Abstract

This paper is presenting the integration of Building Information Modeling with a robotic system for construction tasks. Equipped with advanced sensors, the robot will be able to perform the construction tasks of material handling and site inspection through a mobile application that offers real-time control. It enhances construction efficiency by ensuring precise execution and seamless updates to BIM models. Our experiments prove improved task completion times and accuracy, reducing the need for human labor. The integration of BIM and robotics is so promising in changing the face of construction that this paper provides valuable lessons for further research and development in this area.

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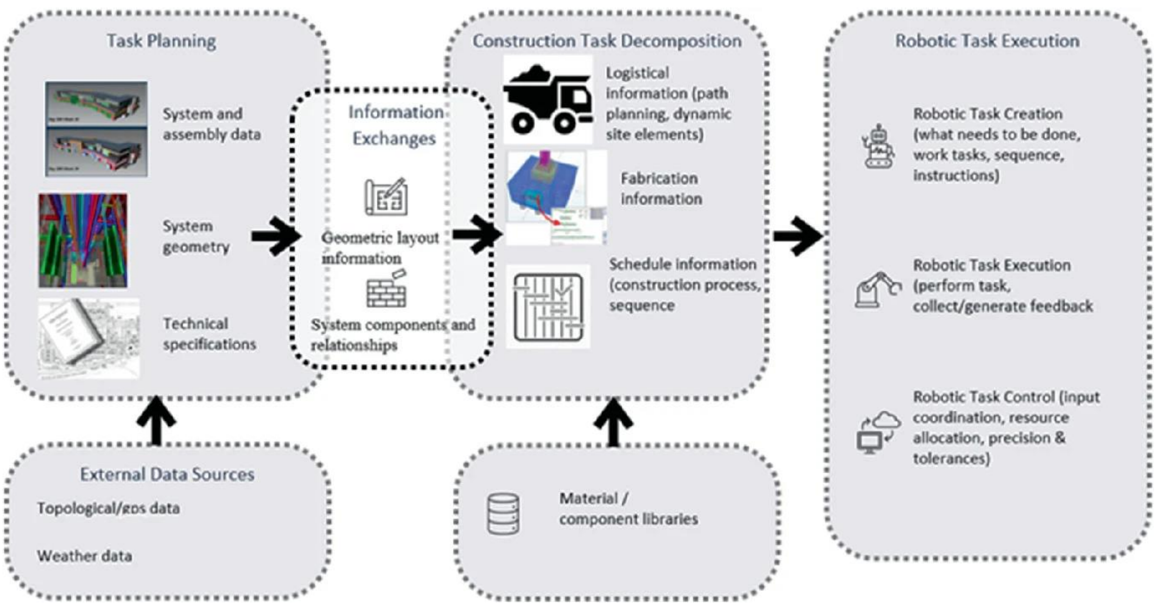
General Discussion of Robotic System Models

1. BIM-to-robot construction system

The three major phases that the system architecture for BIM-to-robot construction would cover are task planning, task decomposition, and task execution. This architecture allows the transfer of detailed data from the BIM model to the robots for execution. In this architecture, sufficiently detailed BIM models tailored for construction purposes are required.



Fig[1] (From: System Architecture for Supporting BIM to Robotic Construction Integration)

The BIM-to-robot construction system architecture begins with task planning, as shown in Figure 1. This is an information-gathering step for a project to identify the work to be executed, focusing on the system to be built, facility data, and site data.

1.1 Task Planning

Identify Tasks: Specify the tasks, systems, or activities that are to be executed by the robot.

Extract and Analyze System Data: Gather system information and analyze it including but not limited to geometry, tolerances, specifications, adjacent systems, and connected components.

The analysis is very important for downstream processes because each of the subsystems in the facility has its requirements and constraints. For instance, ductwork systems have:

It interfaces with many systems, including electrical and structural components that require careful sequencing.

Size, type, and strict tolerances, which vary with the building type, have to be considered.

1. 2Task Decomposition

As shown in Fig 1, the Task Decomposition phase follows the completion of the task planning phase. In this phase, the logistical steps required for the assembly or execution of the tasks identified earlier are identified and formalized. This phase can be divided into three major subtasks:

Logistical Information:

Data extracted during task planning, including storage locations, site hazards, and facility geometry.

Includes dynamic site aspects, like moving equipment, that enable effective robot path planning in later stages.

Fabrication Information:

Addresses tasks that require more fabrication before installation.

For instance, in the case of ductwork, the connection interfaces-flanges-between sections of duct are defined and integrated at this stage.

