

MODELING AND SIMULATION OF DIFFERENTIAL DRIVE MOBILE ROBOTICS SYSTEM

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Abstract

Keywords: Mobile Robotics; Differential Drive; Matlab-Simulink; Virtual Reality.

The growing trend of robotics and automation beyond the boundary of industrial applications has resulted the emerging of mobile robotics study. Due to the multidisciplinary nature and complexity of robotics system, the design and development of mobile robotics system is generally depends upon cutting edge technologies and hence it is relatively time consuming and costly. One effective solution is to develop a platform to simulate the system design before hardware implementation. This paper describes the design and development of a general mobile robotics differential drive model simulation using Matlab-Simulink with 3D Virtual Reality output.

The later part of the system modeling is based on modular concept in order to create standard sub-systems that can be reusable. Every module is coupled by a Matlab-Simulink block which contains the mathematical models and physic properties. The modular model is represented by the equivalent 3D model in virtual reality space. CAD model that created using SolidWorks 2005 is extracted in VRML97 (.wrl) format and edited by V-Realm Builder 2.0 before being imported into Matlab-Simulink by the VR (Virtual Reality) Toolbox. The main objective here is to establish a general platform to simulate mobile robot system for controller design and rapid prototyping. Matlab-Simulink is chosen as the core simulation engine because it is a universal simulation and analysis tool that is widely being used. Virtual Reality Markup Language (VRML) is the current preferred language in creating 3D virtual reality output and is supported by various CAD software. Importing 3D model directly from CAD software can further reduce the step of producing 3D model using other tools and the

model will be a close match with the mechanical structure. The future challenge in this work is to develop the set of standard modules and the integration of the modules in designing a new system. Matlab-Simulink computational capabilities would be advantages to investigate new kinematics techniques whilst analyzing and simulating older techniques.

Introduction

The objective of this work is to model and simulate a mobile robotics system using the differential drive model. Wheel base differential drive system is the most commonly used design in small scale mobile robot systems. Mobile robotics system development is a much complicated work which required knowledge from various areas, such as mechanical design, electronics development and control system. Such projects involve time and cost to develop. Due to this reason, a general mobile robotics system simulation platform might be an effective solution for the research and development. In this work, the modeling and simulation of a general mobile robotics system have been carried out using Matlab-Simulink as the simulation platform. The idea is to design and develop a general simulation platform to facilitate controller design and hardware configurations. The simulation output is being represented by 3D model in Virtual Reality environment for more effective visualization. Besides that, Virtual Reality provides a new way for integrated multisensor simulation under a united environment [1].

Design Model Specifications and Parameters

The design model in this work is based on the specifications from the *Official RoboCup Small Size (F180) League* [2]. Basically the robot dimension is used here. According to *F180 rules* [3], the robot must fit inside a 180 mm diameter cylinder and the height must be 150 mm or less. Based on these specifications, a 85 x 130 mm rectangular box with a height of 95 mm is set to be the robot main body while 2 wheels which 25 mm radius and 20 mm width, are attached at the rear part of the main body as the driving mechanism. This design is adopted to match the hardware implementation design in the RoboBOX projects.

