ISSN 2278-3091

Volume 12, No.4, July - August 2023

International Journal of Advanced Trends in Computer Science and Engineering

Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse051242023.pdf

https://doi.org/10.30534/ijatcse/2023/051242023

Designing and Analysis of an Architecture of Motion Control for a Mobile Robot Using Simulation

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Received Date June 18, 2023 Accepted Date: July 28, 2023 Published Date: August 06, 2023

ABSTRACT

In recent decades, the control of motion and navigation of mobile robots has received the eminent attention of researchers. Motion control is an important technique that allows a mobile robot (MR) to move adaptively and precisely. The main aim of this research work is to design and analyze the architecture of the navigation and motion control systems for a mobile robot by using Simulink modeling. An encoder sensor is used to analyze the motion control. Experimental and simulation techniques are used to prove the application of the encoder sensor and dead reckoning approach to control MR motion. The modeling of the Simulink model for a motion control system for an MR through MATLAB 2022a software has been presented in this article. The main objective of this research work is to control the motion of the robot in forward and backward directions. The presented model in this paper has been verified through real-time simulation, and it shows the performance of the control system in the predefined optimal time range standard. Finally, this article provides a comprehensive survey of future research trends for the control system of MR.

Key words: Dead Reckoning; Encoder Sensors; Human-Robot Interactions (HRI); Navigation System; Motion Control; Mobile Robot (MR); Simulink Model.

1. INTRODUCTION

The mobile robot is a special kind of robot that can navigate freely. Initially, MR was used mainly for military operations when they were discovered during the Second World War. But after the integration of artificial intelligence with mobile robots, nowadays they are applicable in almost every field of operations [1], [2]. In our society, nowadays MR has an efficient and important role in performing different tasks which are hard for a human or in optimizing the quality of functions. The technique of human-robot interaction performs several types of tasks such as medical tasks, entertainment, education, industrial arms management, rescue, and search missions. For performing these tasks, the control system of the robot allows the robot and human to work together. The integration of the control system and operator is recognized along an architecture of the control system to enhance the performance of the MR. Also, the algorithms for the motion control system will be an important part that provides decisions to the machine for an individual task [3]. The types of HRI depend upon the types and environments of the prescribed task for any specific MR. Some MR's are operated remotely through the control system regulated by some specific software designated for this purpose thus the HRI system is also considered a remotely manipulated system.

A. Dead Reckoning

It is the process of finding the current position of the MR during navigation by utilizing an initially estimated position or stable, and incorporating evaluations of velocity, direction or heading, and elapsed time. The encoder sensors integrated into the armatures of motors used in an MR, evaluation of displacement for the traveled path by an MR. That means dead reckoning is used to estimate the localization of position for an MR. This dead reckoning approach used for the navigation of an MR generally utilizes encoder sensors. This type of navigation system is entirely self-contained, and this system might always assist the mobile robot through an evaluated position. Equation 1 shows the basic formula to calculate dead reckoning [4].

$$\text{Dead Reckoning} = \text{Speed} \times \text{Time} \qquad (1)$$

B. Encoder Sensors

Encoders are an important and primary part of all machinery systems used in industries. An encoder is a special kind of sensor that gives feedback signals of machine motion.

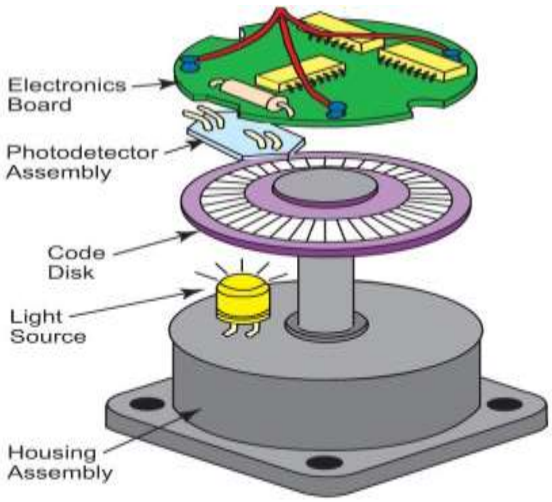

Figure 1: Internal structure of the encoder sensors [5]

An encoder sensor transmits a feedback signal which might be utilized to estimate speed, count, position, or direction. This sensor provides an electrical signal for MR navigation that might be understood through a control device integrated within the motion or navigation control system of an MR, like a Programmable Logical Control (PLC) or counter. The motion control device could utilize the details of the feedback signal to send an instruction for a specific task. The encoders utilize various kinds of techniques to generate a signal, incorporating optical, resistive, magnetic, and mechanical. Optical is generally utilized nowadays, which sends a feedback signal to the command section based on the disturbance of light. Figure 1 shows the internal structure of the encoder sensors.

