Kinematic Control of a Wheeled Humanoid Robot with Redundant Arms

Shifa Sulaiman
PhD Scholar, Department of Mechanical Engineering
National Institute of Technology (NIT), Calicut, India
ssajmech@gmail.com

Shoby George
Artificial Intelligence Engineer, Trois Infotech, Trivandrum, India

Dr. A P Sudheer
Assistant Professor, Department of Mechanical Engineering
National Institute of Technology (NIT), Calicut

Abstract

Conventional control schemes employed for controlling the wheeled humanoid robot consume more computational time due to large number of calculations. A kinematic control scheme with better computational efficiency adopted for controlling wheeled humanoid robot is presented in this paper. The upper body humanoid robot consists of 15 degrees of freedom (dof) and mobile platform consists of 2 actuated wheels. The kinematic control strategies along with PID controllers are implemented using two separate loops for the upper body and mobile robot controls. Simulations are carried out to prove the advantages of the proposed control algorithm for a wheeled humanoid robot.

Keywords
Wheeled humanoid robot, Modelling, Analysis, Kinematic control, PID control.

1. Introduction
Motion tracking control of robots with less computational efforts is very difficult to achieve due to the presence of large number of control parameters and constraints. There are different types of linear and nonlinear motion tracking control strategies available in the area of wheeled humanoid robot control. Various linear and nonlinear model predictive controllers for mobile robots using model predictive control schemes are presented by Nascimento et al. (2018). Tracking control strategy suitable for holonomic and non-holonomic mobile robot is illustrated by Sharma et al. (2020). The robot is considered as a double integrator system. The proposed algorithm is tested using three mobile robots in real time and can be extended to more number of robots. The control strategy adopted for a non-holonomic mobile platform to track a given object using image processing technique is given by Wang et al. (2009). Lyapunov method and computed torque control method are combined together to form a hybrid control algorithm. The control inputs are based on torque values and outputs are the poses of the robot. Ali and Mailah (2019) illustrated the mobile robot motion control using a robust controller. The path followed by the mobile robot is determined using a novel approach called laser simulation technique. The kinematic and dynamic model is incorporated into the control model to reduce the controlling errors. The balancing control of a humanoid robot is presented by Abi-Farraj et al. (2019). Most of the conventional balancing algorithms control the COM of the robot. However, in this paper authors used gravitational and inertial wrench parameters to control the torque of various joints of the humanoid robot during motion. The robustness of the proposed algorithm is tested with forces up to 250 N and the control algorithm is found to be efficient. Ficht and Behnke (2020) presented the whole body motion control of a humanoid robot. The mass of the body is distributed to the limbs as well as trunk portions and used for determining the joint angles employing kinematic equations. The proposed approach reduces the computational time for determining the inverse solutions as well as control the motions of the robot. The proposed control strategy can be combined together with feedback methods to increase the efficiency of the controller in future works. A robust controller is introduced by Ibanez et al. (2012) to control the manipulation tasks during the motion of a humanoid robot. The ZMP related initial control

