Glass Cleaning Robot Arm Project - G24

1st Rasilka P.H.S
dept. Electrical Engineering
University of Moratuwa
210531P
rasilkaphs.21@uom.lk

2nd W.D.L.Rasanjali
dept. Electrical Engineering
University of Moratuwa
210530L
rasanjaliwdl.21@uom.lk

3rd N.S.Rathnayake
dept. Electrical Engineering
University of Moratuwa
210538T
rathnayakens.21@uom.lk

***Abstract*—The design and deployment of an automatic window-cleaning robot for high-rise buildings are presented in this research. To enable efficient and accurate cleaning activities, the system blends modern robotics, motion planning algorithms, and sensory feedback systems. Using computer vision and machine learning techniques, the robot can negotiate complicated building facades and execute complete cleaning chores independently. The suggested design places a premium on safety, energy efficiency, and flexibility in various window geometry. The testing findings illustrate the system's usefulness in improving building maintenance practices and assuring a long-term solution for high-rise buildings.**

I. INTRODUCTION

A window-cleaning robot arm typically operates through mechanical, electrical, and sensory components. A window cleaning robot arm employs adhesion tools for surface grip, programmed navigation for path guidance, and various cleaning instruments for debris removal. Sensors and cameras aid in obstacle detection and safe cleaning. The electrical system enables controlled movements, ensuring stability and efficient performance.

As automation demand rises, robots are crucial in perilous fields like construction and security. They're adaptable to various environments. Manual window cleaning is hazardous and demanding when using water-soaked scrapers for high-rises.

In the pursuit of creating a compact cleaning machine capable of navigating typical obstacles found in residential windows, this study focuses on the development and analysis of our robot arm design and prototype, presented in Sections VI and VII, respectively. Emphasis is placed on the outcomes and encountered challenges during the design and testing phases. Section VIII outlines potential avenues for future enhancements and refinements within the scope of this research endeavor.

II. IMPORTANCE OF WINDOW GLASS CLEANING ROBOT ARM

Window glass cleaning robot arms offer enhanced safety by operating at dangerous heights, ensuring efficient and consistent cleaning for large and complex buildings. Their accessibility to hard-to-reach areas guarantees comprehensive coverage while providing a cost-effective and adaptable solution. Moreover, their consistent performance eliminates human error, ensuring uniform cleaning quality across all windows.

The Occupational Safety and Health Administration (OSHA) investigation found that in the past 10 years, there were 88 glass-cleaning accidents, of which 62 were casualties. For example, a cleaning gondola in Shanghai lost control due to the influence of strong wind. There were 15 casualties during the cleaning work in South Korea in 2016

III. SYSTEM DESIGN AND COMPONENTS

A. *SENSOR SYSTEM*

In our system, we employ lightweight and low-cost optical sensors for detecting surface impurities. Additionally, proximity sensors are utilized for path verification. These sensors ensure cost-effectiveness and accuracy in the detection process

- Optical Sensor

Optical sensors use a variety of approaches to detect dirt or contaminants on glass surfaces based on variations in light reflection or absorption. Several essential processes are involved in the process, which allows the sensor to detect and measure the presence of pollutants. Here's a full explanation of how optical sensors detect dirt in glass

Optical sensors are essential components of automated window and solar panel cleaning methods, guaranteeing accurate and efficient surface upkeep. The procedure begins with purposeful and consistent lighting of the glass surface, which is accomplished by using a controlled light source at a certain angle. The sensors painstakingly catch the reflected light, allowing for a thorough investigation of the surface's optical properties, and revealing critical data regarding its transparency and cleanliness.