2. BACKGROUND INFORMATION

The development of a motion control system to navigate MRs freely in forward and backward directions is a primary and most important task to make an intelligent MR. The main background of this research work is to make the model of the control unit of the MR, data fusion of the encoder sensor, model of the motion control, and check the feasibility of the model.

A. Control Unit of the Mobile Robot

The control system part of a mobile robot is responsible for allowing a predefined solution to execute, during the situation of some indefinite problems occurring in the complete system or model. Thus, the control system unit is the most crucial and important part of the MR and without it, an MR cannot work properly and there shall be a higher degree of unwanted activity. The control unit starts to perform desired actions after receiving a command signal from the required components needed for acting performance.

B. Data Fusion of the Encoder Sensor

The data fusion of the encoder sensor aims to integrate various sensor data to provide conclusions that could not be gathered with a normal sensor. Responding to problems and threats signals can be faster by learning data to fusing data from different sensors. In mobile robotics, data fusion is the procedure of collecting filtered, integrated data, extracted, aggregated, and interpreted data from various sensors to optimize important information and reliability [6].

C. Model of the Motion Control

The motion control system assists as a conductor of motion of the MR to accomplish the movement depending on the expected parameters of motion and trajectories. The entire motion control system of an MR always comprises the interface between humans and drivers, actuators, machine interference, feedback cells, motion controller, and transmission mechanism.

D. Feasibility Check of the Model

A feasibility check of every model for the experiment is required during every step of an experiment to optimize the model. Feasibility checks need a simulation of the MR system to be performed. An automatic feasibility check is required for every assembly sequence in the MR.

3. LITERATURE SURVEY

Many researchers from the area of mobile robotics have been focused for a long back to develop an architecture of motion control system that is suitable and optimal for the autonomous navigation of mobile robots in the predefined or undefined environment. Yu *et al.* [7] present a navigation system in the complex terrain for an MR depending on proprioceptive sensors by utilizing a dead reckoning approach. The kinematic constraints rigid body of an MR has been used in this approach to describe the dead reckoning for a mobile robot in rough or complex terrain. A technique of kinetic model incorporated with the contact angle of wheeled ground is suggested to evaluate the trajectory of relative motion for an MR. Hyun *et al.* [8] present a tracking algorithm and a sensor system based on the dead reckoning technique for MR navigation to evaluate the path whenever a mobile robot finds an undefined enclosed area where landmarks are unavailable. The experimental data has been gathered from the radio-controlled car which is integrated with a sensor system and the traveled path has been tracked by a tracking algorithm. This study is suitable to locate the position of MRs freely without using any external support such as beacons, landmarks, and global positioning system (GPS). Qureshi *et al.* [9] demonstrate a network based on a neural network for the motion planning of MRs. The proposed technique encrypted the provided workplace directly cloud measurement from a position and creates an end-to-end independent environment that is collision-free for the initial and final configurations of the system. The evaluation time of this network is less than one second. Chu *et al.* [10] present a motion control system based on dead reckoning for autonomous small underwater vehicles. The dead reckoning technique based on a depth gauge, compass, and Doppler velocity log is utilized in this experiment. The proposed technique used pool experiments to verify the efficiency. Sabet *et al*. [11] design and analyze a navigation system of a low-cost dead reckoning approach for an underwater autonomous vehicle utilizing an attitude and heading reference system. A novel framework of modeling is proposed in this experiment which used an extended Kalman filter for the evaluation of bias for heading, attitude, and gyroscope sensor utilizing an inertial sensor of a low-cost micro-electro-mechanical system type. This experiment is estimated by experimental tests in multiple bounds of acceleration and availability of outside magnetic disturbances for underwater autonomous vehicles. Mamun *et al*. [12] present a motion control system for an MR of omnidirectional type based on an embedded system. The MR used in this experiment is of a holonomic robot type. Firstly, an embedded system is designed, and secondly, a low-level controller is used. To avoid slippage and fit the planning needs, acceleration, and velocity filters are used. The main outcome of this research is an enhancement in the integrated fuzzy-proportional integral linear quadratic regulator controller over a conventional proportional-integral controller. The result shown in this experiment confirms that external disturbances are negligible. Ruan *et al*. [13] present a study of a motion control system based on vision-teleoperation for mobile self-balancing robots. The main objective of this research work is to develop a remote-control system for the motion control of rescue and search mobile robots. This paper generates a model of a remote motion control panel that has the integration of vision systems and coordination of an efficient hardware control unit.

