THE DESIGN OF THE DRIVE SYSTEM FOR A PERSONAL TRANSPORTER

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(Zainor Faisal bin Zainuddin)

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ABSTRACT

Personal Transporters have been designed to help decrease the pollution emitted and as a substitute to the typical combustion engine vehicle. However, due to its high price and high maintenance cost, not many people can afford to have one. The aim of the project is to design a low cost drive system. However, this report will have a more detailed calculations and design process of the project. In the first phase of the project, the author surveyed information related to the drive system of a personal transporter nowadays. Most of the method used in the project is by analytical calculations since it does not require building a prototype. The second phase of the project is mainly on calculating the forces acted on the PT itself. It is to ensure that the drive power of the designed PT can overcome the forces acting on it. A dynamic analysis was performed to determine the power required to drive the PT at the specified mode of motion. The transmission, battery and steering systems are also designed to meet the motion requirement. The author will then select a design concept on how the PT will look and where the drive system will be located. The design selected is based on suitability, simplicity of the PT and comfort of the users. After that, the author select drive system components with required specifications. Analysis on the components is needed to make sure that the performance are the same if not better than the set specifications set in the objectives. Towards the end phase of the project, the author may provide a detailed design of the proposed personal transporter with some assumptions using CAD which will help designer to actually fabricate the personal transporter. In conclusion, if the project is a success, then it will help the designers to produce a low cost personal transporter which indirectly help the consumers to own a personal transporter of their own. With everyone having the personal transporter, it will help to ease congestion and pollution problem in cities.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

People will keep asking "Why do we need a personal transporter when we have car and motorcycles which is convenient nowadays?" However, after so many years of using these transports, the clean and safe environment we experienced before is getting to an end. Designers today are considering on inventing an alternative motorized transport which is safe towards the environment as well as keeping the users comfortable. Therefore, the invention of personal transporter is an ideal set of idea toward realising the hope.

Although there are invention on electric bicycle in the early year, the modern types of transporter was introduced by Segway in 2001 is a new concept of personal transporter that gives more advanced and mobility with zero contribution to air pollution.

Personal transporter (PT) or personal electric vehicle (PEV) can be define as vehicles which transport a single passenger over trip distances of 1–10 km and employ electricity as the motive energy source. (1) It consists of electric motor, controller, batteries and chassis. Even though it is speculated as future vehicles, most people today still consider it unnecessary.

The drive system and the steering system are considered as the most important component of the personal transporter. For the convenient of the users, designer will have to create a user friendly drive and low cost system to make it affordable to everyone.

1.2 Problem Statement

The design of the personal transporter has been inspired to overcome the problems of the combustion engine vehicles which are:-

I. **High pollutant content released.**

Since the personal transporter does not use its own internal combustion engine as the power source, there will be no exhaust and therefore zero emission. The smog from car engine is one of the reasons for "Green House Effect". (1)

II. **Less reliability**

Compared to the conventional vehicles, personal transporter has less moving parts. An electric motor for example has only one moving part which is the rotating shaft. However, the typical combustion engine has more than 100 moving parts that are designed to work together for them to function properly. This will increase the possibility of engine failure rather than the electric motor. (1)

III. **Too dependent on non-renewable energy sources.**

This is one of the main points that electric powered motor is better than conventional automobiles. Depletion of the resources results in the increasing of crude oil prices. A car using an electric power is less dependent from the fluctuating of the global crude oil prices. (2)

These disadvantages of combustion engine have been overcome by producing the PT. However, the existing PT also have disadvantage which contribute to the lack of consumers usage of the PT that is:-

IV. **Existing Personal Transporter are too expensive**

Today, there are companies that came up with solutions to overcome the short distance, environment friendly vehicles. However, the price of the existing PT not competitive compared to conventional vehicles. An alternative cost saving PT needs to be design so that it can satisfies the group of consumers.

V. **High technology tool used which complicates personal maintenance.**

The existing PT like Segway used complex system. Therefore, it is impossible for consumers to actually maintain the PT without having professional supervision. The equipments used are also considered expensive and not accessible in the market.

1.3 Objectives of the Project and Scope of Study

The objective of the project is to simplify the design of drive system of the existing personal transporter. The simplified drive system will be consisting only the main parts which are the motor, controller, battery and gearing system.

There are several design factors that have to be taken into account such as the weight, speeds and the distance that the PT can travel to ensure users experience a comfortable ride as while making it affordable to public.

1.4 Project Scope

The PT performance will be based on the specifications set by S.Izzat (2009):

- Total Mass (Transporter +Rider) = 110kg (30kg+80kg)
- V_{max} = 20 km/hrs
- Distance travel per full charge = 10 km
- Charging Time = 4 Hrs
- Maximum slope angle of ascent = 25^0

However, these requirements may be changed in order to increase the performance of the transporter. The output of the project will be in the form of detail design using CATIA drawing.

1.5 Significance of the project

Due to the completion of the project, users will be able to experience a zero gas emission vehicle with less money spent. High pollutant content in air will significantly be reduced and promote a clean and healthier environment.

The usage of a personal transporter will also be a perfect alternative to avoid traffic jams on freeways. It will also be a better economy solution since we will not only depend on non retrievable energy source.

The analysis of the drive system may also provide useful information to the designer of the PT.

CHAPTER 2

LITERATURE REVIEW

2.1 Segway Human Transporters

The machine was described as the first self balancing human transporter. Its ability to stand on its own with only two wheels side by side is remarkable. Segway HT uses a lean steering system which enable rider to drive the vehicle forward or reverse by leaning on the handlebar. [4]

At its most basics, Segway consist of a series of sensors, a control system and a motor system. The primary sensor system of Segway is the series of five gyroscopes. These gyroscopes are the spinning wheels inside the HT to resist changes because an applied force moves along with the object. Segway uses the solid state angular rate sensor constructed using silicon which determines the objects` rotation using Coriolis effects.

Figure 2. 1 Segway Human Transporter

In addition, Segway has two tilting sensors that sense its own position relative to the ground. The tilting of the device is processed by two electronics controller circuit boards. They check the position sensors 100 times per second and run advance software that monitor the stability information and adjusting the speed of the vehicle.

Each wheel is driven by a 2 HP motor independently. One motor will operate faster than the other if the rider decides to move to the right or left. The Segway operate a two stage transmission with gear ratio of 24:1.Helical gears are used to reduce noise. Design of a non integer gear ratio is chosen so that gear teeth mesh at different point and gearbox life will be extended. [4]

The motor can received power from either Nickel Metal Hybride (NIMH) or Lithium Ion batteries. Both batteries are rechargeable and can be easily charge with the AC household current. However, the Segway did not have a braking system. It will be stopped when the rider is in upright position without the rider leaning the handle bar forward or backward [4]

2.2 Modified Electric car

A normal engine is modified to turn into an electric car. First of all, an electric 3-phase AC motor is bolted into the transmission with an adapter plate. An AC electric controller is added to control the AC motor. The controller takes power from the batteries and delivers it to the motor. There are potentiometers that will be attached to the acceleration pedal that controls the power that need to be delivered.

