Modeling and Simulation of Garbage Fetching Robot

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Abstract: In light of the advancements that have been made in technology, robotics and automation are becoming an increasingly integral part of the process of making work more effective and minimizing human interference. The proposed design involves the modelling and simulation of a mobile manipulator that will be able to navigate autonomously in unknown environments. In terms of the physical design of the robot, it uses differential drive, ensuring the ability to drive effectively and flexibly. Modeling is done through CoppeliaSim, giving it a realistic environment in which testing can be done. In order to attain autonomy, the use of Simultaneous Localization and Mapping in the construction of a map of the surroundings as well as establishing the position of the robot is incorporated. Extended Kalman Filter and Particle Filter techniques are applied to achieve localization.

1. Introduction

The progress of robotics technology is strongly correlated with progress in different areas of engineering and economy. Within this respect, the simulation of robots is an important part. Without any real application being created, simulation software is used to set different parameters of the robot from a technical aspect as well as in terms of its application purpose. With the help of the simulation process, all phases of the design, creation, and testing of the robot will be done virtually, and thus substantial savings on workforce, material, money, and time may be made.

Hygiene in the environment is necessary in social interactions, human beings as biological organisms require food for their survival, both natural and synthesis (processed) human sources of food. All foods have by-products, such by-products are referred to as domestic wastes, the management of domestic wastes is a social responsibility, and the neglect of domestic waste will lead to natural disasters such as floods and sources of diseases.

Distributing the non-periodic waste is one of the factors behind the collection of waste. The lack of human awareness concerning the non-periodic distribution of the waste leading to disasters. Hence, there is a need for some mechanism that will deal with the distribution of the household waste, for example, through general cleaning crews who daily collect the household waste and distribute it to public dumping sites. One of the difficulties faced in ensuring the periodicity of waste distribution is the limitation by human beings in terms of health.Robotics is a machine used to ease the labour of humans; robots whose purpose is to move garbage from one location to another will solve the problem of accumulation of household garbage. The robotics system designed to lift a load and transport it, such as car robots or mobile robots having a four-wheeled drive mechanism, are perfectly suited to balance the load being lifted.

2. Literature Review

Advances in robotics and automation have increasingly aimed at minimizing human interference and enhancing operational efficiency through autonomous systems. The development of mobile manipulators combining a mobile platform with a robotic arm is essential for tasks requiring both navigation and interaction, such as automated garbage collection. Differential drive systems are a preferred choice for such robots due to their mechanical simplicity and high maneuverability in tight spaces. Rohmer et al. [1] introduced CoppeliaSim (V-REP) as a versatile integrated development environment that allows for realistic physics-based modeling and simulation of complex robotic systems. For effective navigation in unknown environments, Simultaneous Localization and Mapping (SLAM) is critical. Thrun [2] established that SLAM allows a robot to build a map of an environment while simultaneously keeping track of its own location within that map. To handle the inherent noise in sensor data [3], various filtering techniques are employed for precise localization. The Extended Kalman Filter (EKF) is widely utilized for state estimation by linearizing non-linear transitions, making it suitable for differential drive kinematics. Alternatively, Particle Filters (PF) are used to represent the probability distribution of the robot's position through a set of samples, providing robust performance in non-Gaussian environments[4]. Recent studies have integrated these filters within simulated environments to validate autonomous navigation algorithms before physical deployment. The synergy of these technologies enables the robot to navigate and perform garbage fetching tasks autonomously and reliably.Nowadays, mobile robot technology has undergone very rapid development. According to Rodney Brooks [5], behavior-based robotics has significantly influenced real-time robotic applications. Many applications of mobile robots are used in everyday life, such as room cleaning robots, bomb disposal units, intelligent wheelchairs, and industrial transport systems, as discussed by Sebastian Thrun et al. [6].A mobile robot requires an efficient navigation system to move accurately between locations. Roland Siegwart and Illah Nourbakhsh emphasized the importance of autonomous navigation systems in mobile robotics [7]. Smart robots must also perceive and interpret environmental conditions effectively [8].Various navigation and path planning methods have been developed over time. Steven M. LaValle presented key algorithms for motion planning and obstacle avoidance [9].Among modern techniques, Simultaneous Localization and Mapping has become widely adopted. Hugh Durrant-Whyte and Tim Bailey provided a comprehensive overview of SLAM methods [10].For localization, probabilistic approaches such as Extended Kalman Filter and Particle Filter are widely used. Dieter Fox et al. demonstrated the effectiveness of particle filters in mobile robot localization [11-12].Sensor technologies such as LiDAR, cameras, and ultrasonic sensors are crucial for environmental perception. Cyrill Stachniss highlighted sensor fusion techniques for improved mapping accuracy [12-15]. Simulation tools such as CoppeliaSim are widely used for testing robotic systems. Marc Freese discussed the advantages of simulation in robot development [16].Simulation reduces development cost and time while enabling safe testing in virtual environments [17]. Recent advancements integrate artificial intelligence for better decision-making and adaptability, as noted by Stuart Russell and Peter Norvig[18].

