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MECHANICAL DESIGN AND FEASIBILITY STUDY OF AN AUTOMATED DRAIN CLEANING SYSTEM FOR URBAN DRAINS IN SHAH ALAM, MALAYSIA

NORASIAH MUHAMMAD[1*], MOHD SHARIZAN MOHD SHARIF [1], SHARIZA AZWIN YAHYA[1] NORLIDAWATI MOHAMAD[1], MUHD FAIZ MAT[2], AZRI RAHIMI ABD RAHMAN[2]

[1] DEPARTMENT OF MECHANICAL ENGINEERING, POLITEKNIK SULTAN SALAHUDDIN ABDUL AZIZ SHAH, PERSIARAN USAHAWAN, SEKSYEN U1, 40160 SHAH ALAM, SELANGOR, MALAYSIA.
[2] SCHOOL OF MECHANICAL ENGINEERING, UNIVERSITI TEKNOLOGI MARA, 40450 SHAH ALAM, SELANGOR, MALAYSIA.

EMAILS: 1st norasiah@psa.edu.my; 2nd msharizan@psa.edu.my; 3rd shariza@psa.edu.my; 4th norlidawati@psa.edu.my; 5th muhdfaizmat@uitm.edu.my; 6th azrirahimi.ar@gmail.com

Abstract—Clogged drains in rapidly urbanizing cities such as Shah Alam increase flood and health risks, while labour-intensive manual cleaning demands safer automated solutions. To address these challenges, this study presents the design and development of an Automated Drain Cleaning System (ADCS) for Malaysian open-drain profiles. The system employs a dual-slider mechanism in which Slider 1 uses a mesh gate to intercept debris and Slider 2 consists of a bin which can be lifted and deposits the accumulated debris into a collection bin. An ESP32 is used to control the ADCS system in which the cleaning schedules three cycles a day. A 12 V winch provides actuation for the bin and mesh gate. A solar battery is attached to ADCS system to enable off-grid operation. To evaluate the feasibility of the structural design, a CAD model was created in Autodesk Inventor 2023 which later structural analysis was evaluated in Altair SimSolid under representative loads to verify strength and stiffness before actual fabrication. The study applied distributed load of 1000 N to represent about 100 kg of debris on the mesh gate in Slider 1 and downward load on the bin in Slider 2. The results show Slider 1 experiences maximum of 20.71 MPa of von Mises stress with 1.05 mm maximum displacement, while Slider 2 experiences 170 MPa with very small displacement ranging from −0.33 to 0.07 mm which both satisfy the yield strength of the S235 mild steel. Future work will include field testing and integration of IoT for monitoring and remote control.
Keywords— Automated drain cleaning system, Autodesk Inventor, Altair SimSolid, sustainability

I. INTRODUCTION

Rapid urbanization and climate change have intensified the challenges of urban drainage management globally and Malaysia is no exception [1]. Urban flooding has become a recurring menace in Malaysian cities, triggered by heavy rainfall, inadequate drainage infrastructure and clogged drains due to solid waste accumulation [2]. In particular, the city of Shah Alam in Selangor, with its dense development and impervious surfaces make its vulnerable to flash floods when drainage systems fail to cope with stormwater inflows and blockages [3].
A major contributor to urban flooding is the accumulation of debris, plastics, silt and other solid waste inside drain channels [4], [5], [6]. These obstructions reduce flow capacity, lead to overflow onto roadways and worsen drainage failures during high-intensity rain. Routine cleaning is essential to maintain hydraulic capacity. However, conventional drainage maintenance in many municipalities relies on manual labor, which is labor-intensive, costly and exposes workers to health hazards from contaminated water and sewage gases [7].
To address these problems, recent studies have explored mechanical and automated solutions for drain cleaning. For instance, several designs propose conveyor-belt or claw-based mechanisms that collect and remove debris [8], [9]. Some systems also integrate sensors and IoT modules to detect overflow or blockage conditions and trigger responses accordingly. Despite progress, many of these designs remain at the prototype stage and lack comprehensive structural validation using numerical simulation or field deployment in for particular area such as Malaysian urban drain profiles [10].