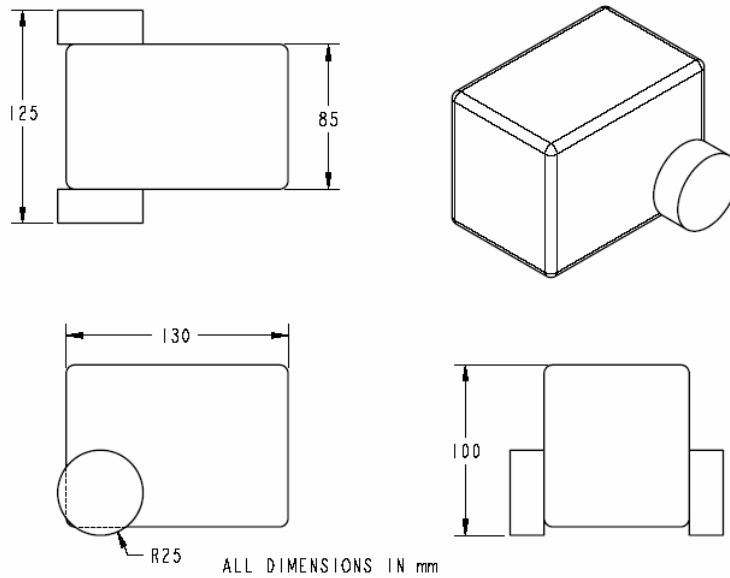


Figure 1: Design model specifications and parameters



Figure 2: RoboBOX hardware prototype

Design and Modeling

The design and 3D modeling are done using CAD software, *SolidWorks 2005*. The CAD environment enables easier 3D model creation for both simulation and hardware implementation. *SolidWorks* allows the 3D model to be exported in VRML (.wrl) format. “*Virtual Reality Modeling Language (VRML)* is a language for describing multi-participant

interactive simulations – virtual worlds networked via the global Internet and hyper-linked with the World Wide Web.”, quoted from Web3D Consortium [4]. The model is exported in VRML format in order to be inserted into Matlab Virtual Reality environment later for simulation.

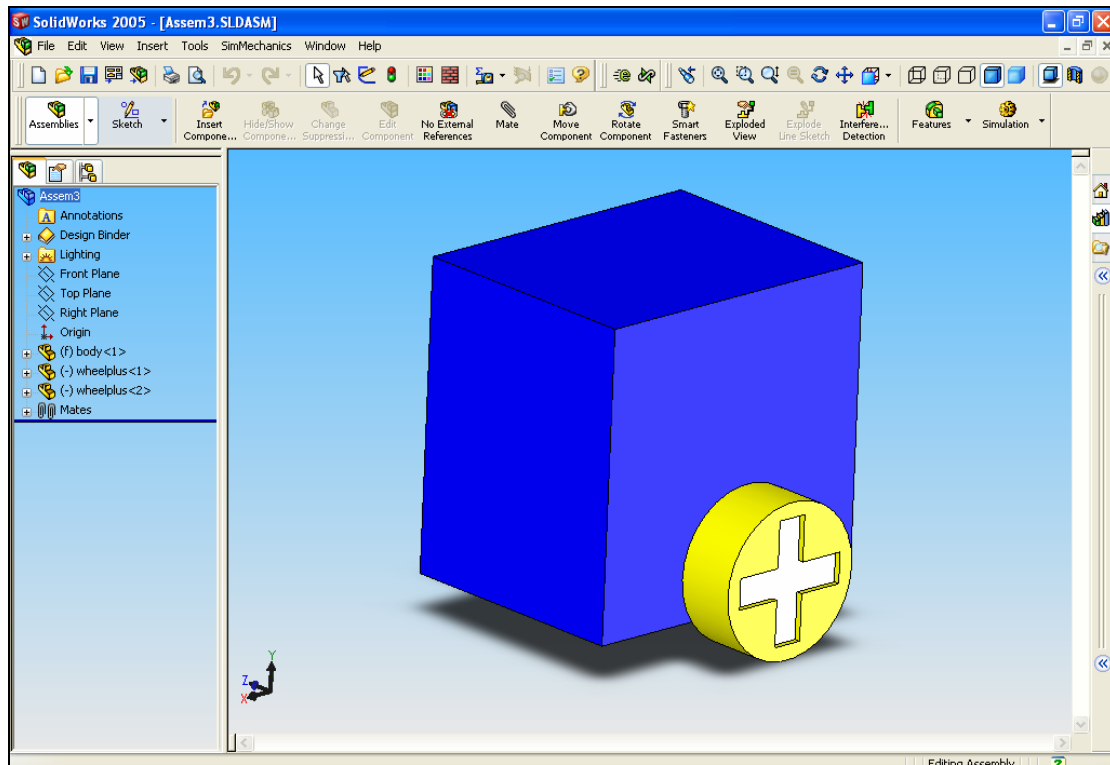
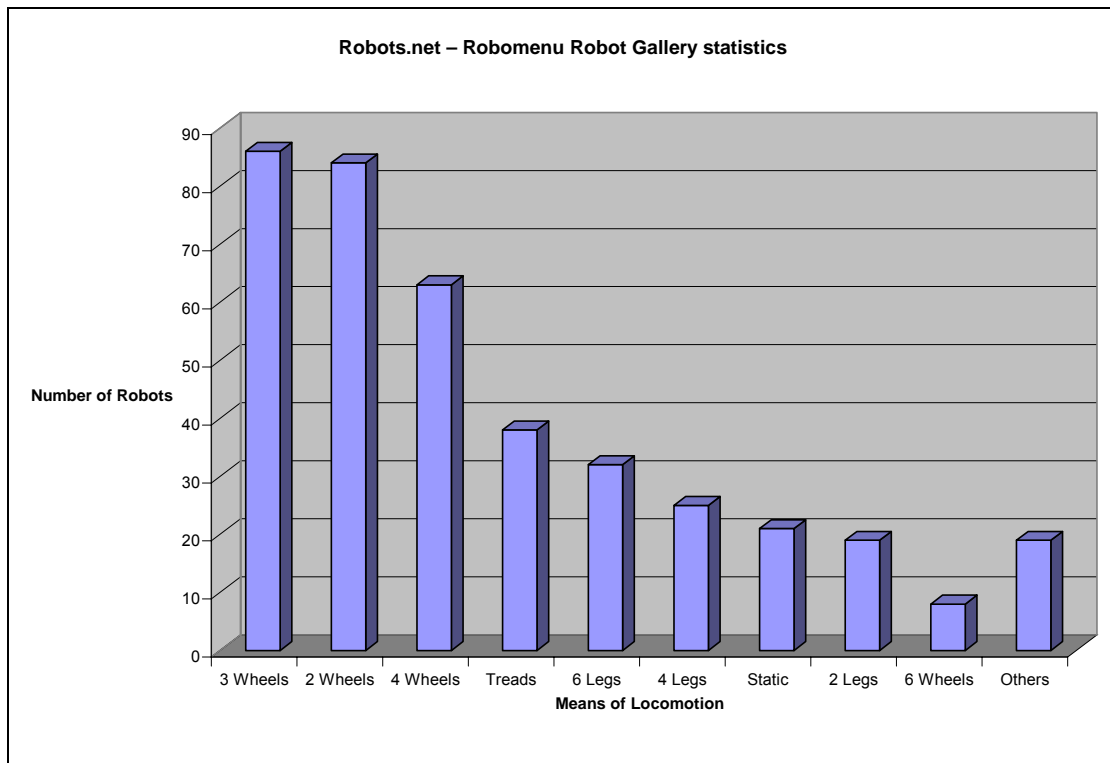