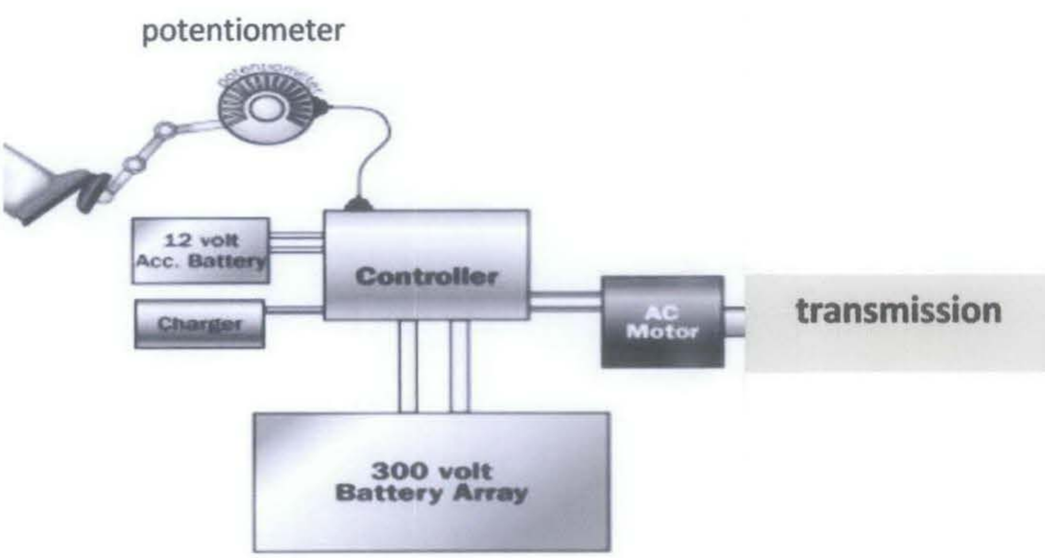

Figure 2. 2 Block Diagram for Modified Electric Car

In order to power the motor for the electric car, 50 units of 12V of batteries are needed to power up to 300V to the controller. The controller will convert the DC current to a 240V AC to the motor. It uses rechargeable lead acid batteries for the power source. The controller also does the pulsing for the rider so that it will conduct a constant voltage to the motor without stepping on and off the pedal. Without the controller, the pedal will acts as a switch unit that will turn on and off to maintain current delivered to the motor. Vacuum pump is used for the power brake.

The electric car is capable to obtain the range of 80km on a single charge. However, the weight of batteries may be a problem for the vehicle which can exceed 500kg. [5]

2.3 Personal Transporter Design by Syahril Izzat

The Personal Transporter proposed by Syahril Izzat is mainly to reduce the cost of the transporter so that it is affordable to most consumers. The transporter was not design for an easy mobility of the vehicle since the total weight of the PT is approximately 95kg. The usage of three batteries consumed the most space and contributes to the total weight of the vehicle.

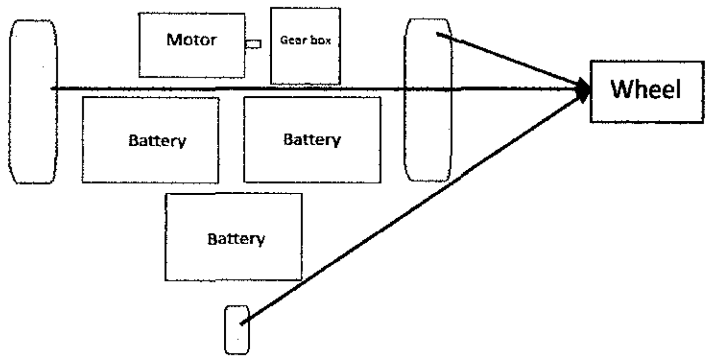

Figure 2. 3 Design arrangement for S.Izzat PT

The PT uses a Forward Wheel Drive with two wheels at the back of the PT and it runs on a single 100W motor that situated at the back. With only one gearbox used, the total cost of the PT is reduced to an affordable price. The speed of the vehicle is 20km/h. [3]

Table 1: Key specification of Izzat's Personal Transporter

Total Weight (Rider+PT)	165kg
Motor	1000W
Batteries	12V and 18Amh
Speed of PT	20km/h
Time Travel	Apprx. 30 minutes
Distance Travel	10km

2.4 Other Types of Personal Transporter

2.4.1 Honda U3-X personal transport device

Honda U3-X is a PT without handle bar produced by Honda. Weighing just less than 10kg, 650mm tall, 30cm long and 15cm wide – this self-righting unicycle is so small that it can fit into the car door of Honda's new concept electric car the EV-N.

Figure 2. 4 Honda U3-X transporter and also how it fit into EV-N door

The U3-X boasts about an hour of battery life and it has top speed of just under 10kmp/h. The key concepts behind the design are simply to make a personal transport device that is easily stored, non-obtrusive if taken on larger public transportation like trains or buses, easy to operate and fun. Table below shows key specification of the model.

Table 2: Key specification of the U3-X personal transporter

Length × Width × Height(mm)	315 × 160 × 650
Weight	less than 10kg
Battery Type	Lithium ion battery
Operation time (with fully charged battery)	1 hour

Honda developed the world's first wheel structure which enables movement in all directions including forward, backward, side-to-side and diagonally. Multiple small-diameter motor-controlled wheels were connected in-line to form one large-diameter wheel. By moving the large-diameter wheel, the device moves forward and backward, and by moving small-diameter wheels, the device moves side-to-side. By combining these movements the device moves diagonally.

2.4.2 Yikebike

The 'Yikebike' by inventor Grant Ryan and engineer Peter Higgins of New Zealand, is a mini-farthing bike designed to battle the increasing urban congestion of today. It uses carbon fiber frame and weighs less than 10kg. Yikebike's electronic can travel at speeds up to 20 km/h and having range of 10 km.

Figure 2. 5 Folded and non-folded Yikebike

The transporter cost around 5,500 USD. It uses Electric brushless DC motor which generates 1 kW of power.

Built from carbon fiber and weighing in at 10kg, the Yike Bike is powered by a custom 1kW motor, a better power to weight ratio than many sports cars, and can be fully recharged in under 30 minutes. Weight limit for the usage is about 100 kg. In terms of form factor, the Yike Bike operates using an electric chainless drive on its front 20' hubless wheel.

2.5 Typical Architecture of Personal Transporter (PT)

The PEV is comprised of the basic function of energy storage, drive system and chassis. The drive system is consisting of one or more motors which transmit power and torque to the wheels through a mechanical transmission.

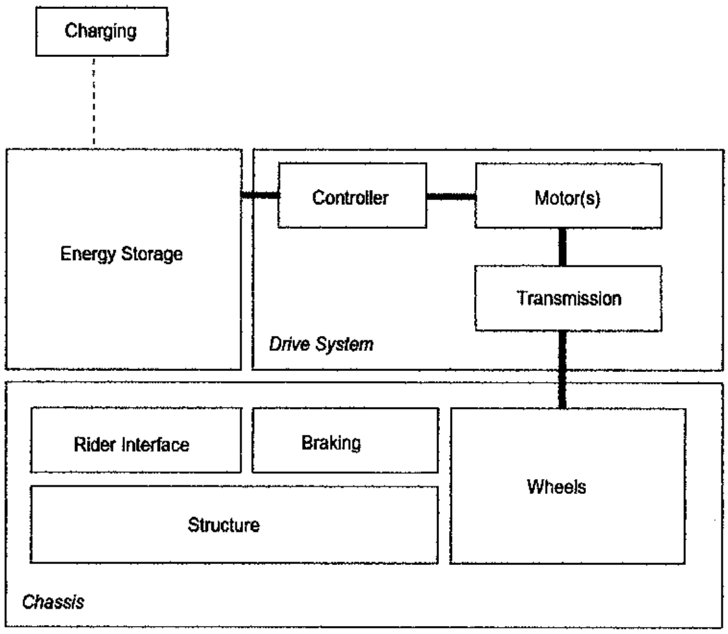

Figure 2. 6 System architecture for Personal Electric Vehicles [6]

The central technology choice for the drive system is between a brushed DC motor and a brushless DC motor. The difference between these technologies lies in the way the motor is commutated. Commutation is the switching of electric power to the appropriate coil in the motor winding at the appropriate angle of revolution of the motor rotor. For brushless motors, the windings are most commonly in the stator and permanent magnets are in the rotor. This arrangement provides better cooling, and therefore higher power levels for a given mass of copper and steel.

