climbing pattern control, anti-free falling, and jamming on the tree trunk etc. Through the research on the available pole and tree climbing robots, this thesis presents a novel mechanism of tree climbing robotic system that could serve as a climbing platform for applications in the forest industry like tree pruning, inspection etc. that requires the installation of powerful or heavy tools. The unique features of this robotic system include the passive and active anti-falling mechanisms that prevent the robot falling to the ground under either static or dynamic situations, the capability to vertically or spirally climb up a tree trunk and the flexibility to suit different sizes of tree trunk. Furthermore, for the convenience of tree pruning and the fulfilment of robot anti-jamming feature, the robot platform while the robot climbs up should move up without tilting. An intelligent platform balance control system with real-time sensing integration was developed to overcome the climbing tilting problem. The thesis also presents the detail kinematic and dynamic study, simulation, testing and analysis.

A physical testing model of this proposed robotic system was built and tested on a cylindrical rod. The mass of the prototype model is 6.8 Kg and can take 2.1 Kg load moving at the speed of 42 mm/s. The trunk diameter that the robot can climb up ranges from 120 to 160 mm. The experiment results have good matches with the simulations and analysis.

This research established a basis for developing wheel-driven tree or pole climbing robots. The design and simulation method, robotic leg mechanism and the control methodologies could be easily applied for other wheeled tree/pole climbing robots. This research has produced 6 publications, two ASME journal papers and 4 IEEE international conference papers that are available on IEEE Xplore. The published content ranges from robotic mechanism design, signal processing, platform balance control, and robot climbing behavior optimization. This research also brought interesting topics for further research such as the integration with artificial intelligent module and mobile robot for remote tree/forest inspection after pruning or for pest control.

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## List of Abbreviations

2WD: two wheel drive.....	117
ABS: anti-lock brake system .....	115
ANN: artificial neural network .....	129
ARX: autoregressive network with exogenous inputs.....	130
B: Kalman filter control matrix.....	87
b_a: accelerometer bias .....	86
b_g: gyroscope bias .....	86
CAD: computer aided design.....	16, 18
d: diameter of trunk .....	39
D: stepper nut translation distance .....	119
DARPA: defence advanced research project agency .....	19
DIC: direct inverse control .....	113
DNN: dynamic neural networks .....	113
DNNC: dynamic neural network control .....	135
DOF: degree of freedom .....	22
dps: degree per second.....	69
e.g.: for example .....	75
e_i: robot wheel i velocity error.....	123
E_r: stepper rotational kinetic energy .....	119
E_t: stepper translational kinetic energy .....	119
EMC: electro-magnetic compatibility .....	71
EMI: electro-magnetic interference.....	71
Eqn.: equation .....	48
ESP: electronic stability program.....	115
etc.: et cetera .....	42
F_1: normal force applied on wheel 1 .....	38
F_f: frictional force .....	48
F_H: horizontal resultant force .....	47
F_M: force from DC motor .....	54
F_r: rolling resistance .....	54
f_s: stepper thread friction force coefficient .....	119
F_s: thrust from stepper lead screw .....	119
F_smax: stepper maximal thrust .....	126
F_V: vertical resultant force .....	47
Fig.: figure .....	19
G: gravity force.....	38
GDP: gross domestic product.....	15, 18
GHz: gigahertz .....	74
H: Kalman filter measurement matrix .....	88
h: vertical distance between wheel 3 and wheel 1, 2.....	39
HF: high frequency .....	79
Hz: Hertz.....	40
i.e.: id est.....	74
I: robot wheel rotational inertia .....	54

IC: integrated circuit.....	78
IMU: inertial measurement unit .....	61
$I_{pp}$ : peak impulse current.....	78
$\text{kg/m}^3$ : Kilogram per cubic meter.....	56
Kg: Kilogram.....	39
kg-cm: Kilogram per centimeter .....	58
L: horizontal distance from the contact point between wheel 3 and trunk .....	39
l: stepper thread lead.....	119
m/s: meter per second.....	41
m: meter.....	42
M: rolling moment .....	49
MCU: microprogrammed control unit .....	42
MEMS: micro-electromechanical-systems.....	69
MFs: fuzzy logic membership functions.....	107
MHz: megahertz.....	74
mm/s: millimeter per second.....	57
mm: millimeter .....	45
$\text{mm}^2$ : square millimeter.....	56
$\text{mm}^3$ : cubic millimeter .....	56
MPC: model predictive control .....	116
N/kg: Newton per Kilogram.....	39
N: Newton .....	39
n: stepper steps.....	119
$n_a$ : accelerometer noise.....	86
$n_g$ : gyroscope noise.....	86
NARX: nonlinear autoregressive network with exogenous inputs.....	130
N-m: Newton per meter .....	57
PCB: printed circuit board.....	53
PCRs: pole climbing robots.....	31
$P_{pp}$ : peak pulse power dissipation.....	78
PVC: polyvinyl chloride.....	25
PWM: pulse width modulation .....	66
$Q_\theta$ : accelerometer variance .....	88
R: radius of tree trunk.....	43
$r_0$ : robot wheel free radius .....	49
$r_r$ : robot wheel rolling radius .....	54
$r_s$ : robot wheel static radius.....	49
RF: radio frequency .....	79
RMSE: root mean square error .....	112
rpm: revolutions per minute .....	57
SEAT: school of engineering and advanced technology .....	4
SMD: surface mounted device.....	73
$T_F$ : robot wheel longitudinal torque.....	119
$T_G$ : robot gravity torque .....	54
$T_M$ : torque from DC motor .....	54
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$T_s$ : stepper actuate torque.....	119
$T_{smax}$ : stepper maximal torque.....	126

TVS: transient voltage suppressor .....	78
$u_k$ : Kalman filter control input .....	87
UART: universal asynchronous receiver/transmitter.....	109
$\dot{v}$ : robot acceleration .....	119
$v$ : robot velocity .....	119
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$V_c$ : clamping voltage .....	78
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$w$ : robot gravity force offset from the center of platform .....	39
WA: weight average .....	105
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$x_k$ : system state matrix at time $k$ .....	87
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$\mu m$ : micrometer .....	67
$\dot{\omega}$ : wheel angular acceleration .....	119
$\omega$ : wheel angular velocity .....	119
$\omega_{ref}$ : robot wheel setting angular velocity .....	123
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