A vital stage in the functioning of optical sensors is the creation of a baseline measurement, which involves the study of a pristine portion of glass. This baseline acts as a critical reference point for further comparisons, making it easier to identify any inconsistencies or irregularities that might indicate the existence of impurities or pollutants. The sensors precisely evaluate data obtained from reflected light using modern signal processing algorithms, allowing exact discrimination between clean and filthy areas on the glass surface. This complete examination gives a qualitative and quantitative assessment of contamination levels, allowing for a more planned cleaning

Identify applicable funding agency here. If none, delete this.

strategy.
Furthermore, the output of the optical sensors, which includes numerical data and graphical representations, acts as an important reference in launching the proper cleaning processes. These visual signals efficiently identify the precise locations and intensity of discovered contaminants, leading to the usage of specialized cleaning techniques involving the use of water and appropriate washing products. This careful method guarantees that the glass surfaces are properly maintained and cared for, allowing for improved functioning and longer lifespan.

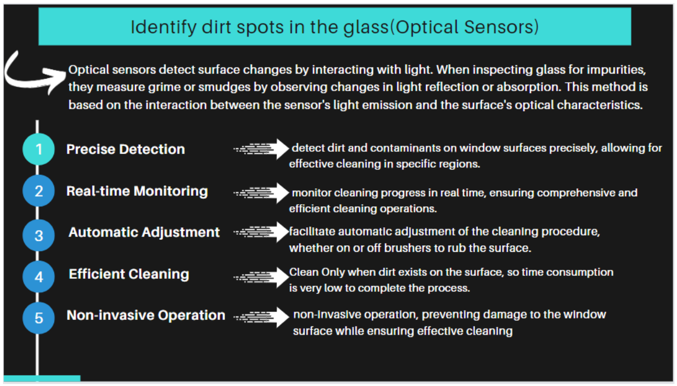

Fig. 1. advantages using optical sensor

- Proximity Sensor

Proximity sensors detect the presence of nearby things without the need for physical contact. They come in a range of sizes and shapes, most of them are compact cylindrical or rectangular shapes with diameters or lengths ranging from 6 to 30 mm. Depending on the type and intended sensing range, the size may vary. We recommend that our sensor be roughly 15mm in size to obtain a typical-size robot arm. These sensors use diverse technologies, such as inductive, capacitive, or photoelectric principles, to detect the presence of items within their detecting range. We employ sensors to detect obstacles with great precision and require detection within 10 mm of the barrier and sensor approximately.
Proximity sensors operate by producing an electromagnetic field or a beam of radiation and then measuring changes in the field or beam when an item approaches. The detection range of the sensor may be modified based on its requirements, allowing for exact object identification within a set distance. Because of their small size, dependability, and high sensitivity, they are ideal instruments for a wide range of proximity-sensing applications.

B. *WASHING PARTS*

- Microfiber Sponges

It is critical to prioritize durability, absorption capacities, and non-abrasive qualities while selecting the appropriate sponge-type material for a window-cleaning robot arm. Because of

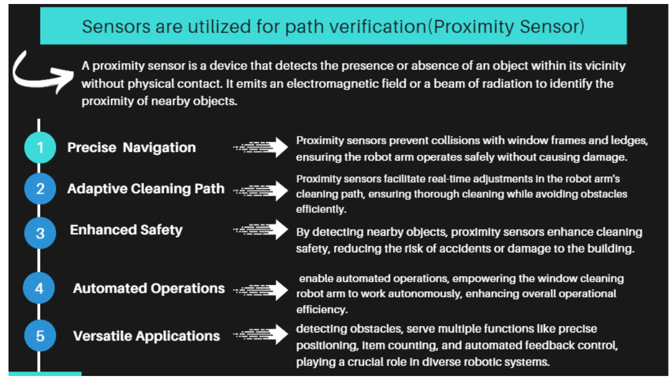

Fig. 2. advantages using proximity sensor

their great water absorption, soft cleaning action, and ability to catch and remove dirt efficiently, microfiber sponges are often used for this purpose. They are soft, non-abrasive, and gentle on glass surfaces, enabling thorough yet safe cleaning without scratching or damaging the surface. Microfiber sponges are particularly well-known for their resilience, allowing for repeated usage with little wear and tear. Furthermore, their quick-drying capabilities make them appropriate for efficient cleaning operations, increasing the overall efficacy of the window cleaning procedure.