strategy is extended to reduce the effects of external disturbances during manipulation tasks. The arms of the humanoid robot are controlled using adaptive and impedance controllers. The controlling of internal forces during manipulation tasks is the future direction of the proposed control algorithm. Model predictive controller approach incorporating optimized contact forces for multi contact tasks for a humanoid robot is depicted by Henze et al. (2014). The control algorithm stabilizes the humanoid robot pose for tracking a desired trajectory. The end effectors apply a desired wrench to the environment as well as balance the external disturbances during multi-tasking. The trajectory tracking of a mobile platform is improved by incorporating an adaptive nonlinear controller based on Lyapunov stability theorem is discussed by Kelouwani et al. (2013). The dynamic properties of actuators are also taken into consideration during the control process. The proposed controller is proved to be offering better performance for linear and curved trajectory tracking tasks in different terrains. A fuzzy based control strategy is introduced by Wong et al. (2008) for a humanoid robot TWNHR -3 with 26 degrees of freedom (dof) to avoid obstacles. Four IR based sensors are fixed on the humanoid robot to calculate the distance between the robot and obstacles. The proposed algorithm is tested through simulations and experimentations. The algorithm is proved to be efficient in avoiding the obstacles along the motion. Vadakkepat et al. (2004) described a fuzzy based controller for soccer playing mobile robots. The tasks are assigned to each mobile robot for the analysis. Fuzzy based controller aids the mobile robot in making decisions, exchange of roles, different behaviors during given task and speed control. The proposed algorithm is validated experimentally using three different mobile robots. Fuzzy controller-based control of a mobile robot motion is explained by Jhang et al. (2018) . Dynamic-group particle swarm optimization (DGPSO) is employed along with fuzzy neural controller to avoid obstacle collisions. A fitness function evaluates the performance of the mobile robot. Asfour et al. (2000) studied the kinematic control of a humanoid robot named ARMAR. The inverse kinematic solutions obtained are fed into the controller as the input variables. The main purpose of the controller is to control the motions of the arms for coordinated tasks by avoiding collisions. Control of a wheeled self-balancing robot is discussed by Velagić (2014). The robot is modelled as an inverted pendulum for the analysis. Model based empirical PD controller is used for providing robot balance in a closed loop controller. Lagrangian formulations are used for deriving the equations of robot. PID tuner in Simulink is used for tuning the controller parameters. The empirical PD controller can compensate noises and external disturbances in the loop and stabilizes the robot. A control scheme adopted for tracking control of a manipulator along with friction compensation of robotic joints are given by Ohri et al. (2008). Adaptive fuzzy hybrid controller is used for compensating the friction based on Lyapunov function based method. Zambella et al. (2019) proposed a whole-body control algorithm for an unstable wheeled humanoid robot. Computed torque model incorporating dynamic model of the wheeled platform is used for the control scheme. The computational time for controlling is found to be reduced compared to conventional control methods. The proposed approach also successful in eliminating the external disturbances during given tasks. The stability analysis of the proposed controller and implementation of the controller algorithm to different mobile systems are the future works.

In this paper, kinematic control of a wheeled humanoid robot with redundant arms are carried out. The kinematic model of the mobile platform and the upper body humanoid robot derived using screw theory formulations are employed in the controller blocks. The controller schemes are designed separately for mobile platform and the upper body humanoid robot for reducing the computational time to control the motions. The controller schemes are combined together to carry out the proposed task effectively.

2. Wheeled humanoid robot

The wheeled humanoid robot with 15 dof upper body and 3 dof wheeled platform with two actuated wheels is shown in Figure 1. The upper body consists of 3 dof hip, 2 dof neck and 5 dof identical redundant arms. The screw theory formulations (Kevin et al. (2017)) are used for modelling the upper body. Wheeled platform consists of two actuated wheels and two caster wheels.

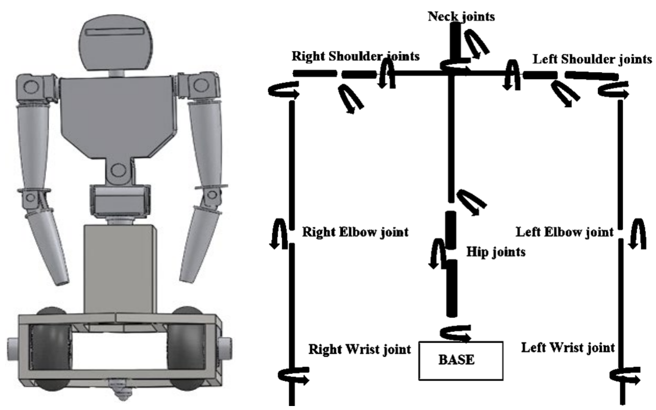

Figure 1. Wheeled humanoid robot with different joint motions

2.1 Modelling and Control of wheeled platform

Wheeled mobile robots are widely used in different sectors. The wheel-base consists of two actuated wheels with radius, R and two caster wheels is shown in Figure 2. The position of the wheeled platform can be represented using two different coordinate systems namely, Inertial coordinate system (x_i, y_i, z_i) and robot coordinate system (x_r, y_r, z_r). The origin of robot coordinate system is taken as A, which is at the midpoint of the axis connecting two wheels.