Motor torque is proportional to motor current. For brushed motors, high levels of current result in substantial inefficiencies due to resistive losses in the brushes. For this reason and because of cooling limitations, brushed motors are most efficient when run at relatively high speeds (5000–20,000 rpm) and low torques. In contrast, brushless motors can operate efficiently at high torques and speeds as low as 1000 rpm. This difference in minimum efficient speed leads to a substantial difference in transmission requirements. Given their inherent ability to operate efficiently at lower speeds, brushless motors can often be configured with a single-stage transmission such as a single pair of spur gears, pulleys, or sprockets, whereas brushed motors are typically best matched to a two or three-stage gear drive with sufficient gear reduction to match the motor speed to the speed of the drive wheel(s). [6]

2.6 Powertrain

Focusing on the target of engines revolution per minute that is low rpm at higher speed, there comes a need on the study of the relation between tractive forces, engine torque, transmission and desired acceleration. [7]

$$T_c = T_e - I_e\alpha_e$$

Where: T_c= torque at the clutch (input to the transmission)

T_e= engine torque at a given speed (from dynamometer data)

I_e= engine rotational inertia

α_e= engine rotational acceleration

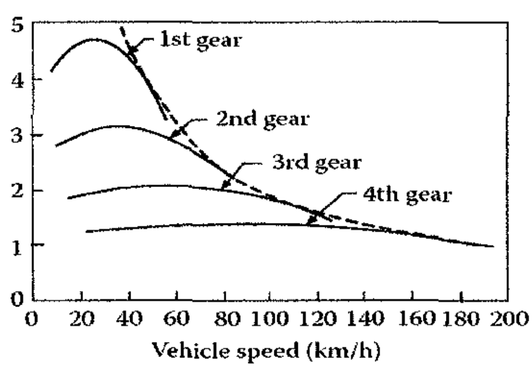

Figure 2. 7 Tractive effort of an IC engine and a multigear transmission vehicle versus speed

The output torque can be approximated by the expression that involved the gear ratio of the transmission: [7]

$$T_d = (T_c - I_t\alpha_e)\, N_f$$

Where T_d= torque output to the drive shaft

I_t= rotational inertia of transmission (as seen from engine side)

N_f= numerical ratio of the transmission

The last stage is where the torque delivered to the axles to accelerate the rotating wheels and provide tractive force at the ground is amplified by the final drive ratio with some reduction from the inertia of the driveline components between transmission and final drive. [7]

$$T_a = F_x r + I_w\alpha_w = (T_d - I_d\alpha_d)N_f$$

Where T_a= torque on the axles

F_x=tractive force at the ground

r= radius of the wheel

I_w= rotational inertia of the wheels and axles shafts

α_w= rotational acceleration of the wheels

I_d= rotational inertia of driveshaft

α_d= rotational acceleration of driveshaft

N_f= numerical ratio of the final drive

These co-related expressions in transmitting the power from the engine to the wheels can be combined into:

$$F_x = \frac{T_e N_{tf}\eta_{tf}}{r} - \{(I_e + I_t)N_{tf}^{\ 2} + I_d N_f^{\ 2} + I_w\}\frac{a_x}{r^2}$$

Where N_{tf}= combined ratio of transmission and final drive

η_{tf}= combined efficiency of transmission and final drive

Knowing the tractive force, we can now predict the acceleration performance of a vehicle. We had to add up a few more external forces such as the expression:

$$Ma_x = \frac{W}{g} a_x = F_x - R_x - D_A - R_{hx} - W \sin \emptyset$$

Where R_x= rolling resistance forces

D_A= aerodynamic drag force

R_{hx}= hitch (towing force)

$\emptyset$= inclination angle of road

Also

$$\omega_d = N_f \omega_w \quad \text{and} \quad \omega_e = N_t \omega_d = N_t N_f \omega_w$$

After we the wheel rotational speed, ω_w we can find the translational velocity of the vehicle.

$$V_x = \omega_w . r$$

Reviewing back to term of N_{tf} that is the combined ratio of the transmission and final drive, which is what the objective is about. To calculate which is the best gear ratio combination for our purpose of low operating rpm since we are desired in making a variable transmission gearing system. [7]

By this equation

$$Ma_x = \frac{W}{g} a_x = F_x - R_x - D_A - R_{hx} - W \sin \emptyset$$

And neglecting the inertia losses

$$F_x = \frac{T_e N_{tf} \eta_{tf}}{r}$$

We can predict the suitable gear ratio after we decide on the value of desired engine torque T_e, forward vehicle's accelerationa_x, and inclined angle of the road Ø. [7]

CHAPTER 3

METHODOLOGY

3.1 Flow Chart

This chapter will describe the methodology employed to implement this project.

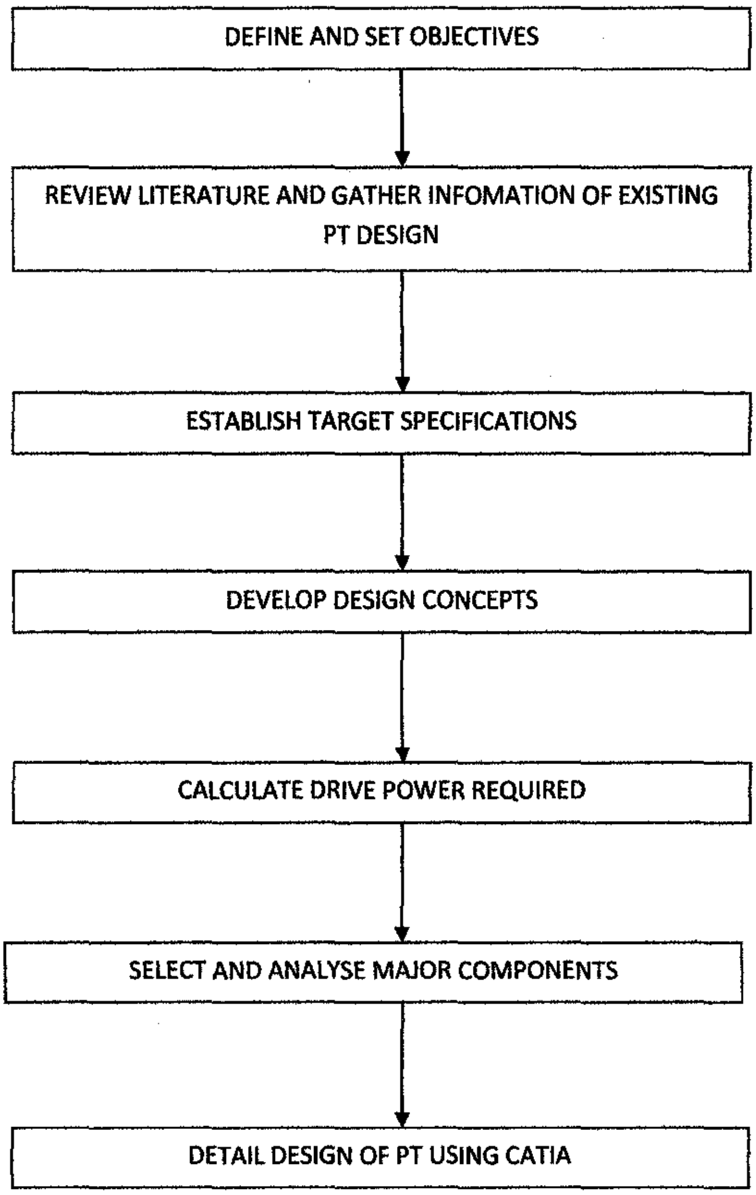

Figure 3. 1 Flow Chart of Methodology

3.2 Brief Description on Methodology

The basic flow of the project is shown in Figure 3.1. The process involve in studying the drive system of a personal transporter consist of several steps. In order to achieve the targeted performance, describing part by part of a drive system is crucial. The methods cover from selecting a personal transporter until achieving the desired performance.

The first step in designing a process is to study the parts which relate to the drive system of a PT. Study will be done with different kind of transporters which have variable types of drive systems. The scope of the drive system consists of the motor, the batteries and the gearing system.

The different types of transporter will be analysed to list out the advantages and disadvantages of the drive system. Detail study on the selected PT will be carried out to compare with each other. The best drive system which has the lowest cost while maintaining a standard performance will be chosen.

The requirements for the drive system are chosen to suit the consumers' choice. The requirement will be based on the objectives of the project that is to produce a low cost and simple drive system for them.

Multiple design concepts will be developed in order to know how the PT is going to run and sample of the initial design of the PT will be produced.

Advance study in the recent design will then be extended to improve the performance of the personal transporter. The selection of the drive system parts are made after further study on them. The design of the transporter will be shown using CATIA software. CATIA software is chosen instead of AutoCAD because extra parameter such as the density of the frame can be added.