II. BACKGROUND STUDY

Urban drainage systems in rapidly growing cities frequently underperform during intense rainfall because solid-waste blockage constrains hydraulic conveyance and triggers local overtopping. Reviews and case studies consistently identify poor waste handling and debris accumulation such as plastics, organics and sediment as recurrent contributors to flood risk in developing urban contexts [5].

Malaysia's national design guidance the Urban Stormwater Management Manual for Malaysia to promote best-management practices, conveyance design and maintenance frameworks. However, the routine blockage control in legacy open drains still relies heavily on frequent cleaning and operational maintenance [11].

To reduce manual exposure and improve reliability, researchers and practitioners have adapted mechanical drain cleaning from stationary trash racks to traveling screens and conveyor mechanisms. Conventional mechanical drain cleaning can be efficient, however it is also high cost of equipment, the need for continuous power, maintenance and potential limitations in hard-to-reach or small areas [11]-[15].

In the last decade, multiple automated drain cleaning prototypes have been reported, typically combining a motorized rake or conveyor with a collection bin. Most show proof-of-concept fabrication and implementation and widespread usage have yet to materialize in structural verification under real debris loads [16]-[19].

For renewable energy, solar-battery power is frequently proposed for low-duty mechatronic devices which can reduce power grid dependence [20]-[22]. The system allows for scheduled operation in locations without stable mains access. Studies demonstrate feasibility for low-power actuation and intermittent duty cycles, especially when paired with simple timers rather than sensor-heavy control loops [24].

This study develops an automated drainage cleaning system (ADCS) for Malaysian urban drains and focuses on the mechanical design, fabrication and structural verification of a dual-slider mechanism. Figure 1 shows the schematic diagram of the frame which anchored at the drain edge which part of the structure sits above the walkway and the working section operates inside the channel. Before actual fabrication, the design is developed in Computer Aided Design (CAD) software to get the conceptual idea. Then, Computer Aided Engineering (CAE) software, Altair SimSolid is used to simulate the structure under representative loads to ensure stress and deflections meet acceptance criteria. This study also proposed scheduled automation with an ESP32 controller that can be program to run three cleaning cycles per day to establish off-grid feasibility with a solar panel, charge controller and 12 V battery size. Furthermore, this study proposed remote monitoring and control through Blynk IoT for live status, notifications logging and manual override when needed.

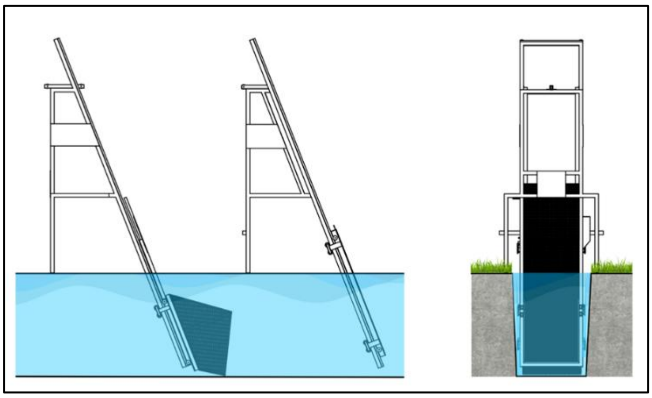

Fig. 1 Schematic diagram of the ADCS

TABLE ICOMPARISON CRITERIA FOR DRAIN CLEANING MECHANISM

Type	Typical use	Operation and Maintenance Effort
Portable Collector	• Temporary hotspots or short trials	• High • Frequent site visits
Fixed passive trap	• Permanent installation at inlets and channels	• Moderate to high. Build-up requires visits
Automated drain cleaning system	• Permanent installation at frequent blockage sites • Suitable for open drain	• Low • Remote monitoring and inspection. Visits for emptying bin collection