3. Design

CoppeliaSim, the robot simulation software, together with its integrated development environment, uses a distributed control system design where each model/object can be individually controlled by an embedded script, plugin, ROS, or BlueZero node, remote API client, or any other user-defined control scheme. Therefore, CoppeliaSim is highly flexible and suitable for multiple robots. Robot controllers can be programmed using C/C++, Python, Java, Lua, Matlab, or Octave programming languages.

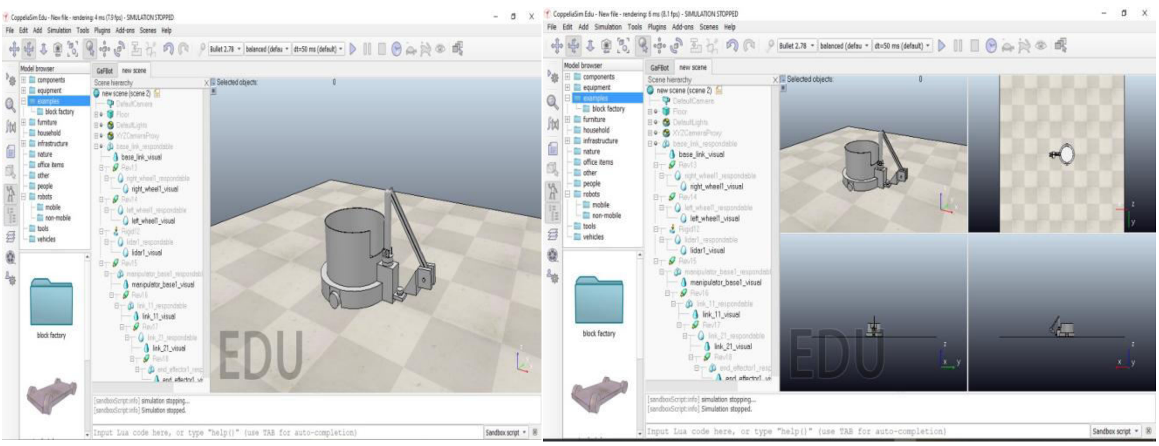
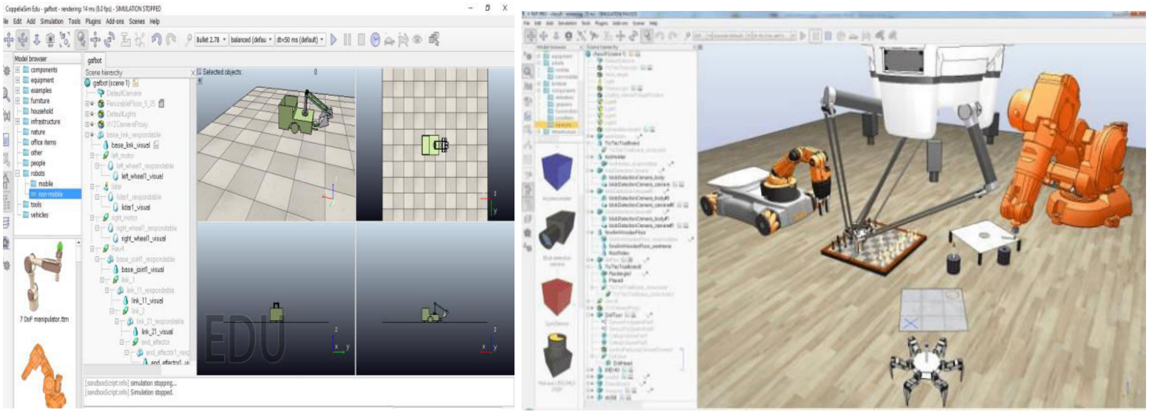


