



TALLINN UNIVERSITY OF TECHNOLOGY

SCHOOL OF ENGINEERING

Department of Electrical Power Engineering and Mechatronics

**TORQUE SENSOR HARDWARE AND SOFTWARE
INTEGRATION WITH ELECTRIC WAGON**

**MOMENDIANDURI RIIST - JA TARKVARA
INTEGRATSIOON ELEKRIKÄRULE**

INTRODUCTION AND LITERATURE REVIEW

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Tallinn 2021

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THESIS TASK

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Study programme, MAHM02/18 - Mechatronics

main speciality: Mechatronics

Supervisor(s): Heigo Mölder, Researcher, PhD

Thesis topic:

(in English) Torque Sensor Hardware and Software Integration with Electric Wagon

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Thesis main objectives:

1. Develop User friendly cart for public and private use.
2. Use different sensors data which allow to maintain balance and control of the cart.
3. Creating a solution which helps to minimize the musculoskeletal problem.

Thesis tasks and time schedule:

No	Task description	Deadline
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2.	Hardware Design Complete	1 th March
3.	Circuit Designing and Programming complete	20 th March
4.	Development of Physical Prototype	20 th April
5.	Thesis defense	1 st June

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PREFACE

The motivation for the thesis is to develop a pulling and pushing electric wagon to carry out maximum load with less force. This thesis proposed by Researcher Heigo Mõlder and the author has enthusiastically accepted the challenge of pursuing it as a Master Thesis. The author is interested in investigating technology and techniques to make the solution easier to use and proficient and moderate. The practical was performed using all hardware and software available in the lab of the Mechatronics department of Tallinn University of Technology.

This study aims to create a versatile and intelligent sensor-controlled cart trolley to aid in the physical delivery of goods. In hospitals, supermarkets, warehouses, and manufacturing settings. Transporting homogeneous and heterogeneous goods is a typical trend. The wagon's handle and driving are all operated by a DC motor connected to the rear wheel and driven by a 24V DC battery. The control board, which consists of a microcontroller, a motor driver, and an ADC converter, serves as the housing for the cart's commands. There was specific software included for 3D model, schematic and coding like, PTC Creo for design the 2D and 3D model with all parameters and dimension, JLCPCB used for schematic. The fixture must be accurate and long-lasting in order to minimize the number of erroneous measurements. Both standard and safety requirements were taken into account during the project's construction and design phases. The key component list and data are provided to build the physical hardware successfully.

The author expresses his appreciation to Prof. Mart Tamre, who helps and guided the author to complete the graduation journey. Also special thanks to my supervisor Heigo Mõlder, who believed and helped the author in every possible way to achieve the core objective of the thesis.

In the last special thanks to my parents for supporting me during my master's while in my home country and to my friends for their unwavering moral support in helping me achieve my goal in the most effective way possible.

Keywords: Programming microcontroller, Mechatronics, digital conversion, PWM, DC Motor Controlling

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1. INTRODUCTION

A Trolley is an object with wheels which is used in daily life to carry out load and move a heavy stuff from one place to another. It speeds up for transferring of goods from shops, garbage from small streets and many other items. In 3rd world countries its quite common of using manual handling. Heavy services and production in industries are dependent on the manual handling and it put burden on the workers. To overcome these problems, management has provided manual vehicle's, such as trucks, carts, wheelbarrows etc.

However, recent studies reported that these vehicles have caused injuries and sufferings to workers in various industries because of the poorly designed cart and misuse of such vehicles increase the risk of musculoskeletal problems. Manual carrying of the load is always responsible for many injuries and risk factors, e.g. the appearance of physical fatigue which occur immediately and the most injuries that happen frequently are: cuts, bruise, fractures and musculoskeletal [1][2]. The back and the limb are more sensitive, especially in the lower back area but they can occur in any area of the body. For this, different kind of carts and trolleys had been introduced in the market to overcome the problem but still these products are difficult to use without proper training and are very expensive.

The usability of manual vehicles and their factors should be sought in 2 ways: having a great attention towards the ergonomic aspects of their design and a thorough guidance for selection of trucks and trolleys (aids) depending on the required tasks and the environments. In order to decide the suitable aid for a particular task or environment there are 5 factors which affect their usability:

1. Design characteristics
2. Load characteristics
3. Environmental considerations
4. Operational conditions
5. User characteristics

Many studies have been conducted in terms of vehicle types, factors and criteria which involve floor type, load weight, direction of motion, different design of carts with two-wheel and four-wheel had been studied. With the advancement of technology, new design of carts and manual vehicles were introduced to overcome the problems and provide ease to workers but still these carts use electric pedal to power up the trolley or controlled with hydraulic which requires special assistance to use. Most of the

companies are developing trolleys for commercial use only whereas huge amount of people had used cart/trolleys for personal use as well [3].

This thesis is based on a qualitative research which includes designing and developing of the electric cart/wagon. The objective is to use different sensors and send the data to the control panel which provide signal to the motor (powered with battery) to run with specific revolution per minutes (RPM) with unspecified weight and allow user to move the cart smoothly with single hand without any external force. As a result, a cost-effective full sensor weight controlled automated electric wagon will be implemented practically for both private and commercial use. Moreover, for future application the mechanism of the project can be used in different areas such as food trolleys abroad aircraft, heavy load suitcase, etc. [4]

2. LITERATURE SURVEY

2.1 Method and Research

This chapter describes the problems, existing solution and research done on different parameters of manual handling and motor controlling.

Manual lifting activities for pulling and pushing remain a regular cause of industrial working place. While mechanical and electrical handling devices and assistive aids have become so common in recent decades within the workplace and household work to minimize the amount of pushing and pulling has always remained the significant part of work. The study was conducted to review the psychophysically obtained maximum acceptable pulling and pushing forces [5]. Pulling and pushing tasks are most common in every industry and used as services in shipping, construction air lines, and gardening and it is estimated that about almost 50% of material handling in industries require it. Pulling and pushing of objective and carts exposed two types of hazards: (I) pressure and stress to the musculoskeletal system at the applied force in hand (ii) slipping or tripping. The studies conducted on epidemiological showed that the actions of pulling and pushing are associated with lower back and shoulder pain and 9 – 18% of the pain are connected with it [6].

Although, there are many automated and manual operated models are available in the market and mostly are expensive for common person to afford especially in developing countries. [7] presented the manual transport duties, peak hand forces met psychophysical thresholds. The power drive decreased peak push and pull forces dramatically. The drive helps the bed to stop much faster than manual control. Force drive may lessen injury hazard or the quantity of guardians required for transport. [8] Presented sugeno fuzzy logic technique to obtain the kinematic boundaries to analyze caterpillar speed of revolution, stage stature and platform height were streamlined utilizing Taguchi strategy. The measurement obtained during the study to stable the robot on two wheel, multiple measurement current, voltage b and in the output final speed and acceleration were obtained. [9] Proposed the cross-sectional analysis, the isometric pull power of the clothing cart/trolley pullers and the muscular function of the upper limbs were assessed. Although the IXTA Data Acquisition System was used to monitor and evaluate muscle function, the Jackson strength measurement system was used to measure isometric pull powers. Electromyographically information of different muscle and their movement was gathered. [10] Proposed the association between these practices and the prevalence of lumbago, low back pain and adverse effects on the

shoulders has been shown in manual handling activities through surgical investigations and epidemiological research. The suggested limits for push and pull are given by ISO 11228-2:2007. The findings of psychophysical experiments carried out under specified speed conditions relating to a slow walk are those values. The goal of this analysis was to analyse the effect on push forces of the difference in motion speed and load conditions.

[11] A depth study on the performance of Buck-boost and Cuk power factor converter-fed sensor-less Brushless DC motor drives is provided in this paper. Because of their high performance, long working life, noiseless running, high torque-to-weight ratio and higher speed ranges, Brushless DC engines are commonly favoured for low-power applications. To achieve inherent power factor correction in the AC mains, the converters are worked in discontinuous conduction mode. VD control is used to change the PFC power factor correction converter switch's job ratio. For sensor-less monitoring of the Brushless DC motor, the Direct Back-EMF Zero Crossing Detection system is used. The output of the drive is calculated over a wide spectrum using the chosen converters. A solidarity power factor is accomplished with power quality records satisfactory inside the suggested furthest reaches of IEEE 519 norm. [12] Field Oriented Control or vector control is the most powerful control system of PMSM. However, knowledge of the rotor location with a high degree of accuracy is needed for the implementation of vector control. Incremental encoders are widely used to collect knowledge about the speed and rotor position. This paper proposes a speed calculation based on Arduino that can be used in incremental encoders.

Moreover, Electric motors are now an important part of our everyday life that we seldom giving them a second thought. We expect it to run rapidly up to the correct speed without questioning the speed it should run at, or how will it take enough energy from supply to speed it up to maintain the required level [13]. With the technology advancement, controlling of speed control of an electric motor became easy with different parameters and through which it is easy to control the motor at the desire speed.

2.2 DC Motor Control System Using Arduino

A research was conducted in Greece by J. Syllignakis, P. Panagiotakopoulos, and E. Karapidakis. DC Motors are widely used in many industries, commercial, and others. The Electric drive systems have variable speed, higher performance and reliability due to their ease of control. The speed motor controller aimed to drive the motor at a specific speed and to take a signal representing the speed required. Therefore, there is much application of controlling the DC motor drives using the microcontroller and motor drives that use power electronics to control the speed, position, and voltages of the DC motor. Microcontrollers provide accurate and easy control of DC motor [14].

Motor can be controlled through many controllers and many have their built in applications.. Arduino UNO system (microcontroller) has been used widely to control signals. Arduino UNO microcontroller was used to drive the DC chopper which is fed by a DC motor. High-frequency PWM (pulse with modulation) signal was driven by the chopper and the controlling voltage of motor terminal was equivalent to the duty cycle of PWM [15]. The main objective of the paper was to achieve the constant speed while running the system at any load.

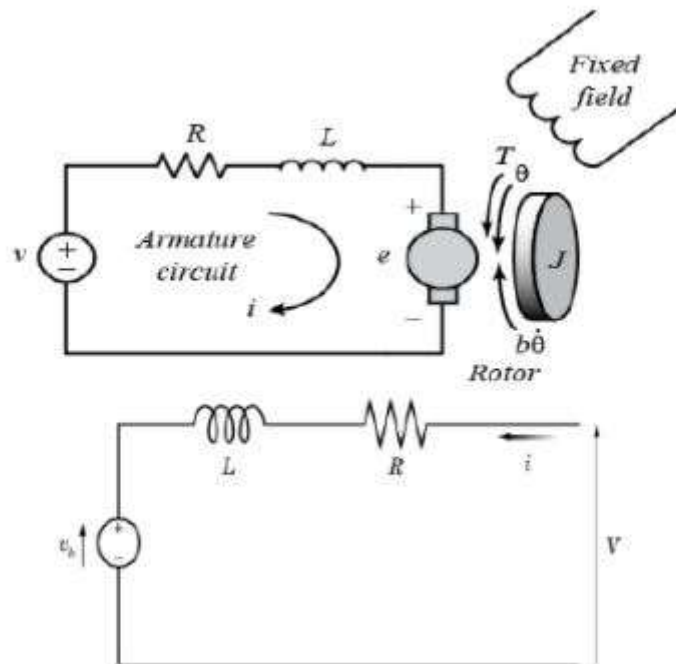


Figure 2.1: The corresponding electrical circuit of a DC motor [14]

To describe the equivalent circuit parameters, it was necessary to create model parameterization by equivalent circuit parameters. The resistor R represents the resistance specified in armature parameter resistance. The inductor L represented the

inductance of armature. The permanent magnets induce the motor to the back emf (electromotive force) v_b in the armature.

$$v_b = kv\omega \quad (2.1)$$

where kv – back-emf constant,

ω - angular velocity,

v_b - back emf in the armature.

Torque generated by the motor, which was directly proportional to current i .

2.3 Fuzzy Logic Speed Controller for PMDC using Arduino

Permanent magnet DC (PMDC) has many precedence over other conventional motors such as better torque characteristics, excessive efficiency, no excitation current, no noise operation and relatively economical. The permanent magnet (PMDC) motors have started being in use in many areas and applications including air conditioners wiper blades, heater and personal computer in recent years [16]. The objective was to use low cost hardware to verify the performance of artificial intelligence (AI) control method using proportional integral derivative (PID) and use the system for engineering undergraduate course by connecting real system to simulink.

In order to control PMDC motor speed, different methods have been applied.

1. The classic PID controller.
2. Intelligent controller (neural and Fuzzy)
3. Advance controller (improving and Adaptive)

Block diagram of a closed-loop PMDC speed control motor on MATLAB interfaced with Arduino and L298N H-bridge is shown in Figure 2.2. In the design system, input speed signal of the Arduino which got from sensor was compared with the set point value by the PID controllers and encoders was install to measure the revolutions of the motors. If the controller did not receive the set values, then the controller was set to decrease the error as much as possible and try to set the motor at desired speed.

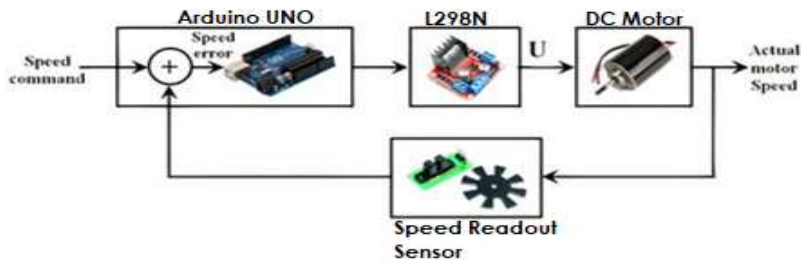


Figure 2.2: A Closed-loop PMDC speed motor control [16]

The result showed that an artificial intelligence (AI) method can be an best solution for the devices based on low cost hardware such as Arduino. Most of the studied PMDC control schemes have used PID controllers but the comparability was done in this study showed that the performance of the PMDC motors can be improved by using a Fuzzy PID controller.[16]

Output resposne characteristics of completed integerated PMDC motor is shown in Figure 2.3.

