DEVELOPMENT OF ROBUST CONTROL SCHEME FOR WHEELED MOBILE ROBOT IN RESTRICTED ENVIRONMENT

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Manufacturing and Mechatronic Engineering Technology
UNIVERSITI MALAYSIA PAHANG

JUNE 2021

ACKNOWLEDGEMENTS

In the name of Allah,The Most Beneficient,The Most Merciful.

As I am one step ahead from completing my master of science, and at the end of my university life, it is a great honor for me to express my gratitude toward people who helped me to make this achievement. I am certain that whatever I would say or write will not be sufficient to pay them back the support and encouragement I have gotten. The first two how deserves my full appreciation and love are my beloved parents *A Radzak Bin Mamat* and *Tengah binti Musa*. I am not exaggerating, if I said that they were the main reason after Allah's blessings for me to complete my master. I would like also to thank my sisters and brother for their moral support, they were the source of strength and encouragement. My relatives, friends, and whoever helped me to accomplish my master deserves my appreciation and thankfulness.

My acknowledgement would be uncompleted, if I do not express my gratitude and gratefulness to my supervisor *Dr. Mohammed Abdo Hashem*. He guided me in every single step of my Research here. His advance knowledge and expertise really help me a lot when finishing the hardware, software and thesis. Moreover, his patience, enthusiasm, and motivation has change my mind to feel that the project is more interesting and easy to be followed. It is good to have this mentor in my research study.

Last but not least, I would like to give special thanks to my friend *Zainal Fahmi*, for helping me to register my desired specialization which is Mechatronics Engineering.

ABSTRAK

Penyelidikan ini bertujuan untuk membangunkan sebuah robot mudah alih beroda (WMR) yang dapat menjejaki secara pasti dan tegas trajektori tertentu dalam persekitaran yang terkawal seperti di jalan raya atau di kilang-kilang. Kawalan robot mudah alih dikawasan yang terhad seperti dijalan raya dan persekitaran dalam kilang semasa pelaksanaan laluan masih merupakan masalah yang rumit dalam penyelidikan robot, kerana ia perlu mengekalkan kesilapan penjejakan di tahap yang sifar dan robot beroda hendaklah mengikuti dengan teguh pra-laluan yang ditentukan menggunakan sistem kawalan yang sesuai, jika tidak ia boleh menyebabkan robot berlanggar dengan objek lain. Novel Algoritma yang dikenali sebagai simulator laser telah dibangunkan untuk menganggarkan masa inersia apabila persekitaran bising dan algoritma logic kabur tidak boleh digunakan. Algoritma ini memberikan kemungkinan untuk mengira fungsi keahlian dengan pembolehubah linguistik yang bertindih dan dengan itu mengeluarkan bunyi bising dalam system. Pengawal derivatif berkadar-kawalan kuasa aktif-simulator laser-maklumbalas pampasan (PD-AFC-LS-FB) yang baru melibatkan penggunaan logik simulator laser dan maklumbalas gelung pantas telah dibangunkan dalam projek ini untuk membuang kebisingan dan gangguan. Satu kajian simulasi kawalan WMR dalam laluan pra-dirancang dalam dua persekitaran, iaitu medan zigzag dan kawasan yang melengkung telah dijalankan untuk mengesahkan algoritma yang dicadangkan dan bandingkan dengan algoritma yang sedia ada. Oleh itu, satu prototaip robot mudah alih beroda (WMR) baru dengan empat roda, dua pembezaan dan dua roda kastor telah direka, dibina dan diperiksa di makmal. Robot mudah alih beroda dilengkapi dengan dua sensor, pengekod dan sensor arus, dan arus terus (DC) motor untuk melaksanakan laluan yang diperlukan dalam persekitaran yang dikawal. Pengawal tertanam telah digunakan untuk mengintegrasikan komponen platform seperti komponen elektronik, komponen mekanikal dan program komputer dengan struktur interfacing yang sesuai. Sistem pengawal PD-AFC menggunakan penggunaan tiga gelung kawalan umpan balik, iaitu gelung pampasan dalaman, luaran dan cepat, telah digunakan untuk mengimbangi gangguan dalam persekitaran yang dikekang. Gelung luaran digunakan untuk mengawal parameter kinematik sistem kawalan, namun gelung dalaman digunakan untuk mengawal sistem dinamik robot dan membuang gangguan. Sebaliknya, gelung pampasan yang cepat telah diperkenalkan untuk mengimbangi perbezaan antara pecutan rujukan dan pecutan yang sebenar. Keputusan simulasi menunjukkan bahawa algoritma yang dicadangkan mempunyai prestasi yang terbaik di antara semua pengawal sama ada dalam persekitaran zigzag atau bulatan, terutamanya apabila gangguan tersebut digunakan. Untuk mengesahkan keputusan simulasi untuk algoritma yang dicadangkan, eksperimen sebenar dalam laluan bulat telah dijalankan untuk menunjukkan bahawa skim pengawal yang dicadangkan cukup kuat dalam kawalan sebenar dan dapat menjejaki robot dengan berkesan pada laluan rujukannya. Hasil keputusan eksperimental menunjukkan keupayaan algoritma yang dicadangkan dan skim kawalan yang baru untuk memacu robot mudah alih beroda secara teguh dalam persekitaran yang terkurung dan eksperimen ini mengesahkan simulasi yang dijalankan.