A. Working Principle of the ADCS

The ADCS is designed to automatically remove plastics, leaves and floating debris from open drains to maintain flow capacity and prevent blockages. The unit can operate off grid using a solar panel, charge controller and 12 V battery to minimize operating cost and support sustainable deployment. An ESP32 controller presets three cleaning cycles per day. During normal operation, the mesh gate on Slider 1 remains at the home position in which debris passes so that Slider 2 can collect it. After the predetermined interval, a winch-driven rake assembly moves the mesh gate downward to block debris while allowing water to pass. Slider 2 then lifts the collected debris and

deposits it into a collection bin. Adjustable roller limit switches define the travel limits to prevent over-travel and mechanical damage to ensure repeatable and safe operation.
The ADCS system also can be integrated with Blynk IoT for real-time monitoring and manual override. The ESP32 can be connected to Wi-Fi to publish live telemetry to a Blynk dashboard such as status tiles, push notifications and camera feed.
By automating routine cleaning on a schedule, the system reduces manual labor, saves time and helps keep drains clear, especially during rain when steady flow matters most. The cleaning system improves drainage reliability and helps create safer cleaner urban areas by reducing flood risk and stagnant water hazards.

B. Design of ADCS

The research began with a literature review to understand current mechanical drain cleaning mechanisms for urban drainage maintenance. This review shaped the system requirements for the ADCS [25].
To compare debris-interception options, evaluations were made for portable collectors, fixed passive traps and automated mechanical cleaners on typical use, removal mode and effort. Portable tools such as floating booms and nets offer light weight, reusability and easy deployment. However, it operates passively and usually demands manual servicing [26], [27]. Fixed traps such as trash racks and screens provide durable, long-life installations that intercept debris continuously, yet it is act passively and often require manual or assisted clearing under heavy loads or rising head loss [28]. Automated drain-cleaning systems with mechanical conveyors actively remove debris on a schedule or when manual override is required, can reduce labor exposure and improve reliability [29]. For clean energy usage, pairing automation with a solar–battery supply enables true off-grid operation and more sustainable maintenance [30]. Table I summarizes the comparison criteria across portable collectors, fixed passive traps and the proposed ADCS. Based on these requirements, this study adopts an automated drain cleaning system as the target solution and refines the requirements toward a automated drainage cleaning system which can operate off-grid sites.

TABLE II SUMMARY OF THE MECHANICAL COMPONENTS AND FUNCTIONS

Component	Function
Mild steel tube	Main structural members for the welded frame
Mild steel angle	Secondary framing, brackets and gussets
Guide bearing (V-groove)	Constrains and guides sliders along V-tracks
Steel plate	Mounting bases for motors, brackets, anchor and splice plates
Stainless steel D-shackle	Corrosion-resistant lifting point for bin and mesh plate
Bearing	Supports rotating shafts
Metal mesh	Allows water flow while retaining trash at Slider 1

C. Geometry Modelling

In this study the ADCS structure was designed in Autodesk Inventor 2023 and the mechanical assembly was organized into modular sub-assemblies to speed up fabrication and maintenance. Fig. 2. presents the dual-structure layout where Slider 1 uses a mesh gate to stop debris from moving downstream during removal and Slider 2 carries a bin that receives and holds waste before lifting it into the collection bin. Fig. 3. also shows the full dimensions of the ADCS structure. The finalized model was exported to Altair SimSolid for structural analysis.