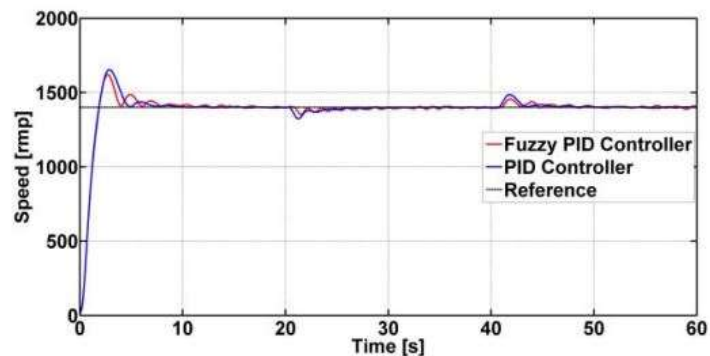


Figure 2.3: Result for step change in load and speed between PID and FPID controllers [16]

The 1.8s was the rise time with the 2.7s of overshoot time, which esclade upto 15.78% overshoot and the 6.44s was settling time. The comparison of response, including overshoot time (T_p), percent overshoot (M_p) rise time and settling time of the the PID controller and Fuzzy PID controller for the PMDC motor had been studied.

The response was observed that the fuzzy logic controller settling time was also low and fast with a small overshoot percentage. Results confirmed the study with the practical model. But this experiment does not include the result of PMDC using PID and fuzzy PID controllers regarding speed variation and load torque.

2.4 Effect of Speed Variation on Initial and Sustained Forces

The pressure to meet the demands of the work and the material and the lack of human resources have led to difficult work conditions and it does not satisfy the current manufacturing systems. The study investigated the human factors and the ergonomics of manual pushing and pulling of the cart. Some studies were conducted which proved that the redesign stratus and handling material brings changes to the lifting, carrying and lowering the pulling task but still current research does not prove the result that pushing and pulling should be favoured. A properly designed cart may allow the movement of heavyweights with lower forces, which could be ideally comfortable for female and men workers. Epidemiological studies showed that pulling and pushing task were associated with lower back pain and shoulder [17]. The International Standard Organization (ISO) has set rules and provided direction for identifying the risk associated and the potential hazard with the whole body while pulling and pushing. The standard gave the steps for taking correct forces measurement and two conditions are required for the initial forces. The swivel casters are positioned in line and set the direction of motion of the trolley and the second condition requires the right angle of the swivel caster to the direction of motion. Maximum forces are defined regardless of the action of the speed of the push/pull.

Table 2.1: ISO requirements for pull and push force measurements [17]

	Initial force	Sustained force
Swivel casters position	In-line direction Right-angle direction	In-line direction
Speed [m/s]	Maximum 1m in 10 s (0.1m/s)	Take 2-3s to reach the speed of 1m in 3s (0.3m/s)
Consistency	Measurements should not differ from each other by more than about 15%.	

The procedure described in the above standard provided the step for taking right force measurements and two different force initial and sustained were measured in three different parameters as shown in Table 2.1.

However, the finding of the study suggested that the speed of motion impacted the sustained and initial forces during pulling.

2.5 Products and Specification

The current market is full of manual and electrically throttle control cart but not a single product available which control through torque sensor or similar technology, the functionality of every product is same but different working principle, most of them using electric throttle to accelerate the cart. Below some products available with different specification.

Table 2.2: Different Product Specification [17] [18] [19] [20]

Product	Product Specification
	<ul style="list-style-type: none"> • Hand Pushing Electric Cart • Battery: 26 V, 12 A • Maximum Speed: 5 km/h • Load Capacity: 200 – 500 kg • Body Type: Stain Steel
	<ul style="list-style-type: none"> • Overland Electric Powered Wagon • Speed Throttle: 0-4 MPH • Battery: 24 V • Electric Motor: 18:1 gear ratio DC motor emit no fumes • Load Capacity: 100 – 250 kg • Body Type: Round Pipes and plastic
	<ul style="list-style-type: none"> • Cargo Electric Tricycle • Load Capacity: 800 – 1000 kg • Max Speed: 25 km/h • Battery: 48 V, 20 A • Usage: Cargo only • Body Type: Open and Steel
	<ul style="list-style-type: none"> • Cubic Electric Power Wagon • Hopper Capacity: 13 cubic feet • Speed: 0 – 3.2 MPH • Battery: 24 V sealed lead acid • Capacity: 200 – 250 kg • Body type: Round pipes and Plastic

2.6 Summary

This literature survey includes study of different fields and subjects with deep and detail analysis.

- Different variation of load does not correspond with the different speed of motor. The efficiency of DC motor fluctuates with high load and different power of motor.
- Torque variation and speed regarding load did not verify with PID controllers.
- Based on a survey conducted, many trucks and trolleys that are in use had poor designs and were inappropriate for different tasks.
- Multiple experiment has been conducted on linear surface to analyse the initial and sustained force but did not define the different angle of holding position in initial and sustained forces required for pulling cart at inclined positions.

2.7 Objective of the thesis

- The main objective of the thesis is design, develop and create low-cost practical model of electrical manual handling pulling cart/wagon, which helps the user to pull out maximum prescribed load with minimum single hand force.
- Experimenting different sensor to get accuracy and precise data which allow to maintain the balance and control of cart/wagon.
- Aim to develop user friendly which can be used for public and commercial use.

3. METHODOLOGY

This chapter will focus on the detailed explanation of the implementation of the proposed solution.

The first chapter gives an outline of the solution that has been presented. The second chapter summaries the literature review and previously work solution comprises on different approaches.

The third will give brief description of the usage of different sensors and components. The fourth chapter respectively will provide the explanation of the hardware design and the software which used to control the system.

3.1 Proposed Solution

As discussed in chapter 1 and chapter 2, a Manual moving cart with a single hand often cause multiple injuries and difficult to move with a heavy load on a plane and on an inclined plane. In the solution, the author is using a load cell to measure the force and use the calculated force to operate the dc motor with calculated force while pulling and pushing and sensors are used to convert analog data to digital data to control the cart according to user usage. Atmel AVR (8-Bit) Arduino microcontroller is used to control the whole mechanism of the system.

3.2 Material and Methods

Design hardware requires considering all parameters, choosing the material and components, For the accurate design, mild steel and softwood are used in the construction of the wagon. Mild steel was bought from the local steel market. The wagon includes another major component: Battery, Sensor, Wheel, Square pipes, DC gear motor.

3.2.1 Square Pipes

The mild steel hollow square pipes were chosen for this research project. When selecting this content, a number of factors were taken into account. Despite the fact that there are many other materials available in the industry, such as stainless steel, which has higher corrosion resistance and is more readily available, mild steel was chosen. However, it is painted dark to diminish its affinity to rust. It has an elasticity of 830 Mpa. For the task, 10 mm in length x 10 mm width, Hollow square pipes were utilized for building up the tire holding outline and for the handle.

3.2.2 Softwood

Softwood alludes to a tree that has been cut from a coniferous or evergreen tree. Softwoods are often utilized for building materials. It is adaptable, lighter in weight, and less thick than most hardwoods and it's generally utilized for creating sheets merchandise like pressed wood and fibreboard. The author utilized two sorts of woods, spruce and yellow pine for the development of weight holding outline and for the pulling handle.

3.2.3 Pneumatic Tires

The prototype would use a high-quality pneumatic tire with a swappable inner tube that can be used in a variety of applications such as carts and barrel trolleys. It facilitates the easy movement of the cart and good enough for the design of the system. The wheel is suitable for industrial heavy-duty sack trucks, hand trolleys, carts, and dollies. Solid center with 2 balls bearings to each hub with plastic rim and wheel material is made of rubber. It can carry upto 150kg of load. The tire has a 90 mm width and a 200 mm thickness.

3.3 Torque and Working Principle

The propensity of a force to induce or alter the rotational motion of a system is called torque (also known as moment, or period of energy). It is a force that bends or transforms an entity. Power and distance are averaged to measure torque It's a vector quantity, meaning it has a magnitude as well as a direction. Object's inertia is changing of the angular velocity or both[21].

$$T = F * r * \sin\theta \quad (3.1)$$

Where T – Torque, Nm,

F – Force, N,

r - distance measured from the axis of rotation to where the application of linear force takes place,

θ – The angle between F and r , Degree.

In the formula, $\sin \theta$ has no unit, r is measured in meter (m), and F is calculated in Newton (N). Multiplying these together, the force unit becomes Newton-meter (N.m).

3.3.1 Forces Acting on an object Moving up on Inclined Plane

Moving an object on an inclined plane with an angle θ requires force especially while moving a heavy object. There are some forces affecting the movement of an object carrying weight over an inclined plane. The major force is force of gravity $m \cdot g$, which pulls the object that is divided into two appropriate forces, $m \cdot g \cdot \cos \theta$ and $m \cdot g \cdot \sin \theta$ and $m \cdot g \cdot \sin \theta$ will act along the inclined plane in the downward direction and $m \cdot g \cdot \cos \theta$ perpendicular to the inclined plane and normal reaction R reacting vertically opposed. To move the wagon upward direction with its handle, the pulling force F_p applied at an angle β , since force F_p takes the wagon into the upward direction, the friction force f_s will act in a downward direction as shown. In figure 3.1, The force F_p has two components which is parallel to inclined plane $F_p \cdot \cos \beta$ and a component that opened up a little bit low $F_p \cdot \sin \beta$.

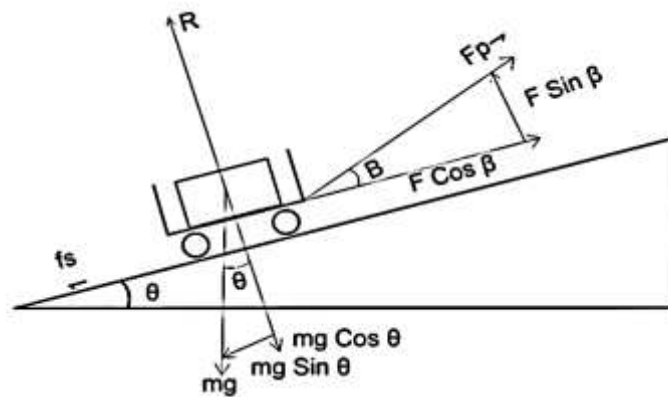


Figure 3.1: Cart moving on Inclined Plane

$$F_g = m * a \quad (3.2)$$

$$a = \frac{F_g}{m} \quad (3.3)$$

Where, F_g - Force of gravity,

m - mass of the object, kg,

a - acceleration of the object. m/s^2 .

For calculating the acceleration, the acceleration of a wagon on the incline is the same as the parallel value:

$$Fg = m * g * \sin \theta \quad (3.4)$$

By putting equation 3.4 into equation 3.3, acceleration of the wagon can be found.

$$a = \frac{m * g * \sin \theta}{m} \quad (3.5)$$

$$a = g * \sin \theta \quad (3.6)$$

Force has two components, parallel and perpendicular, therefore acceleration is the decisive factor. The angle of the inclined plane assumed as $\theta = 30^\circ$ and $g = 9.8 \frac{m}{s^2}$. we can get acceleration; $a = 4.9 \frac{m}{s^2}$. Now take the equilibrium along the y-axis and x-axis. The wagon is on verge of an upward direction so in equilibrium, all the forces are equal to each other if the direction is considered.

Y-axis:

$$R + Fp * \sin \beta = m * g * \cos \theta \quad (3.7)$$

X-Axis:

$$m * g * \sin \theta + fs = Fp * \cos \beta \quad (3.8)$$

$$fs = \mu R = \mu (m * g * \cos \theta - Fp * \sin \beta) \quad (3.9)$$

Now putting equation 3.9 into equation 3.8;

$$m * g * \sin \theta + \mu * m * g * \cos \theta - \mu * Fp * \sin \beta = Fp * \cos \beta \quad (3.10)$$

$$m * g (\sin \theta + \mu * \cos \theta) = Fp (\cos \beta + \mu * \sin \beta) \quad (3.11)$$

$$Fp = \frac{m * g * \sin \theta + \mu * m * g * \cos \theta}{\cos \beta + \mu * \sin \beta} \quad (3.12)$$

Fp is the force to pull the wagon in an upward direction. Where $\mu = 0.5$ is the surface coefficient, if assumed angle $\theta = 30^\circ$, angle $\beta = 20^\circ$ and $m = 60$ kg, the mass of object and wagon. Pulling force can be calculated as $Fp = 577$ N. This is force required to move the wagon with weight on inclined plane without the help of electric power.

3.4 Drive Wheel Motor Torque Calculation

When choosing a drive wheel motor for a versatile cart, various elements should be considered to decide the most extreme force required. The equation presents one strategy for processing this force.[22]

3.4.1 Grade Resistance

The amount of force used to drive the cart trolley mechanism up a hill, grade, or height is known as grade resistance. The highest angle or degree is normally used in the calculation. This is accounted for in the specification in order for the cart to sustain a grade resistance when climbing an inclination angle of " θ " throughout the steering phase.

$$GR = Wg * \sin(\theta) \quad (3.13)$$

Where, GR - grade resistance, kg

Wg - gross vehicle weight, kg

θ - maximum incline angles, degrees

By putting the $Wg=70$ kg and $\theta=30^\circ$, $GR = 35$ kg.