Fig. 3. Microfiber Sponges

C. *STRUCTURE OF ROBOT ARM*

Carbon fiber is a composite material made of thin, woven strands of carbon atoms. One of the lightest and strongest materials on the market, it may be used for many different purposes, such as glass cleaning robots.
Carbon fiber's significance for glass-cleaning robot arms Because carbon fiber has several advantages over other materials, such as steel and aluminum, it is the perfect choice for glass-cleaning robot arms.

One of the strongest materials on the market is carbon fiber, which makes it perfect for robot arms that have to be able to bear large loads and extreme strains. Carbon fiber does not bend or flex readily due to its extreme stiffness. (needs to be strong and lightweight) This is crucial for robotic arms since they must lower weight is important because there are more components attached to the body of the glass cleaner. Also in order to have high efficiency, the minimum weight is an advantageous resistance to corrosion and it is ideal for harsh environments. Also, the power consumption is reduced when the body parts are lightweight and the time needed for cleaning is reduced.

IV. WORKING PRINCIPLE (SELECTED AREA CLEANING BY USING INVERSE KINEMATICS)

A. CLEANING ROBOT ARM

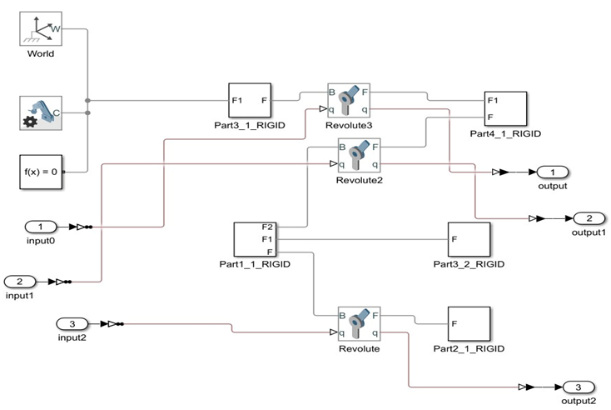

Fig. 4. simulink model of cleaning arm

The utilization of Inverse Kinematics (IK) algorithms in our cleaning arm robotics involves determining the joint angles or values necessary to achieve a predefined position for the end-effector. This pivotal role of Inverse Kinematics is instrumental in the control and programming of robotic arms, enabling precise tasks such as reaching, grasping, and object manipulation in diverse environments.

The design methodology involves utilizing SolidWorks for the creation of robot arm components, followed by linking the assembled final structure to MATLAB Simulink. This integrated approach facilitates the dynamic simulation of the system, allowing for a comprehensive analysis of the design.

In our approach, the working area is divided into eight distinct sections, each assigned a specific name for simplicity and identification purposes. Every part within these areas is associated with specific margins, defined by coordinates, which serve as crucial parameters for the precise control and manipulation of our robot arm.

To enable rotational movement for our glass cleaning robot arm, we have modified the structure depicted in Figure 4 by incorporating a cylindrical joint. This enhancement allows the robot arm to rotate along its base's z-axis, enabling targeted

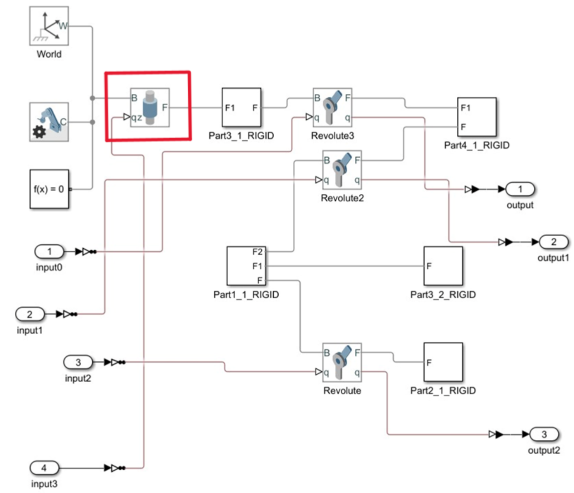

Fig. 5. inserting the rotational joint

cleaning of specific work areas in response to input commands.