Lastly, the final design of the personal transporter will be proposed together with the list of materials chosen.

3.3 Gantt Chart

Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Topic														
Research and Analyse Problems														
Determine the Scope of Drive System														
Comparison and Selection of PT as Main Revision														
Established Requirement														
Develop Design Concept														
Calculation to Achieve Requirements														

Figure 3. 2 The flow of the progress for July'10

Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13
Determine components used													
Analyse Suitability of each components													
Evaluate and select design													
Detail Design of the PT using CATIA													

Figure 3. 3 The flow of the progress for May'11

CHAPTER 4

DESIGN REQUIREMENT

4.1 Design Theory

The specifications of the transporter are based on the study done on articles and journals. There are proves that specifications that had been set are considered safe to run on the pedestrian walk. [8]

Speed – 20km/h

This is a standard running speed of a human being. The highest speed that considered safe on pedestrian walk is less than 30km/h which is the speed of people riding bicycle. The maximum speed also allows easy manoeuvrability and breaking. [8]

Travel Distance – 10km

The PT is a short distance vehicle. The specification that had been set is considered sufficient enough for consumers to travel safely throughout the city.

Maximum Weight – 30kg

Consumers will be expecting a light weight PT which will provide them mobility to catty the vehicle wherever they want. [8]

Slope to overcome - 20^0

The target of the designed Personal Transporter is on the economical aspect of PT rather than the performance. However, the performance of the PT will be design to compete the performance by Segway. [8]

4.1.1 Drive System and Steering System

The proposed design is a three wheeled personal transporter with two front wheels. The transporter will be driven by a motor which will be connected to the rear wheel. The method chosen is due to the simplicity of the design proposed by former student.

The front wheels are the steering wheels for the transporter and is design using the Ackermann theory. It is design to solve the problem of wheels on the inside and outside of turn needing to trace out circle of different radii.

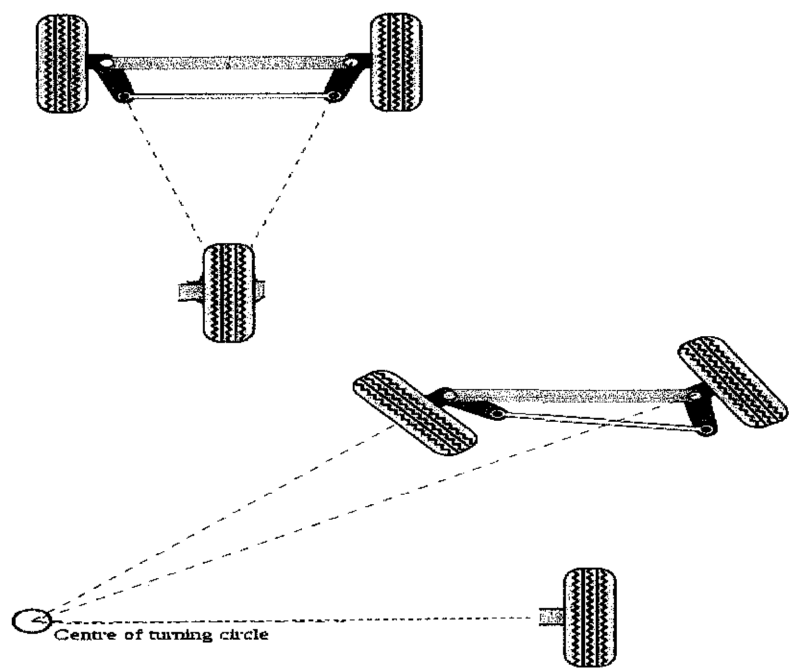

Figure 4. 1 Ackermann Theory Diagram[9]

The first aspect of a design for personal transporter is the drive system of means power transmission. Motor will transmit power to the rear wheel. The motor control will be decided for motor speed and braking. They will be incorporated using a simple joystick to facilitate operation by the user. The diagram for the description of processes involve is shown on Appendix 2.

The difficulty faced for this type of drive system is to get the required speed reduction when the high speed motor is providing power. The problem can be solved by using a gear motor but since the objective of the project is to reduce cost, simple single gear transmission will be conducted in the project.[9]

4.2 Design Process.

4.2.1 Motor Power Determination:

Some calculations are needed to determine how much power required by the motor in order to drive the PT at the desire specification.

Electric motor usually has a mostly ideal speed-torque characteristic. From figure below, as the motor speed increases to the base speed, voltage increases to the rated value while flux remains constant. Beyond that, the voltage remains constant while flux is weakening. This result in constant output power while torque decline hyperbolically. [12]

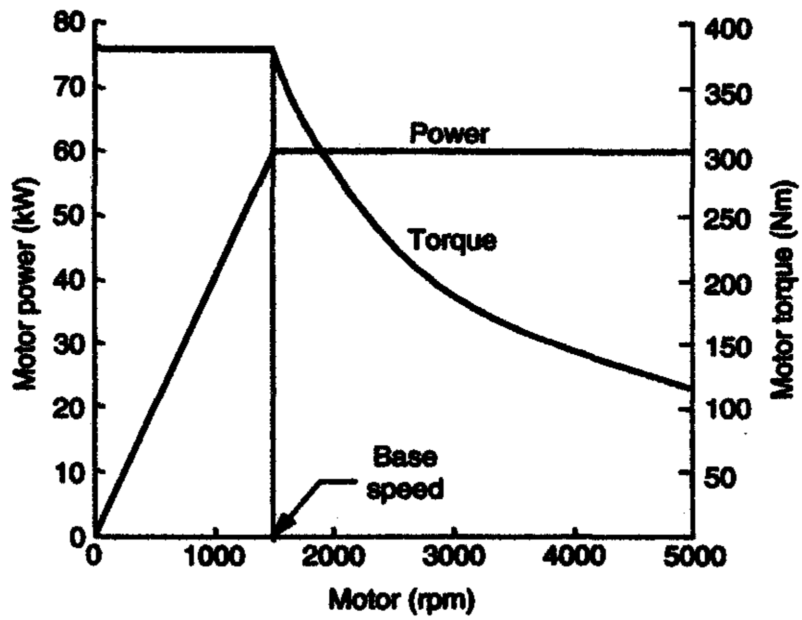

Figure 4. 2 Typical Performance Characteristics of Electric Motor for Traction

The movement behavior of a vehicle along its moving direction is completely determined by all the forces acting on it in this direction.

There are three major forces at work which resist a vehicle from moving:

1. Rolling resistance
2. Air resistance
3. The force of gravity as a vehicle moves up a hill

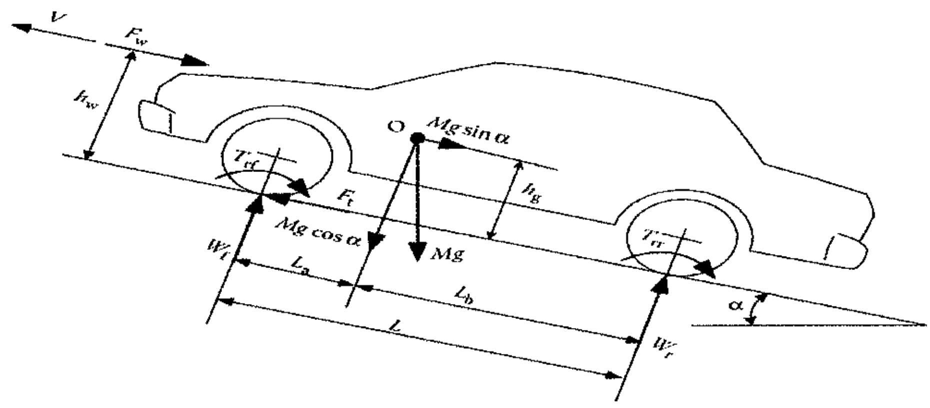

Figure 4. 3 Forces acting on vehicle moving uphill

The tractive effort, F_t, in the contact area between the tires of the driven wheels and the road surface propels the vehicle forward.The total force that needs to overcome is:

$F_{Traction} = F_{Air} + F_{Roll} + F_{Slope}$

4.2.1.1 Rolling Resistance

The force of the rolling resistance is a function of the weight of the vehicle multiplied by a coefficient of the rolling resistance. [12]

This force is mostly independent of car speed.