3.4.2 Rolling Resistance

The force used to accelerate or thrust the formed cart trolley system over a specific surface is known as rolling resistance. The cart's toughest possible surface form can be integrated into the scheme of equations during navigation.

$$RR = Wg * \mu \quad (3.14)$$

Where, RR - rolling resistance, kg

Wg - gross vehicle weight, kg

μ - surface friction coefficient

By putting the $Wg=70$ kg and $\mu= 0.5$, $RR= 35$ kg.

3.4.3 Total Resistance

The resistance that a vehicle encounter in travelling over a surface can be found by adding grade resistance and rolling resistance.

$$TR = RR + GR \quad (3.15)$$

Where, TR - Total Resistance,

By adding rolling resistance and grade resistance, TR can be found as, $TR = 70 \text{ kg}$.

3.4.4 Effective Grade

The effective grade is the total sum of inclined slope and surface friction coefficient. To ensure adequate cart efficiency, higher speeds of the evolved vehicular cart system can necessitate a percentage increase in effective grade.

$$EG(\%) = \text{grade slope} + \mu/10 \quad (3.16)$$

Where EG - Effective Grade,

Grade slope can be found by using selected angle, $\tan=30^\circ \approx 0.58$, maximum slope can be found as 58%. $\mu = 0.5$, surface coefficient. By putting the values effective grade can be found as $EG (\%)= 58.02\%$

3.5 PTC Creo

Creo is a suite of computer-aided design apps supporting product design for discrete manufacturing and it performs calculations in order to determine the best shape and size for a range of applications ranging from mechanical systems to tiny integrated circuits to large-scale charts. Following the selection of a design, the next step in the design process is to dimension the components so that they can fit together.

3.5.1 Design of 2D and 3D Model

After selecting the material and calculating the parameters, the next step to create a 3D model of the project in creo. Solid modelling created according to dimension is shown in the 2D model. All parts have been created with proper dimension figure 3.2. The upper body and the handle were created with softwood material. For the strong base in the front, square pipes were used to developed a tire and handle holding frame and they all are properly welded, control system and DC motor were installed in the rear part in 215 mm x 190 mm square box metallic frame.

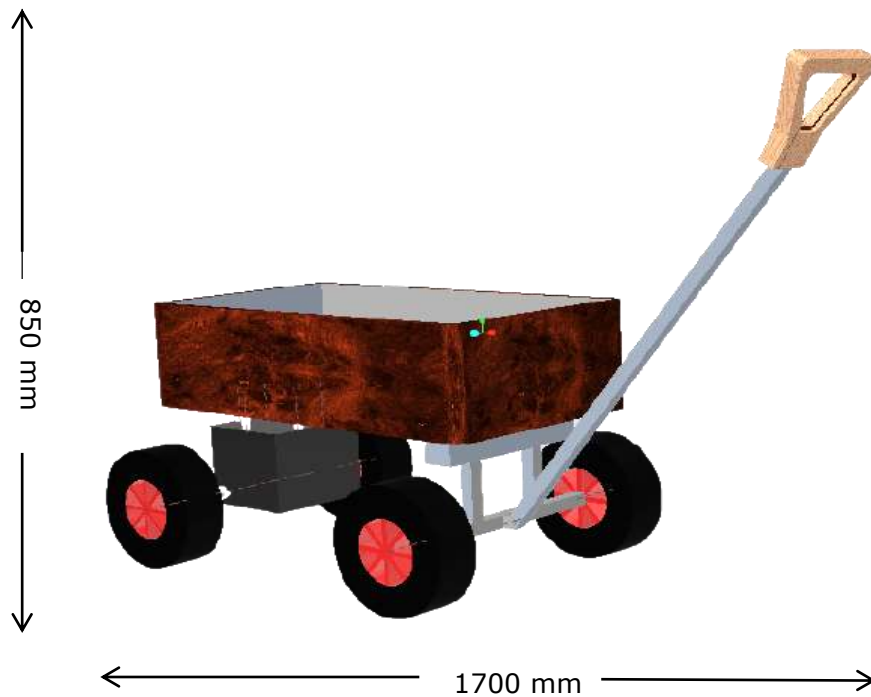
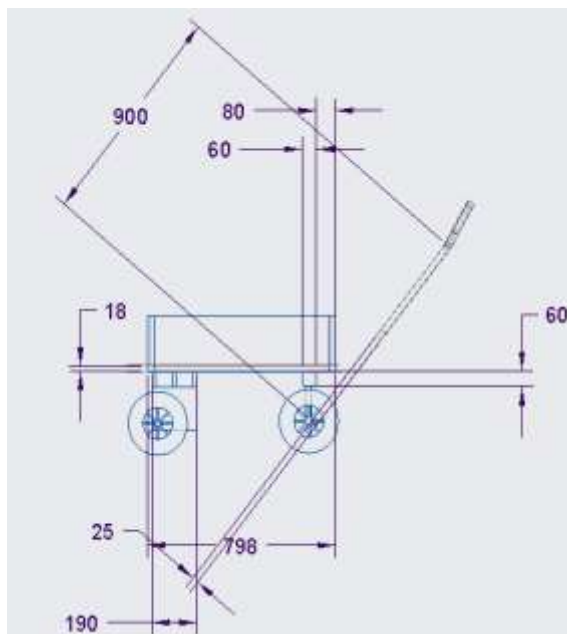


Figure 3.2: 3D model of the electric wagon

The 3D model is created with accurate dimension. In Figure 3.3, 2D model with all parameters has been inserted. The design was created to measure all safety parameters and balance the load upon it.

a)



b)

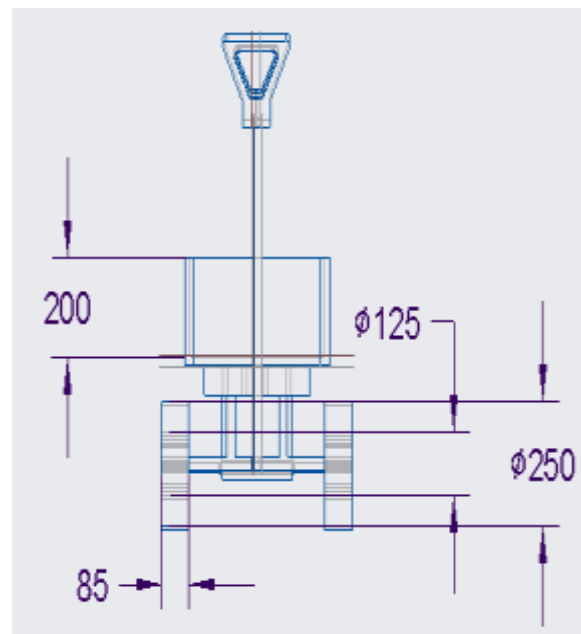


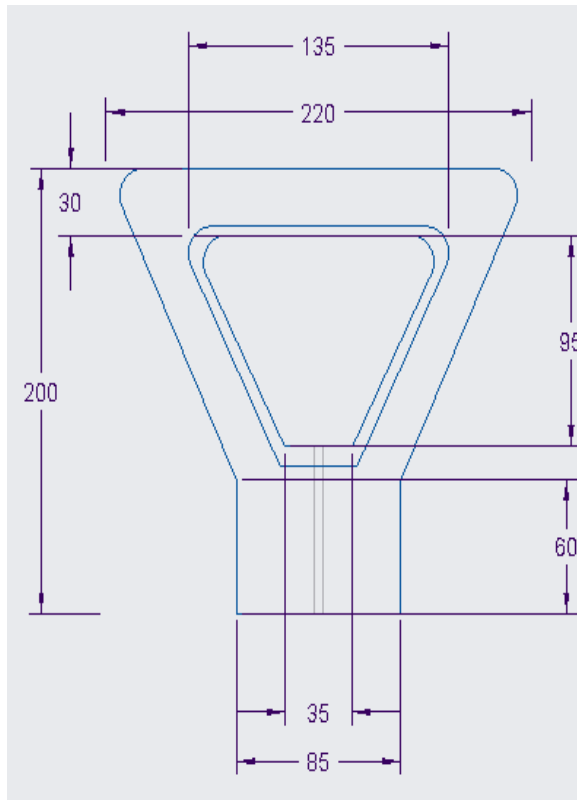
Figure 3.3: Dimension of the wagon in a) right view and b) front view

All measurements are taken into mm(millimeters), After finishing the design, the cart was made with all parameters, This was under consideration that the load should be balanced on the cart while moving. Total fabrication of the cart trolley was achieved after the full design of the system shown in figure 3.6. A few machines for working strategies like welding, securing, cutting, boring were utilized to finish the construction. This turned into completed withinside the university workshop. The cycle associated with manufacture includes Measuring, where materials to be utilized for the development work were estimated the wanted measurements. Marking, this was accomplished in the wake of estimating, by checking diagrams on the work environment to give an exact measurement for compelling creation. Cutting, the stamped materials were sliced to the ideal shape utilizing accessible cutting apparatuses in the workshop. Joining, the cut materials were welded together by the strategy for welding and attaching utilizing screws and nuts. Boring – checked openings were appropriately drilled particularly where screws and nuts are needed for the legitimate fitting of fasteners and nuts. Finishing, a harsh surface which showed up during cutting, welding, and penetrating, perhaps because of welding flash were surface completed to give smooth surface which makes the wagon secure for clients.

3.5.2 Design of Handle with Load Cell

The most important part of the wagon is to design the handle. It was under consideration that the design should flexible that it can be used to hold easily and move the cart. Many prototypes with different parameters have been tried. Different shape and specification of load cell available in the market while designing the handle, it was under consideration that the load cell should be fit inside the handle, it made handle grip strong and maximum force can be applied. The major task was to install the load cell inside the handle. Figure 3.4, The handle was made with softwood material with multiple layers to make it more strong and to carry out the maximum force applied on it.

a)



b)

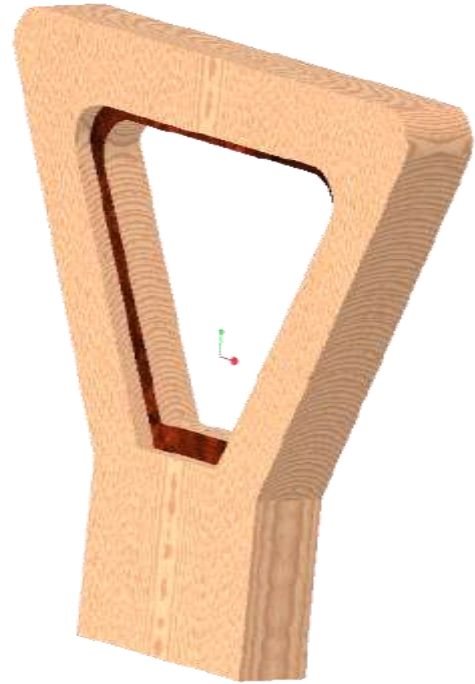


Figure 3.4: a) Front View b) 3D view of cart handle of Holding Handle of the Cart with Parameters

The handle was designed with multiple layers of wood to make it more strong. The height is 200 mm, the upper width is 220 mm, the lower width is 85 mm. From bending curve to endpoint the handle height is 60 mm. The load cell has installed inside the lower part and connected with 900 mm long square pipes which connect the handle to the main body of the cart. After complete all the parameters, Figure 3.7 has the final 3D version of the handle. The final 3D design has achieved with all actual parameters. In practical, the load cell has been installed and connected with the rest of the body. To make it more comfortable, a piece of foam will be attached to the gripping part. It will provide more ease to move the wagon smoothly.

4. COMPONENTS AND SOFTWARE

After calculating all the equations and finalizing the design of the product. The other main objective was to choose the right component for the wagon to make it electrical dependent. The flow chart diagram in figure 4.1, gives a basic understanding of the schematic of the system. The first instrument is the Arduino Uno, which is an open-source microcontroller board based on the microchip ATmega328p, Arduino Uno used to get digital data from S-type load sensor which is converted by HX711 IC, an analog-to-digital converter. 7805 IC is used to provide constant 5V to Arduino.

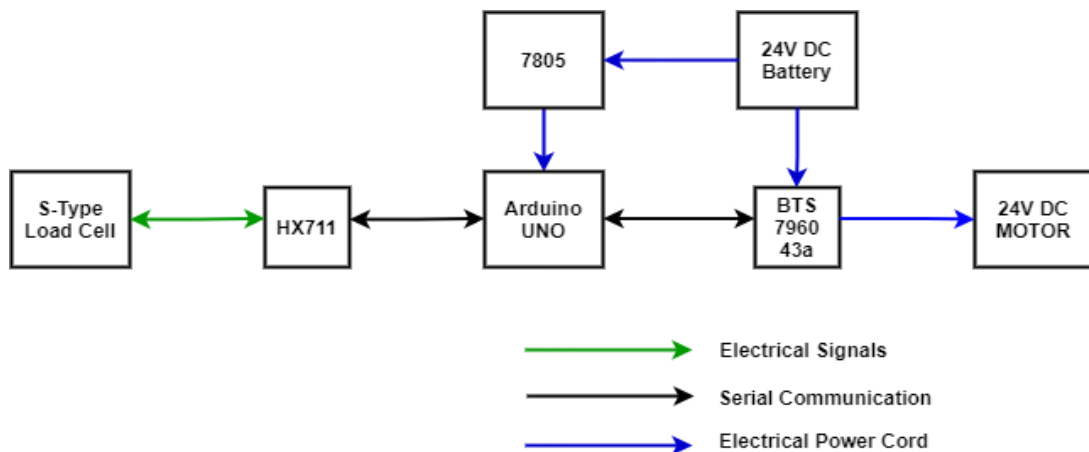


Figure 4.1: Flow chart diagram of electric wagon

The microcontroller uses a pulse width modulation (PWM) signal to operate the 24V DC brush gear motor. The DC motor receives its forward and reverse rotating signals through the DC motor driver BTS 7960 43a. This driver also provides VCC voltage to the Arduino to power it up and data from the microcontroller to operate the DC motor in forward and reverse directions.