In our system, we employ three main models. First, the solver configuration guides the selection of the ODE solver for our simulation. Under the multi-body section, we define the world reference frame to establish the coordinate system used in our model. Additionally, the mechanism configuration is utilized to specify gravity and other forces acting on the mechanism within the model. This integrated setup ensures accurate representation and analysis of the dynamic interactions within our system.

Within our glass cleaning robot arm designed in SolidWorks, we have organized the structure into five rigid body parts subsystems. These subsystems encompass the robot's rods, motors, and suction cups, interconnected through revolute joints under the multi-body gear and coupling section in MATLAB Simulink. Within each subsystem, specific parameters such as mass, radius, and inertia are defined, along with deciding rigid transforms. This detailed configuration allows for accurate representation and simulation of the robot arm's dynamics and performance

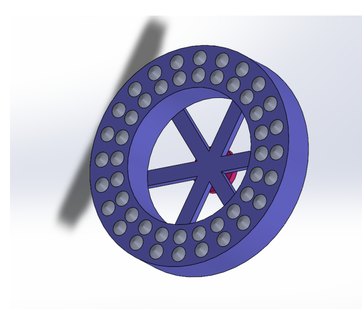

Fig. 6. Cleaning part

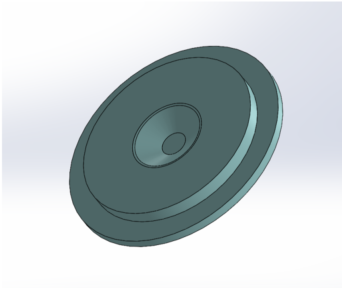

Fig. 7. suction cup

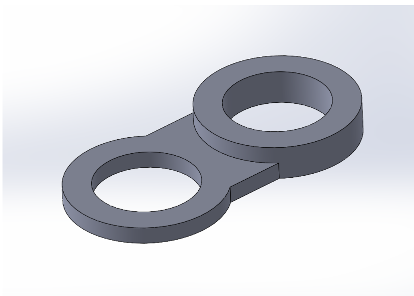

Fig. 8. Secondary Arm

Fig. 9. Base arm

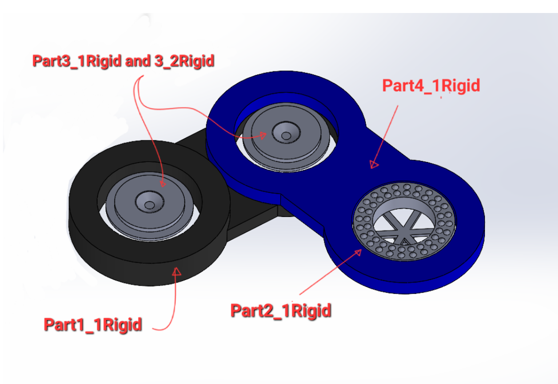

Fig. 10. SolidWorks drawing of cleaning robot arm

B. INPUT OF THE CLEANING ROBOT ARM

In practical applications, the control of velocity and accelerations is of paramount importance. Therefore, careful consideration of these factors is necessary when generating trajectories in the Robotic System Toolbox. Within this toolbox, various tools are available to facilitate the creation of reliable trajectories, taking into account accelerations, end times, velocities, and other trajectory aspects. The robot under consideration is a planar two-link, two degrees of freedom system, restricted to motion within the XY plane. The cleaning part, responsible for movement, is designed to follow a specified yellow path within the robot's workspace, represented by a grey area. To achieve this trajectory, we utilized a single builder block that took coordinates and time values for six waypoints, effectively generating a trajectory for the cleaning part to follow.