Figure 3: SolidWorks 2005 environment

Differential Drive Model

The *Differential Drive Model* is chosen in this work as a general simulation model for mobile robotics system due to its popularity in relatively small-sized mobile robots. It is shown in the statistics from *Robomenu Robot Gallery, Robots.net* that wheel type design is the most popular mean of locomotion for robots and most of the 2-Wheel designs are differential drive system [5]. Differential drive is a *non-holonomic system* [6] where the number of control variables is less than the number of output variables. In this case, there are 2 control variables which are the wheel rotation speeds $\dot{\phi}_1$ and $\dot{\phi}_2$, and 3 output variables, the robot motion \dot{x} , \dot{y} and $\dot{\theta}$.



Graph 1: Robots.net – Robomenu Robot Gallery statistics

Differential Drive System

Differential drive system is a steering system commonly used in small robots. It is different from the ‘*differential drive*’ that used in automotive engineering for certain drive system. Generally it is similar to wheelchair steering concept. Both the wheels are arranged in the same axis and can be rotated independently. When both rotate in tandem, the robot moves in a straight path. But when the rotation speeds vary between the 2 wheels, the robot moves in a curved path. The robot make a point turn, when the wheels rotate in the same speed but opposite directions, where the center of turning located in the middle of the distance between the 2 wheels. [7]

Mathematical Model [8]

The differential drive model is derived from the forward kinematics equations that represent elementary model where all the physical issues such as friction, inertia and mechanical structure inaccuracy are neglected.