4.1 Microcontroller

For physical computing, there are a variety of other microcontrollers and microcontroller platforms to choose from. Both these tools take the microcontroller programming complicated info and put it in a simple-to-utilize bundle. Arduino additionally improves on the way toward working with microcontrollers, yet it offers some benefit over different systems. Arduino Uno ATmega328p based Microcontroller Rev 3. Its 6 Pin used as output. This adapts to all that the microcontroller expects to help; simply connects it to a Computer with a USB cable port or powered by an AC-to-DC connector or a battery to start.[23]

Table 4.1: SMD Microcontroller and Specification [24]





				
Board	Arduino Uno	Arduino Due	Netduino 2	Raspberry Pi
Price	\$ 24	\$49.99	34.99	\$40
Summary	Current official USB board driverless USB-to-serial, auto power switching	Arduino Based on a powerful ARM processor. Packs many new features in a Mega size form factor	Open source microcontroller programmed using the .NET/C programming. Uses an Arduino layout for shield compatibility	Single board Linux computer with video processing and GPIO ports
Special Feature	Onboard USB controller	Android ADK support. 12bit ADC/DAC, USB, CAN BUS support	Programmed with .NET Micro Framework	HD capable Video Processor HDMI and Composite outputs, Onboard Ethernet
Processor	ATmega328	32-bit SAM3XBE ARM Cortex M3	STMicro 32-bit Cortex-M3	ARM1176JZF-S
Processor Speed	16 MHz	84 MHz	120 MHz	700 MHz
Analog Pins	6	12	22 (GPIO- digital or analog)	8 (GPIO-digital and analog)
Digital Pins	14 (6 PWM)	54 (12 PWM)	22(GPIO- digital or analog)	8 (GPIO-digital and analog)
Memory	SRAM 2KB-EEPROM 1KB	SRAM-96 KB	Code 192KB- RAM 60KB	RAM 512MB

Table 4.1 shows different microcontrollers which are available in the market but compare to others it's inexpensive and provides a simple programming environment. Moreover, it can run on Windows, Macintosh, and Linux operating systems. The reason for using the Arduino microcontroller was to operate the DC motor in pulse width modulation (PWM) to perform forward and reverse direction until it receives continuous

data from the load cell. The Pulse Width Control (PWM) is a system that enables a fast switching on and off of force to adjust the standard voltage estimate that goes through the electronic unit. The normal voltage relies upon the obligation cycle, or the measure of time the sign is ON versus the measure of time the sign is OFF in a solitary timeframe. High power DC motor can easily be controlled when the driver attaches to the microcontroller. In the local market, Arduino is cheap and accessible.

4.2 DC Brush Gear Motor (24V 250W)

The reduction motor is essentially the most generally utilized motor and quad's accessible in the market. It is ordinarily found in the better quality quads and bikes available and is classed as a mid-reach mix. There are two wires from the motor, one wire connects positive "+" and the other connects with the negative "-" terminal of the battery to power it up and it much easier than stepper and servo motor. [24]

For the wagon, the brush dc motor has been chosen after calculating the required parameters and design of the wagon. To choose the right motor some factors have been assumed. For motor nominal speed is 0.5 m/s. The maximum speed depends upon other factors [25]. This can be identified but the maximum speed will be in the range of 0.5 m/s to 1.5 m/s. The wagon is not an all-terrain vehicle; it designs as it can also run on a slope. For this, a maximum 57.8% slope has been set, which is equal to the angle (30°). It can be calculated by the angle of incline = $\arctan(0.578) \approx 30^\circ$. After determining the traction and total weight requirement, summarizing all the values:

Robot weight $m_r = 20$ kg
 Max Load weight $m_l = 60$ kg
 Nominal speed $V_n = 0.5$ m/s
 Wheel diameter $D_w = 225$ mm
 Slope $K = 0.578$

Wheel speed rotation can be calculated:

$$Nt = \frac{60Vn}{\pi D_w} \approx 48 \text{ rpm} \quad (4.1)$$

Where, $D_w = 0.200$ m (Diameter of the wheel)

$V_n = 0.5$ m/s (nominal cart speed)

Motor power/torque can be calculated by maximum slope. The amount of thrust used to counteract gravity on a slope with the following formula:

$$F_t = gk(mr + ml) \approx 9.81 * 0.578 * 60 \approx 340 \text{ N} \quad (4.2)$$

Where, $g = 9.81 \text{ m/s}^2$ (gravity)

$k = 0.578$ (Max slope)

$mr = 20 \text{ kg}$ (Robot weight)

$ml = 40 \text{ kg}$ (Max load weight)

The mechanical power used to drive the robot uphill at the nominal speed is:

$$P_u = F_t * V_n = 455 * 0.5 \approx 228 \text{ W} \quad (4.3)$$

Where, F_t – Motor Power, W,

V_n – Nominal Motor Speed, m/s.

This is the required mechanical power for the entire wagon. The human force needed without electric power to pull 60 kg of mass on inclined plane calculated $F_p=577 \text{ N}$ and with electric motor it requires less force $F_t = 340 \text{ N}$. The power calculated with load provide an overview for selecting the dc motor that how much electric power needed to pull the selected mass on inclined plane. The main parameters to be able to select the dc motors have now been estimated. For the time being, the author has left out inertia. In addition, this calculation ignores the acceleration from $v=0$. With the help of this calculation, it becomes clear to choose the right DC motor for the wagon.

They are very incredible for their little size and amazingly dependable. They are utilized for countless various applications that they were never intended for, yet the strength of the form makes them simply go. Figure 4.2 This electric motor with gear decrease creates more low-end force than a standard motor. Motor current can be found with formula:

$$P = I * V \quad (4.4)$$

$$I = \left(\frac{0.33 * 746}{24} \right) = 10.41 \text{ A} \quad (4.5)$$

The selected dc motor contained 0.33 W and as per standards, 1 Hp = 746 W. The maximum current consume by motor is $I = 10.41 \text{ A}$.



Figure 4.2: MY1016Z2 DC brush Gear Motor [23]

The selection of motor requires such parameters like cost, size, rpm and power etc. After getting values from equations 4.1 and 4.2, the motor should be more suitable with wagon size and can easily be fit according to the design. This motor is fit for pivot either clockwise or counter clockwise by turning around the motor's power wires. The width is 128 mm and height is 108 mm. For chain size: Pitch 12.7 mm, Roller diameter 7.62 mm, Roller Width 4.964 mm. In Table 4.2, other key feature is shown.

Table 4.2: Key Feature of DC Brush Gear Motor [23]




Key Feature	Values
DC Operation Voltage	24V
DC Motor Type	Permanent Magnet
No load RPM	3850
No Load Current	< 2.2 Amps
Rated Wattage	250W(0.33 Horsepower)
Rated Load RPM(after Reduction)	3000
Torque (NM)	22
Rated Torque	8 N.m (80 kg-cm)
Stall Torque	40 N.m (400 kg-cm)
Efficiency	78%
Pitch Chain	9 tooth sprocket

4.2.1 DC Motor Driver

Motors next to solenoids, pneumatics, and hydraulics would be the most widely used actuator on any electronic hardware. These DC machines are seen everywhere, from a basic vibration engine within a cellular telephone to complicated phase motors on Industrial robots. To power a motor with the aid of a microcontroller or processor, a motor driver or motor controller is used. The type of engine drivers would also vary, depending on the type of engine and control necessary. The table 4.3, compares various dc driver parameters and selects the correct driver to operate the DC motor using the most common H-bridge Topology using the motor driver.[26]

The motor drivers serve as an intermediary between the engines and the circuits of power. The motor needs high current, while the controller circuit operates on low signal current. The motor drivers have the job of taking a low-current control signal and then converting it into an up-current signal that can drive a motor. In Table 4.3, different drivers were compared and bts7960 was chosen according to project requirement.

Table 4.3: DC Motor driver and Specification [26][27]

			
Drivers	BTS7960	EM-241C	EM-174
Supply	6 ~ 27 Vdc	10 ~ 35Vdc	12 ~ 32 Vdc
Peak Current	43 A	30 A	30A
PWM Frequency	Upto 25 kHz	2 kHz / 16 kHz	25 kHz
Control Input	3.3 ~ 5.5 V	0 ~ 5 V	0 ~ 5 V
Control Mode	PWM or level	PWM or level	PWM or level
Duty Cycle	0 ~ 100%	0 ~ 100%	0 ~ 100%
Dimension	(50x50x43) mm	(42x72x25) mm	(65x70x30) mm
Weight	66 g	75g	80g
Price	\$ 27	\$ 55	\$ 140

4.2.2 BTS7960 43A High Power Motor Driver

The BTS 7960 is a completely coordinated high current full bridge for motor drive applications. It included one p-channel MOSFET high-side and one n-channel MOSFET on the lower side with a single packet of synchronized driver IC. Because of the p-channel high side switch, the requirement for a charge pump is wiped out subsequently limiting EMI. In figure 4.3, Interfacing to a microcontroller is made simple by the coordinated driver IC which highlights rationale level sources of info, determination with current sense, slew rate change, dead time age, and insurance against over-temperature, overvoltage, Under voltage, overcurrent, and cut off.[27]

One p-channel high side of the MOS FET and an n-channel low side of the MOSFET and one driver IC are entirely inter-related with a high current half-bridge. Each of the three chips are mounted on one basic leadframe, utilizing the chip on chip and chip by chip innovation. Science and technology Vertical MOS systems are used in the control switches to ensure optimal on-time. The p-channel highside switch the requirement for a charge pump is dispensed with consequently limiting EMI, The integrated driver IC makes it simple to connect to a microcontroller which highlights rationale level data sources.

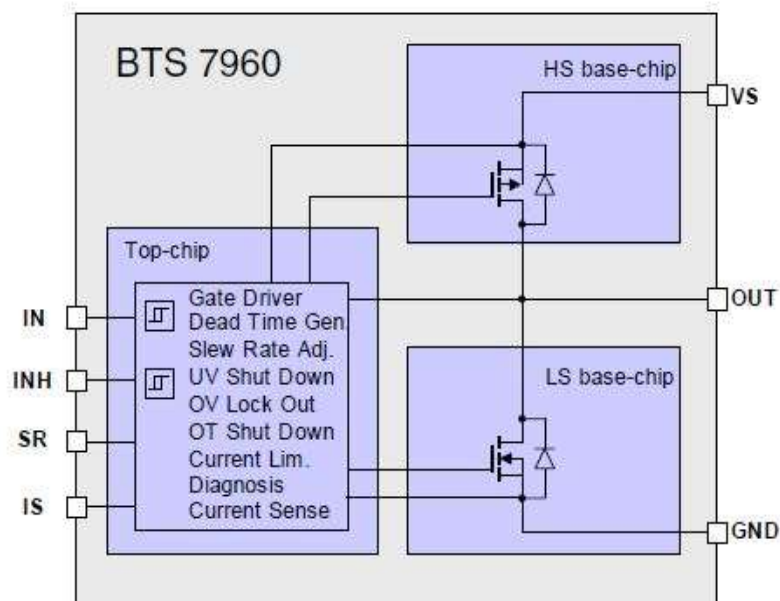


Figure 4.3: Block Diagram of BTS 7960 [27]

BTS 7960B P-to-263-7 used in the module. Its 7 pin chip install on the top of the driver. Two Mosfet switches , one is negative and other is positive, High side is connected with VCC and the low side with the ground. In figure 4.4, Both switches test the current in the bridge. When the forward current in one switch (high side or low side) reaches the maximum I_{CLx} , the switch is deactivated, and the t_{CLS} is activated for another switch.

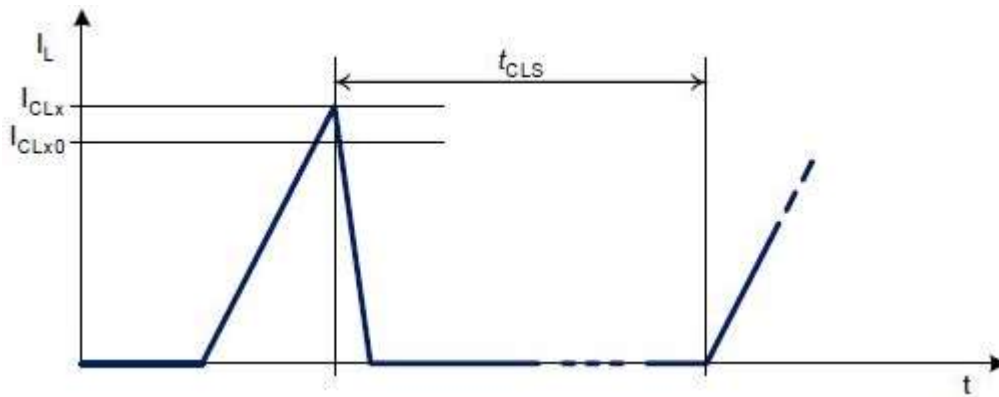


Figure 4.4: Timing Diagram of Current Limitation [27]

During the time all pins are ingored at IN pin. In the other side, all mosfets can also be turned off. The switches revert to their default settings after t_{CLS} . After $2 * t_{CLS}$, the error signal at the IS pin is reset. Quick current spikes unintentionally cause current restriction.

Undervoltage Shutdown, the system shuts down to prevent unregulated motion of the guided motor at low voltages. If the supply voltage VUV(OFF) falls below 5.4V, the motor driver can turn off and not turn back on until the supply voltage rises to 5.5V or above. The driver has overtemperture protection, it is ensured against overtemperature by a coordinated temperature sensor. If driver leads to expected temperature then it prompts a shut down of both output stages.