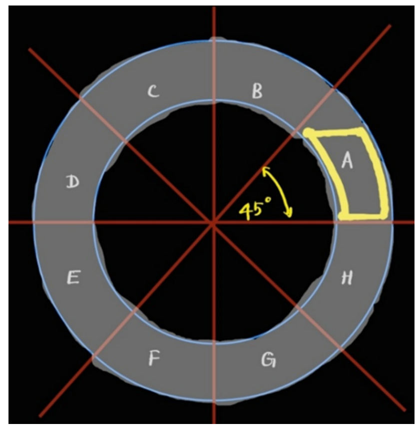

Fig. 11. square shape cleaning reigon

The trajectory planning for the cleaning part involves six waypoints, corresponding to the four corners of the cleaning path. Efficiently drawing the path entails four trajectory segments, where careful consideration is given to velocities and accelerations throughout the robot's movement on this trajectory. At each waypoint, maintaining a zero velocity is imperative to prevent abrupt changes in the direction of the end effector. The trajectory generation blocks within the Robotic System Toolbox offer various options and details, streamlining the trajectory generation process. This functionality proves beneficial by providing flexibility in trajectory design without the need to meticulously manage time and other intricate details.

A Signal Builder was employed to generate a trajectory, and this trajectory was then fed into the Inverse Kinematics block. The Inverse Kinematics block computed the necessary joint angles for the robot's movement. Subsequently, the robot executed the movement based on these joint angles. The measured joint angles were utilized as input for the Forward Kinematics block, yielding the x-y position of the end effector. This positional data was initially provided at the start of the process.

Since the calculation of inverse kinematics take a longer time, we can not calculate them real time. So we saved the matrix obtianed after inverse kinematic calculations. So in the simulink model we can directly import the calculated matrix as a file and so we can have faster activity in real time.

An interface was designed for user interaction, allowing the selection of specific parts for cleaning. Through this interface,users have the capability to control velocities and accelerations during the cleaning process, providing a flexible and user friendly means of customizing the robot's behaviour.Two primary choices, namely soft cleaning and hard cleaning, have been established for selected work areas. As a result, the robot is equipped with eight main matrices, each tailored to accommodate slight variations based on the user's selection.

This approach provides a streamlined and efficient way to address different cleaning requirements. An illustrative example is provided below for part A:

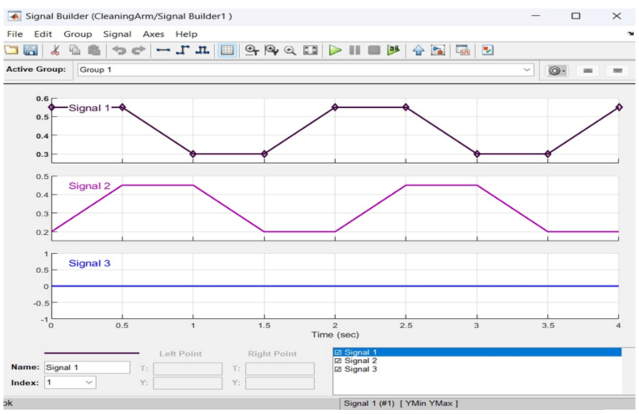

Fig. 12. Signal given to signal builder block

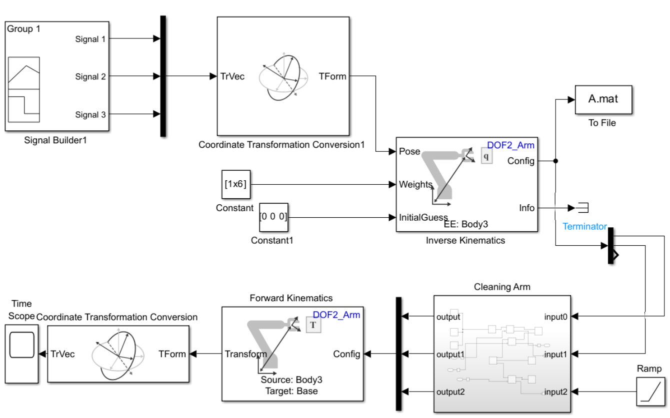

Fig. 13. Simulation diagram

C. OUTPUT OF THE CLEANING ROBOT ARM

In order to enable smooth integration and interoperability between many coordinate systems inside a robotic or control system, coordinate transformation conversion in MATLAB Simulink is essential.

