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DESIGN OF AUTOMATED BASCULE BRIDGE AND COLLISION AVOIDANCE WITH WATER TRAFFIC

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The development of movable bridges is a modern technological advancement that requires the integration of multi-disciplinary concepts such as control, automation, and design. In order to demonstrate how a collision avoidance system works, this research offers the design of an automated double-leaf bascule bridge with a pulley-rope moving mechanism and Pratt truss. The bridge is created where a settled railway or roadway intersection of a navigable stream cannot attain a steep profile. The design took into account the length, height, and width of the bridge as well as automatic ship identification and scaffold leaf movement activity for ship crossing. For the safe passage of cars on the bridge and for stopping vehicles during bridge movement, the system includes a collision avoidance control system and an automated road barrier system. After sensor adjustment, the model bridge's performance under test produced results that were adequate, with a success rate of 100%.

Keywords: Transportation, automation, collision avoidance, bridge engineering, design

1. Introduction

The constant improvement of technology gives people a better place to live (Komol *et al*., 2019; Shoag and Podder, 2020). Technology development knows no boundaries and ushers in a new era. In the modern world, the transportation system is crucial in enabling the communication system (Komol *et al*., 2021a). In today's transportation system, the importance of the movable bridge cannot be overstated. A structure with at least one span that may be instantly moved by mechanical devices mounted on it is referred to as a movable bridge (Birnstiel, 2015). This kind of bridge enables a bridge to be constructed with little vertical leeway while providing a cautious route for traffic to cross an active water-way that would otherwise be hampered by the structure (Wallner and Pircher, 2007). The idea of a movable bridge is advantageous for smart cities since it makes ship and car transit management easier. Additionally, some specialized locations, like the Suez Canal, call for the use of movable bridge technology to allow ships to pass through many gates (Komol *et al*., 2021b). The idea of a movable bridge, which moves the bridge based on sensor readings, can incorporate automation technology. Such technology is implemented using complex control system engineering and dynamics techniques. Understanding the newly developed movable bridge's intricate circuitry and control system is quite challenging, especially for novice students. Additionally, it is challenging for the instructor to create a complicated design for it using mathematical analysis. To eliminate such situations, modern researchers advise using any small model for a demonstration that is readily available for the desired work. Therefore, a variety of miniature models for demonstrations for various uses are available on the market to facilitate the spread of information.

To prevent the bridge structure from suffering severe earthquake damage, a better seismic design method for simply supported girder bridges has been developed (Peng *et al*., 2020). In order to improve wireless communication between vehicles and be-tween vehicles and infrastructure, a heterogeneous vehicular network linking long-term evolution and dedicated short-range communication is designed (Chyne *et al*., 2019). In a student's project work for a transportation application, an energy management strategy for a multisource electric car is devised (Geetha and Subramani, 2020). Recently, a rail transit corridor was created to enhance the economic and social benefits of areas with transport-oriented development (Zhang *et al*., 2021). Novel crowdsourcing approaches have also been created for the micro-mobility ride-sharing strategy, which enhances the urban transportation infrastructure and the transport industry (Elhenawy *et al*., 2021). To illustrate the control system including any movable bridge, however, there isn't a small model for demonstration that is readily available on the market. The planned study so seeks to close the gap. Additionally, most movable bridges currently in use are operated by people. Early arriving ships must dock until the designated opening time of the day, which takes time and patience. The movable bridge has existed since prehistoric times, but there are several obstacles to automating the mechanism, thus it is currently run by humans. It can be difficult to gauge control when ships are approaching quicker and closer while a vehicle is still on the bridge. Further study is still needed on ship sensing and automated operation of this enormous structure. With the development of maritime control technology, some automated control systems are now being incorporated to movable bridges in an effort to eliminate the need for human labour. However, it extends the duration of the bridge's operation, and much more study is still needed to increase the security of the navigation system. In this work, a small demonstration model of an automated bascule-type movable bridge with an on-off control scheme is developed. This model will serve as a platform for demonstrating the use of control engineering in the field of transportation and as a kit for students to conduct and comprehend multiple control system and electrical machine experiments using a single system. An automated moving bascule bridge with a truss construction will be visible in real time thanks to the suggested small model for demonstration. The kit shows how smooth vehicle passing is accomplished on a moving bridge in real-time. To help the learners understand the need of safety guards in any reliable system, how the safety features are implemented to the system is also taken into account. For instance, the ship's emergency stop will be signalled by a siren if the control system fails to clear the vehicle. Overall, the suggested small model for demonstration will offer a platform to demonstrate how system integration is built in order to design a robust system.

The rest of the paper is organized as follows: the next part talks about the bene-fits for students of electrical and electronic engineering. The following sections give an overview of the suggested small model for demonstration modelling, operational procedures, and performance assessment. In the final portion, a conclusion is reached.