In Figure 4.5, The module use the PWM (Pulse Width Modulation) technique to power DC motors. These modules transform a fixed input voltage into a variable motor voltage. The DC motor voltage can be changed to regulate the rpm. PWMs have a fixed frequency that can be changed by adjusting the pulse duration (Duty Cycle).

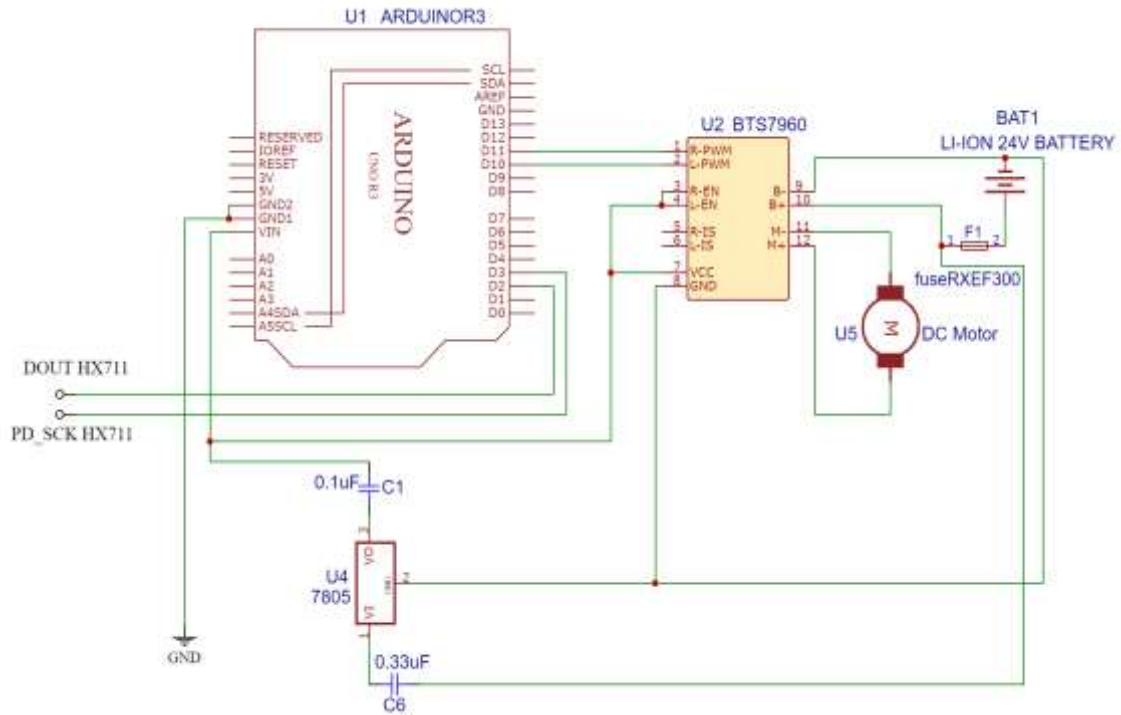


Figure 4.5: Schematic of Electric Wagon Driver Connected with DC Motor

After selecting the DC motor for the project, a powerful driver needed to operate the motor with the desire speed and direction. Used BTS 7960 driver for forward and reverse direction with of motor connect with Arduino. For control, a 24V DC external battery is connected with the system to power up the whole wagon. DC motor receiving power from battery and signal from the driver. Other parts of the driver are connected with Arduino to receive the signal. VCC is connected with Arduino to get 5V supply, R_EN and L_EN are also connected to VCC. For controlling the motor in the forwarding direction, RPWM is connected with the D11 PWM pin and for the reverse direction, LPWM is connected with D10 PWM. The driver getting a signal from Arduino, which Arduino is getting command from the load cell as described below. The code is responsible for defining the PWM pin in Arduino for the motor.

```
#define PWM_0 10
#define PWM_1 11
const int set_pwm = 0;
int freq_0,freq_1;
pinMode(PWM_0, OUTPUT);
pinMode(PWM_1, OUTPUT);
```

4.3 Load Cell and Working Principle

A movement has an equal and opposite response, and force is the measure of contact between bodies.. It's a two-dimensional vector quantity of magnitude and direction. The expression "load" is often used to describe the weight applied to a structure or body. The Newton is the SI-recognized unit for force or load (N). Load cells calculate force or weight directly. By measuring deformations caused by the force or weight, these transducers translate mechanical force into electrical signals.[28]

In table 4.3, the S-type load cell has been used in the project. It gives analog output and HX711 analog to digital converter was install between load cell and Arduino to convert the dataa. The selection of s type load cell was considered because TAS501 S-type load cell fulfills all the requirements according to handle design and after calculating all parameters it easily connected with handle and square pipe through bolt. For the project, 20 kg of capacity load cell was used that measure weight strain and stress and force applied on the load cell. To select the load cell capacity, the calculated force from equation 4.2 subtracted from equation 3.12. The subtracted force is 227 N .

$$1 \text{ kg} = 9.81 \text{ N}$$

$$23 \text{ kg} \approx 227 \text{ N}$$

Table 4.3: Standard Specification of Load Cell's [28][29]

Standard Specification				
Load Cell	S type	Shear Beam	Regular 401	Pancake
Nominal Output	3.0 mV/V	3.0 mV/V	2.0 mV/V	2.0 ±0.004mV/V
Excitation Voltage	9 -12 VDC	9 -12 VDC	10 -15 VDC	9 -12 VDC
Ultimate Load	200% of rated capacity	200% of rated capacity	200% of rated capacity	150% of rated capacity
Non Linearity	<±0.03% of FSO	<±0.025% of FSO	<±0.025% of FSO	<±0.03% of FSO
Creep(30 Min)	<±0.024% of FSO	<±0.030% of FSO	<±0.025% of FSO	<±0.03% of FSO
Input Resistance	350±5 ohms	350±5 ohms	396±10 ohms	700±10 ohms

Output Resistance	350±5 ohms	350±5 ohms	350±5 ohms	700±5 ohms
Temperature Compensation	-10°C to +40°C	-10°C to +40°C	0°C to +60°C	-10°C to +60°C
Temp.Effect to Zero	≤±0.030% of FSO/10°C	≤±0.030% of FSO/10°C	-	<±0.030% of FSO/10°C
Environmental protection class	IP67	IP67	-	-

A four-wire arrangement is popular for full-connect cells. The excitation (often labeled E+ and E, or Ex+ and Ex) wires are connected to the top and bottom ends of the bridge, while the signal (labeled S+ and S) wires are connected to the edges. Perfectly, the distinguishing between S+ and S- is zero and grows proportional to the mechanical burden of the heap cell. Table 4.3 shows the specification of the selected load cell.

4.3.1 HX711 24-Bit Analog to Digital Converter

HX711 is a 24-bit simple to analog to digital converter (ADC) IC. It is implicit a preamplifier that is utilized to intensify low voltage signals. HX711 chip receives the electrical signal as an input and generates a digital signal. The preamplifier treats low voltages. It has an on-chip power distribution regulator that supplies analog power, so no alternative supply regulator is needed. The load cell mostly that is used in scaling the weight and give output voltage in millivolts. HX711 ADC can convert them into a digital signal and measure the low scale voltage and it has a built-in pre-amplifier along with an optional external crystal. It gives output in millivolts and it is only possible to get precise data through a microcontroller. In figure 4.6, the Pin diagram shows the task for each pin. The IC has 16 pins.[30]

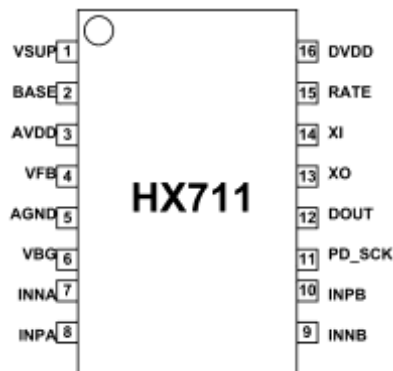


Figure 4.6: HX711 IC with Pin Description [29]

It has two differential input channels; a functioning low clamor PGA is coordinated inside the chip gave gain. The pins are used in all respects to control the IC. Users don't have to program. As the output data rate can be choosing between 10SPS or 80 SPS at the output.

Table 4.4: Pin Description of HX711 IC [29]

Pin #	Name	Function	Description
1	VSUP	Power	Regulator supply: 2.7 ~ 5.5V
2	BASE	Analog Output	Regulator control output (NC when not used)
3	AVDD	Power	Analog supply: 2.6 ~ 5.5V
4	VFB	Analog Input	Regulator control input (connect to AGND when not used)
5	AGND	Ground	Analog Ground
6	VBG	Analog Output	Reference bypass output
7	INA-	Analog Input	Channel A negative input
8	INA+	Analog Input	Channel A positive input
9	INB-	Analog Input	Channel B negative input
10	INB+	Analog Input	Channel B positive input
11	PD SCK	Digital Input	Power down control (high active) and serial clock input
12	DOUT	Digital Output	Serial data output
13	XO	Digital I/O	Crystal I/O (NC when not used)
14	XI	Digital Input	Crystal I/O or external clock input, 0: use on-chip oscillator
15	RATE	Digital Input	Output data rate control, 0: 10Hz; 1: 80Hz
16	DVDD	Power	Digital supply: 2.6 ~ 5.5V

4.3.2 Load Cell Interfacing with HX711 and Arduino

For practical analysis, Interfacing the load cell with HX711 and Arduino. Load cell out terminal with inverting and non-inverting pins for channel A+ and A-. Since this analog channel can directly interface bridge sensors (with differential inputs). The block diagram shows the HX711 chip is used to control the load cell. As a result, there is no need for an alternative power transmitter for this ADC chip. The concept would be more cost-effective. In figure 4.7, the working principle of the schematic with load cell. The force applied on the load cell, the analog voltage is generated at the output pins by the load size. Pin 1 and 16 are connected with the VCC of Arduino for 5V.

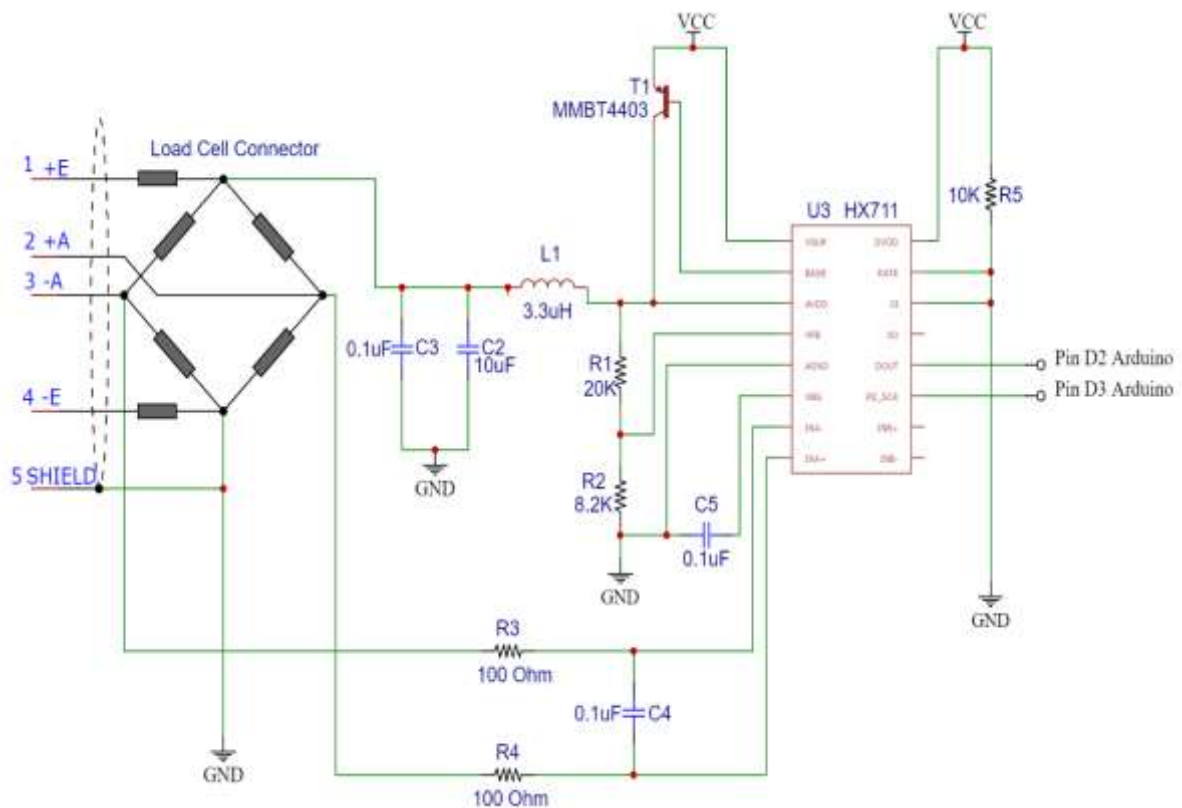


Figure 4.7: Load cell schematic with HX711

Through AVDD pin analog supply goes to excitation voltage and channel A+ and A- lists the performance of sensors via an amplifier programmable and multiplexer and connected with INA- and INA+. The magnitude of the input signal is adjusted by the gain amplifier before being transferred to the interface circuit with digital conversion. A 24-bit digital signal is converted from an analog input circuit of the digital interface. Then through the I2C communication port, Pin 12, DOUT connects to Arduino to read the data, and Pin 11, PD_SCK power-down control and a serial clock input. The code is responsible for fetching data from the load cell.

```
#include <Q2HX711.h>

const byte hx711_data_pin = 2;
const byte hx711_clock_pin = 3;

float sensRead;

Q2HX711 hx711(hx711_data_pin, hx711_clock_pin);
```


4.4 Battery Selection

The battery has been used to power the electric machine when it is not connected to a power source. The benefit of rechargeable batteries over traditional batteries is that they can be recharged, meaning that they can be fully charged and used when driving after being discharged. Today, battery production has progressed to advance development [31], and there are many different kinds of batteries, every battery has its own set of characteristics; based on the project requirement, the right battery has been chosen for the project Nickel-plated-cadmium (NiCd), Nickel-metal hydride (NiMH), Lithium-ion (Li-ion), and lead-acid batteries are the most popular battery types. The amount of energy delivered per unit weight of a battery is known as its energy density, while energy is measured in watt-hours and kilograms in this case,[31]. When space or weight is a concern, energy density is an essential option. The nominal voltage of one element must be understood in order to increase the voltage and capacitance of a battery, which is normally made up of multiple series and/or parallel battery cells [32]. The number of times a given battery can be discharged and then recharged until it loses 80 % of its power is measured in life cycles. This number is inaccurately provided by the manufacturers since each battery behaves a little differently and its lifetime depends heavily on how it is used; instead, it can be used as an estimated estimator rather than precise statistics. However, this predictor is needed when the battery must withstand continuous charging and discharging, such as when batteries are used in a high-energy-demanding situation.[33].