ABSTRACT

This research is aimed to develop a wheeled mobile robot (WMR) that is able to track reliably and robustly a certain trajectory in a constrained environments. The control of MWR in the restricted areas during path execution still a complicated problem in robot researches, since it needs to maintain the tracking errors at the zero level and the wheel mobile robot must follow robustly the pre-defined path using a suitable control system; otherwise it can cause to crash robot with other objects. A novel algorithm so called laser simulator logic (LSL) has been developed to estimate the inertia moment when the environment is noisy and cannot use fuzzy logic algorithm. This algorithm gives the possibility to calculate the membership function with highly overlapped linguistic variables and thus remove the noise. The proposed LSL is then integrated with existing Active Force Control (AFC) and PD to ensure good closed loop performance and reject the noise and disturbances. A simulation study of WMR control in pre-planned paths in two environments namely, zigzag and highly curved terrains, has been conducted to verify the proposed algorithm and compare it with other existed algorithms. Thus, a new WMR prototype with four wheels, two differential and two castor wheels has been designed, fabricated and inspected in the laboratory. The WMR is equipped with two sensors, encoders and current sensor, and direct current (DC) motor to perform the required path in the constrained environments. An embedded controller has been used to integrate the platform components such electronics components, mechanical components and computer programs with appropriate interfacing structure. PD-AFC controller system employing the use of three feedback control loops, namely, internal, external and quick compensation loops, have been used to compensate the disturbance in constrained environments. The external loop is used to control the kinematics parameters of the control system via PD controller, However, the internal loop is used to control the dynamic of robot and disturbance rejection via AFC controller. On the other hand, a quick compensation loop has been introduced to compensate the difference between the reference and actual acceleration via PD controller. The results of simulation show that the proposed algorithm has the best performance among all controllers either in zigzag or circular environments, especially when the disturbances are applied. To confirm the results of simulation for the proposed algorithm, a real-time experiments in circular path has been conducted to show that the proposed controller scheme is robust enough in the real-time control and able to track the robot effectively on its reference path. The experimental results work show the capability of the proposed algorithms and the new controller to robustly move the WMR in the constrained environments, thereby it verifys the simulation counterpart.

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LIST OF SYMBOLS

C	The center of mass mobile robot
d	The distance between the center of mass and driving wheels axis in x-direction
P	The intersection of the axis of symmetry with the driving wheels axis
b	The distance between each driving wheel and the robot axis of symmetry in y- direction
ϕ	Heading rotation angle of WMR
V	Velocity of WMR
km/h	Kilo meter/hour
cm	Centimeter
mm	Milimeter
m	Meter
µ	Micro/mu
≤	Less than or equal to
τ	Torque
Ɵ	Theta
ƛ	Lagrange multipliers vector.
φ	Heading rotation angle of WMR
$\dot{x}$	Velocity of WMR in *x* direction
$\dot{y}$	Velocity of WMR in y direction
$\dot{\varphi}$	Angular velocity of WMR
K	Kinetic energy
v	Potential energy
A^T (q)	Transpose of constraint matrix
K_b	Kinetic body
T	Translational
R	Rotational
m_b	Mass of MWR body
I_b	Inertia moment of WMR body
$K_{wr}T$	Right wheel (Translational)
m_{wR}	Mass of right wheel of WMR body