Scheduling Information:

Creates a timeline for the execution of tasks by analyzing construction processes and sequences.

Considers how subsystems relate to the chosen task in terms of duration of task, resource allocation, and site constraints.

1. 3Task Execution

This is the final stage of the BIM-to-robot construction system architecture. As derived from Figure 1, it dwells on how to empower the robot to develop the capability of executing its tasks regarding information gained from previous steps.

Major Components of Task Execution:

Creation of Robotic Tasks:

Incorporating scheduling and logistical data that comes out of the Task Decomposition phase

Specifies order of operations, including the place of the tasks within a construction site.

It creates task information that will allow the robot to execute the task and inform its sequence of actions.

Robotic Task Execution Control:

The robot performs the job based on the control commands or information input during the creation phase.

Identifies and moves on to the next tasks when the current one is done.

Delivers a construction report with feedback on site conditions included and detection of errors.

Robotic Task Control:

Ensures quality and observance of tolerances in executing the task.

Validates whether the task was completed correctly and, if so, initiates the next task.

Adjusts operations dynamically if errors are detected, such as misalignment or missing components.

1.4 Pros and Cons of Other Robotic Models

Pros:

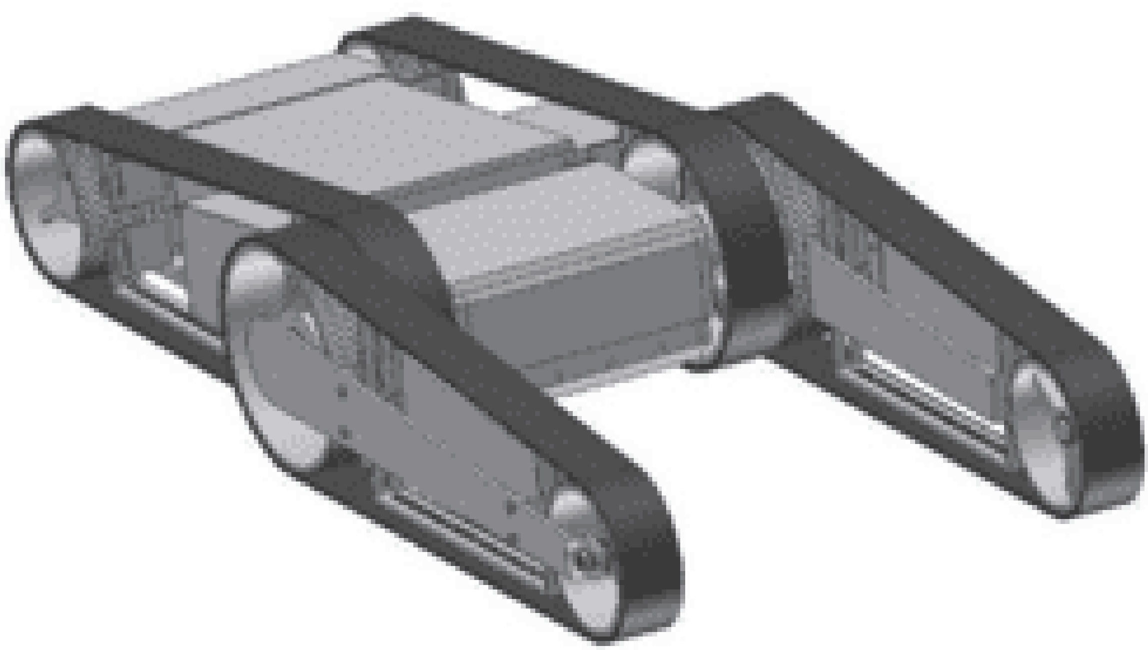
High-accuracy operations in repetitive tasks can be done. Ability to perform duties in hazardous environments. Do the job without deterioration. Advanced sensors and AI help to make decisions autonomously. Integration with BIM models will allow detailed planning of tasks and execution

Cons:

High initial and maintenance costs. Complex to programme and integrate with current systems. May displace workers working on sites. Inability or less capability to handle unexpected site conditions Dependence on accurate and detailed BIM models for effective operation.