Fig.1



CoppeliaSim is utilized for quick algorithm development, automation simulation in factories, rapid prototyping and validation, robotic teaching purposes, remote supervision, safety checks, as a digital twin, and many other applications. For more details about its features, visit this link.

Currently, there are several robot simulator software packages such as Open HRP [1], Gazebo [2] or Webots [3] available. Although some may compete in terms of capabilities provided, most lack in the ability to provide a wide range of programming approaches. Their simulation models as well as controllers are portable in part only, meaning that simulation models, controllers and other components can be distinguished and, therefore, require separate handling. In particular, recompilation of controllers for different hardware and platforms can be required, or there should be special care taken regarding a matching of the simulation model and controllers because they comprise at least two different files.

V-REP Simulator, or the Virtual Robot Experimentation Platform [4] (as depicted in Fig. 1), the principal user interface, was produced through an attempt to integrate all necessary conditions into one versatile and scalable simulation platform. In addition to providing the conventional techniques provided by many simulators, V-REP additionally provides a number of other techniques as well. Section II outlines the control architecture of the V-REP simulator, with a discussion on the different types of controllers available, such as embedded scripts. That is, they are an essential component of a simulation model, hence making them very portable and scalable. The third section provides insight into the general simulation capabilities offered by the system, including their application within the context of simulation models, in the quest for scalability and portability.

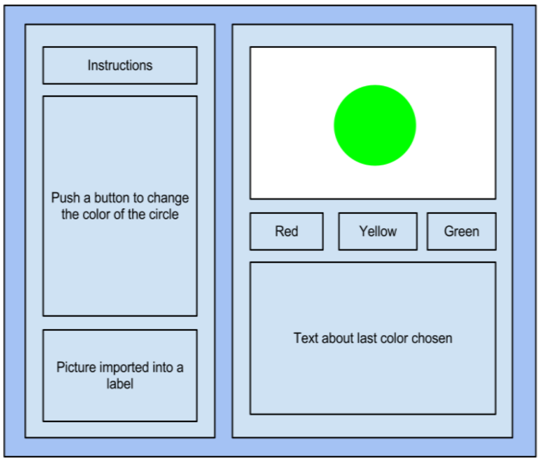
V-REP allows the user to choose among various programming techniques simultaneously and even symbiotically. [11] discussed that a robot is a machine that can automatically do a task or a series of tasks based on its programming and environment. They are artificially built machines or devices that can perform activities with utmost accuracy and precision minimizing time constraints.