2. Educational benefits

The present study puts forth a prototype of a movable bridge in the form of a bascule design, which incorporates an electro-mechanical system, intended for demonstrative purposes. The kit comprises a pulley-rope mechanism for movement and a robust cantilever support featuring a Pratt truss. The Small model utilized for demonstration purposes is akin to a compact laboratory that operates on a +5V DC power source and integrates a microcontroller (Arduino Uno) and a sensor (LDR). The proposed concept can potentially be employed in the micro-processor laboratory and control system laboratory to execute automation-oriented projects. The Small model for demonstration serves as a valuable tool for enhancing students' comprehension of the significance of sensors in robust systems and facilitating their understanding of the operational intricacies of microprocessor units. The Small model for demonstration has the potential to facilitate students' comprehension of the integration of control system and dynamics. The concept of movable bridges holds significant importance in modern transportation systems and can be conveniently demonstrated through a small-scale model in a laboratory setting. The proposed system's impact on automation technology is noteworthy due to its robust sensing unit and security management tool. The Small model for demonstration can facilitate various learning outcomes for students, as depicted in Figure 1. The utilization of the system can prove to be efficacious for students who undertake research work pertaining to automation technology and control systems, as the accessories provide a straightforward and economical platform.

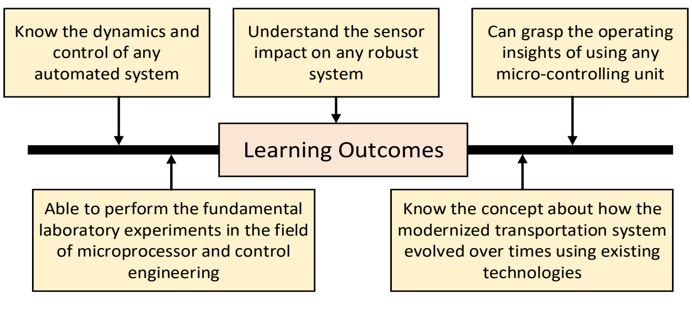

Figure 1. A layout of presenting the learning outcome from the proposed miniature model for demonstration

3. Proposed bascule type movable bridge small model for demonstration

The proposed movable bridge design is of the bascule type. The overall design of the demonstration's small model comprises four primary sections, namely truss design, control part design, integration of system components, and prototype construction, aimed at realizing the concept. The following sections are demarcated as four distinct categories.

3.1. Truss design

The present study proposes the design of a unique variant of a double leaf rolling bascule bridge, which incorporates a pulley rope mechanism. The utilization of a double-leaf rolling bascule bridge is advantageous due to its implementation of a gearing system. Additionally, the incorporation of a three-hinged system in the rolling bascule bridge design enhances its structural integrity, stability, and precision. The bascule bridge possesses the benefit of being deployable in locations where there exists a dearth of space adjacent to the bridge. Expansion or widening of the structure can be achieved by adding supplementary spans in parallel, without impeding the functionality of the pre-existing span or navigation. The bridge leaf is elevated through the utilization of pulley ropes in this context. The present design incorporates electrical motors for the purpose of executing the operation of the bridge's opening and closing. According to reference (Buxton-Tetteh, 2004), the necessary amount of torque will be produced for this specific objective. The spinning of a single leaf is accompanied by minimal elongation to facilitate the enigmatic fusion of the two rotating leaves. On the contrary, the alternate leaf that was spun possesses a cavity of a necessary shape, allowing the protruding part to fit onto the cavity flawlessly. This process facilitates the alignment of mobile components such as fixed bridges, resulting in a smooth transition for the vehicle as it traverses the joint, akin to a flat surface devoid of any irregularities or jolts. Figure 2 shows a computer-aided design (CAD) of the designed sample of the bridge's horizontal fixed position and vertical moving position.

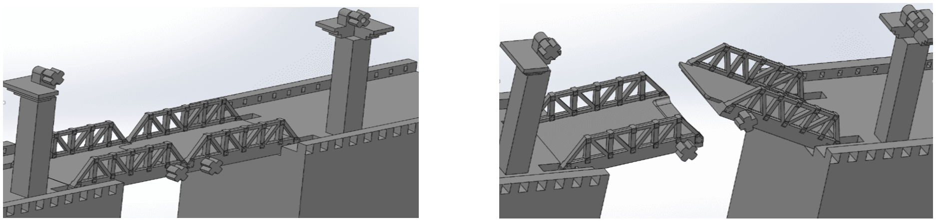

Figure 2. CAD design of the model bridge in a closed and open position

The Pratt truss system is a preferred method for enhancing the rigidity of a bridge in the settled state. In contrast to other bridges, it provides a more distinct and well-defined shape. The Pratt truss, in contrast to the Howe truss, features vertical members and diagonals that are inclined towards the centre. The vertical components are experiencing compressive forces, while the diagonal components are subject to equilibrated loading. The utilisation of unalloyed strain components in the diagonals may necessitate the incorporation of crossing components in the vicinity of the centre to accommodate concentrated live loads during the traversal process, as stated in reference (Catbas and Malekzadeh, 2016).