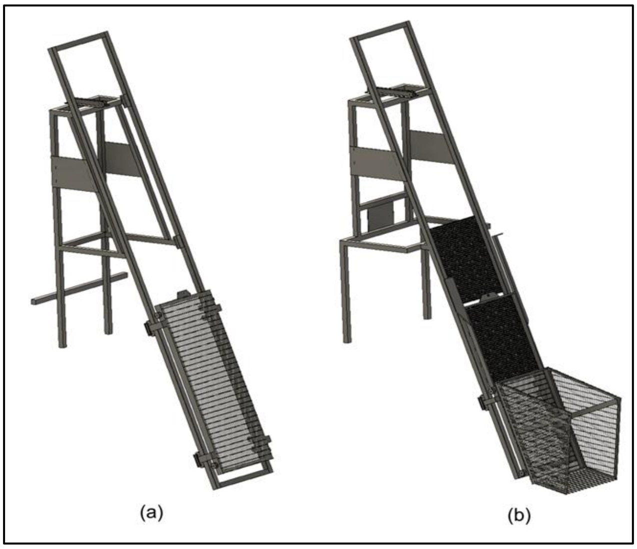

Fig. 2 CAD model of the ADCS structure. (a) Slider 1 and (b) Slider 2

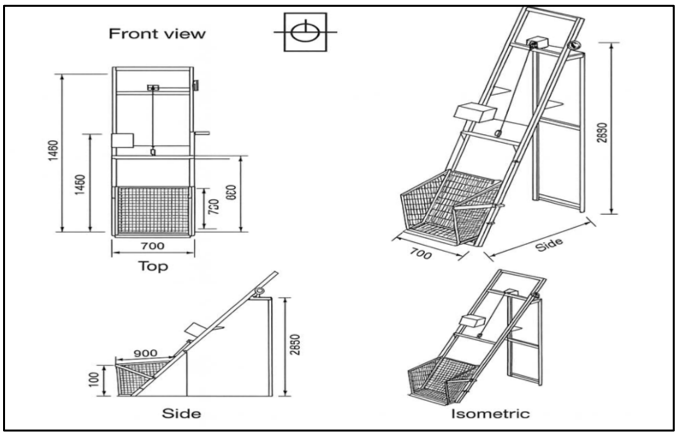

Fig. 3 Orthographic layout of the ADCS structure with dimensions in mm

D. Boundary Condition

In conventional finite element workflows, components are discretized (meshed) before loads and supports are applied. In contrast, Altair SimSolid eliminates traditional mesh generation and operates directly on the original CAD geometry using an external-approximations approach with adaptive solution, thereby reducing effort in meshing preparation while retaining accuracy for structural response prediction [31], [32]. In SimSolid, the user still needs to define boundary conditions which are supports such as fix, slider or hinge supports and loads such as force or pressure loads. Fig. 4. illustrates the boundary conditions assigned at the bases of both sliders, where fixed supports were applied on the leg contact surfaces. A distributed load of 1000 N, oriented normal to the mesh gate on Slider-1 was used to represent the effect of stranded trash during interception shown in Fig. 4. (a). Similarly, a distributed 1500 N normal load was applied to the trash bin on Slider-2 to simulate the lifting of the collected trash shown in Fig. 4. (b). These load cases were solved in Altair SimSolid to enable rapid evaluation of stresses and deflections without conventional meshing.

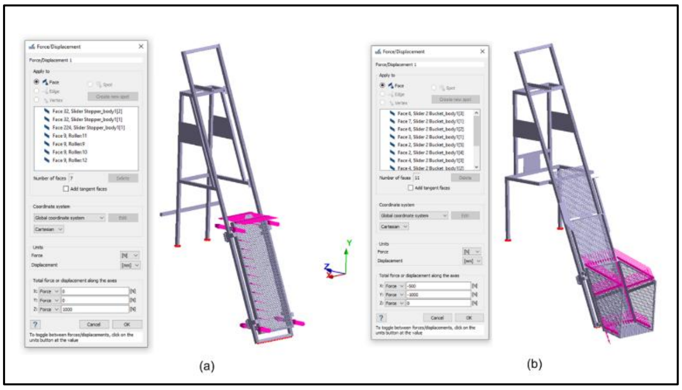

Fig. 4 Locations of the applied force in (a) Slider 1 and (b) Slider 2 as defined in Altair SimSolid

E. Mechanical component

The ADCS mechanical assembly is fabricated primarily from mild-steel tubes and angles to forming a stiff and weldable frame that anchors at the drain edge and supports all moving elements. Steel plates provide mounting faces for brackets, motor seats and safety guards, while guide bearings run along matching tracks to guide for both sliders with low friction and good alignment. Standard bearings are used at rotating shafts to transmit torque from the drive to the rake/conveyor path. The area of metal mesh acts as debris interceptor surface is sized to typical trash while allowing water passage. Mechanical connections and serviceability are ensured with bolts, nuts and screws. Stainless-steel D-shackles provide corrosion-resistant for lifting bin and metal mesh gate. This modular construction simplifies fabrication to enhance robustness under repetitive duty and eases replacement of wear and tear parts. Table II summarizes all the mechanical components and functions used in the ADCS structure.