The reliability, which indicates how much of the input energy is extracted from the battery, is the final metric. This statistic is critical if you try to choose the most cost-effective battery. When it comes to selecting batteries, performance is less important because energy capacity provides enough detail, but efficiency in battery manufacturing and invention is highly important because many other important battery parameters, such as power capacity and life cycles, are dependent on it. [29]

Table 4.5: Battery Comparison [29]

Specification	NiCd	NiMh	Li-ion	Lead Acid Battery
Energy density, Wh/Kg	46 – 80	60 - 120	100 -160	30 - 50
Battery Cell Voltage, V	1.25	1.25	3.6	2
Spontaneous emptying, %/month	20	30	10	5
Life Cycle	1500	200-500	300-1000	200-300
Efficiency, %	60-70	~70	~95	75-85

Each battery, it can also be used to power an electric cart motor, was made for this purpose. Table 4.5: Since, the required power is not very high and the weight of the object with the wagon is much higher than the battery's efficiency, the energy density is not a significant factor in the battery selection. Except in pleasant weather, it is unlikely that an electric wagon would be driven often. As a result, Li-ion and lead batteries are preferable because their self-discharge is considerably smaller than that of other compared batteries, as seen in Table 4.5. Finally, lead-acid batteries or lithium-ion batteries are the safest options, so 24v 40Ah Li-ion batteries were chosen with the calculation. To find the stall current, values taken from table 4.2:

No load speed of DC motor speed = 3850 RPM

No load current = 2.2 A

Nominal Speed = 3000 RPM

Nominal Current = 10.41 A

Nominal Torque = 80 kg.cm

Stall Torque = 400 kg.cm

Finding change in current:

$$\Delta I = \text{nominal current} - \text{no load current} = 8.21 \text{ A} \quad (4.4)$$

Finding change in torque:

$$\Delta T = \text{Stall torque} - \text{Nominal torque} = 320 \text{ kg.cm} \quad (4.5)$$

Stall torque can be found by the formula:

$$I_{\text{Stall}} = \left(\frac{\Delta T}{\text{Nominal torque}} \right) * \Delta I = 32.84 \text{ A} \quad (4.6)$$

The maximum current consumed by motor $I_{\text{Stall}} = 32.84 \text{ A}$. The value calculated theoretically, it can consume more and less ampere. The selected motor operating voltage was 24V. The selected battery should be pass more than 33 A. For this 24V, 40Ah li-ion battery were selected for project, which provide 40A per hour. The measured current was 3A with selected load. The battery can provide 13.33 hours run time by single charge.

4.5 Working Principle and Final Prototype

The objective was to control the DC motor in forward and reverse direction with a digital signal and move smoothly with maximum load. Arduino was used to controlling the motor with PWM (pulse width modulation) signals. While pulling the handle force applied to the load cell which is installed inside the handle of the wagon. HX711 analog to digital converter (ADC) was installed between the load cell and Arduino to convert analog data into digital data and get very precise values. First Arduino was connected with a PC to install the code into its memory, the code was written in an Arduino compiler with its own language and send a PWM signal to the motor. Electrical components and motors are regulated using pulse width modulation (PWM). In general, the DC motor speeds are equal to the power voltage, and so the speed would be half what it initially was by reducing the voltage from 24 volts to 12 volts. In fact, however, adjusting the supply voltage all of the time to change the speed of a dc motor is not possible. A DC motor's speed controller PWM operates by changing the average voltage supplied to the motor. PWM is a high-frequency square wave generally. This square wave has a different duty cycle such that the power provided varies to the load. The PWM controller acknowledges the control signal and changes the PWM signal's service cycle to Arduino signals. Figure 4.8, TON (On time) is the time when the signal is at peak position, and TOFF (off time) is the time when the signal is zero. The period is the total sum of when the signal is on and off. In figure 4.9, the actual PWM signal was measure from the project.

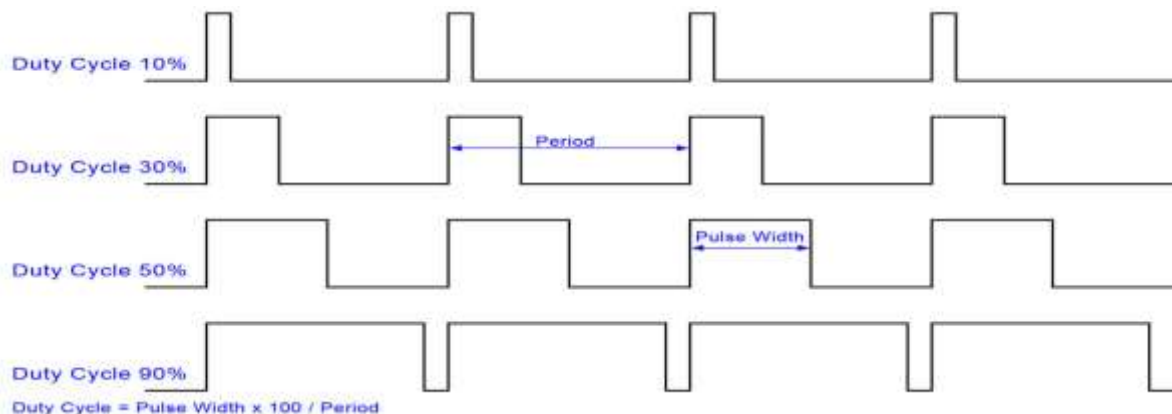


Figure 4.8: PWM signal with duty cycle

a)

b)



c)



Figure 4.9: a) PWM signal is low, b) 30% duty cycle, c) 95% duty cycle

4.5.1 Hardware Implementation

The final process was to implement the hardware with electrical component and perform the actual test. After all the calculation, design, programming everything was compile together as one product. In figure 4.10, DC motor was install inside the black box and gear was fixed outside the box which attached through round metal rode connecting both tires and motor, the left tire was free wheel to maximize the rotation. In figure 4.11, All the control system was install at the box, all the required components are connected via Vero board. The wagon won't move until and unless some external force applied to it in forward and reverse direction.

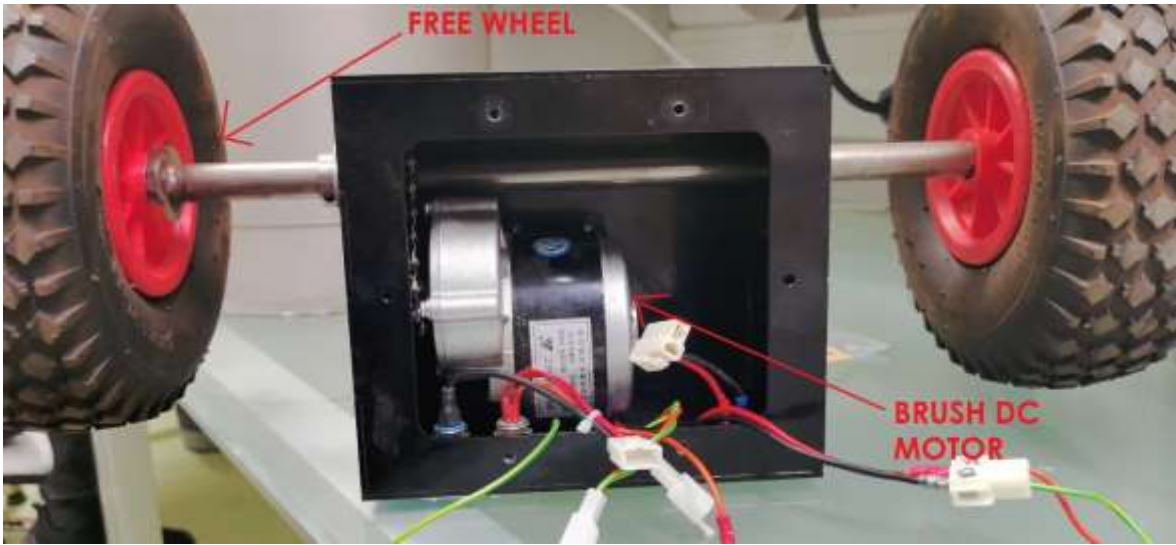


Figure 4.10: DC Motor installed at black box

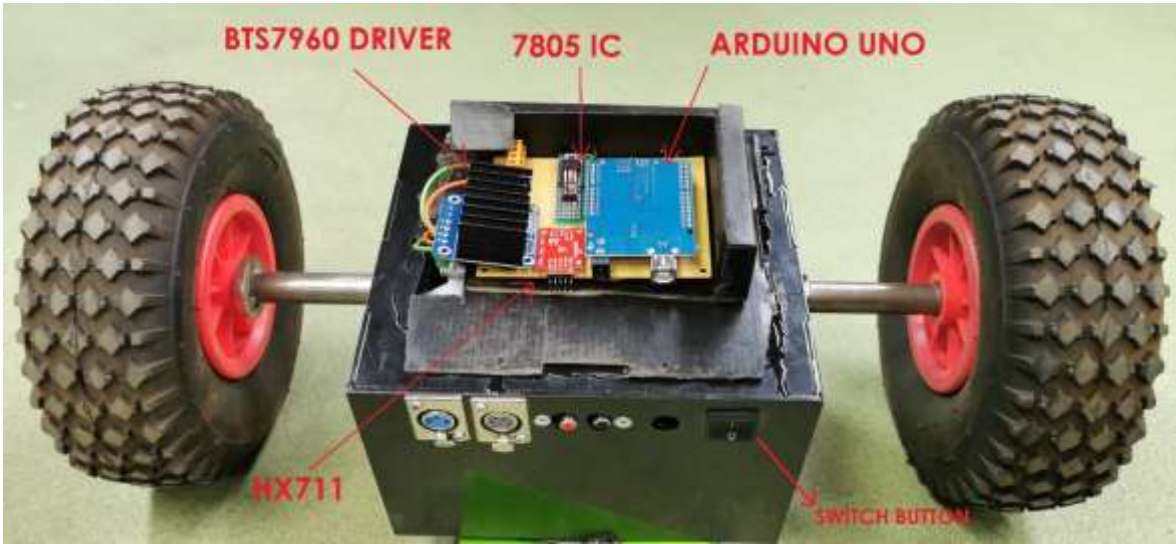


Figure 4.11: Control system of electric wagon

Figure 4.12, shows the fabricated prototype of torque sensor integrated with hardware and software.

a)



b)



c)



Figure 4.12: a) Top View, b) Top-Right View, c) Side view

4.5.2 Performance Test and Evaluation

The physical prototype was made of local-based materials of the sensor-controlled convertible wagon. A 50 kg load was used to demonstrate the accuracy test. The rear wheels serve as input power to the wagon. Battery was install inside the black box. The detailed design results indicate that the induced axial tensile force that is present on the vehicle, the force required for pulling the vehicle, the motor current, the torque of the motor, moving strength, grade resistance, speed, the maximum load the wagon will transport, and the overall tractive force measured.

Table 4.6: Detail Result of Design

Description	Calculated/Measured Values	Unit
Number of legs	4	-
Weight of each tire carry	150	kg
Axial Tensile force acting on the body	300	N
Motor Voltage	24	V
Motor Current	10.41	A
Motor Power	250	W
Current of the motor with load	3 (Measured)	A
Wheel speed rotation	48	Rpm
Motor torque with load	340	N
Power required for motor on uphill	288	W
Pulling force with max load	577	N
Total speed required by the wagon	220	mm/s
Total mass of the wagon	20	Kg
Wheel diameter x 4	220	mm
Total dimension of wagon (w*h)	1700x850	Mm
Grade Resistance	35	Kg
Rolling Resistance	35	Kg
Total Resistance	70	Kg
Time required to achieve maximum speed	2.5	Sec
Effecting Grade	58.72	%
Maximum Load wagon can carry	60 (including wagon)	kg

5. SUMMARY

A trolley is a wheeled vehicle that is used in everyday life to hold loads and transport large items from one location to another. It accelerates the movement of goods from supermarkets, small street waste, and many other goods. According to recent reports, these vehicles have caused accidents and distress to employees in a variety of sectors due to the badly built cart, and their abuse increases the likelihood of musculoskeletal issues. Many accidents and risk factors are often associated with manual load handling.