The present study involves the evaluation of a prototype movable bridge that features a Pratt truss structure, which is being taken into account for the purpose of design assessment. The proposed prototype bridge is accompanied by a framework that calculates static load in a comprehensive manner. The prototype bridge was designed with a width of 6 metres to accommodate the flow of traffic in both directions, which was estimated to be 3 metres wide. In the context of ship crossings, it was determined that a bridge length of 25 metres and a truss height of 2.6 metres, consisting of 21 truss members and 12 joints, would accommodate ships with a width of 18.5 metres. The prototype bridge truss is subjected to static loading, and in this regard, a TATA Truck LPT 809 model vehicle has been selected for analysis. Table 1 displays the necessary model vehicle data required for the computation of static loads on bridges.

Table 1. Model Vehicle Specification

Model Vehicle	**Vehicle Information**		
	Length	Width	Gross Weight
TATA Truck LPT 809	6.579m	2.489m	8500 kg

In order to ensure safety, the vehicle weight has been established at 10000 kg, and it has been assumed that a maximum of six TATA Truck LPT 809 will be in motion on the bridge simultaneously. The aggregate weight amounts to 60000 kilogrammes, which is equivalent to 588.6 kilonewtons (60 multiplied by 9.81 kilonewtons). The lower chord of the truss is designated as having a joint number of 10 on both sides of the truss. Assuming uniform loading of the bridge, the load per joint is calculated to be 59kN. Figure 3 depicts the load diagram schematic of the truss design, including both forces and reaction forces.

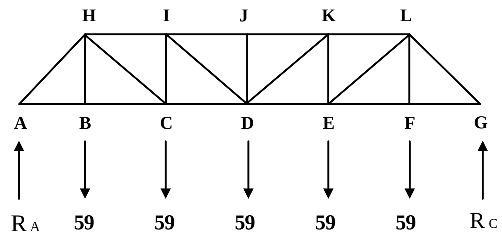

Figure 3. Load distribution diagram for the designed truss with forces and reaction forces

The utilisation of wrought steel is being contemplated as a potential material for the construction of trusses. The yield stress of as-rolled wrought steel is regarded as 33.09 MPa, as stated in reference (Gupta *et al*., 2017). A factor of safety of 4 is assumed for loads that are repeated, reversed, or gradual in nature. The design stress, sd, has been determined to be 8.2737 MPa based on the specified criteria (Faires, 2016). The calculation of static loads on various members of the truss was per-formed for one-half of the bridge (Beer and Johntson, 1977). Additionally, the minimum required cross-sectional areas were determined using the equation A = F/sd (Pytel and Singer, 2009).

3.2. Control system design

Our control strategy is based on the automated operation of movable bridge spans for naval transportation, utilising the on-off type control method. The Arduino UNO microcontroller was employed as the central processing unit to regulate the movement of the envisaged bascule configuration mobile bridge. A com-pact prototype intended for illustrative purposes. The rolling mechanism was facilitated by a pair of gear motors, each of which was linked to a motor driver L298. This configuration enabled the gear motors to achieve the required speed and reverse rotation. The control system was powered by a pair of 6V batteries. In order to automate the control system, a pair of laser emitters and two light-dependent resistors (LDRs) were employed for the purpose of ship sensing. On one side of the bridge, a laser emitter and a light-dependent resistor (LDR) are positioned to detect the entrance of a ship. Similarly, on the opposite side of the bridge, another laser emitter and LDR are situated to detect the passage of a ship that has already traversed the bridge. The LDRs are shielded and safeguarded against solar radiation, while a low-light setting is maintained to accurately detect and interpret the laser signal that is received. In addition, various extant sensors are utilised for the purpose of object detection, including but not limited to the ultrasonic sensor, infrared ray (IR) sensor, and PIR sensor. Ultrasonic sensors employ sonic waves, however, their dispersion is considerable and their range is inadequate for the purpose of ship detection. The range of both IR and PIR sensors is constrained. In contrast to other light sources, the laser produces a high-intensity beam that exhibits exceptional range and concentration, and is readily detected by the LDR sensor. The LDR exhibits a significantly elevated resistance magnitude in response to laser illumination compared to conventional incident light, and it operates over a vast distance.

The implementation of a laser-LDR connection enables the activation of two servo motors equipped with roadblock barriers located at either end of the bridge. Upon detection of a ship, the servo motors are triggered and effectively obstruct the road, thereby halting any vehicular movement. The road barrier assumes an open position to allow vehicular movement prior to the detection of the ship. Alternatively, the road barrier is in a state of obstruction.