4. PROPOSED SIMULINK MODEL

An architecture for the motion control system using the Dead Reckoning algorithm for an MR through Simulink modeling by using MATLAB 2022a software has been developed in this experiment, which is shown in Figure 2. This model contains several blocks gathered from the Simulink library such as Encoder, Gains, Add, Chart, constant, Robot Simulator, Scopes, States, etc. We developed this Simulink model to control the motion of MRs in a linear direction. The main purpose of this model is to control the motion or navigation of an MR in the Simulink modeling environment for a specific distance of 1m.

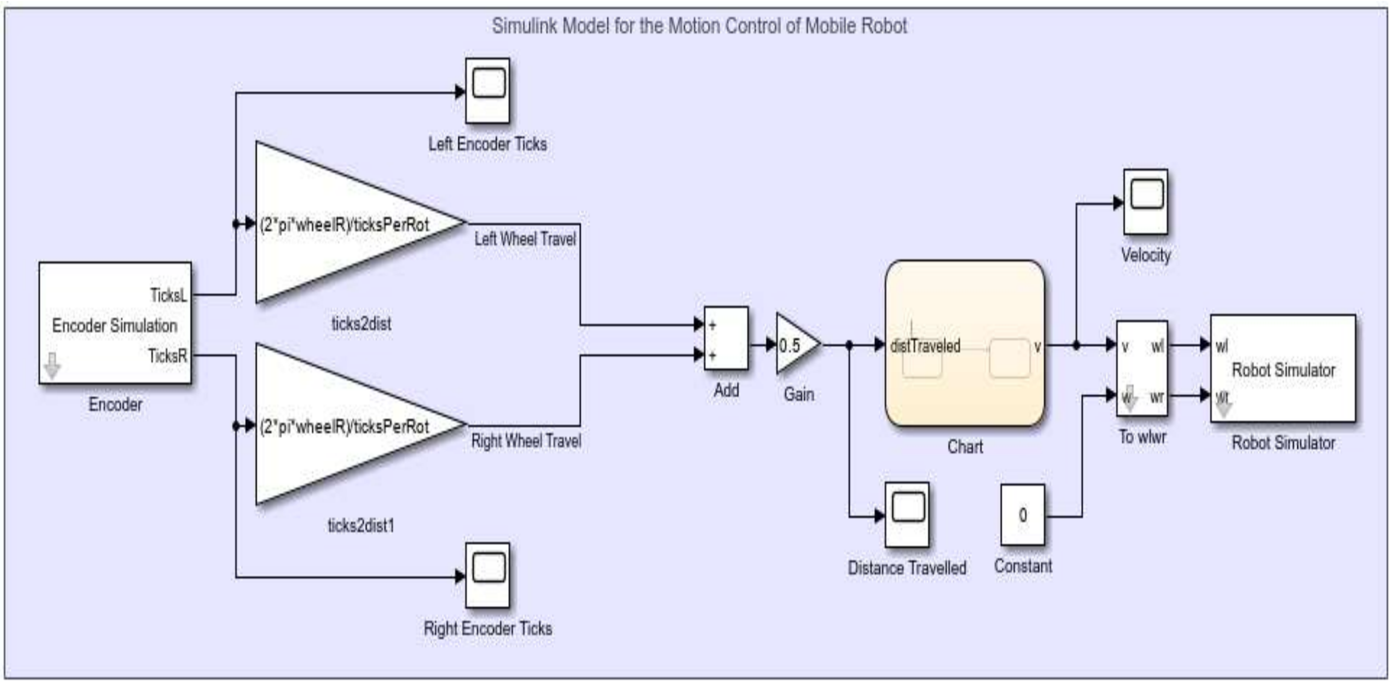

Figure 2: Proposed Simulink model of the experiment for the motion control of MR [14], [15].

