Velocity analysis of a six wheel modular mobile robot using MATLAB-Simulink

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Abstract. This paper presents the modelling and simulation of a six wheeled three body modular robot in MATLAB Simulink. The modules are modelled as an independent differential drive wheeled mobile robot. Velocity and distance were measured using three different configurations: two wheel, four wheel and six wheel configuration. The simulation result was able to predict the response of the modular body in different configurations in terms of velocity and distance with contact forces acting upon it.

1. Introduction

Modular reconfigurable robots or MRR are made up of modules that can rearrange themselves to different configurations to perform certain tasks. Modular self-reconfigurable systems, size, robustness and performance have been continuously improving however there are challenges for these systems to realize their promise of adaptability, robustness and affordability. MRR faces hardware design and Software control challenges [1-3]. Modular Robots are consisting of several independent modules that have different capabilities that can connect or form into a different configuration. These hardware and mechanical structures such actuators, a sensing communication device, structural strength, connection mechanism, and others are required in order for it to function properly. To perform certain task a modular system, have complex software requirements that help them run independently, as a swarm, form an organism, task shape matching, reconfiguration, planning and control.

A Six-wheel independent drive is considered to have better performance, efficient power utilization & stability over other wheeled vehicles such as four wheel drive. Due to the advantages over conventional axle drive systems; All wheel independent drive vehicles are getting popularity in special purpose as well as commercial purpose vehicles. This configuration is good in obstacle climbing, off-road maneuvering, failure handling of few wheels, because of independent wheel motion control, used in exploration, search and rescue [4].

Several researches use a six or more wheel configuration design for climbing, transport and exploration [5-7]. The concept of [5] is to develop a detachable modular robot capable of cooperative climbing and multi agent exploration and will improve the task and exploration coverage but there are a variety of optimal control problems that might pose in this system. [7] Develop an end to end system for addressing tasks with modular robots and demonstrate that it can accomplish challenging multi part
tasks. They use a SMORES-EP Modular robot that has 6 different configurations depending on the number of connected modules and the stair climber configuration has a total of 4 modules. [8] Uses an S-bot in a chain of three or more to transport the object. With these different studies they use 3 modules to accomplish certain tasks and a six wheel configuration is ideal in an exploration and rover application. There has been a lot of interest in optimizing, formulation and control of actuators for six-wheel independent drive vehicles to maximize its exploration capabilities [4].

A six wheeled three body modular mobile robot was modeled, and the dynamics were simulated. To understand and analyse its capability and see the effect of several interconnecting module bodies to the whole system such as velocity, distance, climbing capacity, pulling capacity and other parameters that will affect its performance on different tasks. To understand if the configuration would yield an advantage or disadvantage to the modular system.

2. Methodology
2.1. Design Model
A differential drive design model was used per module that consisted of two wheels and was then combined to form a six wheel. Equation 1 shows the differential drive modular body system. The system state x can be described by the robot’s location xR and yR, forward velocity v, heading θ, and angular velocity ω. Mathematically, this is described as $x = [xR; yR; v; \theta; \omega] T$. Taking our inputs as $u_l$ and $u_r$, the forces exerted by the left and right wheels respectively, system.

$$
\begin{align*}
x &= f(x) = \\
&= \begin{bmatrix}
   v \cos \theta \\
   v \sin \theta \\
   \frac{u_r + u_l}{M} - b_v \\
   \frac{\omega}{M} \\
   \frac{B(u_r - u_l)}{I_z} - b_r \omega 
\end{bmatrix}
\end{align*}
$$

(1)

where $M$ is the vehicle mass, $b$ is the linear drag constant, $B$ is the length from the center of the vehicle to the wheel, $I_z$ is the moment of inertia, and $b_r$ is the turning drag constant. We assume the magnitude of each input $u_l$ is bounded by $u_{max}$ and the velocity is bounded by $v_{max}$. The proponent will use a differential ground drive robot for each module and will be simulated in a six wheeled configuration.

