IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Vol. 10, Issue.12, December 2022 E-ISSN: 2347-2693

Design and Implementation of a Solar-Powered Load-Controlled Tower Crane Robot

Abubakar Aliyu Badawi[1*], Ibrahim Nasir Said[2], Abdulkadir Ayo Adewale[3]

[1]Department of Mechatronics Engineering, Bayero University, Kano, Nigeria
[2]Department of Electrical Engineering University of Newcastle, United Kingdom
[3]Department of Mechatronics Engineering Abubakar Tafawa Balewa University, Bauchi, Nigeria

Corresponding Author: badawi.abubakaraliyu@gmail.com, Tel.: +234-80369-41401

DOI: https://doi.org/10.26438/ijcse/v10i12.17 | Available online at: www.ijcseonline.org

Received: 25/Oct/2022, Accepted: 28/Nov/2022, Published: 31/Dec/2022

***Abstract*—** In construction and heavy equipment sites, tower cranes are extensively used to hoist and move materials over a high-rise height. At present, there are some imperfections in the tower crane protection device. For the purpose of monitoring the time running state and eliminating the overloaded security issues of the tower crane, this paper proposes a way to implement a tower crane robot that consists of a load monitoring system using a load sensor, the objective of the system was to read weight carried by the tower crane in traditional analog to digital conversion, and also to attain high accuracy in measuring and calibrating the weight of the object. The components used for this research are a tower crane robot, an HX711 load cell amplifier, an Arduino-Uno microcontroller, an OLED display, a NEMA17 Stepper motor, and a DC motor. The load cell used in this research weighs 40kg. It sends an analog output signal to the HX711 module of the weight of the object, which converts it to digital, amplifies it, and sends it to the Arduino-Uno microcontroller and finally, the digital signal is sent to the OLED display. The robotic crane is made of the 'MAST', the main supporting tower of the crane. The 'JIB' is the operating arm of the crane, the 'COUNTER JIB' will be two-thirds the length of the jib used to carry the counter load, and the counter load will be movable along the axis of the counter jib in other to facilitate the process of counter-balancing.

***Keywords*—**Solar-powered load-controlled tower crane, an Arduino micro-controller programmed in C++, an HX711 module load cell

I. Introduction

Cranes are among the most commonly used and shared resources on construction sites. It is estimated that there are approximately 125,000 cranes in the construction industry in the United States alone[1]. Following the trend of global Manhattanizing, tower crane usage has increased sharply each year [2] As well, and crane-related accidents at high-rise building construction sites have claimed 10 to 59 lives each year in Korea since 1996 [3]. With the advancement of technology, many human operations especially those that involve repetitive work, and dangerous tasks have been replaced with automation with the help of sensors, computer vision, and control [4]. Several researchers have suggested robotic tower cranes as an alternative to address these productivity and safety concerns [5],[6],[7].

A tower crane is a common piece of mechanical tool in the modern construction of tall buildings and in heavy equipment sites. It perhaps provides optimal height and lifting capacity. Technological malfunction and overload miscalculations can result in tower cranes exceeding their factor of safety and tipping over. An overhead crane is described as a mechanical system that lifts and moves loads through a hook suspended off a moving arm. When lifting is required, ballasted or anchored cranes are often used in the construction industry [8]. The main deliberations in the present field of technologies are; control and automation, power consumption, and cost-effectiveness. Providing robust and reliable tower cranes is a construction site's most important and expensive responsibility. Load-controlled tower cranes designed based on some critical parameters can reduce the risk associated with overloading a tower crane [9].