This research succeeded in converting a traditional cart-trolley into a sensor-controlled convertible cart-trolley. The objective of this master thesis was to develop an inexpensive prototype force-less electric wagon using a torque sensor. The standard of the advanced smart wagon, proceed in the forward, right, reverse, and left direction, is improved extravagantly. In the first and the second chapter, the author discussed the existing problem and possible solutions. Redesigning the whole wagon from the scratch took a lot of time and researched on different materials to choose the right one for the project. In the third chapter, necessary calculation was calculated to obtain the actual data to select the required components and designed the 2D and 3D model with exact parameters. In chapter four, all the electrical components are discussed with their substitute available in the market and the detail for choosing the specific component. The hardware implementation was also presented with practical data. Both of the chapters provided the calculation and described the detailed methodology of the project.

During the execution of the project, there were few failures. The first designed schematic had a problem fetching data and operating the DC motor in both directions then the whole new schematic was designed and tested successfully on the hardware.

The project of the master's thesis has been conducted with the funds in mind. The compact, economical electrical components that are used still provide considerable ability. As the operator keeps the handle, the operator can do the movement quickly. There is no need to learn how to operate a wagon. It was designed and implemented with all safety parameters. The speed of the wagon therefore depends on the earth's surface and slope. With the most usable capital, the final concept was applied.

For future improvements the idea is to make wagon for employees who work in industries, manufacturing plants where large loads have to pass each day more effective and convenient to use. The prototype of the project was initial development for the new beginning of electric wagon. The current design of the wagon improves further by redesigning the frame. Square and circular pipes were used to make it strong. Shock

absorber with coil spring can be installed then the weight will be balance with any surface. The future design, new components can be install with existing schematic, a Bluetooth module which help to connect with mobile application, a digital screen which will show battery life, speed and other parameters. Moreover, the new concept has many applications, it can be used in the house and parks so the children can sit and easy to move for the parents. It will be very useful for old people in Estonia to carry their grocery and other stuff from shop to the home.

The wagon was driven by a battery and checked with a load on it. The designed wagon trolley is extremely useful in both domestic and commercial settings, especially in rural and urban areas. mechanical, and fast-moving consumer products in supermarkets, hospitals, labs, and other work environments can be easily transported from point of origin to point of destination.

5.KOKKUVÕTE

Käru on igivana ratastega leiutis, mida kasutatakse igapäevaelus suurte esemete vedamise abiliseks ühest kohast teise. Käru võimaldavad näiteks kaubanduskeskustes kaupade, jäätmete ja paljude muude asjade liikumist. Hiljutiste uuringute kohaselt on need lihtsad ilma mootorita abivahendid põhjustanud paljudes sektorites töötajatele õnnetusi ja stressi ning nende liigse koormusega kasutamine suurendab inimestel luu- ja lihaskonna probleemide tõenäosust. Palju õnnetusi ja riskitegureid seostatakse sageli käsitsi laaditavast koormast tingitud probleemidena.

Antud uurimistööga üritatakse traditsiooniline käru muuta nutika lahenduse abil dünaamiliselt juhitavaks elektrikäruks. Magistritöö eesmärk oli välja töötada odav elektrikäru, mida juhitakse käepidemesse paigaldatud momendianduri abil. Momendiandur mõõdab kärule rakendatavat tõmbe ja tõukejõudu ning lisab elektrilist jõudu juurde, nii, et olenemata kärule asetatud raskusest, on inimesel ikka sama rakse käru tõmmata või tõugata.

Esimeses ja teises peatükis käsitles autor olemasolevat probleemi ja võimalikke lahendusi mis juba eksisteerivad selles valdkonnas turul. Kogu tavalise mehhaanilise käru kontseptsioon disainiti ringi, mis võttis palju aega ja mille käigus uuriti erinevaid materjale, kontraktsioone, et kõige sobivam lahendus elektrikäru jaoks leida. Kolmandas peatükis arvatati välja tekkivad mehhaanilised jõud, et saada reaalsed andmed elektroonika komponentide valimiseks. Lisaks tehti kärust nii 2D kui ka 3D mudelid, et disaini ja komponentide sobivust täpsustada. Neljandas peatükis käsitleti erinevaid elektroonika komponente, koos turul saadaval olevate alternatiividega ja tehti konkreetsete komponentide valik. Esitati komponentide valiku arvutused ja kirjeldati projekti elluviimise meetodikat.

Projekti teostamise ajal tekkis ka teatud tagasilööke. Esimesel katsel kavandatud isetehtud elektroonikaskeem ei andnud soovitud tulemusi, misjärel protsessi kiirendamiseks valiti turul saadaolevad moodul komponendid ja pandi uus riistvara kontseptsioon kokku.

Magistritöö projekt läbiviimisel oli suured rahalised piirangud. Sellest olenemata suudeti leida kompaktsed ja ökonoomsed komponendid, mis lubas ellu viia peamised funktsiooni. Peamiseks funktsiooniks oli, et operaator saab käru käepideme kaudu käru liikumiskiirust ise dünaamiliselt valida. Loodud elektrikäru spetsiaalset käsitsemist pole vaja eraldi õppida. Arvesse on võetud ja rakendatud ka paljusid ohutusaspekte. Piiratud on näiteks käru kiirus sõltuvalt maapinna kaldest.

Pikem eesmärk on selline käru muuta kasutatavaks tööstussektoris, kus on reeglina suured koormad, mida on vaja vedada iga päev. Antud prototüübi raames testiti uutset idee kontseptsiooni ja seda kui dünaamiliselt on võimalik selline käru momendianduri abil liikuma saada. Tulevikus on eesmärgiks käru disaini veelgi parandada, lisades näiteks vedrustuse ja nutitelefoni rakendused, mis võimaldaks läbi bluethooth andmeside, logida näiteks käru kasutusaega, kiiruseid, asukohta ja aku täituvust. Loodud elektrikäru oleks paljudes sektorites erinevaid rakendusi. Võimalik oleks kasutada näiteks lapsevanematel loomaajas laste vedamiseks, vanuritel toidukauba koju vedamiseks, ehitussektoris jne.

Uudse disainiga käru katsetati akutoitel ja koormaga laboris. Projekteeritud lahendus peaks sobima kasutamiseks nii koduses majapidamises kui ka ärikeskkonnas, nii maa- kui linnapiirkonnas, haiglates, kaubanduskeskustes, laborites ja muudes töökeskkondades, kus on vaja suuri koormaid kiiresti dünaamiliselt ühest punktist teise vedada.

REFERENCES

- [1] A. Garg, T. Waters, J. Kapellusch, and W. Karwowski, "Psychophysical basis for maximum pushing and pulling forces: A review and recommendations," *Int. J. Ind. Ergon.*, vol. 44, no. 2, pp. 281–291, Mar. 2014, doi: 10.1016/j.ergon.2012.09.005.
- [2] M. C. Jung, J. M. Haight, and A. Freivalds, "Pushing and pulling carts and two-wheeled hand trucks," *Int. J. Ind. Ergon.*, vol. 35, no. 1, pp. 79–89, Jan. 2005, doi: 10.1016/j.ergon.2004.08.006.
- [3] K. Mack, C. M. Haslegrave, and M. I. Gray, "Usability of manual handling aids for transporting materials," *Appl. Ergon.*, vol. 26, no. 5, pp. 353–364, Oct. 1995, doi: 10.1016/0003-6870(95)00056-9.
- [4] M. Cai, Q. wei Shen, X. gang Luo, and G. Huang, "Improving sustainability in combined manual material handling through enhanced lot-sizing models," *Int. J. Ind. Ergon.*, vol. 80, Nov. 2020, doi: 10.1016/j.ergon.2020.103008.
- [5] C. M. Lind, "Pushing and pulling: an assessment tool for occupational health and safety practitioners," *Int. J. Occup. Saf. Ergon.*, vol. 24, no. 1, pp. 14–26, Jan. 2018, doi: 10.1080/10803548.2016.1258811.
- [6] E. B. Weston, A. Aurand, J. S. Dufour, G. G. Knapik, and W. S. Marras, "Biomechanically determined hand force limits protecting the low back during occupational pushing and pulling tasks," *Ergonomics*, vol. 61, no. 6, pp. 853–865, Jun. 2018, doi: 10.1080/00140139.2017.1417643.
- [7] N. Wiggermann, "Effect of a powered drive on pushing and pulling forces when transporting bariatric hospital beds," *Appl. Ergon.*, vol. 58, pp. 59–65, Jan. 2017, doi: 10.1016/j.apergo.2016.05.015.
- [8] A. C. Abhijeet S. C. , Dayal R. P. , Animesh C. Abhijeet S. C. , Dayal R. P. , "(PDF) Control and Balancing of Two-Wheeled Mobile Robots using Sugeno Fuzzy Logic in the domain of AI Techniques," 2018. .
- [9] Z. Rashid *et al.*, "Assessment of isometric pulls strength of industrial cart pullers - An electromyography study from an apparel manufacturing industry," in *Procedia Manufacturing*, 2019, vol. 39, pp. 1438–1446, doi:

10.1016/j.promfg.2020.01.307.

- [10] L. Botti, F. G. Galizia, C. Mora, and G. Zecchi, "A thorough investigation on pushing activities in industry: The impact of the variation in the speed of motion and load conditions on initial and sustained forces," *Appl. Ergon.*, vol. 85, p. 103080, May 2020, doi: 10.1016/j.apergo.2020.103080.
- [11] V. Aishwarya and K. Gnana Sheela, "Performance analysis of Buck-Boost and Cuk converter-fed brushless DC motor drives," *Mater. Today Proc.*, vol. 24, pp. 1865–1873, 2020, doi: 10.1016/j.matpr.2020.03.611.
- [12] N. Vijayan, J. Sandeep, and R. Ramchand, "An arduino based speed and rotor position measurement technique for electric drives," Aug. 2019, doi: 10.1109/PETPES47060.2019.9003851.
- [13] A.Huges, *Electric Motors and Drives*, Great Britain: Elseiver Ltd., 2006
- [14] J. Syllignakis, P. Panagiotakopoulos, and E. Karapidakis, "Automatic Speed Controller of a DC Motor Using Arduino, for Laboratory Applications," 2016.
- [15] A. K. Dewangan, N. Chakraborty, S. Shukla, and V. Yadu, "PWM Based Automatic Closed Loop Speed Control of DC Motor," *Int. J. Eng. Trends Technol.*, 2012, Accessed: Jan. 14, 2021. [Online]. Available: <http://www.internationaljournalsrsg.org>.
- [16] Z. Tir, O. Malik, M. A. Hamida, H. Cherif, Y. Bekakra, and A. Kadrine, "Implementation of a fuzzy logic speed controller for a permanent magnet dc motor using a low-cost Arduino platform," in *2017 5th International Conference on Electrical Engineering - Boumerdes, ICEE-B 2017*, Dec. 2017, vol. 2017-January, pp. 1–4, doi: 10.1109/ICEE-B.2017.8192218.
- [17] "Electric Shopping Cart Pusher | Motorized Shopping Cart Pusher + Puller." <https://www.djproducts.com/product/shopping-cart-retriever-pusher-puller/> (accessed Apr. 27, 2021).
- [18] "Amazon.com : Overland Electric Powered Wagon with 9 Cubic Foot Hopper on Heavy Duty 27-Inch Chassis, 750-Pound Capacity: Garden & Outdoor." <https://www.amazon.com/Overland-Electric-Powered-750-Pound-Capacity/dp/B01M3R84UT> (accessed Apr. 16, 2021).
- [19] "Garden Trolley Wagon Cart Hand Truck Steel Platform Trolley Cargo Electric

- Tricycle - Buy Cargo Electric Tricycle,Steel Platform Trolley,Garden Trolley Wagon Cart Hand Truck Product on Alibaba.com." https://www.alibaba.com/product-detail/garden-trolley-wagon-cart-hand-truck_62133340889.html (accessed Apr. 27, 2021).
- [20] "Utility Wagon with 13 Cu. Ft. Metal Hopper - Overland Carts." <https://www.overlandcarts.com/utility-wagon-13-cu-ft-metal-hopper/> (accessed Apr. 27, 2021).
- [21] "Torque Formula: What is Torque, Definition, Derivation." <https://www.toppr.com/guides/physics-formulas/torque-formula/> (accessed Apr. 07, 2021).
- [22] "EML2322L-MAE Design and Manufacturing Laboratory Drive Wheel Motor Torque Calculations Reference Citation: White Hydraulics Drive Products."
- [23] "Arduino Uno Rev3 | Arduino Official Store." <https://store.arduino.cc/arduino-uno-rev3> (accessed Apr. 16, 2021).
- [24] "24V 250W MY1016Z2 Electric Motor for E-Bike, electric tricycle ,Electr." <https://robodo.in/products/24v-250w-my1016z2-electric-motor-for-e-bike-electric-tricycle-electric-motor> (accessed Apr. 18, 2021).
- [25] "10 Steps to Choosing the Right Motors for Your Robotic Project | by Radek Jarema | Husarion Blog | Medium." <https://medium.com/husarion-blog/10-steps-to-choosing-the-right-motors-for-your-robotic-project-bf5c4b997407> (accessed May 07, 2021).
- [26] "What is Motor Driver: H-Bridge Topology and Direction control." <https://components101.com/articles/what-is-motor-driver-h-bridge-topology-and-direction-control> (accessed May 12, 2021).
- [27] "Interfacing BTS7960 43A High Power Motor Driver Module with Arduino." <https://electropeak.com/learn/interfacing-bts7960-43a-high-power-motor-driver-module-with-arduino/> (accessed Apr. 19, 2021).
- [28] "TAS501 S TYPE LOAD CELL." <http://www.htc-sensor.com/products/105.html> (accessed Apr. 19, 2021).
- [29] "S-Type Load cell Steel." <http://www.standardloadcells.com/s-type-loadcell-stype-2210.html> (accessed May 11, 2021).