![Figure 1](image.png)

**Figure 1** Two wheel differential drive module

A single module body will be modeled as a differential drive robot. $L$ as a wheelbase body and $r$ as the wheel radius. The robot will be controlled by moving the two wheels. The input on the wheel on the left and the wheel on the right. As the configuration changes from four wheel to six wheel they will be simulated and check the response of the configuration pertaining to the action of each module. If they
will increase the module capacity of the whole system in terms of total velocity or distance. The configuration set-up which is the four wheel, or six wheels will check the effect of velocity and distance travel of different configurations. As mentioned in [5-7] they have certain advantages and disadvantages when they are in a collective manner or as an individual. They will be simulated by checking the response of the system when the whole module has inputs on their wheel and varying each module's wheel input to check the interaction of the modules in the simulated configuration.

![Figure 2](image)

**Figure 2** Propose six wheel 3 module setup

Contact modelling was used in the modular body to approximate the physical phenomena of the mass of the module as well as the rolling of the tires. This helps in the analysis of the mechanical system. A sphere to plane contact force library was used to simulate the design model of the modular body and compare the result of the individual and whole configuration. This contact force library implements a contact force between two bodies which is the sphere (wheels) and the plane(floor). To check the movement of the wheel with respect to different forces such as gravity and friction forces. Static and Kinematic Friction are set up in this library as well as the density of the body to signify the effect of the gravitational phenomena.

![Figure 3](image)

**Figure 3** Contact Forces acting on a body

### 2.2. MATLAB Simulink

Contact force library was used in the simulation [9]. Figure 3 shows a Simulink model of a two wheel differential module. Each component of the system has a force acting on the body from the weight of the plate to the ground; Rotational motion of the wheel to the body; The surface contact and weight of the wheel to the ground. A ramp up signal is used each wheel to simulate its movement; the floor is used as a world frame reference for rigid transformation in order to set the gravitational force direction. The wheel is connected to the body via a revolute joint transformation. The wheel is in contact in the floor via prismatic joint transformation. Velocity and distance are measured via a Simulink transformation sensor relative to the ground and wheel in contact. In simulating different configurations for a four wheel and six wheels, the mass is changed and depends on the number of modules with each wheel having an independent motion. To evaluate the effect of the different configuration on velocity and distance.
3. Results and Discussion

The six wheel three module body was modelled and simulated in MATLAB Simulink pertaining to the movement of wheels. A total of three configurations were tested in two wheel, four wheel and six wheel set-up and then tested on one module moving the body. Figure 5 shows the design model of the module in the MATLAB Simulink. It was modeled in the MATLAB Simulink with estimated parameters of one module will have $L = 80\text{mm}$ and $R = 16\text{mm}$ with thickness of $7\text{mm}$ as the module size is reference to a Micromouse platform [15] and other modular reconfiguring robots are at the micro size level. Contact forces are set to default such as gravity, kinetic and static friction. The density of the material is set to $1000\ \text{kg/m}^3$ to simulate the mass of the module. A ramp up signal was introduced to both wheels and it yielded a simulated velocity of 0.1596 m/s in a one module differential drive set-up. It was tested on a 10 second time trial and the measure the distance that it recorded on the Simulink scope is 1.589 m that can be seen in figure 6. Dimension such as body and wheel size will affect the output result due to weight. In this set up we investigate the effect of the module configuration to the capacity of the system which we define as velocity and distance. Different parameters and different set up will yield different results.
Velocity and distance were tested for the two wheel one module body, four wheel two module body and a six wheel three module body. Every module is identical. The simulated output results of the four wheel and six wheels can be seen in figure 7 and 8. The four wheel two module set up resulted in an increase of velocity and distance travel. There is a slight increase from 0.1596 to 0.16 m/s as simulated while distance travel increases from 1.589 to 1.595m. The initial start-up as seen in the graph is faster compared to the single module configuration. However, results from the 3 module configuration resulted in a decrease in velocity and distance due to the total weight having a velocity of 0.1594 and distance travel of 1.57m in 10 seconds. The initial start-up of velocity was also slow in comparison to the two module set up even though it is in six wheel configuration. This result give a in terms of velocity and distance travel however if we use the stability, terrain capabilities and other advantages of a six wheel such as climbing, pulling capacity and other things will be different.
4. Conclusion
The study was able to model and simulate the dynamics of a six wheel three body modular robot with interaction forces acting upon it such as gravity and contact surfaces. Measuring the different configuration velocity and distance and understanding its effect on the system. The simulation is used as a tool to check the proposed strategy in measuring the dynamics of a six wheeled modular mobile robot that will aid in measuring other capacities such as climbing, torque, push, pulling and other capabilities on different configurations. Further simulation and validation of the study will be continued and analysed by the researcher.