$F_{roll} = u_{roll} M a_{gravity}$ (eq 4.2.1)

Where:

u_{roll} – is the rolling resistance coefficient. Typical values for the rolling resistance coefficient (u_{roll}) = $0.0136 + 0.04 * 10^{-6} * (v * 3.6)^2$, where v is the function of speed

M – is the mass of the vehicle (kg)

$a_{gravity}$ – is the force of gravity (9.8 m/s^2)

4.2.1.2 Air Resistance

The force of the air resistance is proportional to the square of the speed, the density of the air, the silhouette area of the car, and the drag coefficient for the vehicle. (10) A vehicle travelling at a particular speed in air encounters a force resisting its motion, referred to as aerodynamic drag resulting from two components: shape drag and skin friction.

$$F_{air} = ½ C_d A p v^2 \qquad \text{(eq 4.2.2)}$$

Where:

C_d – is the Drag coefficient (no dimension)

A – is the surface area of the car and rider (m^2)

p – is the density of the air (1.2 kg/m^3 at sea level at normal temperatures)

v – is the speed of the vehicle (m/s)

PT area: $A_{PTr} = 0.2\ m^2$

Human body area: $BSA = \sqrt{}(h * m / 3600) = \sqrt{}(180cm * 80kg / 3600) = 4$

Where: h = 180cm and m = 80kg[1]

$FSA = 2/5\ BSA = \ = 2/5\ (4) = 1.60\ m^2$

Total air resistance area: $A = 1.60 + 0.2 = 1.80\ m^2$

With; Air density: $\rho = 1.225\ kg/m^3$

Drag Coefficient, $C_D = 1.5$

4.2.1.3 Force required going uphill

The force required to lift a car uphill is a function of the angle of the hill and the force of gravity. [12] When a vehicle goes up or down a slope, its weight produces a component that is always directed in the downward direction.

$$F_{slope} = \sin(\%\ \text{grade of slope})\ M\ a_{gravity} \qquad \text{(eq 4.2.3)}$$

Where:

M – is the mass of the vehicle (kg)

$a_{gravity}$ – is the force of gravity (9.8 m/s^2)

4.2.1.4 Power required for Forward Motion

Power is a measurement of work per unit time. Work is a measurement of a force moved some distance. Therefore to determine the power required moving a vehicle at a certain speed, it is simply the total of all forces to overcome multiplied by the speed. [10]

$$P = (F_{roll} + F_{air} + F_{hill})\, v$$

4.2.1.5 Power required for Acceleration

The PT is set to accelerate at the rate of $1 m/s^2$. To calculate the power required to accelerate a vehicle, first determine the amount of energy required to accelerate a vehicle from 0 to a speed v:-

$$E_k = ½ M v^2$$

Where:

M – is the mass of the vehicle (kg)
v – is the final speed of the vehicle

Then to calculate the power, divide the energy required by the time it takes to accelerate the vehicle:

$$P = E_k/t$$

Where:

E_k – is the energy required to accelerate the vehicle to the speed
t – is the time is takes to accelerate the vehicle to the speed

4.2.2 The Speed Control.

Motor controller is required to turn the control signal from the microcontroller into a varying power level to drive the motor. The PT will have a Pulse Width Modulation (PWM) controller as the speed controlling device. PMW is one method to communicate between micro controllers to a motor controller.

Another type of speed controlling device that can be used is Resistive motor control. It consisted of two switches. One switch operated the motor at a slow speed, running current through a power resistor, and the second resistor shorted out the resistor, giving full speed. Knowing the voltage and current we wanted to limit in slow speed, a value for resistance was calculated using Ohms law. [11]

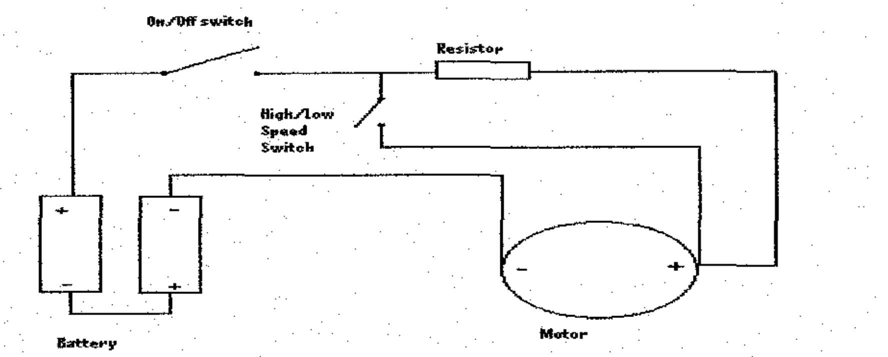

Figure 4. 4 Resistive Motor Controller Schematic Diagram

Ohms Law states **V = IR**, therefore,

R = V/I, where:-

V = Voltage, I = Current,

R = Resistance

The only advantage that Resistive controller has against PWM is that it may potentially more reliable. The PWM offers better performance in speed control and have improve efficiency of vehicle. [11]

4.2.3 Gearing system Determination.

Since the speed-torque motor is close to ideal, single gear or double gear transmission is usually employed. [10]For this project, a single gear transmission will be employed.

The basic equations used here are:

$P = (1/60)*\Pi*N*T$

$N_1/N_2 = M_2 / M_1$

Where,

P – Power in KW

N – Speed in Rpm

T – Torque in N.m

M- Number of teeth of the respective gear.

4.3 Design Calculations.

4.3.1 Total forces encountered

From equation (4.2.1),

$F_{roll} = u_{roll}\, M\, a_{gravity}$

$= (0.01862)(110\ kg)(9.81\ m/s^2)$

$= 20.02\ N$

From equation (4.2.2)

$F_{air} = ½\, C_d\, A\, p\, v^2$

$= ½\, (1.5)(1.8\ m^2)(1.225\ kg/m^3)(5.56\ m/s^2)^2$

$= 51.12\ N$

From equation (4.2.3)

$F_{slope} = \sin$ (% grade of slope) $M\, a_{gravity}$

$= \sin 25(110\ kg)(9.81\ m/s^2)$

$= 456.07\ N$

The total traction forces that PT will encounter are:-

$F_{Roll} = 20.02$ N, $F_{Drag} = 51.12$ N and $F_{Slope} = 456.07$ N

$F_{traction} = F_{Roll} + F_{Drag} + F_{Slope} = 527.18\ N$

The highest possible forces will be taken into the calculation in order to get the maximum traction forces that the PT will faced.

4.3.2 Torque required at wheel

Using T_w= Fr

T_w=Torque

F_t= Total Traction Forces

r = Radius of the Driven Wheel

Therefore, the torque at wheel is 105.44 Nm. The torque that has been calculated is the smallest torque that the wheel needs in order to move the PT. Any value less than the torque will not move the PT.

4.3.3 Rotational Speed and Torque at Wheel

Since the torque has been calculated, the rotational speed of the wheel is needed in order to move the PT to the required speed that is 5.56m/s translational.

Using:-

v=wr, where:-

V – Translational Speed of PT

W – Rotational Speed of PT

R – Radius of wheel (0.2m)

The required rotational speed required is calculated to be 27.8 rad/s to achieve translational speed of 5.56m/s.

4.3.4 Gearing System

Figure 4. 5 Electric motor selected for PT model MY1020

For the project, a 24V 500W DC Electric Motor has been chosen to run the PT. The specifications of the motor are shown below:-

Table 3: Specifications for Motor Selected [12]

Model	MY1020
Type	Brush
Voltage	24V DC
Rated Speed	2500RPM
Rated Current	27.4Amp
Sprocket	8mm, 13 tooth pinion gear
Output Power	500W
Dimension(Length X Weight X Height)	174.00mm X 72.00mm X 184.00mm

The required torque for the PT is 110.32Nm at the wheel. Calculations to find free torque of the motor are shown below:-

500 W = 0.67 HP

HP $= T_p * N/63025$ [12]

Therefore,

T_p = 0.67HP*63025/2500 rpm

= 16.89 Nm

Where:-

T=Free Torque of motor (ft.lbs)

N=Rotational Speed (RPM)

From equation above, the free torque of the motor is 16.89 Nm and needed to be increased by using gear ratio. However, the rotational speed required will also be considered during the calculation. The lowest rotational speed produced using gear ratio is 27.7 rad/s.