To achieve automated bridge nullification, a pair of distinct road barriers are positioned at the entry and exit lanes of both sides of the bridge. Additionally, four autonomous cameras have been installed to monitor the entry and exit lanes on both sides of the bridge. The purpose of this connection is to facilitate the ongoing detection and enumeration of vehicles traversing the bridge, both upon entry and exit. The phototransistor known as LDR falls under a specific category. The resistance of the material exhibits a dependence on the intensity of incident light, and a laser beam is characterised by a significantly high level of light intensity. The maintenance of Laser-LDR connectivity results in a substantial increase in resistance value of the Light Dependent Resistor (LDR) owing to the persistent presence of a concentrated light beam. Upon interruption of this connection, the resistance of the Light Dependent Resistor (LDR) experiences a substantial de-crease, resulting in notable disparities between the aforementioned values. The aforementioned principle is employed in this context for the purpose of detecting bridge vehicles. The counting algorithm is utilised to quantify the values of the bridge vehicle entering and exiting the bridge. Upon entry of a bridge vehicle through the designated entry lane, the laser-LRD connection experiences a temporary interruption, resulting in a significant decrease in the LDR resistance value. Upon the laser's passage, the connection is re-established and the resistance value experiences a significant increase. The if-else construct executes a block of code based on a specified range of values, and if the resistance value falls below said range, the construct outputs a message indicating the detection of a single vehicle. In the case of entry lanes, a decrease in the LDR resistance below a certain threshold result in an increment of one to the corresponding value. This process is ongoing and cumulative, with one unit being added to the value for each vehicle entrance. In the case of exit lanes, a decrease in the LDR resistance within a certain range result in a deduction of one value. This deduction is then applied for each subsequent vehicle passing through the exit lane. The temporary decrease in resistance value dropout is observed independently for each individual vehicle.

The act of granting vehicle access at entry lanes is assigned a value of one, which is subsequently incorporated into the cumulative count of vehicles that have entered the premises. The overall cumulative rise is directly proportional to the quantity of vehicles that access the bridge. Upon exiting the bridge through the designated lanes, the value that was previously added to the aggregate is deduct-ed from the total sum. Consequently, in order to ensure the uninterrupted conveyance of vehicles across the bridge, a perpetual tallying process is employed whereby the value attributed to each vehicle upon entry is incrementally added to the aggregate sum, while the value corresponding to each vehicle upon exit is correspondingly deducted from the total sum.

Upon detection of the ship by the primary buoy, the bridge control system initiates the automatic closure of the entry lane road barrier. This restriction disallows any additional vehicular access to the bridge. At the current pace, the abundance of supplementary benefits comes to an end, and the overall sum is predominantly levelled. As vehicles traverse the exit lanes on either side of the bridge, the overall aggregate gradually decreases until it reaches zero, signifying the departure of all vehicles from the bridge via the exit lanes. The state of having zero counts is commonly referred to as a nullified bridge. Currently, the exit lane road barriers are automatically closed to facilitate the clearance of the bridge vehicle. Subsequently, the bridge initiates its mobile mechanism to expand its width and facilitate the secure passage of aquatic vessels.

3.3. Integration of system components

Figure 4 depicts the connection and circuit diagrams of the automatic movable bridge control system, including all electrical components. The entire system is powered by a 12V DC power supply. Upon the provision of power, both lasers emit a coherent and collimated beam of light towards the Light Dependent Resistor (LDR) that is interconnected in a linear configuration. This assigns a present numerical value to LDR. In the event of a disruption of a laser beam originating from laser-1 and directed towards LDR-1, the Arduino UNO (Khan *et al*., 2017) is notified of a decrease in the value of LDR (Amhani and Iqbal, 2017). The specified action results in a 90° rotation of the servo motors, as well as an anti-clockwise rotation of both dc motors for a predetermined duration. In the event of an interruption of the laser beam emanating from laser-2 to LDR-2, the servo motors undergo a 90° rotation in the oppo-site direction, while both dc motors execute a clockwise rotation for a predetermined duration.

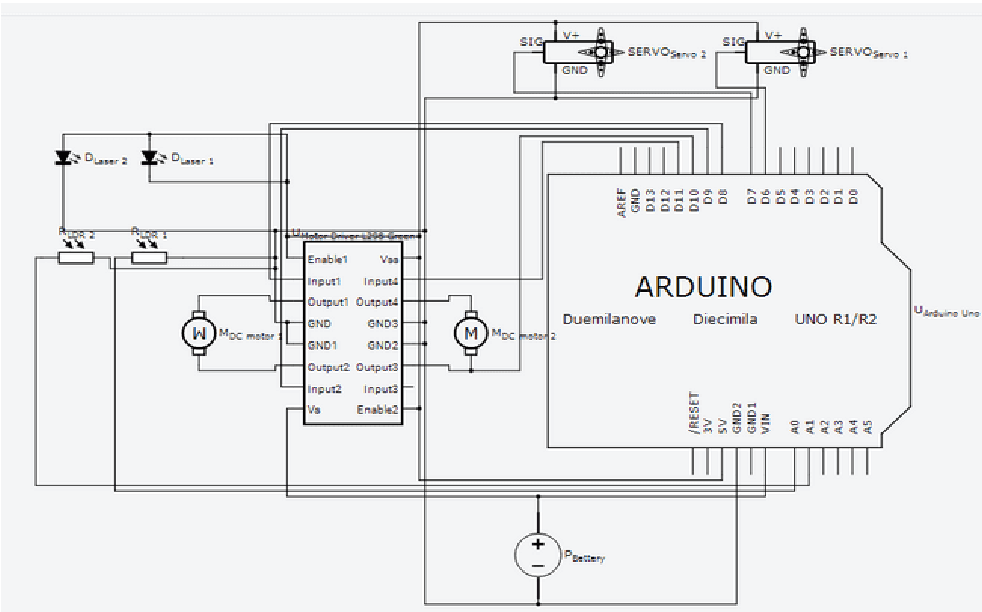

Figure 4. An illustration for showing the integration of system components with the control unit

