Design and Development of a Reconfigurable Screw-wheeled Omnidirectional Mobile Robot

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Abstract. Omnidirectional mobility plays an important role for mobile robots to provide flexibility in their motion. However, most of the existing omnidirectional mechanisms are only superior in indoor applications, but inappropriate for outdoor purposes. This paper introduces the design and development of an omnidirectional mobile robot with reconfigurable screw-wheeled mechanism. The orientation of the screw wheels is adjustable in order to enable flexibility in traction control to provide more propulsion drive in certain conditions. The experimental results are given to demonstrate the performance of the omnidirectional mobile robot on different ground surfaces and different wheel’s orientation.

1. Introduction

Standard wheel with tyre is one of important invention in human history to provide good traction and fast locomotion system on the ground. However, the performance of the standard wheel may weakening in rough and soft terrains. There are many other alternatives provided by the researchers to solve the locomotion on these kind of terrains such as screw-wheels propelled vehicles [1]. The screw wheel or screw propelled wheel actually are develop by following the concept of the Archimedes screw conveyor that consists of a helix surface surrounding a central cylindrical shaft which are located inside a hollow pipe. The screw-wheel vehicles are good in the operation on the extreme terrains such as muddy, sandy, snowy, clay and grassy area. It can give a better performance of the movement on those kind of terrains compared to the wheel that can be seen mostly at normal vehicles such as cars, buses and motorcycles. The screw-wheels vehicles move based on the direction of rotation that are applied to the wheel with helical edges on its surface [2]. The helical surface on the wheel will produce a resisting force which is able to push enough of the material to attain motion. Besides, the different rotation of the screw wheel can cause the vehicles to move with the direction whether moving forward or backward, it depends the sequence of rotation of the wheel in clockwise or counter-clockwise direction [3,4]. By utilizing this principle and proper design, a new mechanism that can work in omnidirectional motion is developed [5]. This paper introduces a new improvement to the developed reconfigurable screw-wheeled omnidirectional mobile robot (RSOMR) by introducing a Variable Wheel Angle Mechanism (VWAM). The robot design and the principles of the VWAM is discussed in Section 2. Meanwhile, the performance of the new improvement is experimentally tested and evaluated in Section 3.

2. Robot Design and Kinematics

The kinematics model of the reconfigurable screw-wheeled omnidirectional mobile robot (RSOMR) is shown in Figure 1. The RSOMR is constructed by four screw wheels which are arranged in diagonal
structure. The helical angle of each wheel is designed at the angle of 45 degrees in order to produce equivalent driven power at the lateral and longitudinal direction of the wheel. Each screw wheel is independently driven and attached to the steering mechanism, Variable Wheel Angle Mechanism (VWAM). By utilizing this VWAM, the orientation of the wheel can be steered at any angle between 0 and 45 degrees as shown in Figure 2.

![Kinematics Model of RSOMR](image)

**Figure 1.** Kinematics Model of RSOMR

![Screw wheel’s arrangement](image)

(a) Standard Configuration (0 degree)  
(b) Variable Angle Configuration (<45 degree)

**Figure 2.** Screw wheel’s arrangement for RSOMR

The omnidirectional motion is produced at the centre of the RSOMR as the result of the resultant force induced from each individual wheels. This relationship is described by the forward kinematics shown in Equation 1 which is the extended equation presented in [5].
where, $\mathbf{v} = [v_x, v_y, v_z]^T$ is the robot velocity which includes the linear velocities at $xy$–axes direction and angular velocity about $z$–axis and $\omega = [\omega_1, \omega_2, \omega_3, \omega_4]^T$ is the angular velocities of the wheels. The matrix $A$ is given by

$$A = \frac{r_w}{4k} \begin{bmatrix} -1 & -1 & -1 & -1 \\ 1/\tan a & -1/\tan a & -1/\tan a & 1/\tan a \\ 1/b & -1/b & -1/b & 1/b \end{bmatrix}$$

where, $r_w$ is the radius of the wheel, $a = \theta + 45^\circ$, $\theta$ is the angle of wheel arrangement, $k = \cos \theta \tan a - \sin \theta$ and $b = L \tan a + l$.