This procedure is necessary to align reference frames, interface with sensors or actuators operating in multiple coordinate spaces, and provide precise communication between diverse system components, among other reasons. Coordination, accuracy, and system design compatibility are all improved when coordinates transformation conversion is used in the Simulink environment.

Hence, the utilization of coordinates transformation conversion tools is integral on both the input and output sides of the system. This approach ensures consistency and coherence in handling different coordinate systems, contributing to seamless integration and effective communication between components within the MATLAB Simulink environment.

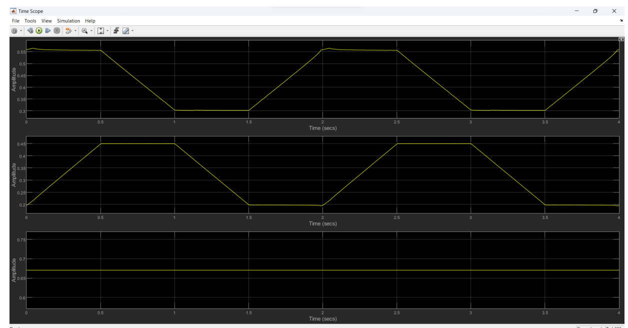

Fig. 14. Timescope results of forward kinematics

V. WORKING PRINCIPLE (ROTATIONAL CLEANING)

A. CLEANING ROBOT ARM

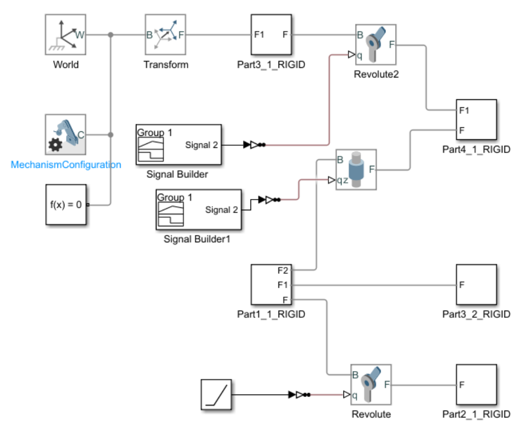

Fig. 15. rotational cleaning model

Two signal builders are used with the same configuration of the previous robo arm model. These signal builders give the signal to the motors of the two cleaning arms to perform a completely covered cleaning

B. INPUT OF THE CLEANING ARM

for the motor connected at base, a ramp signal is given to get a rotational motion. A ramp signal with constant signals in middle is used to rotate the second arm by 45 degrees after having one rotation.

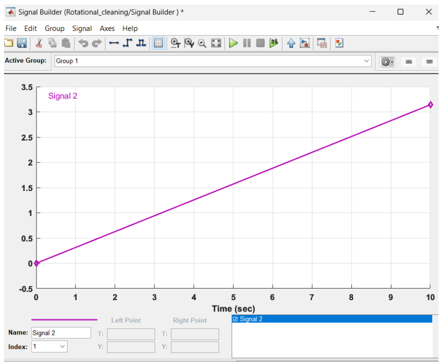

Fig. 16. signal 01

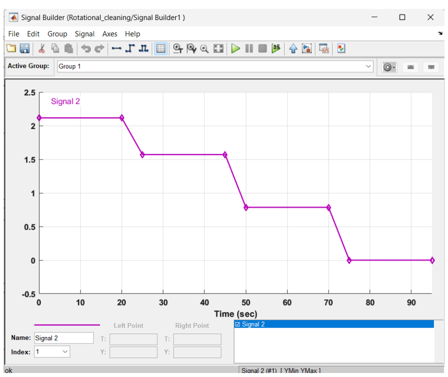

Fig. 17. signal 02

VI. WORKING PRINCIPLE (IMAGE DETECTION TO IDENTIFY DIRT SURFACE

Using image processing techniques, the system autonomously detects dirt and modifies the cleaning arm's joint angles to achieve precise and targeted cleaning. It reduces the need for human intervention by integrating sensor data, computing adjustments, and coordinating arm movements.