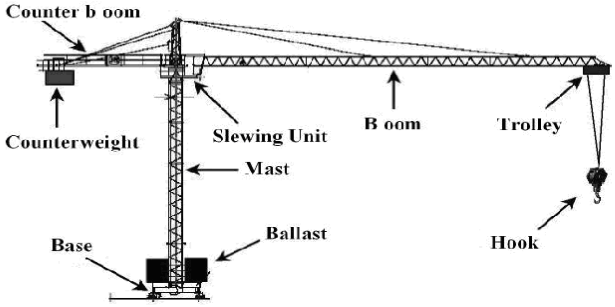

Figure 1. Overview of Crane Parts

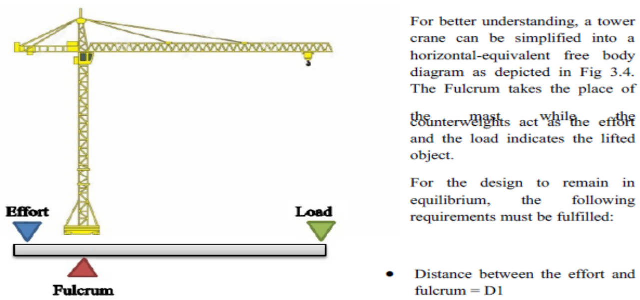

Figure 2. Distribution of forces in a Tower Crane

Table 1. General Specification of the Tower Crane

Specification	Value
Crane type	Tower
Material	Alloy with rubber rope
Length of the boom	51.5cm
Width of the bottom	9cm
Height of the tower	51.5cm
Movement	360^0 rotations
Weight of the load	2kg

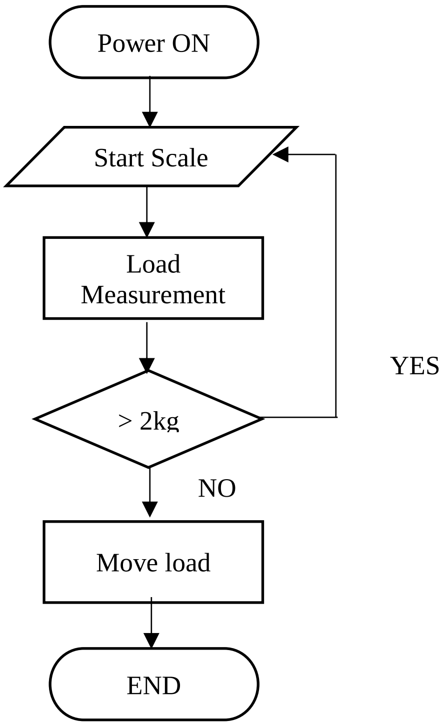

Figure 3. Flow chat of the proposed load measurement

II. Related Work

This section provides an overview of the tower crane industries including its major players, patents, and technology used in the production of modern top-slewing tower cranes. Additionally, the latest advancement in automation and lifting technology in the crane market will be discussed. Technology. In 2008, statistics showed that Liebherr was a leader in terms of crane sales, with a 16% increase in lifting sales from the previous year and a total sale of 4,194 million USD [6].

In the past, various systems were developed to monitor tower crane operation, with the goal of improving safety on construction sites. These systems typically generate alarm signals in hazardous conditions by measuring mechanical and electrical variables, loads, wind speed, and other factors. Some of the technologies used in these systems include RFID, wireless video, black box models, broadband, and Building Information Modeling (BIM) [8 - 10].

In addition to systems that monitor safety, other systems have been developed to measure variables related to productivity and crane operation. For example, [8] presents a system that includes data acquisition, control, communication, and alarm subsystems. The acquisition subsystem in this system consists of four mechanical variables related to crane operation and one for wind speed. In [9], CAN bus and ZigBee technologies are used to supervise the operating status and position of a tower crane. [10] provides a detailed description of a safety system used for the operation of tower crane groups, which uses a sensor to send information via GPRS or 3G to terminals. Additionally, the scheme presented in [11] allows for the acquisition, integration, management, and control of data at a construction site using several communication systems based on ZigBee, 3G, and an IoT sensor network connected via a CAN bus. However, only a few of these systems have been deployed in the field, and commercial systems that provide information on operational conditions are often prohibitively expensive and inflexible.

II.I Problem statement

Nowadays, tower cranes are involved in a lot of accidents which are caused due to several factors. Among the major factors is due to the overload of real-time miscalculation. When a crane is overloaded, it is obviously subjected to structural stresses that may cause irreversible damage, which in most cases results in loss of lives and billions of dollars in properties [10]. Moreover, the nature of the materials used in most tower cranes also negatively affects the performance and ease of transportation [11]. In this paper, a pulley-based tower crane was designed and implemented that calculates a real-time load carried by the crane.