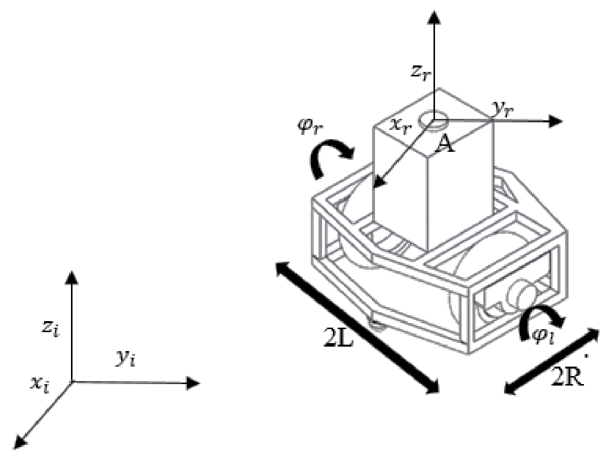

Figure 2. Wheeled platform with coordinate frames

The pose of the robot (x, y, θ_w) in inertial frame is given in equation (1)

$$q = \begin{bmatrix} x \\ y \\ \theta_w \end{bmatrix} \quad (1)$$

The linear velocity of mobile robot, V is given in equation (2)

$$V = \frac{v_r + v_l}{2} = \frac{R(\dot{\varphi_r} + \dot{\varphi_l})}{2} \quad (2)$$

where v_r and v_l are the linear velocities of right and left wheels respectively as given in equations (3) and (4)

$$v_r = R\dot{\varphi}_r \quad (3)$$

$$v_l = R\dot{\varphi}_l \quad (4)$$

The angular velocity of mobile robot, ω is given in equation (5)

$$\omega = \frac{v_r - v_l}{2L} = \frac{R(\dot{\varphi_r} - \dot{\varphi_l})}{2L} \quad (5)$$

Velocities of mobile robot, $\dot{q}$ in inertial frame is given in equation (6).

$$\dot{q} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta}_w \end{bmatrix} = \begin{bmatrix} \frac{R}{2}cos\theta & \frac{R}{2}cos\theta \\ \frac{R}{2}sin\theta & \frac{R}{2}sin\theta \\ \frac{R}{2L} & -\frac{R}{2L} \end{bmatrix} \begin{bmatrix} \dot{\varphi}_r \\ \dot{\varphi}_l \end{bmatrix} \tag{6}$$

Kinematic model of differential drive mobile robot in terms of linear and angular velocities is given in equation (7)

$$\dot{q} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta}_w \end{bmatrix} = \begin{bmatrix} cos\theta & 0 \\ sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \tag{7}$$

The control scheme adopted for controlling the mobile platform wheels is shown in Figure 3. The mobile platform is assumed to be traversing a given path (x, y, θ_w). The corresponding wheel motions (φ_l, φ_r) are determined. The desired motions are fed into the robot for following the given path. The feedback from the robot in the form of output motions are given to the PID controller for correcting the errors.

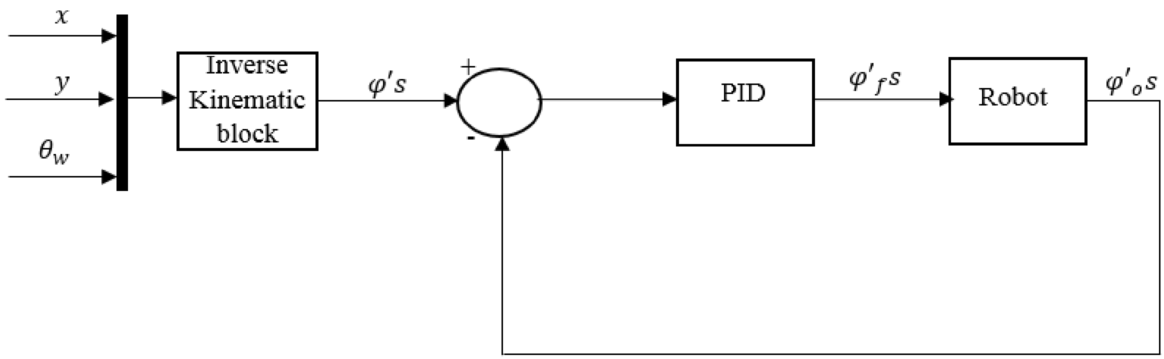

Figure 3. Control scheme for the wheeled platform

The control scheme equation for determining $\varphi'_f s$ with error, $e_w(t)$ is given in equation (8)