2. mechanical model

2.1The main body



Fig[2] (From: Design, Development & Evaluation of a Prototype)

The locomotion system of the proposed robot consists of two tracks, which are good in stability and adapt easily to a wide range of terrains. Key components, power systems, motorized actuators, and computational units compose the structural backbone of this design, placed inside the main chassis. It is achieved with two parallel tracks driven by an independent motor. Such a configuration provides differential steering, hence enabling the platform to make precise movements in linear motion and rotation, including zero-radius rotations. Its tracked design means very low ground pressure, enabling movement over difficult surfaces like soft soils, gravel, or stairs without significant loss of traction and stability. Design such that it connects the tracks with mechanical arms to the robot chassis has been done in such a way that ground clearance for the robot is altered to increase terrain adaptability and allows negotiation of obstacles while keeping balance on the ground that is unbalanced. Its system design is in line and made modular to further provide scalability and integration of many sensors or tools for accomplishing particular missions, for either exploration, rescue, and any industrial application. The tracked system provides the robot with multis-skilled locomotion capabilities, at the same time very strong and reliable in both controlled and dynamic operational environments.

2.2 movement

Fig[3] (From: Design, Development & Evaluation of a Prototype)

The robotic platform, therefore, has a locomotion system with dual tracks owing to the negotiations on a difficult terrain, such as graceful climb ups and downs in a staircase, with the weight equally distributed, thus providing very good traction; tracks are also independently powered to attain precision control, differential steering for high maneuverability within constrained space. The mechanical design of the robot includes linkage arms that are adjustable, connecting the tracks to the main chassis. These allow the robot to change its posture, ensuring good ground contact when either climbing or descending stairs. This adaptability allows for greater stability and nonslipping, hence making it fit for operations in multilevel environments. Apart from stairs, the robot shows its strength in uneven outdoor terrain, like on gravel, sand, or an inclined surface. Wide tracks and a strong chassis design maintain performance even under very harsh conditions. These features make the robot highly suitable for search-and-rescue missions, industrial inspections, and other exploratory tasks. With the marriage of a rugged design and advanced mobility, this robot can operate with real effectiveness across varied environments meeting both the requirements and challenges presented by urban and off-road scenarios.

2.3 component body

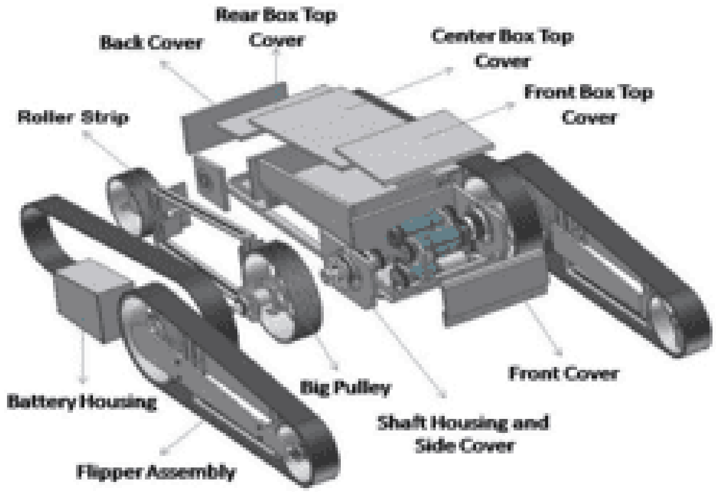


Fig. 2. Exploded View of the Platform

Fig[4] (From: Design, Development & Evaluation of a Prototype)

Centrally located, the Center Box Top Cover acts to shield the vital internal components such as the power unit and the processing units. With its protection of vital electronics, it holds an essential role in ensuring the structural soundness of the robot. Material used to make this cover is usually high strength, designed to absorb impacts and other environmental elements that may reach the internal systems. The Front Box Top Cover is located in the front part of the robot. Inside this casing are forward-facing electronics and sensors that are extremely crucial to the navigation and interaction of the robot with the environment. Most of these designs have easy access for maintenance or upgrade of necessary parts. One of the devices used in reducing friction between the tracks of the robot and its frame is the Roller Strip. This provides ease of movement over any available surface by extra bracing to the track. The roller strip would usually be made up of tough material that resists wear and tear but offers minimal friction to the movement. The Big Pulley is mounted on the motor system, which connects with the robot's tracks to transfer torque for use in the movement of the robot. Being a main drive pulley, it will be very important in providing traction, especially in heavy-duty robots. Its size and material are designed in such a way that great amounts of stress and strain can be borne by them so that the motor system works effectively while maintaining stability. The battery housing serves to keep the power source of the robot in its place, hence totally safeguarding the batteries from any kind of physical damage or environmental elements. It further helps in maintaining stability and balance by keeping the distribution of weight as near ideal as possible. A number of them are even designed for easy replacement or recharging so that the robot will work without any disruption or at most for minimal downtime. Flipper assembly: It allows the robot to surmount obstacles or stairs. With that, the adjustment in track position optimizes contact to the ground and hence can let the robot easily jump to uneven surfaces. Flipper system: normally a motor-driven system that may be extending or re-positioning of the tracks for superior traction and balance over complex terrains. Each of these plays important functions in the design, functionality, and general performance of the robot. Bringing all these together, one would be contemplating how the engineers would ever better this robot in carrying out a great number of things with huge mobility and stability and in greater efficiency. Upgrading these will continually drive the development of robotic technologies, extending the use of many areas through further research.