II.I Objectives

This paper presents a load-controlled tower crane model based on specified materials and dimensions to ease transportation for effective safety using a load detection unit (load censor), an Arduino-Uno microcontroller programmed in C++. The circuit also consists of a high torque stepper motor that controls the slewing unit of the tower crane, a DC motor to control the hook position, an Organic light-emitting diode (OLED) display to display the status and weight of the load interfaced to the Arduino microcontroller, a rotary encoder reset the calibration as well as switch between different units of measurement and finally a voltage regulator to regulates the input voltage of the DC motor, the objectives are summarized as follows:

- Program Arduino Uno
- Design a variable voltage supply unit
- Configure a load censor
- Configure a stepper motor
- Configure a DC motor
- Interface load sensor with an Arduino Uno

III. Methodology

III.I System architecture

The complete circuits consist of a battery that is charged by a solar panel. The charged battery provides the power supply to the Arduino-Uno microcontroller which is programmed to detect load as well as enough voltage to drive the DC and stepper motor. The stepper motor (NEMA- 17) is attached to the slewing unit of the robot crane and consists of a voltage rating of 4V and 1.8^0 step angle. The hardware for the implementation of the project was constructed based on the design and availability of the components for the system realization. The complete block representation of the system is shown in the figure below.

Figure 4. Flow chat of the weight measurement

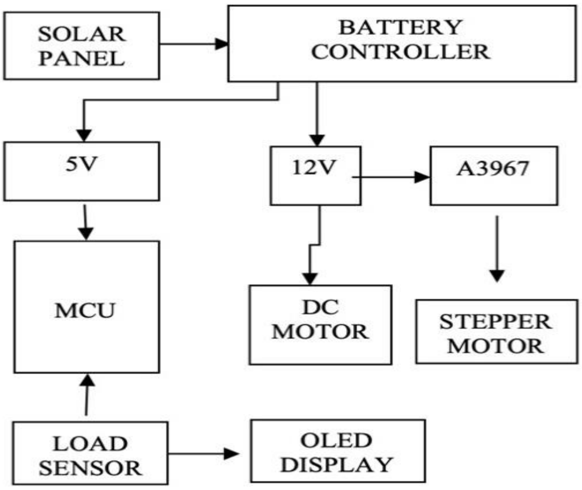

Figure 5. Hardware architecture of the Tower Crane Robot

III.II Controlling the vertical position of the hook using a 12DC motor

To control the vertical position of the hook, we use a 12V, 300 R.P.M permanent magnet DC motor with a maximum input current of 2A because of its high torque than a 6V or 3V. Having a higher torque means the motor can lift a heavy load. The DC motor controls where the load can be placed on the vertical axis and is located near the tower crane's counterbalance for extra support. The speed of the motor is controlled with the help of an adjustable positive linear voltage regulator (LM317) with an output voltage of (1.25 – 3.7) V. The vertical movement of the load is achieved using a Double Pole Double Throw (DPDT) Switch which helps in reversing the direction of the current passing, by so doing reversing the direction of the DC motor, the circuit is developed and tested using the Proteus software shown below.

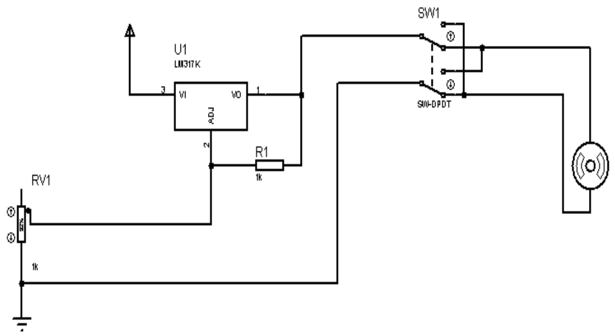

Figure 6. Circuit Diagram for Controlling the Speed and Direction of the Hook Using a DC Motor and an LM317 Variable Voltage Regulator

III.III *Forward and reverse movement of the 12v dc motor using a DPDT switch to control the position of the hook*

A Double Pole Double Throw (DPDT) switch is a switch consisting of two inputs (C & D) and four outputs (A,B, E & F) where every input has two equivalent outputs [6] as shown below.