References
[1] Seo J, Paik J and Yim M 2019 Modular reconfigurable robotics Annual Review of Control, Robotics, and Autonomous Systems 2 pp 63-88
[2] Brunete A, Ranganath A, Segovia S, de Frutos J P and Hernando M 2017 Current trends in reconfigurable modular robots design International Journal of Advanced Robotic Systems 14(3) 1729881417710457
[3] Yim M, Shen W M, Salemi B, Rus D and Moll M 2007. Modular self-reconfigurable robot systems [gran challenges of robotics]. IEEE Robotics & Automation Magazine 14(1) pp 43-52
[4] Prasad R and Ma Y 2019 Hierarchical control coordination strategy of six wheeled independent drive (6WID) skid steering vehicle IFAC 2019
[5] Turlapati S H, Srivastava A, Krishna K M and Shah S V 2017 Detachable modular robot capable of cooperative climbing and multi agent exploration 2017 IEEE International Conf. on Robotics and Automation (ICRA) 255-260
[6] Turlapati S H, Shah M, Teja S P, Siravuru A and Shah S V 2015 Stair climbing using a compliant modular robot 2015 IEEE/RSJ International Conf. on Intelligent Robots and Systems
[7] Jing G, Tosun T, Yim M and Kress-Gazit H 2016 An end-to-end system for accomplishing tasks with modular robots, Robotics: Science and Systems
[8] Groß R, Tuci E, Dorigo M, Bonani M and Mondada F 2006 Object transport by modular robots that self-assemble Proceedings 2006 IEEE International Conf. on Robotics and Automation
[9] Miller S 2020 Simscape Multibody Contact Forces Library (https://www.mathworks.com/matlabcentral/fileexchange/47417-simscape-multibody-contact-forces-library), MATLAB Central File Exchange
[10] Christensen A L 2008 Fault Detection in Autonomous Robot, Université Libre de Bruxelles
[11] Fourlas G K, Karkanis S, Karras G C and Kyriakopoulos K J 2014 Model based actuator fault diagnosis for a mobile robot *2014 IEEE International Conf. on Industrial Technology (ICIT)* 79-84

[12] Bandala A A, Dadios E P, Vicerra R R P and Lim L A G 2014 Swarming algorithm for unmanned aerial vehicle (uav) quadrotors–swarm behavior for aggregation, foraging, formation, and tracking *Journal of Advanced Computational Intelligence and Intelligent Informatics*

[13] Bandala A A and Dadios E P 2012 Development and design of mobile robot with IP-based vision system *TENCON 2012 IEEE Region 10 Conf.*

[14] Del Rosario J R B, Sanidad J G, Lim A M, Uy P S L, Bacar A J C and Cai M A D 2014 Modelling and characterization of a maze-solving mobile robot using wall follower algorithm *Applied Mechanics and Materials* 446 pp 1245-1249

[15] Gavin Nielsen 2017 Micro Mouse Modelling Simscape MultiBody

[16] Ramakrishnan R, Elayaraja D and Ramabalan S 2014 Adaptive control of nonholonomic wheeled mobile robot *ICAIT.*

[17] Angel L, Hernández C and Díaz-Quintero C 2013 Modeling, simulation and control of a differential steering type mobile robot *32nd Chinese Control Conf.*

[18] Khnissi K 2019 3D Simulator for Navigation of a Mobile Robot Using Simscape-SIMULINK *ICCAD*