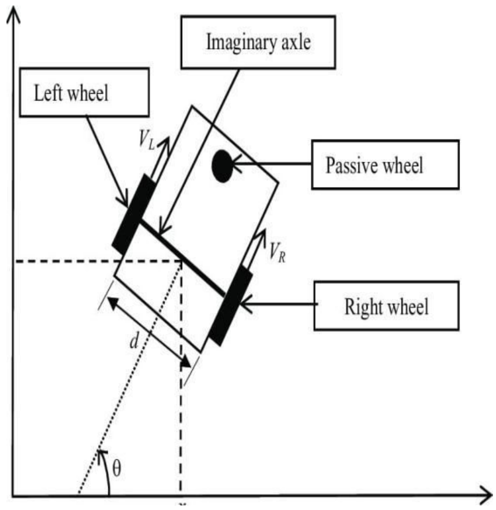
Remote API python- Coppeliasim :

The remote API is one of several ways an application can connect with CoppeliaSim. It allows communication between CoppeliaSim and an external application (i.e. an application running in a different process, or on a different machine), is cross-platform, supports service calls (i.e. blocking calls), and is also bidirectional data streaming. It comes in three distinct versions/frameworks. The remote API interface in VREP allows interacting with V-REP or a simulation, from an external entity via a socket communication. It is composed of remote API server services and remote API clients. The client-side can be embedded as a small footprint code (C/C++, Python, Java, Matlab & Urbi) in virtually any hardware including real robots, and allows remote function call, as well as fast data streaming back and forth. On the client-side, functions are called almost as regular functions, with two exceptions, however: remote API functions accept an additional argument which is the operation mode, and return the same error code. The operation mode allows calling functions as blocking (will wait until the server replies), or non-blocking (will read streamed commands from a buffer, or start/stop a streaming service on the server-side). The ease of use of the remote API, its availability on all platforms, and its small footprint makes it an interesting alternative to the ROS interface.The CoppeliaSim gives access to an application or to a simulation as an external entity through the remotely accessible API interface. This interface consists of an API server and a client that sends/receives requests and/or streams data to/from the server over a socket connection between the two entities. The client application can use code to interact with the server that will fit onto any device that has processing power real robot as a very small size, and that will allow remote procedure calls and very fast data streaming. The invocation of API functions appears the same as calling normal procedures except for two differences: one is that you include an extra parameter to specify your operation mode as well as to receive the appropriate error code back. The second is that the API functions may behave as blocking this will cause the client application to wait until the server has responded or non-blocking this will allow the client to read the command stored in the server's message queue, as well as to start/stop streaming services on the server.The modeling and simulation of a garbage-fetching robot represent a key point where autonomous navigation meets practical environmental automation. By using a mobile manipulator with a differential drive system, the robot gains the maneuverability needed to move through complex and unknown terrains while keeping stable enough to collect objects. CoppeliaSim creates a realistic virtual environment that allows for thorough testing of Simultaneous Localization and Mapping (SLAM) algorithms without the risks of physical prototyping. Within this setup, Extended Kalman Filters (EKF) and Particle Filters (PF) help ensure accurate state estimation and localization. This enables the robot to effectively combine noisy sensor data and keep its position on a map that changes dynamically. This blend of solid mechanical modeling and effective probabilistic filtering builds the basis for a reliable, fully autonomous waste management system that can work with little human input.

4. GUI

It is often useful to map out what the GUI is going to look like before starting on it so that all the frames can be nested appropriately. A sketch should be made for the GUI so that it can be visualized,





Robot Model-Differential Drive

A differential wheeled robot is a mobile robot whose movement is based on two separately driven wheels placed on either side of the robot body. It can thus change its direction by varying the relative rate of rotation of its wheels and hence does not require an additional steering motion.To balance the robot, additional wheels or casters may be added.If both the wheels are driven in the same direction and speed, the robot will go in a straight line. If both wheels are turned with equal speed in opposite directions, as is clear from the diagram shown, the robot will rotate about the central point of the axis. Otherwise, depending on the speed of rotation and its direction, the center of rotation may fall anywhere on the line defined by the two contact points of the tires. While the robot is traveling in a straight line, the center of rotation is an infinite distance from the robot. Since the direction of the robot is dependent on the rate and direction of rotation of the two driven wheels, these quantities should be sensed and controlled precisely.A differentially steered robot is similar to the differential gears used in automobiles in that both wheels can have different rates of rotations, but unlike the differential gearing system, a differentially steered system will have both wheels powered. Differential wheeled robots are used extensively in robotics since their motion is easy to program and can be well controlled. Virtually all consumer robots on the market today use differential steering primarily for their low cost and simplicity.