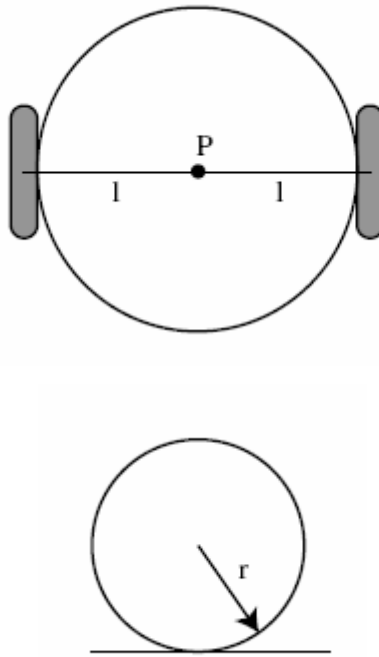


Figure 4: Forward kinematics model

From the model, the speed of each wheel is $r\dot{\phi}_i$ and hence the translational speed is the average velocity:

$$\dot{x}_R = r \frac{\dot{\phi}_1 + \dot{\phi}_2}{2} \quad \dots\dots (1)$$

The instantaneous rotation of P for one wheel:

$$\omega_1 = \frac{r\dot{\phi}_1}{2l} \quad \dots\dots (2)$$

The total rotation:

$$\dot{\theta} = \frac{r}{2l}(\dot{\phi}_1 - \dot{\phi}_2) \quad \dots\dots (3)$$

In order to define the robot motion, firstly we need to have the *robot references frame* (R) with refer to the general *inertial reference frame* (I).

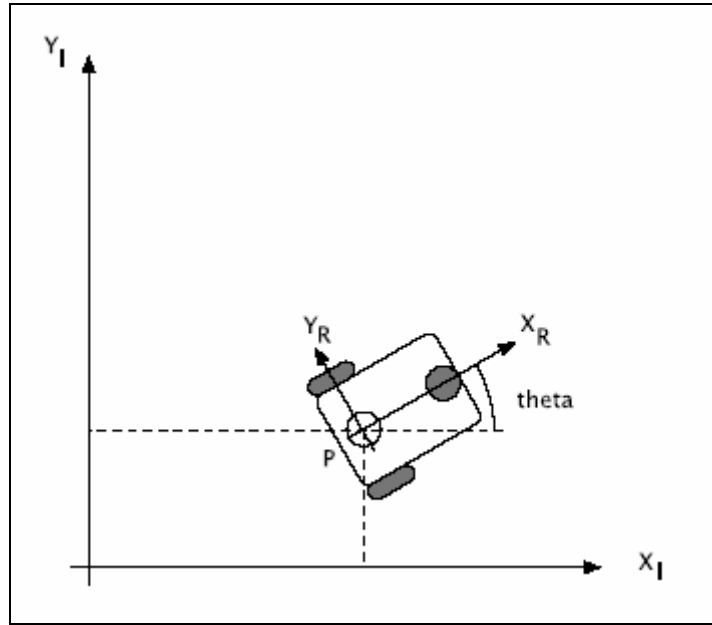


Figure 5: Reference Frames Transformation

We define the robot motion as:

$$\dot{\xi}_I = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = f(l, r, \theta, \dot{\varphi}_1, \dot{\varphi}_2) \quad \dots\dots (4)$$

The relation between the references frame is through the standard orthogonal rotation transformation:

$$R(\theta) = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 0 \\ -\sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \dots\dots (5)$$

Thus, the robot motion between frames:

$$\dot{\xi}_R = R(\theta)\dot{\xi}_I \quad \dots\dots (6)$$

$$\therefore \dot{\xi}_I = R(\theta)^{-1}\dot{\xi}_R \quad \dots\dots (7)$$

Consider a simple 90° point turn where $\theta = \frac{\pi}{2}$ and substitute into equation (5):

$$R\left(\frac{\pi}{2}\right) = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\therefore \dot{\xi}_R = R\left(\frac{\pi}{2}\right)\dot{\xi}_I = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \dot{y} \\ -\dot{x} \\ \dot{\theta} \end{bmatrix} \quad \dots\dots (8)$$

Inverting the standard orthogonal rotation transformation, equation (5):

$$R(\theta)^{-1} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \dots\dots (9)$$

Substituting equations (1), (3), (8) and (9) into (7), we obtain the differential drive model:

$$\dot{\xi}_I = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \frac{r}{2} \begin{bmatrix} \dot{\phi}_1 + \dot{\phi}_2 \\ 0 \\ \frac{\dot{\phi}_1 - \dot{\phi}_2}{l} \end{bmatrix} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} \quad \dots\dots (10)$$

Matlab

The mathematical differential drive model is transferred into Matlab Simulink model. Firstly, we model the inverse standard orthogonal rotation transformation into a Matlab function block. Using the LU Solver block, we are able to solve the function to obtain the output robot motion $(\dot{x}, \dot{y}, \dot{\theta})$. Simulation has been done with random inputs to verify the modeling.