F. Operation of the automated solar drain cleaning system

The ADCS control architecture uses an ESP32 microcontroller, adjustable roller limit switches and a 12 V DC winch to run scheduled cleaning cycles safely. The ESP32 serves as the central controller and scheduler, issuing timed commands to the winch through a relay interface. During normal operation, the mesh plate on Slider 1 rests above the water and the bin on Slider 2 sits in the water. At the start of each cycle, the controller energizes the winch to lower the mesh gate on Slider 1, blocking debris while allowing water to pass. The winch on Slider 2 then lifts the bin and deposits the accumulated debris into the collection bin. As motion continues, the adjustable roller limits travel and provides hard-position feedback to prevent over-travel. When a switch engages at the prescribed endpoint, the ESP32 reads the signal and de-energizes the winch to complete the step. This open-loop sequence repeats three times per day and delivers consistent operation with minimal supervision. Fig. 5 shows the block diagram of the ADCS open-loop control system.

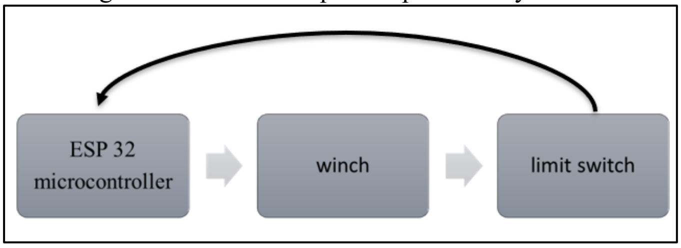

Fig. 5 Block diagram of open loop method for ADCS's system

III.Result And Discussion

A. Result of Static Analysis on ADCS structures

The static analysis evaluates structural response under the prescribed distributed loads and fixed supports at the leg edges to verify slider stability and frame integrity. Previously in Fig. 4. (a), a 1000 N load or 100 kgf was applied normally to the surface mesh gate on Slider 1 to represent the impact of 100 kg of debris stranded at the structure. Similarly, A same load with downward direction was applied on the bin of Slider 2 to represent the impact of lifting debris on the structure shown in Fig. 4. (b). Under these conditions, Fig. 6. shows Slider 1 experience peak displacement of 1.05 mm towards inside the structure and a maximum von Mises stress of 20.71 MPa, which is well below the yield strength of S235 mild steel indicates strong structural integrity. Fig. 7. shows Slider 2 exhibits very small downward deflection with a range of 0.40 mm but a higher local stress of 170 MPa concentrated at the bin and frame surface. Table III summarized the results of ADCS structures which indicate sliders can withstand minimum of 1000 N force without failure. Based on these results, the ADCS design was finalized to be fabricated.

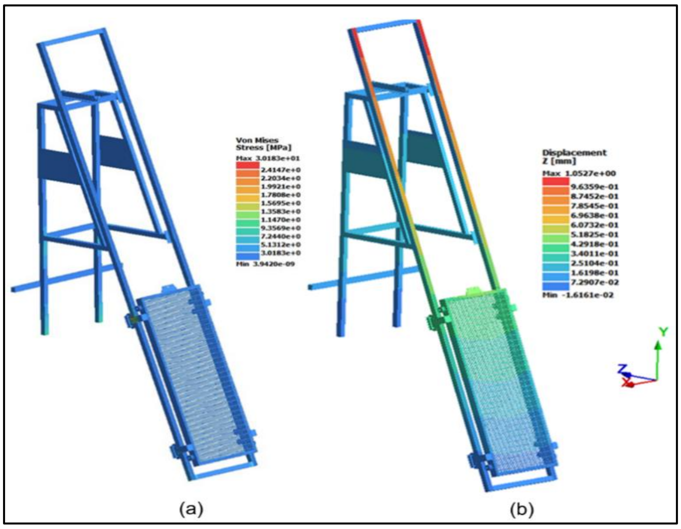

Fig. 6 Altair SimSolid results for Slider 1: (a) von Mises stress distribution and (b) Z-direction displacement