3.4. Construction of the proposed bascule type movable bridge small model for demonstration

In order to achieve exacting standards in construction, the model bridge was initially conceptualized with precise measurements utilizing computer-aided design (CAD) software. Subsequently, simulations were conducted to determine the appropriate mechanical drawings. The ratio of 40:1 was upheld in maintaining the dimension of the model that was constructed in relation to the prototype. Table 2 presents a comparison of the dimensions between the CAD-designed proto-type and the proposed Small model constructed for demonstration purposes.

Table 2. Dimension Specification of Model Bridge and Prototype Bridge

Parameter	Prototype	Model	Exact Ratio (Prototype: Model)	Rounded Ratio (Prototype: Model)
Length	24.384 m	0.62 m	39.34:1	40:01:00
Width	6.096 m	0.15 m	40.64:1	40:01:00
Truss Height	2.560 m	0.065 m	39.40:1	40:01:00

The Small model intended for demonstration purposes was fabricated using the prototype bridge dimension ratio as indicated in the aforementioned table. Moreover, precise dimensions were established for various parts and sections of the model bridge prior to its construction. Figures 5 and 6 depict the CAD designs of the right-half bridge and left-half bridge, respectively, including precise measurements. All measurements are presented in meters.

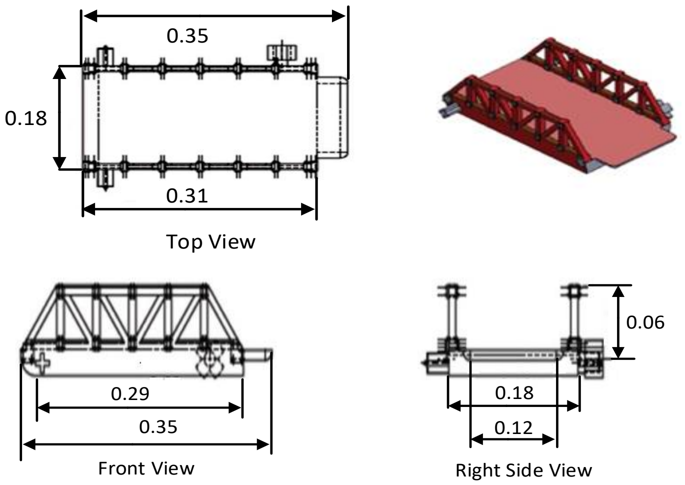

Figure 5. The top, front, and right-side view of the right half edge of the proposed Small model for demonstration with dimensions

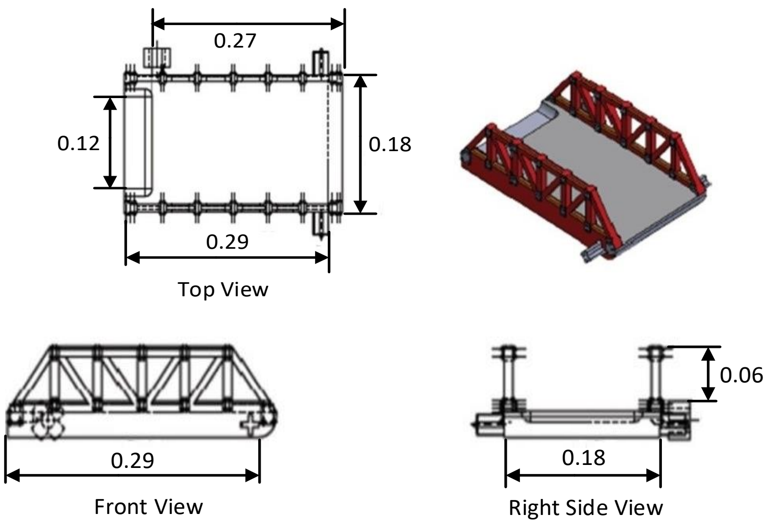

Figure 6. The top, front and right-side view of the left half edge of the proposed small model for demonstration with dimensions

In order to fabricate the proposed small model for illustrative purposes, it is necessary to procure both mechanical and electrical components. The mechanical components of the structure comprise the Pratt truss, bridge leaf spun, cantilever support, and road barrier system. On the other hand, the electrical elements encompass the design of the controller, electronic equipment, and soft programming. In Figure 7, a schematic of the construction components required for the development of the proposed small model for demonstration is presented.