Where Encoder is used to find the behavior of the MR when it moves in a straight line, Gain is used to converting Encoder ticks into the distance traveled, left Encoder ticks and right Encoder ticks are used to evaluate the distance traveled by the left wheel and right wheel of MR consecutively, the Add block is used here to integrate the left wheel and right wheel together, Gain block after Add block is used to find the average of distance traveled by the left and right wheel of MR, the state flow chart is used in this model to provide the logical part of the architecture, where the state flow chart contains two state blocks which used the transition to provide the limitation of distance and velocity for the mobile robot navigation, the utility block 'To wlwr' is used to convert linear velocity into wheel velocity, and Robot Simulator is used to visualize the real-time motion control of the MR during running the Simulink model.

Figure 3 shows the algorithm of the Dead Reckoning approach used in this experiment. Where, the velocity and meter, are denoted by v and m, respectively. The value of v is set at 0.1 m/sec. The MR traveled 1m for estimating the motion control system in the proposed architecture of Simulink modeling as set for the experiment.

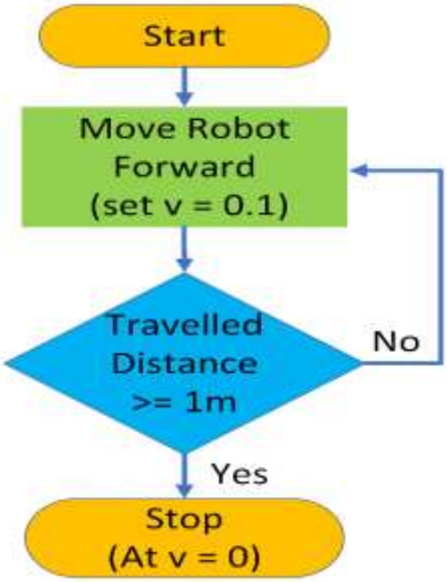

Figure 3: Dead Reckoning algorithm [14], [15].

5. EXPERIMENTAL RESULT AND ANALYSIS

The Simulink model for the real-time motion control of an MR in forward and backward directions has been described in this experiment. The experimental parameters have been taken accordingly described in [15].

TABLE I. VALUES OF PARAMETERS USED IN THE EXPERIMENT

Total Encoder ticks	*Total number of ticks per rotation of the wheel*	*Wheel radius*	*Axle length*
360	360	0.052 unit	0.28 unit

TABLE I. presents the detail of the parameters used in this experiment. Figure 4 shows the graphical representation of the distance traveled by the MR through the execution of the Simulink model for a motion control system.

Figure 4: Distance traveled by a mobile robot.

Figure 5 shows the graphical representation of MR velocity during the experiment. It shows that the mobile robot has a constant velocity of 0.1m/sec until 10sec and after that MR stopped because the specified distance for the experiment has been set up at a maximum of 1m.

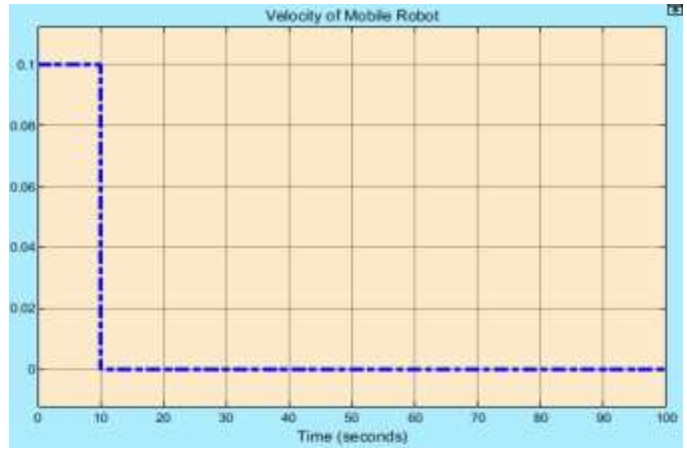

Figure 5: Velocity of the mobile robot during motion.

The traveled distance by the MR for values of parameters specified in TABLE I can be estimated by the formula given in Equations 2 and 3 [14], [15]. The number of wheel rotations taken is 1, thus distance traveled by the mobile robot will be equivalent to the circumference of the wheel.

$$\text{Distance Travelled} = \text{No. of wheel rotation} \times 2 \times \pi \times R \quad (2)$$

$$\text{Distance Travelled} = \frac{\text{Total Encoder Ticks}}{\text{Ticks Count Per Rotation}} \times 2 \times \pi \times R \quad (3)$$

Where R is the radius of the wheel of the MR.