Therefore, to get a total torque at least 110.32 Nm:-

Gear Ratio, i_o = 105.43 Nm/16.89 Nm

= 6.25

However, the gear system of the PT will not have a perfect efficiency of 100%. The author assumes that the gear system has 98% efficiency. Therefore, using the formula:-

$T_w = i_0 n_t T_p$

$i_o = T_w / n_t T_p$

= 105.43 Nm/(0.98)(16.89 Nm)

= 6.46

With all the consideration taken, the gear ratio of at least 6.5 needed to be used.

4.3.4 Performance of PT

In order to get the required standard, the gear ratio of 7 will be used. The performance of the PT is calculated to be:-

Torque on the Wheel= 16.89 Nm*7

= 118.23Nm

Rotational Speed = 261.8 rad/s/7

At Wheel = 37.4 rad/s

The PT will have translational speed of 7.48 m/s or 26.9 km/h. This speed is considered safe since the required speed set is at least 20 km/h and more than 30km/h is considered dangerous too drive on pedestrian walk.

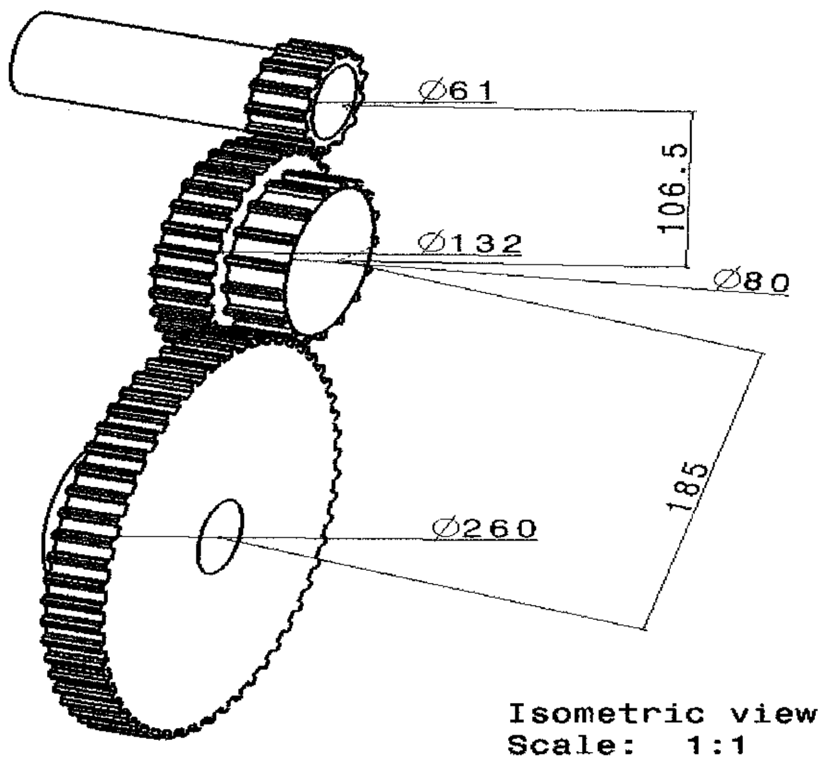

Figure 4. 6 Spur gears arrangement for PT

Table 4: Specification for Gears Selected

Parameter	Gear A	Gear B	Gear C	Gear D
Diametral pitch, P	6.000	6.000	6.000	6.000
Number of teeth, N	13.000	28.000	17.000	55.000
Base Diameter, d (mm)	61.000	132.000	80.000	260.000
Module, m	5.000	5.000	5.000	5.000
Circular pitch, p	0.628	0.628	0.628	0.628
Pressure angle	20^0	20^0	20^0	20^0
Dedendum, b	0.225	0.225	0.225	0.225
Material: Ductile Iron Grade 60, Density; 7.10g/cm^3				

Train Value TV = $VR_{a\text{-}b} \times VR_{b\text{-}c}$

$= N_b / N_a X N_d / N_c$

Train Value TV = 28/13 X 55/17

= 6.97 (which is approximate to 7)

4.3.5 Battery performance

Before selection of battery being made, the time needed for the PT to travel at least 10km with the speed of 26.9km/h is calculated:-

Time to travel = 10km / (26.9km/h)

= 0.371 hour (22.3 minutes)

The motor is drawing a steady 27.4 A of current and the PT needs the motor to run for at least 0.371 hour. Thus:-

Capacity battery needed = 27.4 A * 0.371 hour

= 10.1654 Ah

However, in real life, it is impossible to run the battery all the way on every charge cycle to zero. The battery should have at least 20% left of the total capacity. Therefore:-

Capacity Battery = 10.1654 Ah / 0.8

= 12.71 Ah

To power the motor, a 24V 13Ah NimH battery pack is selected. This type of battery is widely used for Hi-Power E-bike and robots. It consist of 20 pieces of F sized13Ah NimH Cell in a plastic container. The battery needs to be charged using the Smart Charger (1.8A) with 3 pin connector which is installed to the home plug. (12)

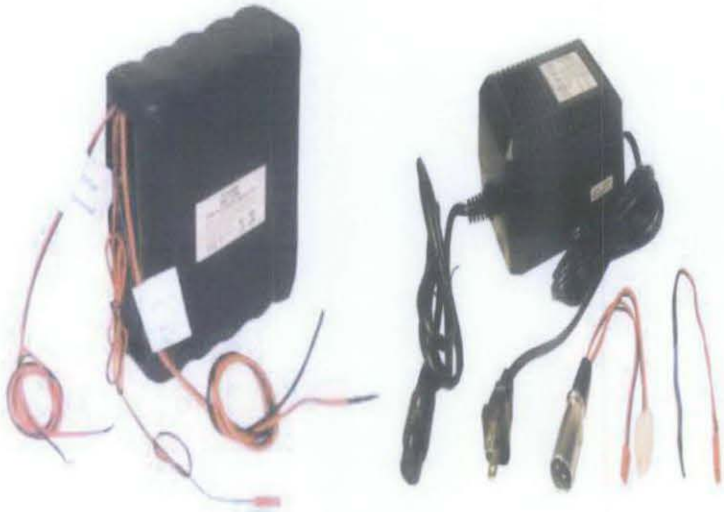

Figure 4. 7 Battery and Charger for PT

Table 5: Specification for Battery Selected [12]

Nominal Voltage	24V
Nominal Capacity	13Ah
Standard Discharge Time	13A
Charging Time	160min
Weight	5.4kg
Dimension(Length X Weight X Height)	76.22mm X 168.3mm X 181.0mm

The performance of the battery will be based on the assumption that the vehicle is operated at an elevated surface where the inclination is 0^0.

Therefore, the battery will last for T where:-

T = 13Ah/27.4A

= 0.474h

= 28min 28sec

The vehicle will operate at a speed of 26.9km/h. So, the total distance that the vehicle may cover is D, where:-

D = 26.9km/h*0.474h

= 12.75km

Since the objective of the project is to get a total distance of at least 10km, therefore the objective is achieved.

4.4 Steering Mechanism

Steering mechanism plays an important part in providing comfortable way to control the direction and accelerating the PT. Many considerations had been made during the designing progress. Two of the rejected ideas were wheel mounted in the upright post in front of the PT and a simple knob on the post itself. It was decided that twist grip would be the most appropriate for the project. It seems simple for user to use as well as the designing process.

The basic idea of accelerating the PT is using a potentiometer in the twist grip handlebar to control the current going through the electric motor. Therefore, the speed of the motor can be controlled by manipulating the resistance on the potentiometer.