- [30] "Tutorial to Interface HX711 Balance Module With Load Cell: 9 Steps (with Pictures) - Instructables." <https://www.instructables.com/How-to-Interface-HX711-Balance-Module-With-Load-Ce/> (accessed Apr. 21, 2021).
- [31] "Energy density - Energy Education." https://energyeducation.ca/encyclopedia/Energy_density (accessed Apr. 29, 2021).
- [32] "The Composition of EV Batteries: Cells? Modules? Packs? Let's Understand Properly!" <https://www.samsungsdi.com/column/technology/detail/54344.html> (accessed Apr. 29, 2021).
- [33] "How to Prolong Lithium-based Batteries - Battery University." https://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries (accessed Apr. 29, 2021).

APPENDICES

Appendix 1 – Programming for PWM

```
#include <Q2HX711.h>

const byte hx711_data_pin = 2;
const byte hx711_clock_pin = 3;

#define PWM_0 10
#define PWM_1 11
const int set_pwm = 0;
int freq_0,freq_1;
float sensRead;

Q2HX711 hx711(hx711_data_pin, hx711_clock_pin);

void setup() {
  Serial.begin(9600);
  pinMode(PWM_0, OUTPUT);
  pinMode(PWM_1, OUTPUT);
}

void loop() {

  sensRead = (((hx711.read()) / 10000) - 832);
  (analogRead(A0))*4; // Emulating torc sensor

  sensRead = ((sensRead > 255)|| (sensRead < -255)) ? 255 : sensRead;

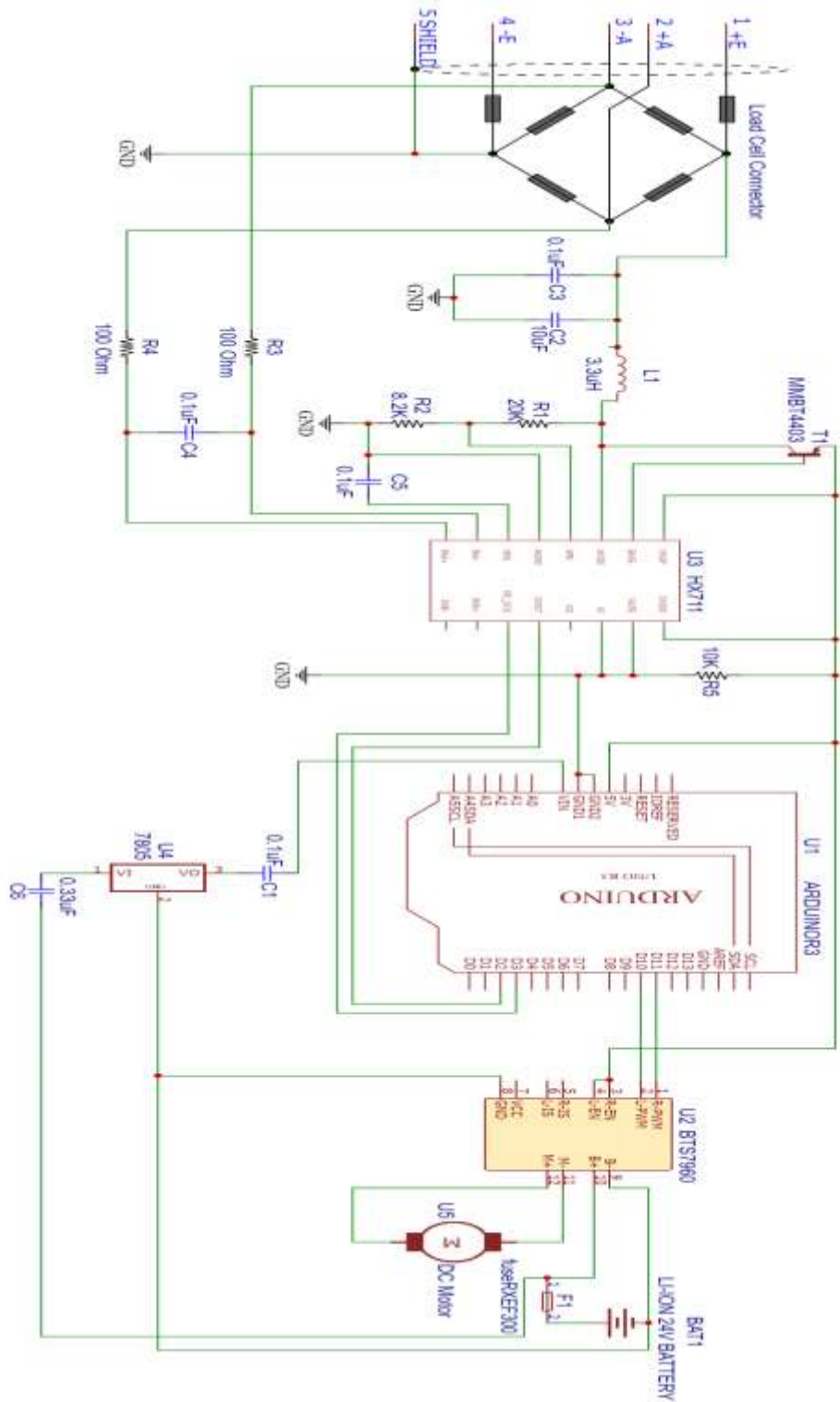
  analogWrite(PWM_0, 0);
  analogWrite(PWM_1,0);

  if((sensRead > 15)|| (sensRead < -15))
  {
    if(sensRead < -15){ // Forward direction
      analogWrite(PWM_1,0);

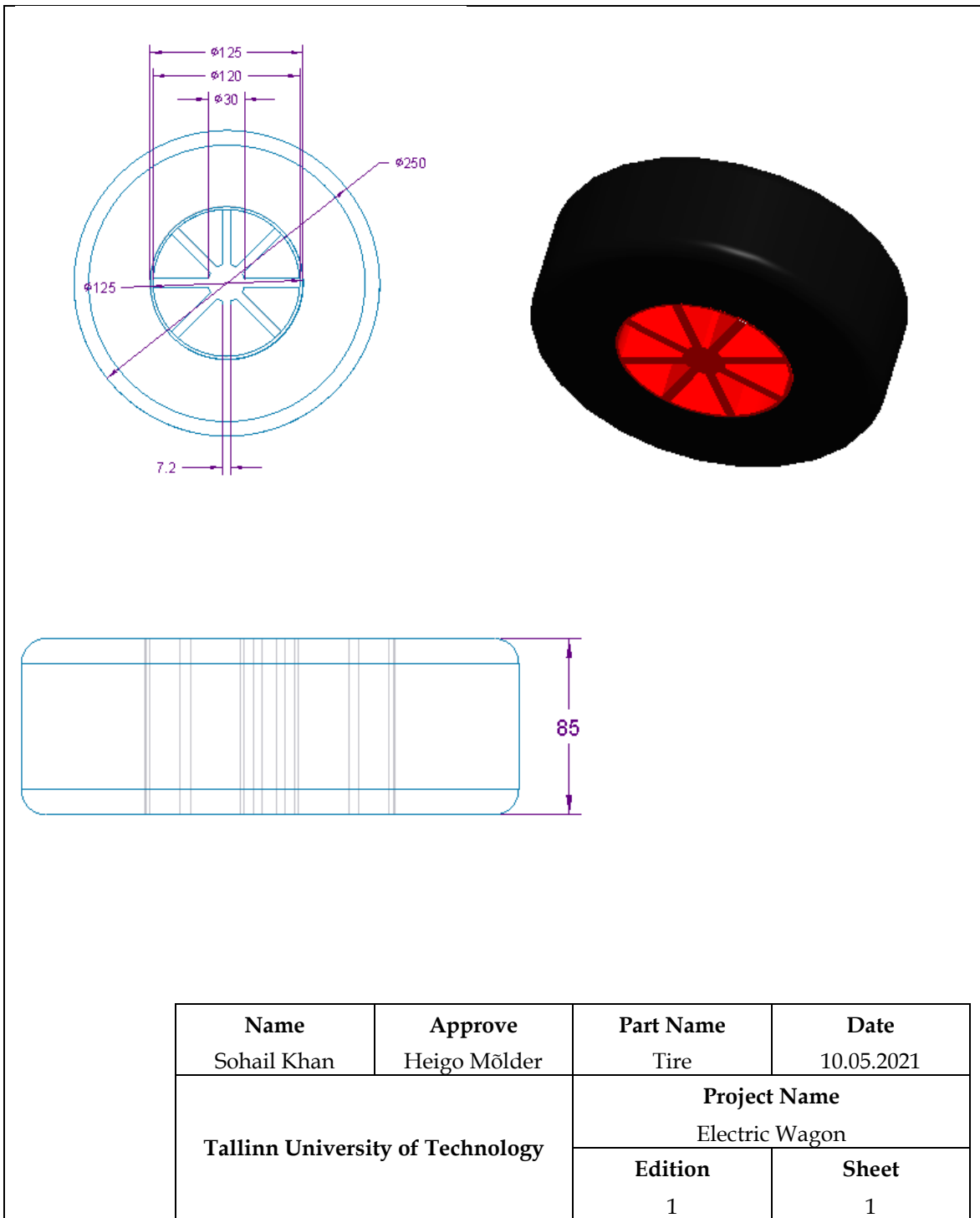
      sensRead +=15;
      analogWrite(PWM_0, -sensRead);
      delay(10);
      Serial.println(-sensRead) ;
    }
    if(sensRead > 15){ // Reverse direction
      analogWrite(PWM_0, 0);

      sensRead -=15;
      analogWrite(PWM_1, sensRead);
      delay(10);
      Serial.println(sensRead) ;
    }
  }
  Serial.println(sensRead) ;
}
```

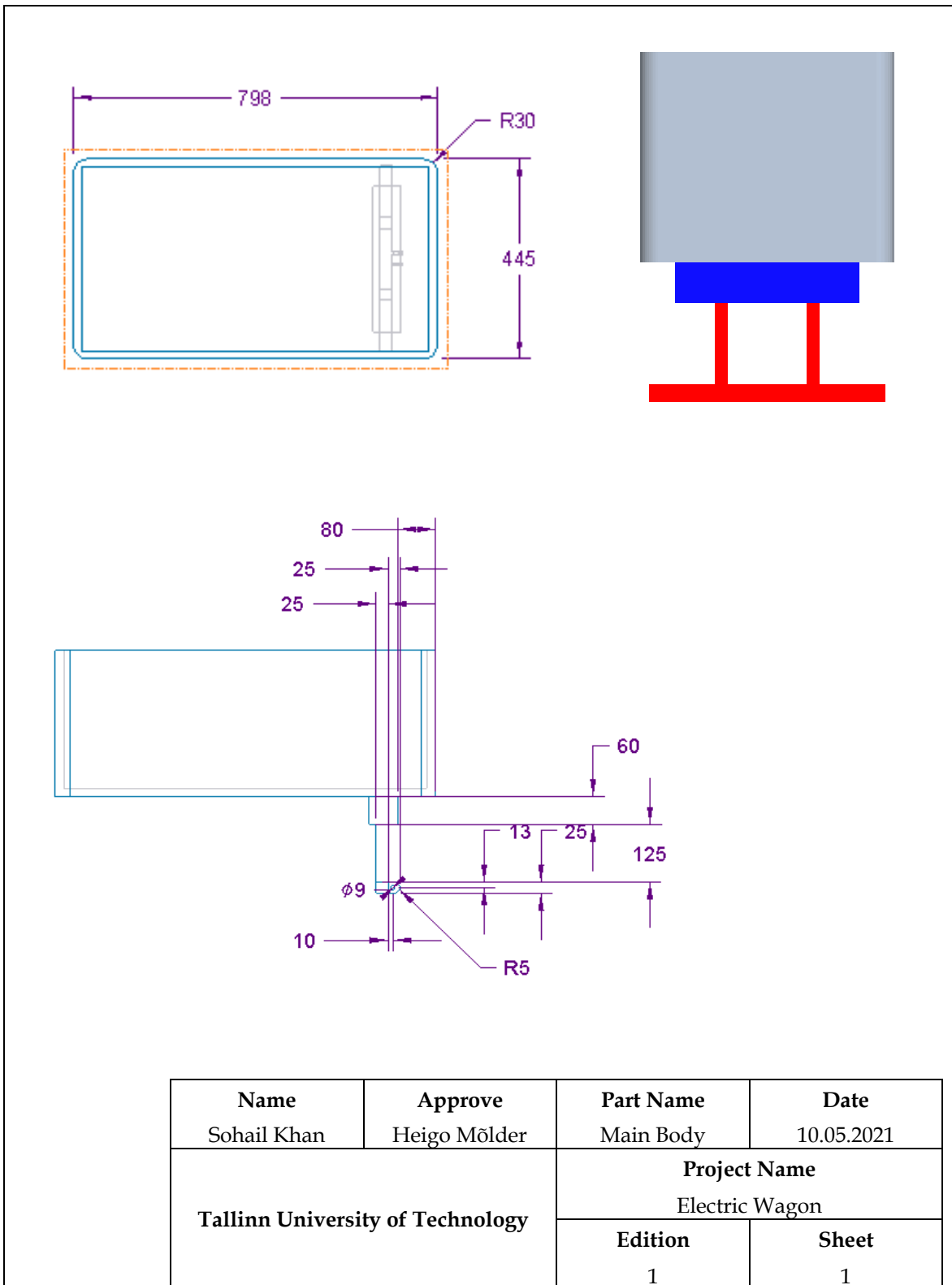

Appendix 2 – Schematic of Control Panel



Appendix 3 – Diemension of Tire



Appendix 4 – Dimension of Main Body



Appendix 4 – Diemension of Black Box