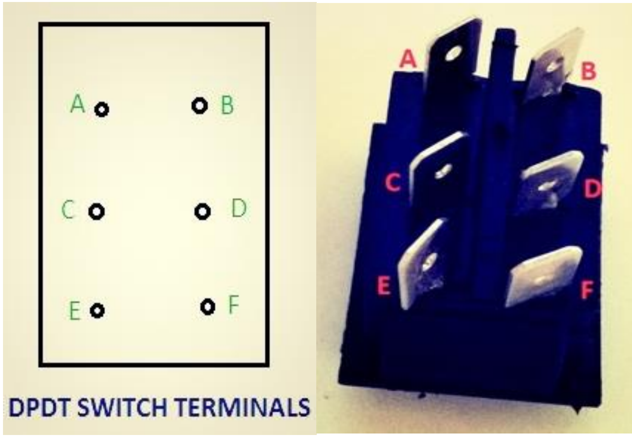

Figure 7. Double Pole Double Throw Switch Used for Reversing the Direction of the DC Motor

We Solder A & F as well as B & E terminal together. When the switch is pushed in the forward direction, points A and C, as well as B and D, come in contact which makes the motor move in a forward direction because the battery is connected in a forward direction to the motor as shown below.

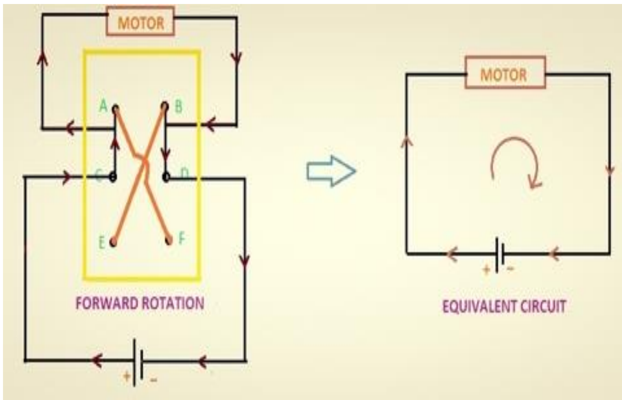

Figure 8. Forward Rotation Mechanism of the DC Motor

To achieve the reverse rotation of the motor, point C is connected to E, likewise as point D is connected to F as shown in the figure below

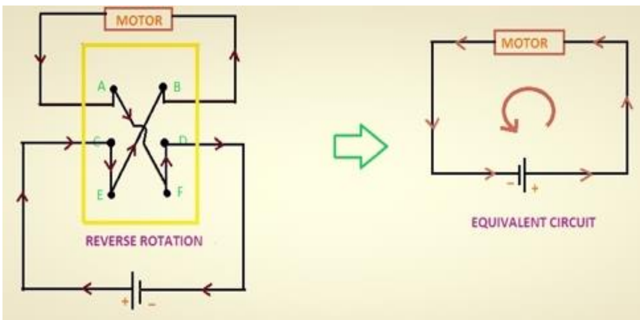

Figure 9. Reverse Rotation Mechanism of the DC Motor

Finally, when the switch is in the middle the DC motor is in the off state because there is no contact between the motor to any terminal in the switch.

III.IV *controlling slewing unit of the tower crane robot using a NEMA-17 stepper motor*

A NEMA-17 stepper motor with a holding torque of 3.2 kg-cm is used to control a full 360^0 rotation of the slewing unit which is driven by an A3967 stepper motor driver. The Arduino-Uno microcontroller cannot supply sufficient current to drive the NEMA-17 stepper motor[13], a motor driver is used in order to provide the required voltage and current needed for the smooth operation of the stepper motor.

Color code	RED	BLUE	GREEN	BLACK
Bipolar driver	**COIL A+**	**COIL A-**	**COIL B+**	**COIL B-**

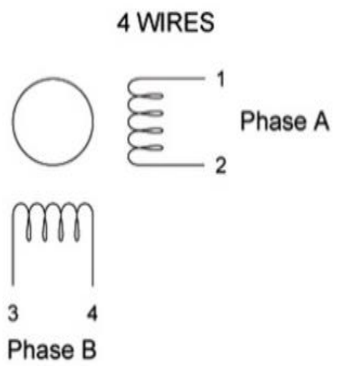

Figure 10. Stepper Motor to A3967 Stepper Motor Driver Connection

A C++ code is developed to control the rotation of the crane. 2 push buttons were used to control the rotation, every 180 degrees. Pin 8 and 9 of the Arduino-Uno were set to control the stepper motor's steps and direction, respectively.