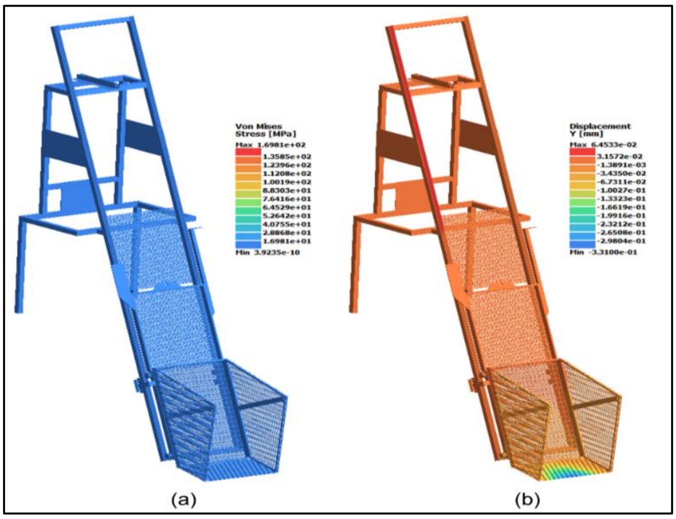

Fig. 7 Altair SimSolid results for Slider 2: (a) von Mises stress distribution and (b) Y-direction displacement

TABLE III STATIC-ANALYSIS RESULTS FOR ADCS STRUCTURES

	Slider 1	**Slider 2**
Von misses Stress	20.71 MPa	170 MPa
Displacement	Range from -0.02 mm to 1.05 mm	Range from -0.33 mm to 0.07 mm

B. Fabrication process

Fig. 8 shows the fabrication process began based on the CAD drawing with cutting mild-steel tubes, angles and plates to size on the metal cut-off saw, followed by profiling base plates and gussets on the cutting machine. Holes were drilled on the bench drill press for anchor points, bearing mounts and adjustable limit-switch brackets with all edges were deburred. The frame and sliders were assembled and welded to members and brackets using Metal Inert Gas (MIG). After welding, an angle grinder removed spatter and blended weld toes for a smooth finish, especially at bracket transitions and rail contact area. Final steps included a check of alignment and squareness, verification of free slider travel, surface cleaning and painting for rust prevention. The final fabricated parts are shown on Fig. 9.

Fig. 8 Fabrication processes of the mechanical components for the ADCS structure

Fig. 9 Fabricated component of the ADCS structure

TABLE IV SUMMARY OF THE HARDWARE FOR AUTOMATION COMPONENTS AND FUNCTIONS

Component	Function
12 V winch	Provides the mechanical actuation to move the sliders during each cleaning cycle.
Adjustable roller lever limit switch	Defines start and end positions and prevents over-travel by signalling the controller to stop motion.
ESP32 microcontroller	Schedules three daily cycles, reads limit-switch inputs, drives relay control signals and Wi-Fi connectivity for IoT
Control box (enclosure)	Housing for electronic components
8-channel optocoupler module	Electrically isolates ESP32 GPIO from relay coils to protect logic and reduce noise coupling.
5 V buck converter	Steps 12 V battery voltage down to a stable 5 V rail for the ESP32 and low-power electronics.
Xiaomi camera	For visual monitoring operations.
200 W solar panel	Generates DC power to charge the battery
12 V 17 Ah lead-acid battery	Stores energy to power the winch and electronics

C. Proposed automated system

In this project the ADCS uses an ESP32 microcontroller as the scheduler and controller. Roller-lever limit switches provide position feedback to the ESP32 to stop motion at the end positions. A 12 V 17 Ah lead-acid battery supplies the system and charges from the solar array through a solar charge controller. A 5 V buck converter powers the ESP32, the optocoupler inputs and other low-power electronics. The ESP32 sends logic signals to an 8-channel optocoupler module for galvanic isolation. The optocoupler outputs then drive a reversing winch relay that switches on and off the 12 V DC winch shown in Fig. 10. Electrical interlocks ensure only one direction can energize at a time and the limit switches which wired in normally closed for fail-safe behavior. Battery powered solar feeds an ESP32 through a divider to enable low-voltage cut-off. The hardware components and their functions are summarized in Table IV and the complete circuit diagram shown in Fig. 11.