2.4 Pros and cons of the Robot's Design

Pros of the Robot's Design

1. **Stability on Difficult Terrain:**

    - The dual tracks and adjustable mechanical arms offer excellent stability, even on challenging surfaces like gravel, sand, soft soils, or stairs.
    - The low ground pressure enables the robot to handle soft terrains with minimal loss of traction.
    - High maneuverability in tight spaces, which is crucial for operations in constrained environments.

2. **Adaptability:**
    - The design includes features like adjustable linkage arms and ground clearance alterations, allowing the robot to adapt to a variety of environments, including uneven and multilevel terrains.
    - The ability to climb stairs and overcome obstacles enhances its versatility for exploration and rescue missions.
3. **Durability:**
    - The robust design, including high-strength materials for the chassis and covers, ensures the robot is durable and can withstand environmental elements such as impacts, wear, and weather conditions.
    - The roller strip and big pulley contribute to the smooth and efficient movement of the robot on various surfaces.
4. **Ideal for Harsh Environments:**
    - The robot's strong chassis and wide tracks maintain excellent performance under harsh conditions, including in search-and-rescue operations and industrial settings.

Cons of the Robot's Design

1. **Complexity:**
    - The design features, such as the adjustable arms, flipper assembly, and differential steering, add to the mechanical complexity of the robot, which could lead to potential maintenance challenges or technical failures if not properly managed.

2. **Weight and Size:**

- The dual tracks, large pulleys, and robust chassis might add significant weight to the robot, potentially limiting its ability to operate in highly constrained or tight spaces.
- The size of the robot may not be ideal for tasks requiring compactness or stealth.

3. **Cost:**

- The use of high-strength materials and the inclusion of advanced features like adjustable arms, roller strips, and a flipper system may increase the overall cost of production and maintenance.
- The need for specialized components and parts for upgrading could further drive up costs.

3. components

3.1 Hardware Components

Smart robots rely on a combination of specialized hardware to function effectively. Key hardware components include:

processor

- Raspberry Pi: A compact and affordable computing board widely used in robotics for its versatility and ease of integration with sensors and actuators.

Fig[5]

- Arduino Boards: Microcontroller-based boards ideal for real-time control and processing in robotic applications.

Fig[6]

Sensors

Sensors provide the critical ability to perceive the environment. Common types include:

- Cameras: Enable computer vision applications such as object detection and tracking.

Fig[7]

Actuators

Actuators convert electrical energy into mechanical motion, enabling robots to move and manipulate objects. Examples include:

- Servomotors: Precise rotational control, commonly used in robotic arms.

Fig[8]

- Stepper Motors: Ideal for incremental movements in applications like 3D printing.

Fig[9]

Power Supply

Power supply systems are crucial for robot operation. Key considerations include:

- Lithium-Ion Batteries: Common in mobile robots for their high energy density.

Fig[10]

Communication Modules

Communication hardware enables robots to interact with other systems or devices. Examples include:

Wi-Fi and Bluetooth Modules: Provide wireless connectivity for remote control and data transmission.

Fig[11]

Fig[12]

4.Software

4.1 Functionality

A Robot Vacuum Cleaner is essentially a vacuum cleaner that could move on its own. The mechanism of detecting obstacles like walls, furniture, and other objects and moving around them in order not to collide is implemented in it. A dust sensor is fitted with an RVC that detects the dust/dirt particles and starts up the motor for cleaning by triggering it. It also has a display interface that shows battery status and operational status.System Interfaces

Display Interface:

The display interface depicts critical information on the level of the battery, charging status, and operational status of the RVC. This interface also forms the main interaction with the RVC as the device is turned on/off from this point and its status monitored.

Motor and Cleaner Interfaces:

The motor interface receives signals from sensors to move the RVC in different directions, that is, left, right, or forward. The cleaner interface acts to trigger the cleaning motor for operation once signals from dust sensors indicate the presence of dirt for cleaning to begin.