Robot Result and Discussion:

The design of GaFbot was built in Fusion 360 software. Fusion 360 is a cloud-based 3D modeling, CAD, CAM, CAE, and PCB software platform for product design and manufacturing. Design and engineer products to ensure aesthetics, form, fit, and function. Reduce the impact of design, engineering, and PCB changes and ensure manufacturability with simulation and generative design tools. Directly edit existing features or model fixtures with the only truly integrated CAD + CAM software tool.

Kinematics of the robot :

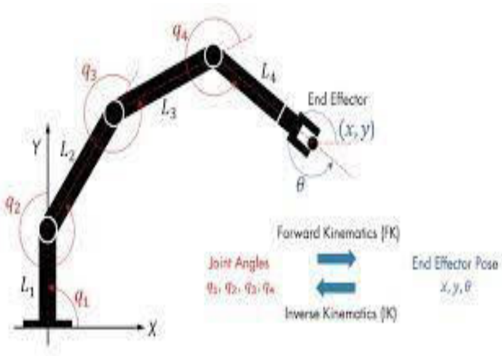
Robot kinematics applies geometry to the study of the movement of multi-degree of freedom kinematic chains that form the structure of robotic systems. The emphasis on geometry means that the links of the robot are modeled as rigid bodies and its joints are assumed to provide pure rotation or translation.Robot kinematics studies the relationship between the dimensions and connectivity of kinematic chains and the position, velocity, and acceleration of each of the links in the robotic system, in order to plan and control movement and to compute actuator forces and torques. The relationship between mass and inertia properties, motion, and the associated forces and torques is studied as part of robot dynamics.

A fundamental tool in robot kinematics is the kinematics equations of the kinematic chains that form the robot. These non-linear equations are used to map the joint parameters to the configuration of the robot system. Kinematics equations are also used in the biomechanics of the skeleton and computer animation of articulated characters.

Forward kinematics uses the kinematic equations of a robot to compute the position of the end-effector from specified values for the joint parameters. The reverse process that computes the joint parameters that achieve a specified position of the end-effector is known as inverse kinematics. The dimensions of the robot and its kinematics equations define the volume of space reachable by the robot, known as its workspace.There are two broad classes of robots and associated kinematics equations: serial manipulators and parallel manipulators. Other types of systems with specialized kinematics equations are air, land, and submersible mobile robots, hyper-redundant, or snake, robots, and humanoid robots.

- ❖ Forward kinematics

Forward kinematics specifies the joint parameters and computes the configuration of the chain. For serial manipulators, this is achieved by direct substitution of the joint parameters into the forward kinematics equations for the serial chain. For parallel manipulators substitution of the joint parameters into the kinematics equations requires a solution of a set of polynomial constraints to determine the set of possible end-effector locations.