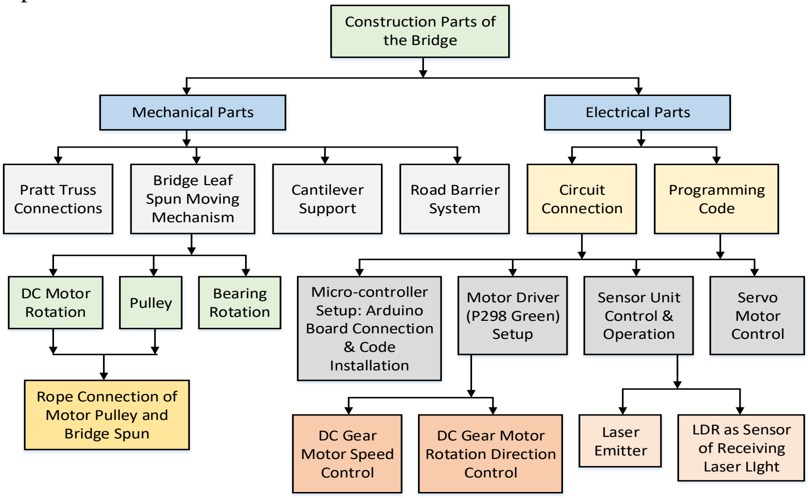

Figure 7. Flow chart of the construction works of the model bridge

The model bridge was equipped with the Pratt truss system. The bridge-leaf is flanked by 24 members of uniform dimensions on either side, and the truss com-prises 21 joints. The model bridge employed riveted connections to interconnect its various members. The movable bridge in question was designed with a vertical rotation capacity of approximately 85 degrees, and features a horizontal configuration similar to that of a double-leaf rolling bascule bridge. Bearing connections were affixed to the rear end of each bridge leaf, thereby enabling rotation along a horizontal axis. A DC motor was utilized to facilitate the rotation of the bridge-leaf by means of a pulley-rope connection located at both ends of the leaf, as opposed to a direct connection of the motor at the rear end with a gear. This particular connection was selected due to its ability to offer a mechanical advantage in vertical movement across the bridge, as well as its lower power consumption requirements for the motor. A roller was utilized to secure the rope, which had been fastened to the bridge, by rolling and tying it. Cantilever support was employed for both leaves during the downward reversal rotation, thereby enabling the bridge to attain a precise horizontal position and impeding any further mechanical rotation. The front end of each leaf joining point was designed in a re-versed triangular shape, facilitating easy detachment of both leaves during up-ward movement and proper connection and overlapping upon downward rotation. Therefore, the structure serves as a means of facilitating traffic flow, such as a conventional road or bridge, and has the ability to adjust its position to accommodate the passage of taller ships. Figure 8 depicts the small model that has been constructed for the purpose of demonstrating the movable bridge. The LDR covers are kept open to allow for the visualization of the LDR. It was necessary to cover the Light Dependent Resistor (LDR) in order to mitigate potential sensing inaccuracies that could arise from the presence of incident light.

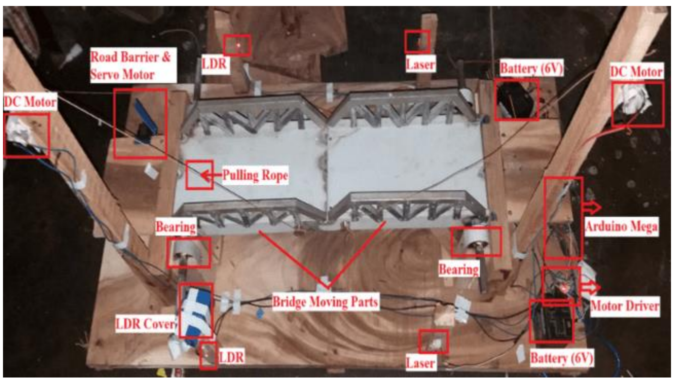

Figure 8. Constructed movable bridge with labelling

4. Operating methodology

In order to regulate the passage of a ship, it is imperative to have a mechanism for detecting the presence of the vessel. Typically, human operators engage in the task of monitoring the ship's presence and ensuring the safe passage of traffic by operating the bridge-leaf span through means of visual observation or by responding to alarm signals from the control room. Within this particular system, the detection of a passing ship is achieved through the interruption of laser-LDR transmission between the sensor towers. In the event that the height of a shipping vessel falls below the predetermined threshold value, the transmission of the laser to the Light Dependent Resistor (LDR) remains uninterrupted. Consequently, the bridge control system does not require any intervention as these ships can safely navigate beneath the bridge. The activation of the control system to close the road barrier on both sides of the bridge and prevent vehicle entry occurs solely in response to the interruption of laser transmission to the LDR by ships of higher threshold value. Upon receiving a command from the controller, the servo motor executes a 90-degree rotation, thereby causing the road barrier to close and preventing any further vehicular entry onto the bridge. The deployment of cameras on either side of the bridge has verified the complete absence of vehicular and pedestrian traffic on the bridge. Upon verifying the absence of any obstruction, the bridge leaf ascends. Both direct current motors facilitate the rotation of coils, which in turn causes the rope to wrap around the pulley and vertically elevate the bridge-leaf. Upon the vessel's traversal of the bridge, it is detected within the second sensing tower through the disruption of the laser trans-mission to the second light-dependent resistor (LDR). The bridge-leaf gradually descends by means of the reversal of the dc motors and the release of the ropes coiled in the pulley, thereby verifying the secure passage of the vessel. Upon the restoration of the bridge leaf to its original straight joint position, the road barrier is automatically raised to facilitate vehicular passage across the bridge, resembling that of a conventionally fixed bridge. Figure 9 shows the photographic representation of the constructed model bridge, captured in both stationary and dynamic orientations.