$K_{wr}R$	Right wheel (Rotational)
K_{rw}	Kinetic right wheel
IwR	Inertia moment of the right wheel
K_bT	Kinetic body (Translational)
K_bR	Kinetic body (Rotational)
$\dot{\theta}_R$	Angle velocity of right wheel
$K_{wl}T$	Left wheel (translational)
m_{wL}	Mass of left wheel of WMR body
K_{lw}	Kinetic left wheel
IwL	Inertia moment of the left wheel
$\dot{\theta}_L$	Angle velocity of left wheel
I	Moment inertia of robot
I_w	Moment inertia of the wheel
$\ddot{\theta}_L$	Angle acceleration of left wheel
$\ddot{\theta}_R$	Angle acceleration of right wheel
m	Total mass of mobile robot
τ_r	Applied torques on the right wheels
τ_l	Applied torques on the left wheels
q_{ref}	Reference position values of *x*, *y*, *phi*
q_{act}	Actual position values of *x*, *y*, *phi*
$\dot{q}_{ref}$	Reference velocity values of *x*, *y*, *phi*
$\dot{q}_{act}$	Actual velocity of *x*, *y*, *phi*
$\ddot{q}_{ref}$	Acceleration reference values of x, y, phi
K_p	Proportional constant
K_v	Deriavative constant
τ_d	Disturbance torque
θ_{act}	Actual rotation of the wheel.
$\dot{\theta}_{act}$	Actual angular velocity
$\ddot{\theta}_{act}$	Actual angular acceleration

LIST OF ABBREVIATIONS

AFC	Active Force Control
AI	Artificial Intelligent
DC	Direct Current
FB	Quick Feedback Compensation
FL	Fuzzy Logic
IMU	Inertial Measurement Unit
IN	Inertia Matrix
LS	Laser Simulator
NMPC	Nonlinear Model Predictive Control
PD	Proportional-derivative
PID	proportional integral-derivative
PWM	Pulse Width Modulation
RAC	Resolved Acceleration Control
RBF	Radial Basis Function
RTK	Real Time Kinematic
SMC	Sliding Mode Controller
WMR	Wheel mobile robot

REFERENCES

Abdullah, S., Mailah, M., Tang, C., & Hing, H. (2013). *Feedforward Model Based Active Force Control of Mobile Manipulator using MATLAB and MD Adams*. *12*(6), 314–324.

Abhishek, V. (2016). *Dynamic Identification and Model based Control of an Omni-wheeled Mobile Robot*. 595–600.

Ali, M. A. H., Mailah, M., Yussof, W. A. N. A. B., Hamedon, B. I. N., & Yussof, Z. B. M. (2017). *An Intelligent Robust Control of Wheeled Mobile Robot in Restricted Environment*. *2*, 6–11.

Anwar P.P. A. M., Zahari Taha, Muhammad Amirul Abdullah, Kamil Zakwan Mohd Azmi and Muhammad Aizzat Zakaria (2018). The control of an upper extremity exoskeleton for stroke rehabilitation: An active force control scheme approach. *Advances in Robotics Research*, Vol. 2, No. 3 (2018) 237-245

Bahru, J. (2011). *Modelling and control of a piezo actuated micro robot with active force control capability for in-pipe application Yaser Sabzehmeidani , Musa Mailah * and Mohamed Hussein*. *13*(4).

Boukattaya, M., Damak, T., & Jallouli, M. (2011). *Robust Adaptive Control for Mobile Manipulators*. *8*(February), 8–13. https://doi.org/10.1007/s11633-010-0548-y

Chen, Chih-yang, Li, T. S., & Yeh, Y. (2009). EP-based kinematic control and adaptive fuzzy sliding-mode dynamic control for wheeled mobile robots. *Information Sciences*, *179*(1–2), 180–195. https://doi.org/10.1016/j.ins.2008.09.012

Chen, Chunyu, Torre, F. D. La, & Dong, W. (2014). *Distributed Exponentially Tracking Control of Multiple Wheeled Mobile Robots* *. 4014–4019.

Chen, J., Dixon, W. E., & Dawson, D. M. (2006). *Homography-Based Visual Servo Tracking Control of a Wheeled Mobile Robot*. *22*(2), 407–416.

Chiu, C. S., Chiang, T. S., & Ye, Y. T. (2016). Fuzzy obstacle avoidance control of a two-wheeled mobile robot. *CACS 2015 - 2015 CACS International Automatic*

Control Conference, 1–6. https://doi.org/10.1109/CACS.2015.7378356

Cui, M., Liu, W., & Liu, H. (2016). *Wheeled Mobile Robots in the Presence of Wheel Slipping*. 3335–3340.