Whenever the "digital Write (9, HIGH);" call is executed, the NEMA-17 stepper motor will rotate 1/8th of a full step. It has 1.8 degrees per step, which will result in 200 full steps per revolution or 1600 micro steps per revolution, which makes it 800 steps for 180 degrees. Each complete pulse will take 2ms of time when the STEP signal is 1ms high and 1ms low. One second contains 1000 milliseconds, so 1000/2 = 500 microseconds. The delay will be set to 10ms for the stepper motor to move at 50 micro steps/second.

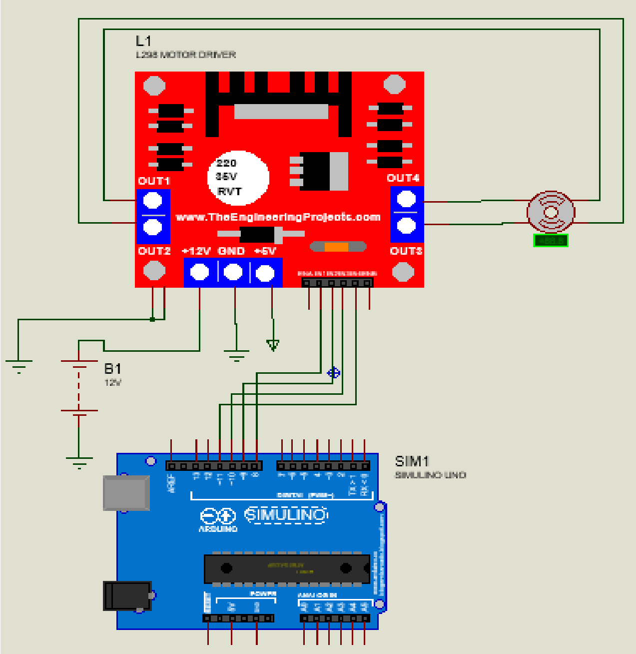

Figure 11. NEMA-17 Stepper Motor Control Circuit

III.V Weight measurement using the loadcell and HX711 model

A load cell of 40kg (rated capacity) is used to measure the load the tower crane carries, it measures force and outputs this force as an electrical signal [14], to easily interface it with an Arduino-Uno an HX711 load cell amplifier module was used because the voltage change inside the load cell is so small for the Arduino-Uno to measure. Lastly, we use an OLED display because it consumes less power than a regular 16X2 LCD to display the value of the load.

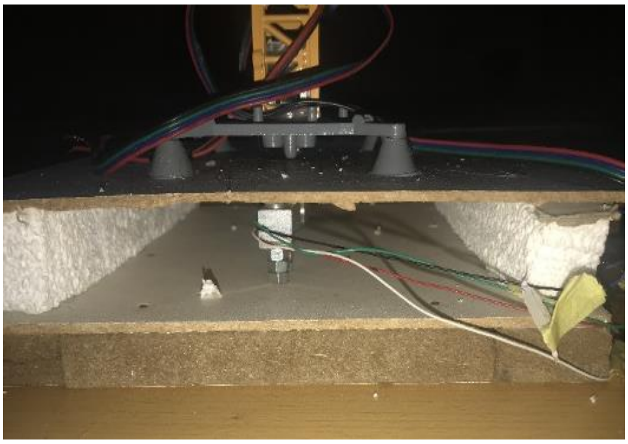

Figure 12. Load Cell Setup for Measuring the Weight the Tower Crane Robot Carries