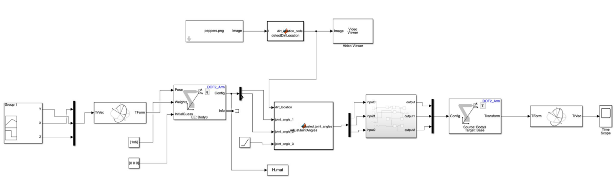

Fig. 18. Simulation diagram

Areas with accumulated dirt or contaminants are detected and identified by applying various image processing techniques to the visual data obtained from the sensor system. These methods use algorithms to segment and categorise areas that contain dirt from captured images. The output gives exact locations or coordinates where cleaning is needed.

```
function dirt_location_code = detectDirtLocation(I)
    % Input:
    % - I: Input image for dirt detection

    % Output:
    % - dirt_location_code: Numerical code representing the dirt location

    % Convert the image to grayscale
    I_gray = rgb2gray(I);

    % Perform thresholding to detect dirt
    threshold_value = 100;
    binary_image = I_gray > threshold_value;

    % Analyze detected regions to determine dirt location (example logic)
    % Replace this logic with your actual dirt location determination
    if sum(binary_image(:)) > 0.5 * numel(binary_image)
        dirt_location_code = 1; % Example: Code 1 for detecting more dirt on the right
    else
        dirt_location_code = 2; % Example: Code 2 for detecting more dirt on the left
    end
end
```

Fig. 19. Detecting dirt location

The system modifies the cleaning arm's joint angles for focused cleaning in response to dirt detection. The system calculates the necessary joint angle adjustments by using data about the detected dirt locations and the current arm configuration. By calculating the best arm configurations, cleaning operations can be carried out more effectively by guiding the arm to the designated dirty areas.

```
function adjusted_joint_angles = adjustJointAngles(dirt_location, joint_angle_1, joint_angle_2, joint_angle_3)
    % Inputs:
    % - dirt_location: Received from image processing
    % - joint_angle_1, joint_angle_2, joint_angle_3: Joint angles from IK and Ramp blocks

    % Outputs: Adjusted joint angles based on dirt location

    % Example logic to adjust joint angles based on dirt location
    % Modify this logic according to your dirt location and arm adjustment needs

    if strcmp(dirt_location, 'left')
        % Example adjustment for 'left' dirt location
        adjusted_joint_angles = [joint_angle_1 + 5, joint_angle_2, joint_angle_3];
    elseif strcmp(dirt_location, 'right')
        % Example adjustment for 'right' dirt location
        adjusted_joint_angles = [joint_angle_1 - 5, joint_angle_2, joint_angle_3];
    else
        % No adjustment needed for other cases
        adjusted_joint_angles = [joint_angle_1, joint_angle_2, joint_angle_3];
    end
end
```

Fig. 20. Adjusting joint angles

An integrated system processes the dirt location data and calculates the necessary joint angle adjustments, controlling the cleaning arm's movements and adjustments. By coordinating the actions of the arm's actuators and detection mechanism, this system makes sure the arm is positioned precisely for effective cleaning.

The system's ability to detect dirt on its own and clean specific areas reduces the need for human intervention, increasing efficiency and lowering operational errors. This system combines the cleaning arm's precise joint angle adjustments with the dirt detection process to create a cleaning mechanism that is both autonomous and effective. It can navigate and clean designated areas without constant human supervision.

VII. POWER SYSTEM

The power input can be done by connecting through a plug and a connector. There are wires connected for the glass cleaning robot. The length of the wire can be selected according to the user needs. There are two powerful motors connected in the two rotating ends of the middle arm of the robot. For the cleaning purpose there should be four motors located at the end of each arm. The suction cups perform the action with the help of four vacuum pumps per each. These vacuum pumps get the signal in a definite pattern to perform the cleaning process.