Table 1 shows the three basic motions of the omnidirectional mobile robot. Using the same magnitude of angular velocity at each wheels, $\omega$, the RSOMR can be controlled to move in the direction of longitudinal, lateral or rotation just by changing the direction of the angular velocity.

| Movement                | Angular Velocities | Wheel 1 | Wheel 2 | Wheel 3 | Wheel 4 |
|-------------------------|--------------------|---------|---------|---------|---------|
| Longitudinal (Forward)  | $-\omega$          | $\omega$| $\omega$| $\omega$| $-\omega$|
| Lateral (Right Sideway) | $\omega$           | $\omega$| $\omega$| $\omega$| $\omega$|
| Angular (Clockwise)     | $\omega$           | $\omega$| $-\omega$| $-\omega$|

3. Result and Discussion

3.1. Prototype Development

Figure 3 shows the developed prototype of the RSOMR. The omnidirectional mobile robot is controlled by using Arduino microcontroller. It has four wheels and each of the wheel is driven by a DC geared motor. Meanwhile, the VWAM steering mechanism is actuated by a stepping motor which enables a steering angle between 0 to 45 degrees. The helical part of the screw wheels is a 3D printed PLA plastic and it is wrapped to a hollow PVC pipe to construct a screw wheel. Figure 4 shows the RSOMR in 0 degree and 45 degrees orientation, respectively.

3.2. Performance Evaluation

An experimental work is conducted to evaluate the performance of the RSOMR in different ground conditions. There are four angle of screw wheel arrangements tested in the experiment which are 0, 15, 30 and 45 degrees. Each screw wheels arrangement are tested on three ground conditions which are tiles, asphalt and soft soil. The desired velocity of RSOMR based on the angle are shown in Table 2.
Table 2. Desired velocity of the RSOMR

| Wheel Angle (deg) | Desired Velocity (m/s) |     |     |
|-------------------|------------------------|-----|-----|
|                   | Longitudinal          | Lateral |
| 0                 | 0.048                  | 0.772 |
| 15                | 0.044                  | 0.140 |
| 30                | 0.032                  | 0.135 |
| 45                | 0.033                  | 0.066 |

Figure 3. The developed prototype of RSOMR

Figure 4. RSOMR in different configurations

(a) 0 degree  
(b) 45 degrees
Figure 5 shows the performance of the RSOMR for longitudinal movement in three different ground conditions. In general, the RSOMR is possible to produce a longitudinal movement, except for the wheel arrangement of 45 degrees. In most cases the produced velocity is lesser than the theoretical value. The RSOMR also is found to operate better on the soft-soil condition with comparison to another two ground conditions. The soft-soil which flows at the screw wheels is expected to provide more traction force. Figure 6 shows the performance of the RSOMR for lateral movement in three different ground conditions. The velocity of the screw wheel during on the tiles surface is nearer towards the theoretical value. It is because during on the tiles, the rolling force of the wheel has less resistance to attain the obstacle so that the less resistance of obstacle let the rolling forces stay high during the movement compare to the asphalt and soft-soil surface. Therefore, screw wheel has a good locomotion in horizontal on the tiles in any type of angle of wheel arrangement.

![Figure 5](image)

*Figure 5. Result for longitudinal movement on different types of surface with different angle of wheel arrangement.*
4. Conclusion
In this study, an omnidirectional mobile robot with screw wheels is designed and developed. The experimental results show that the omnidirectional mobile robot is capable to produce the desired motion at the right direction, but the performance are poor and varies according to the ground conditions and wheel’s orientation. This performance issue may be caused by uneven contact in rough ground and insufficient traction due to helical design or materials.

5. References
[1] Morath JA 1899 Agricultural Machine US Patent 635501
[2] Nagaoka K, Otsuki M, Kubota T, and Tanaka S 2010 Terramechanics-based Propulsive Characteristics of Mobile Robot Driven by Archimedean Screw Mechanism on Soft Soil Proc. IEEE/RSJ Int. Conf. on Intell. Robots and Systems 4946–4951
[3] Osiński D and Szykiedans K 2015 Small Remotely Operated Screw-Propelled Vehicle Progress in Automation, Robotics and Measuring Techniques Advances in Intelligent Systems and Computing 351 191-200
[4] Liedke J, Winkler L and Wörn H 2013 An Alternative Locomotion Unit for Mobile Modular Self-reconfigurable Robots Based on Archimedes Screws 9th International Symposium on Mechatronics and its Applications (ISMA) 1-6
[5] Safar MJA, Chandradekaran Y, Basah SN, Basaruddin KS, Hashim MSM 2016 Kinematics Analysis of a Screw Wheeled Omnidirectional Mobile Robot 10 1-15