Figure 9. A photographic view of the (a) horizontal and (b) vertical position of the pro-posed small model for demonstration

In this work, the avoidance of clashes is imperative due to the paramount im-portance placed on human safety. The evacuation of the bridge during the ship's crossing is imperative due to the potential risk of the bridge span lifting with any vehicles, pedestrians, or property that may be present on it. Upon the ship's traversal of the laser beam connecting the two towers, the Light Dependent Resistor (LDR) detects the interruption of the laser and subsequently transmits signals to the control system indicating the presence of the ship. As a result, the road barriers situated on either side of the bridge are immediately lowered. Consequently, the countdown is initiated to facilitate the bridge's clearance from vehicular and pedestrian traffic. Prior to the ship's approach for crossing, all life and property situated above the bridge are effectively evacuated. Under certain circumstances, the occurrence of a collision and subsequent accidents may arise if the system does not successfully alleviate the traffic congestion on a bridge. In order to pre-vent such an occurrence, it is imperative that the vessel's velocity be reduced significantly upon crossing the laser beam situated between the two towers. In the event of a failure of the controlling system to evacuate the vehicle, an audible alarm will be emitted to activate the emergency stop mechanism of the vessel. Therefore, it is imperative to enforce a reduction in ship speed within the bridge zone. Figure 10 represents the methodology flowchart for the operation of con-trolling and moving a bridge.

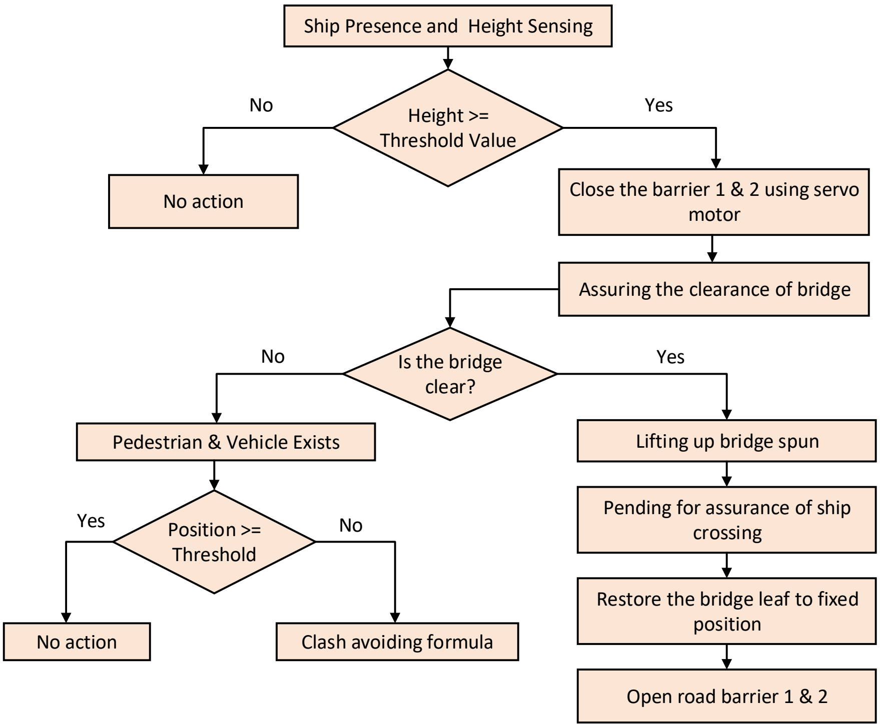

Figure 10. Flow chart of the methodology of the bridge controlling and moving operation

5. Performance evaluation and results

To assess the efficacy of the small model, six tests were conducted using a dummy ship specimen measuring 0.11m. Initially, the experiment was conducted 10 times in the absence of LDR covers to substantiate the influence of LDR covers on the assessment of model performance. Table 3 presents the outcomes obtained from the administered assessments.