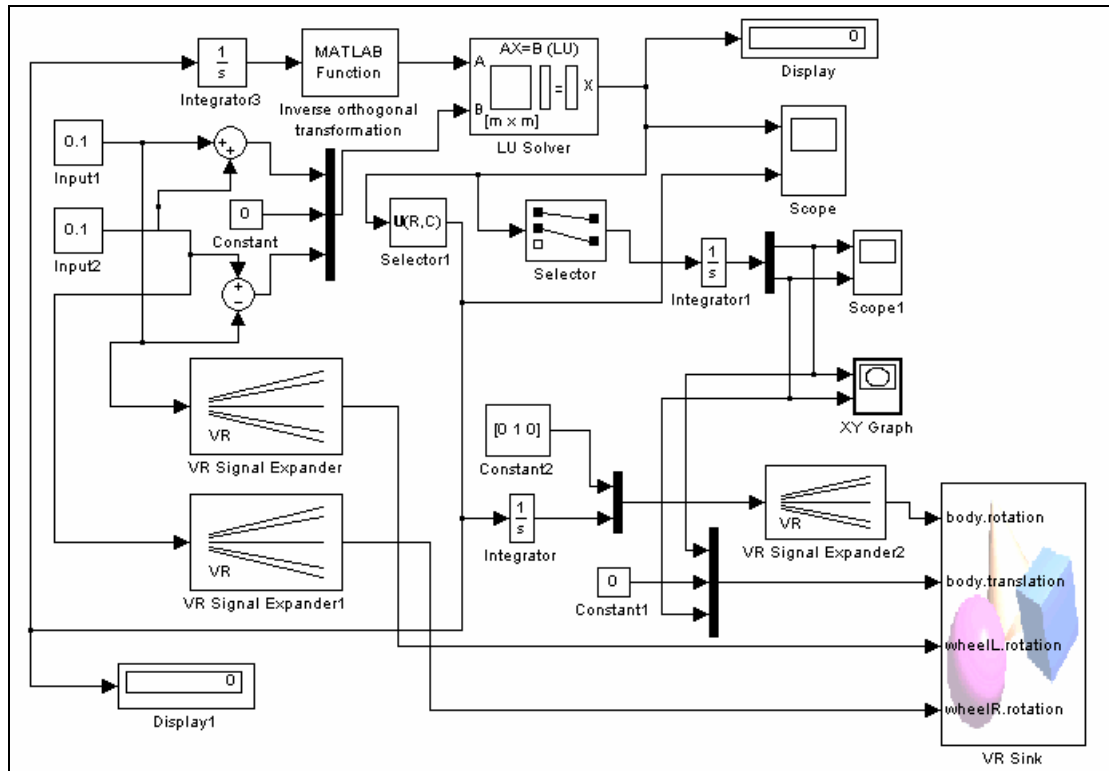


Figure 6: Simulink Differential Drive Model

Most of the current mobile robot simulations are in 2D environment [9]. One major improvement in this work is the 3D representation of the simulation. In order to have a 3D visualization for the output robot motion, the robot CAD model has been imported into Matlab and linked to the Simulink model via the Virtual Reality Toolbox. Before importing into Matlab, the VRML model from SolidWorks has to be processed using the V-Realm Builder 2.0 that comes along with the Virtual Reality Toolbox. This process is to rearrange the nodes and parent-child relationship in order to be used by Simulink. Once the model is imported, the output robot motion can be linked with the model via a VR Sink block.