$$\varphi'_f s = k_{pw}e_w(t) + k_{iw}\int_0^t e_w(t)dt + k_{dw}\frac{de_w(t)}{dt} \tag{8}$$

where k_{pw}, k_{iw}, k_{dw} are the corresponding proportional, integral and differential gains respectively. The errors, $e_w(t)$ are calculated as given in equations (9) to (11)

$$e_w(t) = \varphi'_o s - \varphi' s \tag{9}$$

$$\int_0^t e_w(t)dt = \int_0^t (\varphi'_o s - \varphi' s) \tag{10}$$

$$\frac{de_w(t)}{dt} = \dot{\varphi}'_o s - \dot{\varphi}' s \tag{11}$$

2.2 Control of upper body humanoid robot

The control scheme adopted for controlling the upper body joints is shown in Figure 4. A desired trajectory (*x, y ,z*,ε_x, ε_y, ε_z) is given to the end effector of the redundant arms for carrying out a cooperative task. The corresponding inverse solutions for different joints of the upper body are computed. The joint values, $\theta's$ are fed into the robot for carrying out the desired task. The feedback from the robot in the form of output joint values are given to the PID controller for correcting the errors.

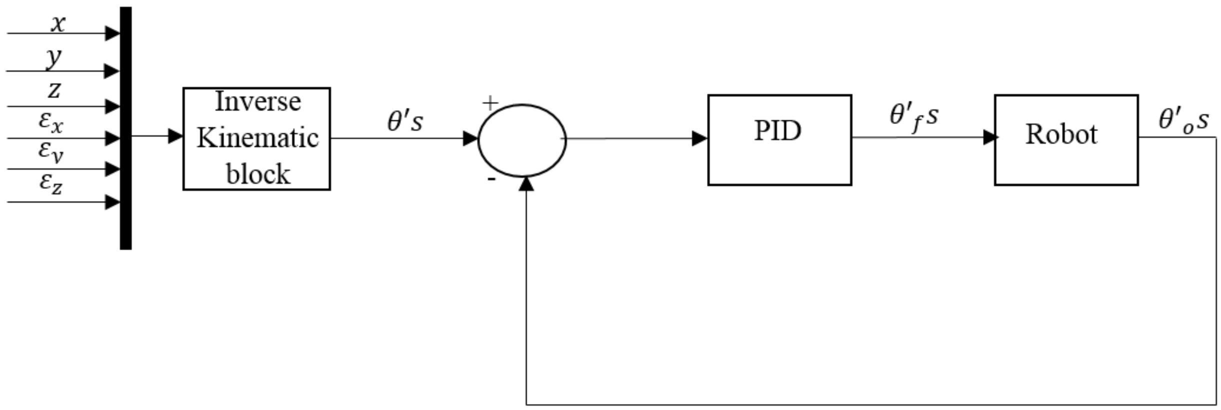

Figure 4. Control scheme for the upper body humanoid robot

The control scheme equation for determining the corrected joint motions, $\theta'_f s$ is given in equation (12)

$$\theta'_f s = k_{pu}e_u(t) + k_{iu}\int_0^t e_u(t)dt + k_{du}\frac{de_u(t)}{dt} \tag{12}$$

where k_{pu}, k_{iu}, k_{du} are the corresponding proportional, integral and differential gains respectively. The errors, $e_u(t)$ are calculated as given in equations (13) to (15)

$$e_u(t) = \theta'_o s - \theta' s \tag{13}$$

$$\int_0^t e_u(t)dt = \int_0^t(\theta'_o s - \theta' s) \tag{14}$$

$$\frac{de_u(t)}{dt} = \dot{\theta}'_o s - \dot{\theta}' s \tag{15}$$

3. Results and Discussion

The kinematic control of a wheeled humanoid robot is carried out in this paper. The kinematic control of wheeled platform and upper body humanoid robot is carried out separately for reducing the computational time. The simulations are carried out on an Intel core i7 processor, 16 GB RAM computer. The algorithms are coded in MATLAB R2021 software. Simulations are carried out for proving the advantages of the proposed control algorithm.