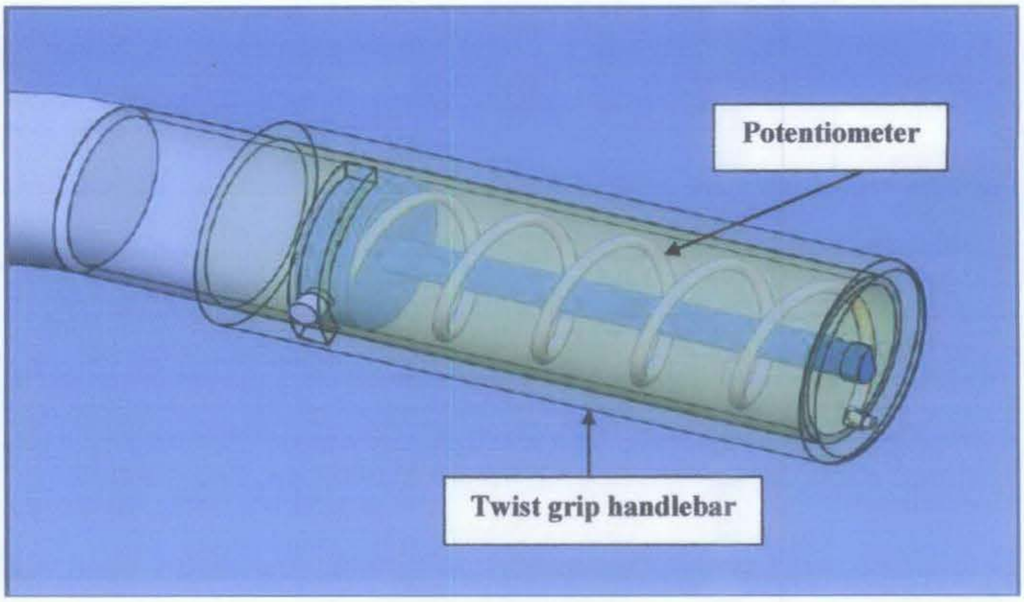

Figure 4. 8 Steering mechanism of PT using potentiometer

4.5 Cost Analysis

This section provides a summary of the cost associated with the PT. The table below shows the list cost of major component in the drive system.

Table 6: Cost analysis of the drive system components

ITEM	**COST**
DC Motor	RM 450
Batteries and charger	RM 195
Controller	RM 150
TOTAL	**RM 795**

*These pricing are based on the current reseach on the website www.monsterscooter pats.com.

The total price of RM 750 is only based on the drive system of the PT. However, the cost is 3.75% of the total price of Segway Human Transporter which cost about RM 20,000 in Malaysia.

4.6 PT Detail Design

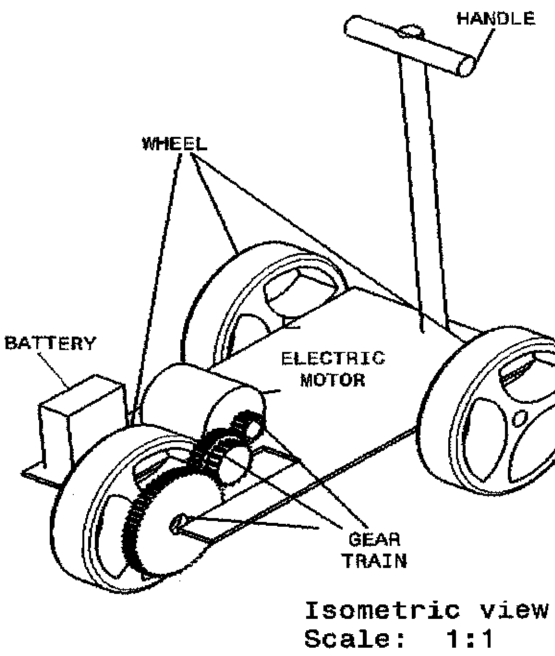

Figure 4. 9 Isometric view of PT without chassis

The figure above shows the output product of the PT design by the author. It runs on a single motor Rear Wheel Drive which simplifies the design of the PT. Since it only runs one wheel, there is no need a drive shaft to be installed. The two front wheels are steered by turning the handlebar to left or right. The steering system is accomplished by the Ackermann Theory.

The drive system of the PT is assembled at the back of the PT to balance out the PT with the user at the front. Therefore, the center of gravity of the PT will be located at the center and the PT will not be flip over. The lower the center of gravity, the balance the PT. The calculation to find the center of gravity of the PT is shown below:-

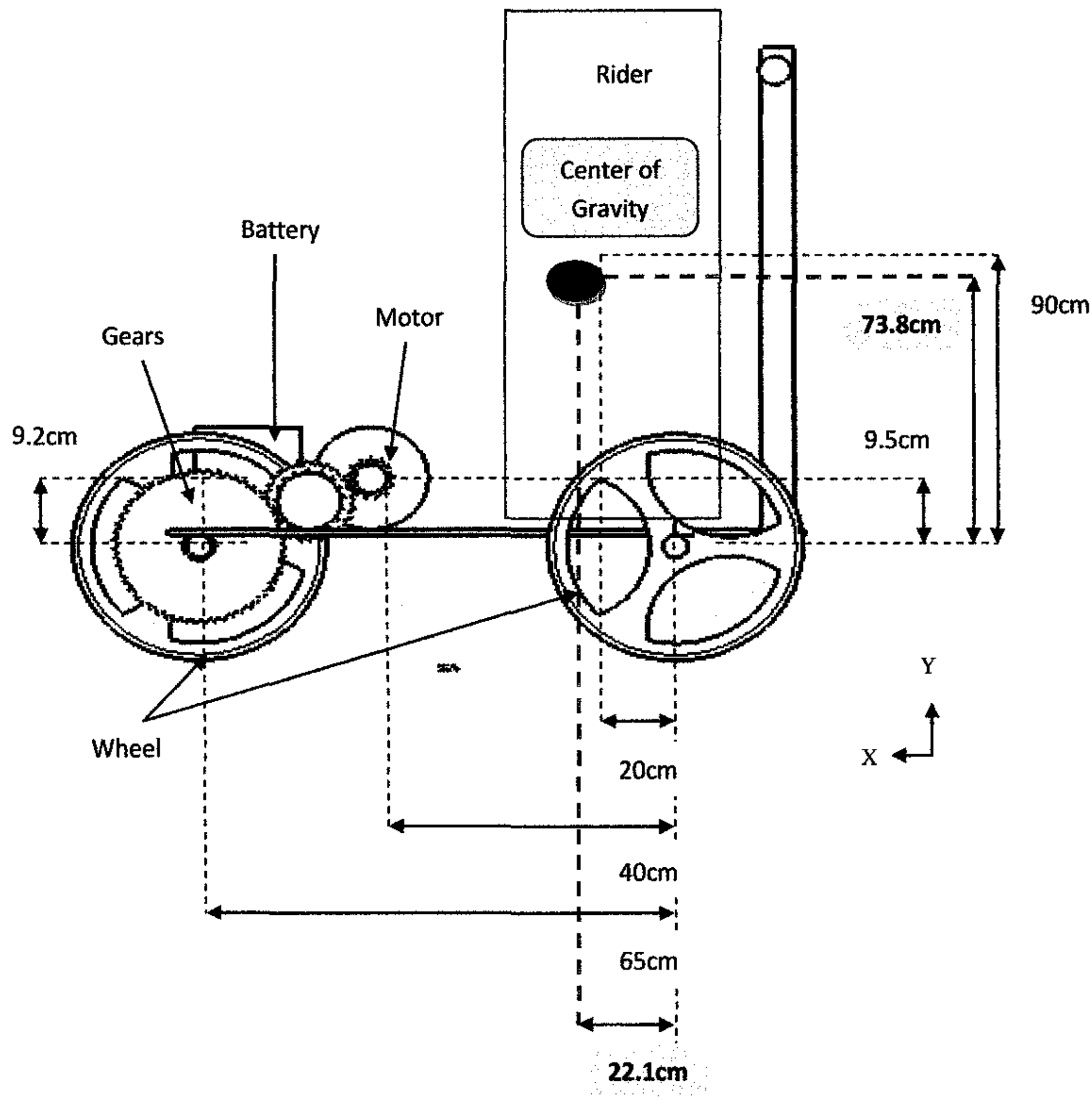

Figure 4. 10 Free body diagram of PT

Human (Height 180cm, weight 80kg)

Battery (Weight 6.0kg)

Electric Motor (5.0kg)

Mass = 135 kg

Weight = 891.7 N

To obtain center of gravity acting the composite body;

$$X = \Sigma xW / \Sigma W$$

$$Y = \Sigma yW / \Sigma W$$

$X = [(65 \times 6.0) + (40 \times 5.0) + (80 \times 20)] / (6.0+5.0+80)$

$= 22.12$ cm

$Y = [(9.2x6.0) + (9.5x5.0) + (90.0x80)] / (6.0+5.0+80.0)$

$= 73.8$ cm

From Figure 4.10, the red dot shows where the center of gravity of the PT with the rider on it. Since the location of the center of gravity is not at the end of the PT, it can be considered balance and will not flip.