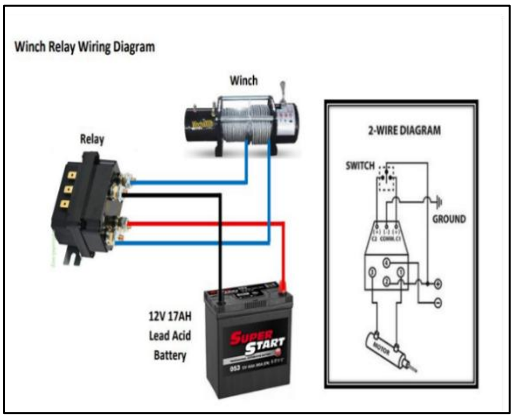

Fig. 10 Schematic diagram of winch wiring diagram

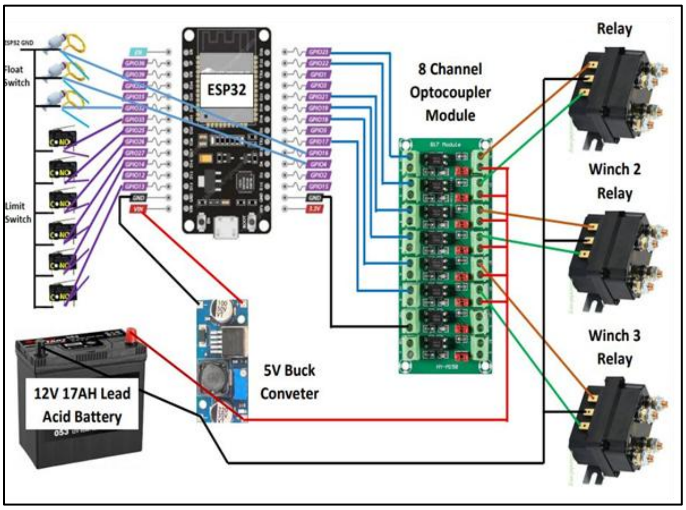

Fig. 11 Schematic diagram of ADCS's control system

D. Proposed System Programming

This phase used the Arduino IDE to develop the ESP32 firmware in C++ for winch control and limit-switch handling. The code is to set GPIO modes and configures timer to schedule for three daily cycles. A simple state machine governs motion: at the scheduled time the ESP32 commands the winch at Slider 1 to move the slider until it engages the roller limit switch. The current position will stop the winch and triggers another winches at

Slider 2 which the function is to lift, tip the bin and return home. Fig. 12 shows the summary of code development for all the winches movement control based on the limit switch.

Fig. 12 Source code in the Arduino IDE implementing winch motion with limit switches.

E. Proposed Internet of Thing (IOT) for the ADCS

ESP32's built-in Wi-Fi allows the ADCS system to support IoT development. The IoT layer adds supervision and remote control on top of the current system. Blynk IoT provides the mobile or PC dashboard for real-time monitoring and manual override can show live status such as cleaning cycle, battery voltage and a camera view for visual confirmation. The Blynk application is accessible through the mobile app or from any web browser on a phone, PC or laptop via https://blynk.io. The ESP32 firmware initializes Wi-Fi to connect to Blynk client, then publishes lightweight telemetry and accepts authenticated commands from a mobile or web dashboard. Together these tools deliver a low-cost, reliable control and monitoring layer for the ADCS without adding environmental sensors.

IV. CONCLUSIONS

This work successfully designed, verified, and fabricated ADCS for Malaysian open drains. Structural analysis indicates the components can withstand a debris load of up to 100 kg without failure. The fabricated prototype demonstrates a robust, low-maintenance design that supports scalable deployment. Future work will include field trials to validate the simulation results and integration of IoT for monitoring and control.

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