3.1 Mobile platform control

The kinematic motion control of a wheeled humanoid robot is carried out in this paper. The waypoints of the path are calculated and mobile robot traverses through the generated waypoints. The control scheme is adopted for controlling the motion of mobile platform through the determined waypoints. The Simscape model of the mobile platform is generated using MATLAB Simulink software. The comparison of desired trajectory (solid line) and controlled trajectory (dotted line) of the wheeled mobile robot during simulation is shown in Figure 5.

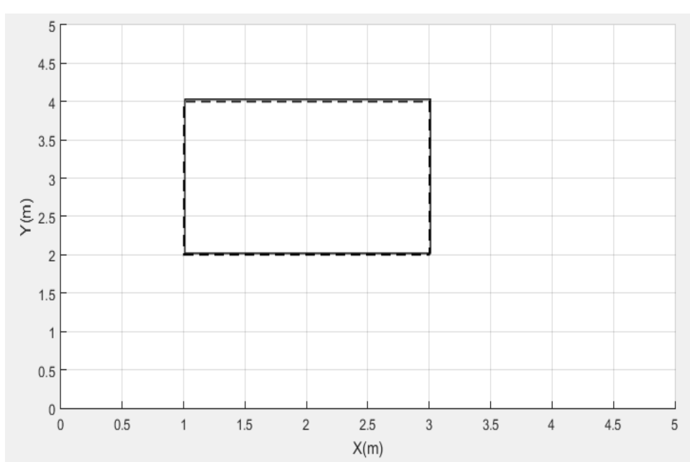

Figure 5. comparison of desired and controlled trajectories of mobile platform motion

The X and Y errors during the mobile platform motion are shown in Figure 6.

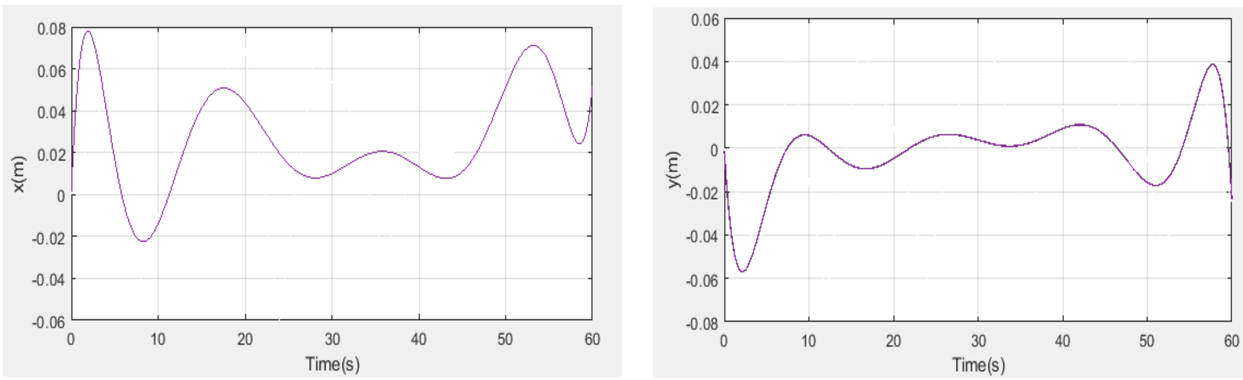

Figure 6. X axis errors (b) y axis errors

The RMSE value of x axis and y axis errors are obtained as .077m and .058 m respectively. The obtained error values are in safe range and the proposed algorithm control the motions of the mobile platform through desired path effectively.

3.2 Upper body humanoid robot control

The upper body of the humanoid robot is modelled in the Simscape. The feedback is obtained from the robot model in the form of joint angles and fed to the PID controller for decreasing the errors. The desired cubic spline trajectory traversed by the right arm end effector is shown in Figure 7.