The position of MRs at the initial state during the start of the experiment and the final state after the completion of the simulation of the Simulink model is shown in Figure 6. In the experiment, at the initial state position, the coordinate is (1, 1) and at the final state position, the coordinate is (2, 2) for the MR. Finally, the MR traveled a linear distance of 1m. Thus, we can see in this experiment that the mobile robot is completely controlled for moving in forward and backward directions in a pre-defined range for navigation. This motion control experiment was tested and validated by the simulation of Simulink modeling.

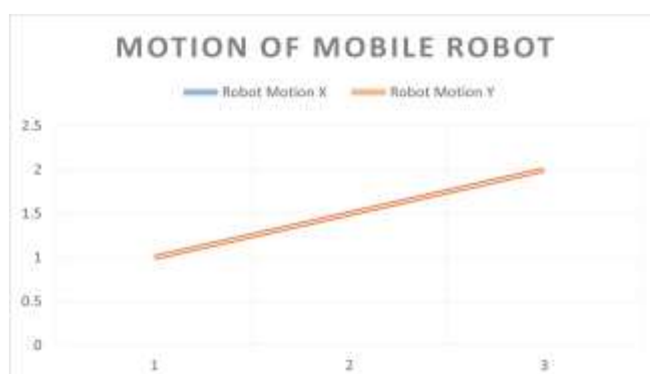

Figure 6: Positions of the MR during mobility.

6. FUTURE RESEARCH TRENDS

In recent decades many mobile robotic researchers have been working towards developing an efficient and intelligent MR. Because healthcare centers, warehouses, agricultural businesses, logic companies, and military operations are all looking for ultra-modern and new ways to increase safety, improve speed, ensure precision, and improve the efficiency of operations. To develop an intelligent and autonomous MR, the control system must be considered first. Integration of MRs and artificial intelligence can make MRs more efficient and important for various applications. Artificial intelligence integration with mobile robotics systems will help MRs to perform their prescribed tasks more efficiently and precisely. The research is still open and important for planning of motion control system in an unknown environment for an MR, estimation of the environment for MR navigation, coordination among manipulability and mobility for an MR, modeling of environments for MR using modern and advanced sensing technologies and developing an intelligent non-linear control system of MR’s.

In recent years, HRI has attracted enhancing attention, both in industries and in academia. In HRI assembly, mobile robots are generally needed to dynamically change their pre-defined control parameters and trajectories to interact with humans in a shared workplace. Although, industrial robots utilized nowadays in industries are still controlled through pre-defined steady codes that cannot assist efficient HRI that needs runtime adaptability. For the requirement of higher adaptability, the prediction of motion by a human is important for both the case of proactive assistance and collision avoidance. Deep learning is validated to become the most efficient for the identification of context awareness, recognition, and classification of various objects [16]. Thus, we can say that HRI requires more attention from researchers and technologists in the near future.

The safety and optimization issues for the MR application also require the focus of researchers. It is still most important to get an optimized motion control system, augmentation of the accurate path for movement, and reduction of time for finding the augmented path for MRs. Intelligent MRs are playing an important role in making the economy of the IoT (Internet of things) and machines better and fully realized. Also, higher in-depth industrial implications can be given with advancement in automation techniques, 5G (5th Generation) technology, artificial intelligence, machine learning, deep learning, and cloud-native technologies [17]. Development in computer vision due to advancements in technology is also playing a vital role in making intelligent mobile robots and this area needs more attention from researchers.

5. CONCLUSION

In this article, the motion control system for an MR using a dead reckoning approach and encoder sensor has been proposed. The architecture of the control system is modeled by using Simulink modeling in MATLAB 2022a software. The proposed architecture is tested and validated on real-time simulation through Simulink modeling. This experiment clearly explains the motion control system of an MR in the forward and backward directions. This research work is the first step toward developing an intelligent control system of an MR for the autonomous navigation of an MR. This experiment provides an outstanding introduction to the motion or navigation control system of an MR for early-stage researchers. This experiment will be further considered as the base of research to develop an intelligent architecture of an MR control system for obstacle avoidance and in the development of a control system for autonomous navigation using computer vision and human-robot interactions (HRI).

ACKNOWLEDGEMENT

The research was supported financially by the AGH University of Science and Technology, Krakow, Poland, subvention no. 16.16.230.434.

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