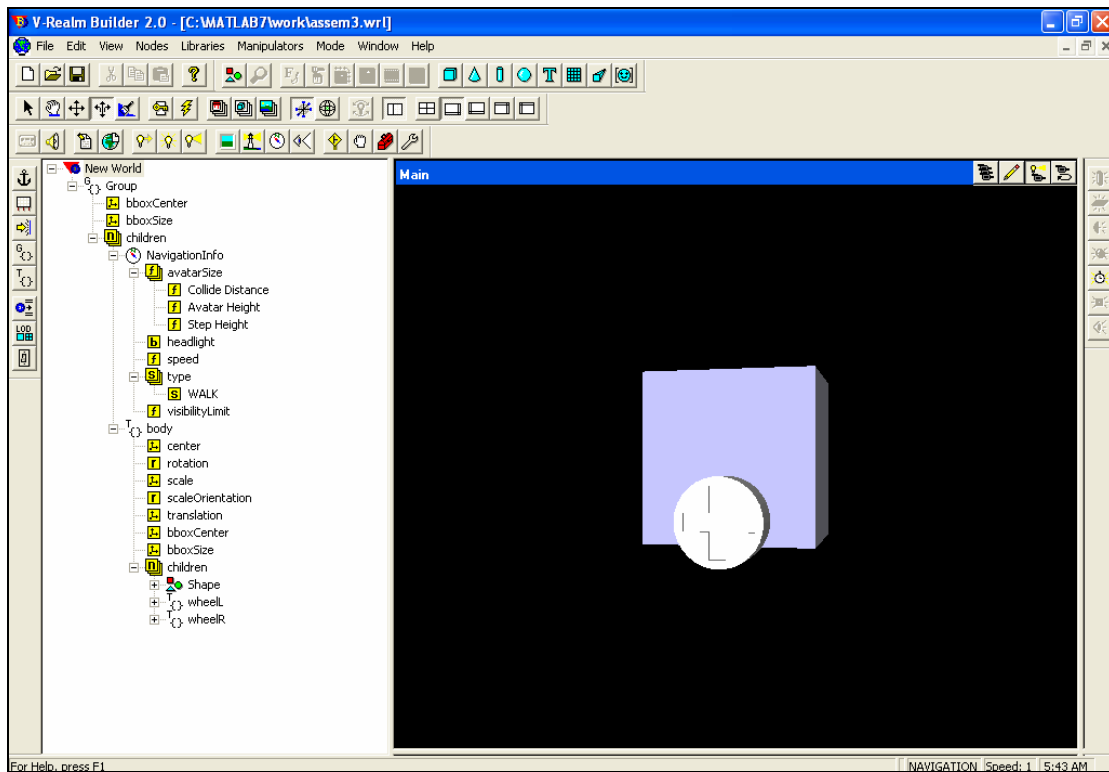


Figure 7: Processing VRML model using V-Realm Builder 2.0

Conclusions

The modeling and simulation of a differential drive mobile robotics system has been developed in this work. After setting the model requirements, the CAD model has been created using SolidWorks. The CAD model is being exported in the VRML format for Virtual Reality representation later. The differential drive mathematical model is derived in order to develop a Simulink model in Matlab for the simulation. The simulation is then linked together with the Virtual Reality model to complete a 3D simulation on the differential drive robot system.

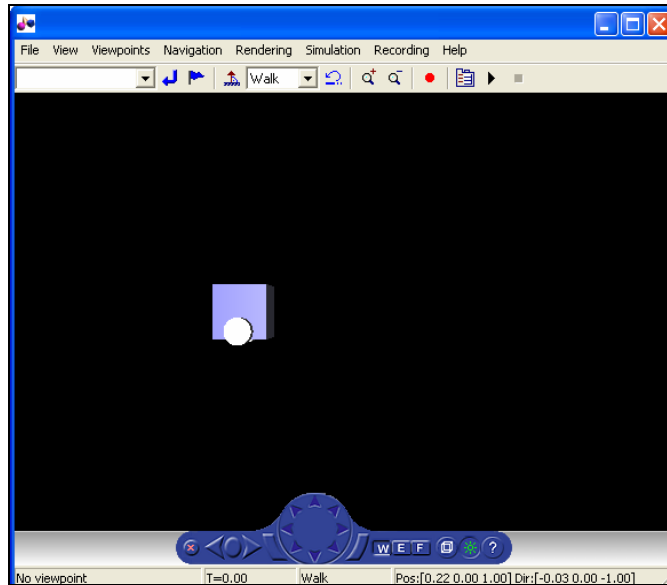


Figure 8: Final Virtual Reality output of the robot system simulation

As the first phase of the overall project to develop a general mobile robotics system simulation, this work has established the fundamental simulation model for the future work. The next step will be modularizing the components to provide flexible modeling for different parameters. Another important element will be the control algorithm for the robot system. But before this, the feed back system in the Virtual Reality environment has to be done. The interactive environment is needed in order to simulate the controller system. With these, it will become a complete package for mobile robotics system simulation.

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