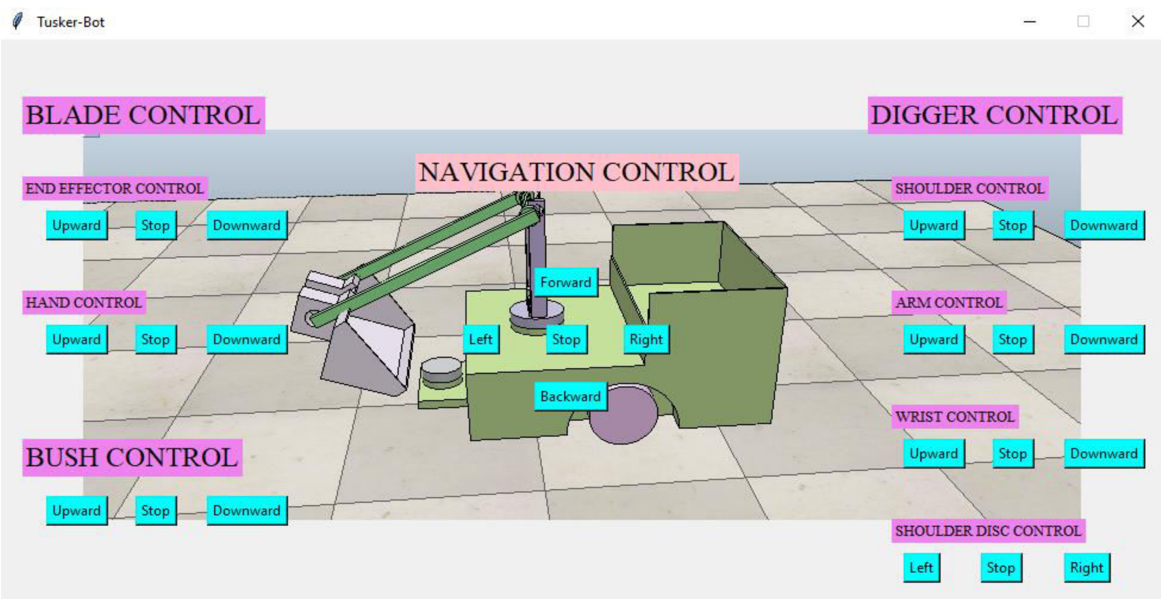
- ❖ Inverse kinematics

Inverse kinematics specifies the end-effector location and computes the associated joint angles. For serial manipulators, this requires the solution of a set of polynomials obtained from the kinematics equations and yields multiple configurations for the chain. The case of a general 6R serial manipulator a serial chain with six revolute joints yields sixteen different inverse kinematics solutions, which are solutions of a sixteenth-degree polynomial. For parallel manipulators, the specification of the end-effector location simplifies the kinematics equations, which yields formulas for the joint parameters.

Teleoperation :

Telerobotics is the area of robotics concerned with the control of semi-autonomous robots from a distance, chiefly using Wireless networks like Wi-Fi, Bluetooth, the Deep Space Network, and similar or tethered connections. It is a combination of two major subfields, teleoperation and telepresence.Teleoperation indicates the operation of a machine at a distance. It is similar in meaning to the phrase "remote control" but is usually encountered in research, academic and technical environments. It is most commonly associated with robotics and mobile robots but can be applied to a whole range of circumstances in which a device or machine is operated by a person from a distance. [14] explained that Industry 4.0 is a trending revolution in the present society, especially in the circular economy system. The latest advances in the domain of data science, artificial intelligence (AI), robotics, the Internet of Things (IoT), big data, augmented reality, and virtual reality have opened the door for smart waste treatment systems.

The tendency to build robots has been to minimize the degrees of freedom because that reduces the control problems. Recent improvements in computers has shifted the emphasis to more degrees of freedom, allowing robotic devices that seem more intelligent and more human in their motions. This also allows more direct teleoperation as the user can control the robot with their own motions. The teleoperating control of GaFbot is shown below.



5. Conclusion

The GaFbot really shows how structural engineering and autonomous systems can work together in CoppeliaSim. Using Autodesk Fusion 360, the team nailed the robot's physical design, so it's tough enough to handle tricky mobile tasks. With SLAM and teleoperation built in, GaFbot navigates and maps unknown environments smoothly. Testing proved it can spot obstacles and pick up objects on its own the control setup works.This design closes the gap between simulation and real-world needs for waste management robots. GaFbot's the kind of solid prototype you want: its combination of probabilistic localization filters and detailed modeling actually delivers a reliable autonomous robot. The results give a strong base for eventually bringing hardware into messy, unpredictable real environments. The mobile manipulator hits all its design targets in the virtual test area. The GaFbot cuts out a lot of human effort, showing how automation can transform tough jobs. This study lays out a practical, scalable framework for future generations of autonomous robots that fetch garbage ready to take on almost any setting.

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