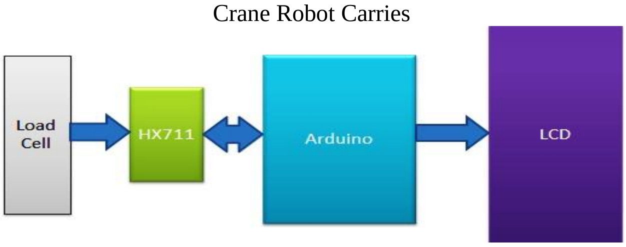

Figure 13. Block Diagram Showing the Process of Displaying the Weight

Calculation of the load cell's mathematical characteristics
The rated capacity of the load cell--------------2kg
The rated output of the load cell----------------1mv/v
The excitation voltage of the load cell------5v
(the load) 2kg→5mv (the output voltage)
If 2kg (2000g)→5mv
1g == X
2,000X == 5
X == 125 * (5/2,000)
X ==
5/2,000 = 0.0025
X→25µm 1g→25µm
Maximum weight→2kg
Therefore, the Minimum Volt for 1g→25µm

There are 4 resistors laid out in a weighbridge pattern, and the circuit has two compression and tension pairs, when no pressure is applied all the resistor's values are equal which makes the voltage to be 0v. When you put some weight on the load cell the compression and tension resistance values are going to change in opposite directions letting current flow from top to bottom, the voltage difference is being measured.

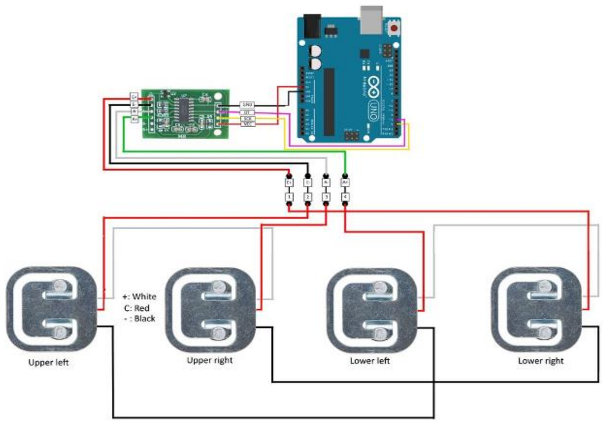

Figure 14. HX711 to Arduino-Uno Connections

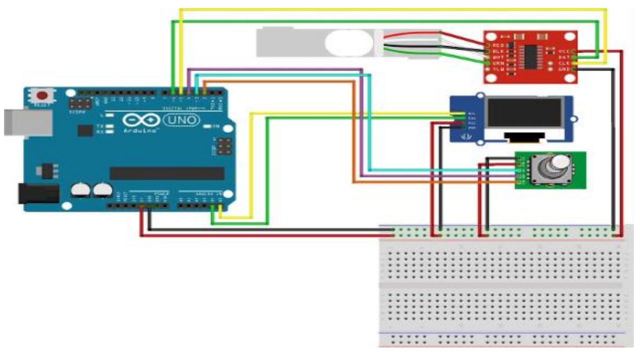

Figure 15. Load Measurement Circuit Diagram

IV. Results and Discussion

IV.I *HX711 analog to digital module calibration*

Using an analog-to-digital converter, the (HX711 module) amplifies the low-output electric current from the load cell and converts it to digital form [15]. The DOUT and CLK of the HX711 ADC are connected to pins 6 and 7 of the Arduino-Uno respectively, a C++ code was developed to take an average of 20 readings from the scale, and a known weight of 125g is used to obtain the scale factor by taking the average of the 20 readings and divided by the reading from the known weight of 125g.

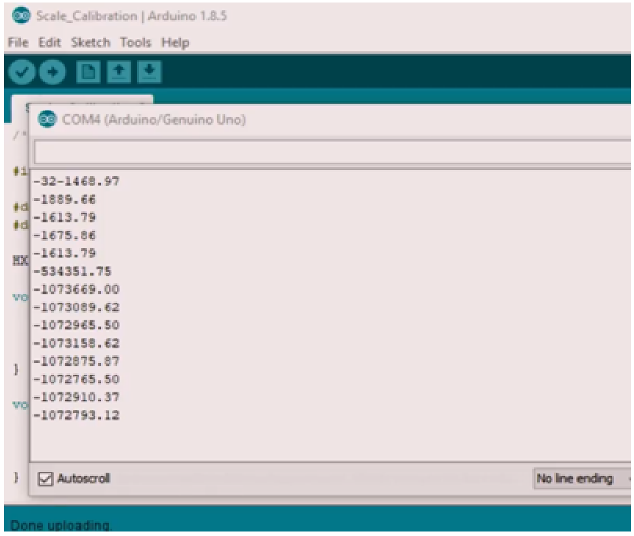

Figure 16. Scale Factor Readings Obtained From the 20Kg Weight

The result indicates the successful operation of the 'solar-powered load-controlled tower crane robot. The circuit is placed in a location that receives sunlight and utilizes radiation from the sun to power the system. The hook used is made of iron, while the overall dimension of the tower crane model is 51 x 51 cm. In practice, the system is consistent and robust with the tower crane safety monitoring requirements. The diagram for the control box and the constructed working prototype is shown in Fig 5.1 & 5.2 below.