The user interface:

An RVC has a very simple user interface, which includes primarily the display interface. This allows the users to switch the RVC on and off and monitor the status of the RVC. The simplicity of the user interface ensures ease of use for users who are not used to advanced technology.Hardware and Software Interfaces

4.2 Software Interface

- Display Interface: Gives information related to battery and operational status.
- Motor and Cleaner Controllers: Take input from sensors and give commands for movement and cleaning.

4.3 Operation

The working of an RVC involves the following major steps:

1. Power-Up: The user switches on the RVC for cleaning.
2. Cleaning: The RVC moves forward, detects dust, and activates the cleaning motor. It avoids obstacles by changing direction based on sensor inputs.

3. Charging: When the battery is low, the RVC stops and requires charging. The user can monitor the battery status through the display interface.

4. Turning Off: The user can manually turn off the RVC when cleaning is not required.

4.4 Product Functions

1. Automatic Cleaning: The RVC starts cleaning automatically when turned on, using dust sensors to detect and clean dirt.

2. Obstacle Avoidance: The RVC continuously moves forward and changes direction to avoid obstacles detected by its sensors.

3. Display Information: The display shows battery and operational status, informing the user when the battery is low and requires charging.

4. Manual Control: Users can manually turn the RVC on and off as needed.

4.5 User Characteristics

The RVC is designed to be user-friendly, requiring minimal interaction. Users primarily turn the RVC on and off and monitor the battery status through the display interface. The automated cleaning process ensures that users do not need to manually control the device during operation.

Constraints

1. No Timer: The RVC lacks a timer to stop cleaning after a specific period. It continues cleaning until no dust is detected for three minutes.

2. House Security: Users must ensure all doors are locked to prevent the RVC from leaving the house and cleaning outside areas.

3. Furniture Arrangement: Users should arrange furniture to allow the RVC to navigate and clean efficiently.

Assumptions and Dependencies

1. Battery Monitoring: Users must regularly check the battery status and ensure the RVC is charged before cleaning.

2. Cleaning Area: The cleaning area should be free of small toys and liquids to prevent damage to the RVC.

4.6 Specific Requirements

External Interface Requirements

1. User Interface: Includes the cleaner and display interfaces, allowing users to control the RVC and monitor its status.

2. Hardware Interface: Manages motor and cleaner operations, including movement and cleaning functions.

3. Software Interface: Processes sensor inputs and generates commands for motor and cleaner control.

Functional Requirements

1. Obstacle Detection: Sensors detect obstacles and generate commands to navigate around them.

2. Dust Detection: Sensors detect dust and trigger the cleaner motor. The system stops cleaning if no dust is detected for three minutes.

Performance Requirements

1. Obstacle Detection Speed: The system should detect obstacles within one second to ensure smooth movement.

2. Motor Control Response: Commands to the motor should be processed within two seconds to maintain cleaning efficiency.

3. Cleaner Control Response: Commands to the cleaner motor should be processed within one second to ensure effective cleaning.

4.7 Design Constraints

1. House Security: Ensure all doors are locked to prevent the RVC from cleaning outside areas.
2. Furniture Arrangement: Arrange furniture to facilitate the RVC's navigation and cleaning.
3. Toy and Liquid Removal: Ensure the cleaning area is free of small toys and liquids to prevent damage to the RVC.
4. Battery Status: Regularly check and charge the RVC's battery to ensure efficient cleaning.

4.8 Software System Attributes

1. Reliability: The RVC should clean efficiently until no dust is detected.
2. Availability: The display interface should inform the user when the vacuum bag is full or when the battery is low.
3. Battery Management: The system should manage battery usage by stopping the RVC when the battery is low.
4. Maintainability: The display interface should indicate errors or damage, allowing users to perform maintenance.

4.9 Pros and Cons of Robot Vacuum Cleaners

Pros

1. **Convenience:** RVCs automate the cleaning process, saving time and effort for users.
2. **Efficiency:** Advanced sensors and cleaning algorithms ensure thorough cleaning.
3. **User-Friendly Interface:** Simple controls and clear display information make RVCs easy to use.
4. **Versatility:** RVCs can clean various surfaces, including carpets and hard floors.

Cons

1. **Initial Cost:** RVCs can be expensive compared to traditional vacuum cleaners.
2. **Maintenance:** Regular maintenance, such as emptying the vacuum bag and charging the battery, is required.
3. **Navigation Issues:** RVCs may struggle with complex furniture arrangements or small obstacles.

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