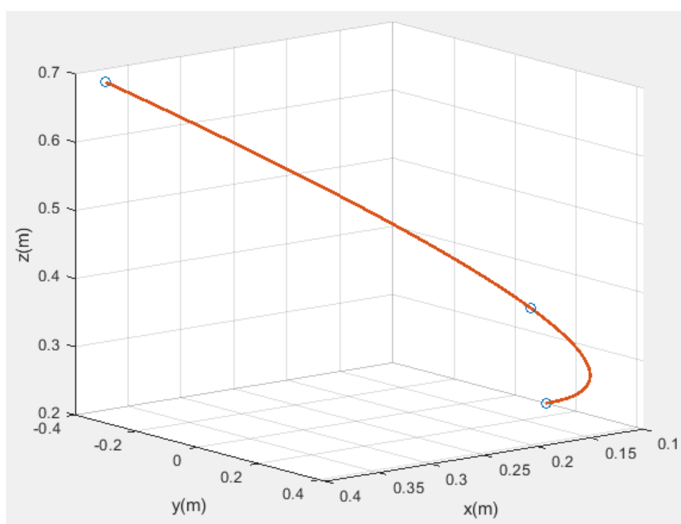

Figure 7. Desired trajectory of arm end effector

The desired and controlled angles of 5 dof right arm are evaluated and the error plots obtained for the different joints are shown as in Figure 8.

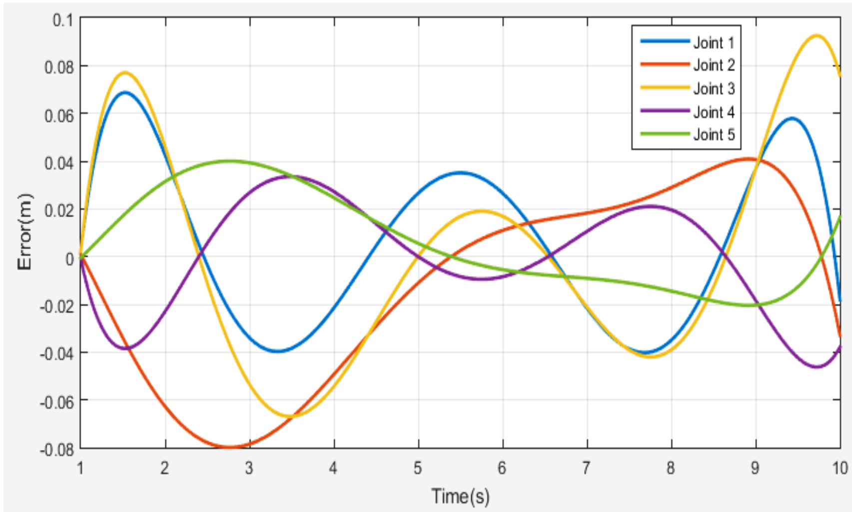

Figure 8. Error plots of different joint angles

The obtained error values are in safe range and the proposed algorithm controls the motions of the mobile platform through desired path effectively.

4. Conclusion

This paper discusses a kinematic control strategy to control the motion of a mobile platform and upper body humanoid robot. 15 dof humanoid robot with a non-holonomic platform is controlled using a kinematic control scheme. The kinematic equations of the upper body are derived using screw theory approach is used in controller strategy. The wheeled platform kinematic equations are derived based on non-holonomic constraints. The separate control loops adopted for upper body humanoid robot and mobile robot controls the given task with less computational effort. The proposed controller algorithm can be proved as robust controller in the future works by evaluating the performance in the presence of external disturbances.

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Biographies

Shifa Sulaiman is a Ph.D. scholar in Mechanical Engineering Department, National Institute of Technology Calicut (NITC). She has 5 years of experience in teaching at various educational institutions. She is specialized in Humanoid Robotics and currently doing research in modelling and control of wheeled humanoid robots.

Shoby George is an M. Tech graduate from Electrical Engineering Department, National Institute of Technology, Calicut. He is currently working as a Software Engineer specialized in AI related projects.

Dr. Sudheer. A. P. is currently working as Assistant Professor, in the Mechanical Engineering department, National Institute of Technology Calicut (NITC). He is engaged in teaching, research and academic administration for the last 25 years. He has over 100 publications in International and national journals and conferences. He is guiding UG, PG and PhD students. He has filed for more than 10 patents in the area of robotics. His research interests includes kinematics, dynamics and control of robotics, mobile robotics, under water robots and vision systems. He is a member of “the Robotics Society India"(TRS-India) and ISTE and Presently is the editor of TRS India.