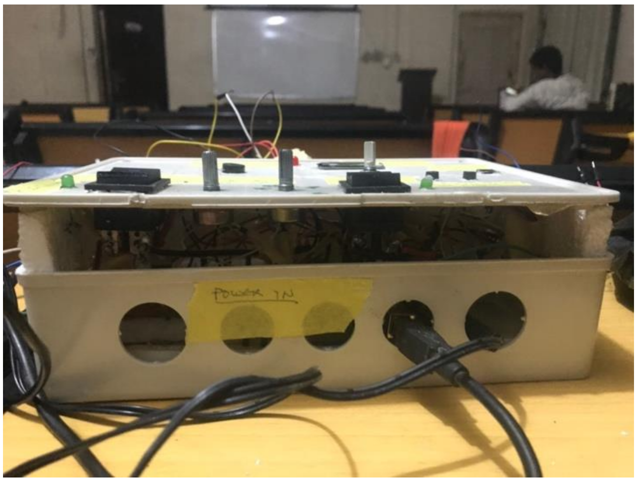

Figure 17. Control Box

It should include important findings discussed briefly. Wherever necessary, elaborate on the tables and figures without repeating their contents. Interpret the findings in view of the results obtained in this and in past studies on this topic. State the conclusions in a few sentences at the end of the paper. However, valid colored photographs can also be published.

V. Conclusion and Future Scope

This paper resent the details of an early stage development of a solar-powered load-controlled tower crane robot, and the function of the individual components was explained. The design and development of a variable voltage supply unit, stepper motor control, and load measurement, HX711 calibration were all achieved. All the modules were assembled. The tower crane robot was capable of transporting loads to different places while measuring the load it carries. Thus the crane is capable of executing its duty smoothly and independently. The picture of the constructed tower crane robot is shown in the figure below.

Figure 18. The Final Setup of the Tower Crane Robot

Table 2

SN	COMPONENTS
1	24V DC Motor
2	NEMA-17 Stepper Motor
3	Control Box
4	Load cell setup
5	Load
6	Slewing Unit
7	Solar Panel

In the future, we can implement the project using an electromagnet rather than a hook for easy transportation of the load. Furthermore, we can add another DC Motor to control the horizontal position of the load.

References

[1] S. Kang and E. Miranda, "Planning and visualization for automated robotic crane erection processes in construction," in the proceedings of the future of ACE Industry, Las Vegas, **USA**, pp.**1-15**, **2005.**

[2] G. Lee, H.-H. Kim, C.-J. Lee, S.-I. Ham, S.-H. Yun, H. Cho, B. K. Kim, G. T. Kim, and K. Kim, "A laser-technology-based lifting-path tracking system for a robotic tower crane," Automation in Construction, Vol.**18**, Issue.**7**, pp.**865–874**, **2009**.

[3] H.-H. Kim and G. Lee, "A quantitative analysis of fatal accidents related to cranes using the fmea method," Journal of the Korean Institute of Building Construction, Vol.**7**, Issue.**3**, pp.**115–122**, **2007.**

[4] F. Lamb, Industrial automation: hands-on. McGraw-Hill Education, **USA**, pp.**245 – 247**, **2013.**

[5] J. G. Everett and A. H. Slocum, "Cranium: Device for improving crane productivity and safety," Journal of Construction Engineering and Management, Vol.**119**, Issue.**1**, pp.**23–39**, **1993.**

[6] D. Lee, K. Son, and S. Kim, "Analysis of operation efficiency of tower crane in form work construction for multi-family housing," 28th International Symposium on Automation and Robotics in Construction (ISARC 2011), Seoul, **South Korea**, pp.**23 – 30**, **2011.**

[7] U.-K. Lee, K.-I. Kang, G.-H. Kim, and H.-H. Cho, "Improving tower crane productivity using wireless technology," Computer-Aided Civil and Infrastructure Engineering, Vol.**21**, Issue.**8**, pp.**594–604**, **2006.**

[8] M. Z. Othman, "A new approach for controlling overhead travelling crane using rough controller" International Journal of Intelligent technology, Vol.**1**, Issue.**3,** pp.**23 - 44**, **2006**.