Table 3. Performance Test Result

No. of Observation.	Ship Passing (Height above)	Vehicle Barrier Movement	Bridge Movement	Result
1	Ship entering	Barrier moved down	Bridge rises up	Ship Sensing and bridge automation success
	Ship leaving	Barrier lifted up	Bridge lowered to horizontal.	
2	Ship entering	Barrier moved down	Bridge rises up	Ship Sensing and bridge automation success
	Ship leaving	Barrier lifted up	Bridge lowered to horizontal	
3	Ship entering	Barrier moved down	Bridge rises up	Ship Sensing and bridge automation success
	Ship leaving	Barrier lifted up	Bridge lowered to horizontal	
4	Ship entering	Barrier position unchanged	Bridge stationery	Ship Sensing failed due to the effect of higher incident light on LDR and bridge automation failed
	Ship leaving	Barrier position unchanged	Bridge stationery	
5	Ship entering	Barrier moved down	Bridge rises up	Ship Sensing and bridge automation success
	Ship leaving	Barrier lifted up	Bridge lowered to horizontal	
6	Ship entering	Barrier moved down	Bridge rises up	Ship Sensing and bridge automation success
	Ship leaving	Barrier lifted up	Bridge lowered to horizontal	
7	Ship entering	Barrier moved down	Bridge rises up	Ship Sensing and bridge automation success
	Ship leaving	Barrier lifted up	Bridge lowered to horizontal	
8	Ship entering	Barrier moved down	Bridge rises up	Ship Sensing and bridge automation success
	Ship leaving	Barrier lifted up	Bridge lowered to horizontal	
9	Ship entering	Barrier position unchanged	Bridge stationary	Ship Sensing failed due to effect of higher incident light on LDR and bridge automation failed
	Ship leaving	Barrier position unchanged	Bridge stationary	
10	Ship entering	Barrier moved down	Bridge rises up	Ship Sensing and bridge automation success
	Ship leaving	Barrier lifted up	Bridge lowered to horizontal	

6. Discussion

The automated component of the small model intended for exhibition experienced two instances of malfunction as a result of the impact of elevated levels of incident light on the Light Dependent Resistor (LDR). Based on the aforementioned results of the performance test, it can be inferred that ship sensing and bridge automation were successful in 80% of the incidents. Two instances of ship sensing errors resulting in failure have been identified. The observed phenome-non can be attributed to an elevation in incident light levels on the Light Dependent Resistor (LDR) sensor. This increase in light intensity overlaps with the laser light, resulting in a malfunction in the ship sensing mechanism. The present study reports an 80% success rate in the automation of movable bridges. In order to enhance the success rate, LDRs were shielded with LDR covers and the experiment was repeated 10 times. In this instance, we have achieved a success rate of 100% in the domains of automation and ship sensing. The analysis reveals that the implementation of LDR covers effectively mitigates the sensing error caused by incident light and enhances the automation success rate of our movable bridge by approximately 20%. The Small model proposed for demonstration exhibits satisfactory performance across all observations.

7. Future studies

Subsequent research endeavors may center on the utilization of a simulation software to conduct stress testing and determine the static pressure at each point on the bridge in accordance with the load. Therefore, it is evident that certain aspects may require more robust substantiation. To enhance security, a sensor array with appropriate spacing can be employed as a viable measure to mitigate the aforementioned error. By computing the velocity of the transition occurring between the sensors, it is possible to pre-determine the speed of the vessel, thereby enabling timely notification to the ship. In the event that the vessel fails to decelerate despite prior cautionary measures, alternative mechanisms may be readied to safeguard the bridge. In contemporary times, several sophisticated technologies have been implemented to enhance road safety. These include the cooperative intelligent transportation system (C-ITS), connected vehicle technologies, and various collision awareness safety messages communication systems (Komol *et al*., 2022; Komol *et al*., 2021c; Elhenawy *et al*., 2018; Aniss, 2016; Sjoberg *et al*., 2017; Tong *et al*., 2020). These technologies have the potential to be advantageous for maritime safety in the movable bridge zone.

8. Conclusion

The global landscape is undergoing significant advancements and modernization, with transportation infrastructure serving as a critical component in this process. The construction of larger and more intricate bridges serves to enhance transportation and communication, ultimately benefiting society. The movable bridge under consideration is of the bascule type. Mobile bridges protect trade-critical areas like ports and the Suez Canal. Marine traffic management is crucial to ship and product mobility in important places. Europe-Asia traffic passes through the Suez Canal. Vessel traffic is high. Shipping requires movable bridges. The canal bridges allow ships to pass while restricting access. Ports and harbours—global trade hubs—benefit from movable bridge technology. These zones are only accessible to authorized ships and vehicles. Port traffic is controlled by movable bridges. It allows authorities to control entry, decreasing security risks. The utilization of automated technology within a miniature prototype holds the potential to enhance the efficiency of transportation infrastructure. The afore-mentioned system is an integration of electro-mechanical components and principles of control systems and dynamics. The implementation of automated ship sensing and bridge leaf operation has been found to enhance safety measures and serve as a contingency plan for collision avoidance systems. The LDR sensor is capable of detecting the emission of laser light, thereby indicating the presence of the ship. The curriculum will cover the topics of sensors in resilient systems and microcontroller system operations through the use of a compact model, providing students with a comprehensive understanding of these concepts. This instructional approach promotes children's acquisition of knowledge. According to a poll of 50 individuals, the small model utilized for demonstration purposes may impact the development of automation technology and smart transport systems. The demonstration model can also be utilized in control systems and microprocessors laboratories. The proposed idea is expected to yield benefits for the pedagogy of control engineering.

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