Ghiasvand, M., & Alipour, K. (2013). Formation control of wheeled mobile robots based on fuzzy logic and system dynamics. *13th Iranian Conference on Fuzzy Systems, IFSC 2013*, *0*(1). https://doi.org/10.1109/IFSC.2013.6675674

Hewit, J. R., & Burdess, J. S. (1981). Fast dynamic decoupled control for robotics, using active force control. *Mechanism and Machine Theory*, *16*(5), 535–542. https://doi.org/10.1016/0094-114X(81)90025-2

Koubaa, Y., Boukattaya, M., & Damak, T. (2014). Adaptive sliding-mode control of nonholonomic wheeled mobile robot. *STA 2014 - 15th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering*, 336–342. https://doi.org/10.1109/STA.2014.7086759

Lei, C., & Ma, B. (2015). A nonlinear formation control of wheeled mobile robots with virtual structure approach. *Chinese Control Conference, CCC*, *2015-Septe*, 1080–1085. https://doi.org/10.1109/ChiCC.2015.7259784

Li, Z., Wang, Y., Song, X., & Liu, Z. (2015). *Neural Adaptive Tracking Control for Wheeled Mobile Robots*.

Liu, Y., Yu, S., Gao, B., & Chen, H. (2015). Receding horizon following control of wheeled mobile robots: A case study. *2015 IEEE International Conference on Mechatronics and Automation, ICMA 2015*, 2571–2576. https://doi.org/10.1109/ICMA.2015.7237892

Low, C. B., & Wang, D. (2008). *GPS-Based Tracking Control for a Car-Like Wheeled*. *13*(4), 480–484.

Mailah, M., Abdullah, S., & Hing, T. H. (n.d.). *Tracking Performance on Feedfoward Model Base Active Force Control of Mobile Manipulator using Matlab and Adams*. 83–88.

Mu, J., Yan, X., Spurgeon, S. K., & Mao, Z. (2015). *Trajectory Tracking Control of a Two-Wheeled Mobile Robot Using Sliding Mode Techniques ∗*. 3307–3312.

Nagarajan, U., Kantor, G., & Hollis, R. L. (2009). *Trajectory Planning and Control of an Underactuated Dynamically Stable Single Spherical Wheeled Mobile Robot*. 3743–3748.

Park, B. S., Yoo, S. J., Park, J. B., & Choi, Y. H. (2009). *Adaptive Neural Sliding Mode Control of Nonholonomic Wheeled Mobile Robots With Model Uncertainty*. *17*(1), 207–214.

Partovibakhsh, M., & Liu, G. (2015). *Slip Ratio Estimation and Control of Wheeled Mobile Robot on Different Terrains*. 566–571.

Raeisi, Y., Shojaei, K., & Chatraei, A. (2015). Output feedback trajectory tracking control of a car-like drive wheeled mobile robot using RBF neural network. *6th Annual International Power Electronics, Drive Systems, and Technologies Conference, PEDSTC 2015*, (February), 363–368. https://doi.org/10.1109/PEDSTC.2015.7093302

Song, Z., Ren, H., Zhang, J., & Ge, S. S. (2016). Kinematic Analysis and Motion Control of Wheeled Mobile Robots in Cylindrical Workspaces. *IEEE Transactions on Automation Science and Engineering*, *13*(2), 1207–1214. https://doi.org/10.1109/TASE.2015.2503283

Wheels, D., Guan, X., Zhang, P., Fang, M., Hu, Y., & Zhang, J. (2014). *The Adaptive Control for the Outdoor Mobile Robot with*. (61105132), 1096–1101.

Xie, D., Xu, Y., Wan, J., Han, D., & Lu, F. (2017). Trajectory Tracking Control of Wheeled Mobile Robots Based on RTK-GPS. *Jiqiren/Robot*, *39*(2), 221–229. https://doi.org/10.13973/j.cnki.robot.2017.0221

Yang, H., Fan, X., Shi, P., & Hua, C. (2016). *Nonlinear Control for Tracking and Obstacle Avoidance of a Wheeled Mobile Robot With Nonholonomic Constraint*. *24*(2), 741–746.

Yoon, J., Oh, J. H., Park, J. H., Kim, S., & Lee, D. (2014). Autonomous dynamic driving control of wheeled mobile robots. *Proceedings - IEEE International Conference on Robotics and Automation*, 5274–5279. https://doi.org/10.1109/ICRA.2014.6907634

Yunhua L., Liuyu L., & Liman Y. (2013). Path-following Control for Multi-axle Car-like Wheeled Mobile Robot with Nonholonomic Constraint. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)* 5424–5342. https://doi.org/10.1109/ICRA.2013.6904356

Zidani, G., Drid, S., Chrifi-Alaoui, L., Arar, D., & Bussy, P. (2014). Nonlinear tracking control of a wheeled mobile robot. *STA 2014 - 15th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering*, 325–330. https://doi.org/10.1109/STA.2014.7086727