[9] Rubio, Jose de Jesus & Alcantara Ramirez, Roberto & Ponce, J. & Siller-Alcalá, Irma. (2007). Design, construction, and control of a novel tower crane. International Journal of Mathematics and Computers in Simulation. Vol.**1,** Issue.**7**, pp.**119-126**, **2015.**

[10] B. Andonovski, L. Jianqiang, S. Jeyaraj, A. Z. Quan, X. Yonggao and A. W. Tech, "Towards a Development of Robotics Tower Crane System," 2020 16th International Conference on Control, Automation, Robotics and Vision (ICARCV), pp.**345-350**, **2020.**

[11] J. Vaughan, D. Kim and W. Singhose, "Control of Tower Cranes With Double-Pendulum Payload Dynamics," in IEEE Transactions on Control Systems Technology, Vol.**18**, Issue.**6**, pp.**1345-1358**, **2010**, doi: 10.1109/TCST.2010.2040178

[12] Paipetis, S. A.; Ceccarelli, Marco (2010). The Genius of Archimedes -- 23 Centuries of Influence on Mathematics, Science and Engineering: Proceedings of an International Conference held at Syracuse, **Italy**, pp.**416 - 417**, **2010**.

[13] A. -A. POP and E. -D. MAER, "Control technique for unipolar and bipolar step motor using Arduino and LabVIEW," XVIII International Scientific-Technical Conference Alternating Current Electric Drives (ACED), Delhi, **India**, pp. **1-5**, **2021**

[14] Sandip N. Rikame, Pradip W. Kulkarmi. "Digital Electronic weighing machine operate on solar energy with emergency LED light," International Journal of Emerging Technology and Advanced Engineering. Vol.**4** Issue.**7**, pp.**117 – 125, 2014.**

[15] A. Suryana, R. Ananda, T. R. Maulana and M. Rizal, "Rice Controller Using Half Bridge Load Cell and NodeMCU ESP8266 In Rice Dispenser," 2019 5th International Conference on Computing Engineering and Design (ICCED), California, **USA**, pp. **1-6**, **2019** doi: 10.1109/ICCED46541.2019.9161142.

[16] P. Schlott, F. Rauscher and O. Sawodny, "Modelling the structural dynamics of a tower crane," 2016 IEEE International Conference on Advanced Intelligent Mechatronics (AIM), Alberta, **Canada**, pp.**763-768**, **2016** doi: 10.1109/AIM.2016.7576860.

AUTHORS PROFILE

Abubakar Aliyu Badawi holds a Bachelor of Engineering Degree in Mechatronics Engineering from Bayero University, Kano in 2020. He is an experienced engineer in the power sector. He is a registered member of the Nigerian Society of Engineers (NSE), and also a member of the International Association of Engineers (IAENG). His main research work focuses on Robotics, Artificial Intelligence, and Renewable energy.

Ibrahim Nasir Said holds a Bachelor of Engineering Degree in Mechatronics Engineering from Bayero University, Kano, and a Master of Science in Control and Automation from the University of Newcastle, UK. in 2021. He is an experienced engineer in the Oil and Gas sector. He is a registered member of the Nigerian Society of Engineers (NSE), and also a member of the Council of Regulation of Engineering in Nigeria (COREN). His main research work focuses on Automation & Robotics.

Abdulkabir Ayo Adewale holds a Bachelor of Engineering Degree in Mechatronics Engineering from Abubakar Tafawa Balewa University, Bauchi in 2020. He is an experienced engineer in the power transmission sector. He is a registered member of the Nigerian Society of Engineers (NSE), and also a member of the International Association of Engineers (IAENG). His main research work focuses on Robotics, Artificial Intelligence, and Renewable energy.