The power system should be sufficient to provide a maximum power for these motors and pumps.

VIII. WATER SUPPLY SYSTEM

The proposed system facilitates selective water supply to a single circle, prioritizing reduced rotation probability. An internal network efficiently distributes water without disruption. Water, combined with user-applied soap or detergent, is directed into the system. Valves are designed to operate exclusively when optical sensors detect activation, synchronized with pump activation in ON mode.

This configuration ensures water conservation and optimized functionality. By limiting the water supply to one circle, the system mitigates unnecessary resource consumption, contributing to enhanced sustainability.The integrated design emphasizes efficiency and ecoconsciousness, aligning with contemporary efforts for responsible resource management and conservation.

IX. FUTURE IMPLEMENTATION

In accordance with the rapidly evolving landscape of automated cleaning technologies, we present a comprehensive set of future implementations for our automatic window cleaning system. These enhancements are designed to enhance the system's efficiency, usability, and sustainability:

A. Autonomous Mobility

We propose the development of an autonomous mobility feature to enable the system to navigate to cleaning locations independently. This innovation eliminates the need for manual placement and enhances overall operational efficiency

B. Remote Control Capability

Our plan includes the integration of a remote control system, affording users the convenience of initiating, stopping, and scheduling cleaning sessions via remote control. This feature enhances accessibility and flexibility

C. Solar Panel Integration

Sustainability is at the forefront of our design. We propose the integration of solar panels to facilitate on-the-go charging, reducing the system's reliance on external power sources and contributing to eco-friendliness.

D. Enhanced Dirt Detection

The accuracy of dirt detection will be improved by enhancing the system's image processing capabilities with cutting-edge algorithms like deep learning models. By enabling reliable contamination classification and localization, these techniques maximise cleaning effectiveness and efficiency by enabling the cleaning arm to precisely target and clean affected areas.

E. Real-Time Adaptive Control Strategies

In the context of cleaning arm movements, adaptive control strategies introduce dynamic real-time adjustments to joint angles based on dirt locations that are detected. With this method, the system can react quickly and adjust its course of action, allowing for precise real-time arm movement and optimal cleaning.

REFERENCES

[1] Washing Parts(Microfiber — ScienceDirect Journals and Books,https://www.sciencedirect.com/topics/chemistry/microfiber

[2] Closed range sensor (Proximity Sensor),Heinz, E.; Mettenleiter, M.; Kuhlmann, H.; Holst, C. Strategy for Determining the Stochastic Distance Characteristics of the 2D Laser Scanner Z + F Profiler 9012A with Special Focus on the Close Range. Sensors 2018, 18, 2253. [Google Scholar] [CrossRef] [PubMed]

[3] D. Liu, Y. Shi, and X. Li, "Design and control of a glass cleaning robot arm based on deep reinforcement learning," in *IEEE Robotics and Automation Letters*, vol. 7, no. 1, pp. 154-161, Jan. 2022, doi: 10.1109/LRA.2021.3131373.

[4] Z. Wang, C. Xu, and H. Liu, "A novel window cleaning robot arm with adaptive cleaning path planning," in *IEEE Transactions on Industrial Electronics*, vol. 68, no. 10, pp. 9791-9800, Oct. 2021, doi: 10.1109/TIE.2020.3024965.

[5] X. Yang, L. Cao, and Y. Zhang, "Design and implementation of a glass cleaning robot arm using a deep learning-based controller," in *Proceedings of the 2022 IEEE International Conference on Robotics and Automation (ICRA)*, Philadelphia, PA, USA, May 2022, pp. 3324- 3329, doi: 10.1109/ICRA55269.2022.9555949.

[6] J. Li, Q. Huang, and H. Wang, "A glass cleaning robot arm with vision-based navigation and control," in *IEEE Transactions on Industrial Informatics*, vol. 17, no. 6, pp. 4153-4163, Jun. 2021, doi: 10.1109/TII.2020.3031493.