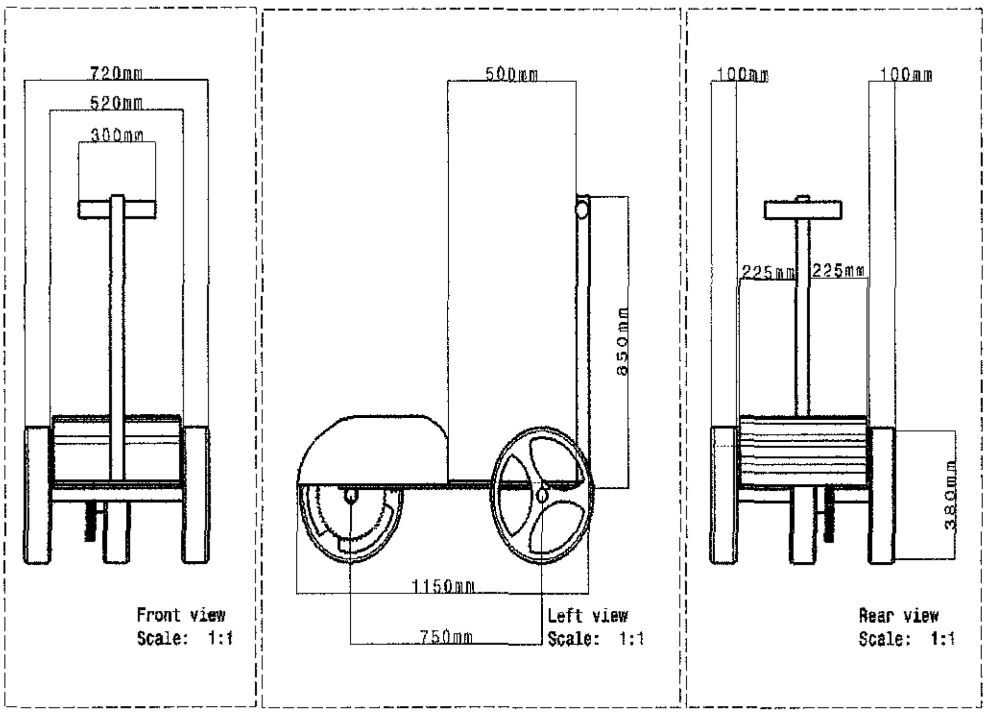

Figure 4. 11 Technical view of PT (From left : front view, left view, rear view)

The dimension of the PT is shown on the Figure 4.11. The size of the PT is considered fit enough for a single person transporter. The center of gravity of the transporter which located at nearly the center of the transporter proved that the PT is highly balance and will not flip over at static or moving state.

The final product of the proposed Personal Transporter is illustrated using CATIA software.

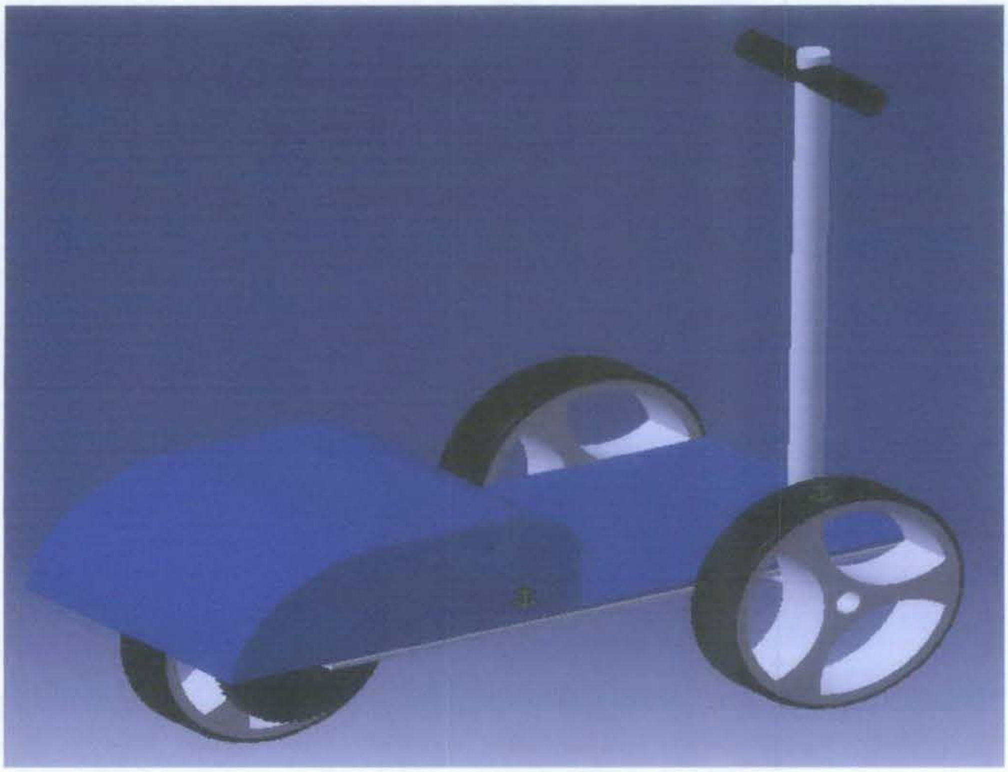

Figure 4. 12 Final product of PT design using CATIA

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

After all the research and analysis done, the author is able to decide on a three wheel rear drive PT. A 24V DC motor with 500W power enables it to achieve a speed of 26.9km/h and a total distance of 12.75km. The power source of the PT is a 24V 13Ah NimH battery pack that can run about 28 minutes with a single charge. With a gear ratio of 7 and maximum torque of 118.23 Nm at the wheel, the PT would be a perfect choice for a single rider with less than 80 kg body weight to ride on a flat surface up till 20^0 inclination plane. The author hope simplify version of the PT is more user friendly and enables users to maintain it easily.

By cutting down the usage of sophisticated components on the PT, it is hoped that the cost of the PT can overcome the problem of high prices in the existing PT. The design of the simplified PT cost no more than RM 1000 which only 3.75% of the cost of Segway. Thus, more users will be aware of the sickening environment.

Last but not least, the author also hopes that this report is able to become a reference in helping the designers to fabricate the personal transporter in the future.

5.2 Recommendation

1. Produce a prototype.

Analytical analysis would not provide an exact result compared to a prototype. Therefore, a real experiment of the PT needed to be done in order to get the best result outcome. By doing this, the uncertainties that might be encountered can be detected and solved. The motor, battery and gear train will not have 100% efficiency and thus require performing the experiment to determine the exact efficiency of the components.

2. Material Selection

The types of material used for the PT will have a significance effect on the PT. The lighter the weight of the material, the higher the efficiency of the drive system. Since the author only covers the drive system design, all of the material selections and weight are considered negligible. Therefore, the analytical analysis will not have an exact result of the performance of the PT.

3. Detail study on maintainability of PT

The quality of a product lies on the maintainability of the product itself. With a detail study on this, components that will need retaining to a specified condition within a specified period can be known. Therefore, a lifespan of the product can be expanded due to the continuous improvement and maintenance.

4. Mass production

Another objective of the project is to reduce the total cost of the PT. However, if a product is produce in a limited amount, the price of the product will be higher. Thus, a mass production of the PT will eventually decrease the total cost of the PT with an accurate manufacturing procedure.

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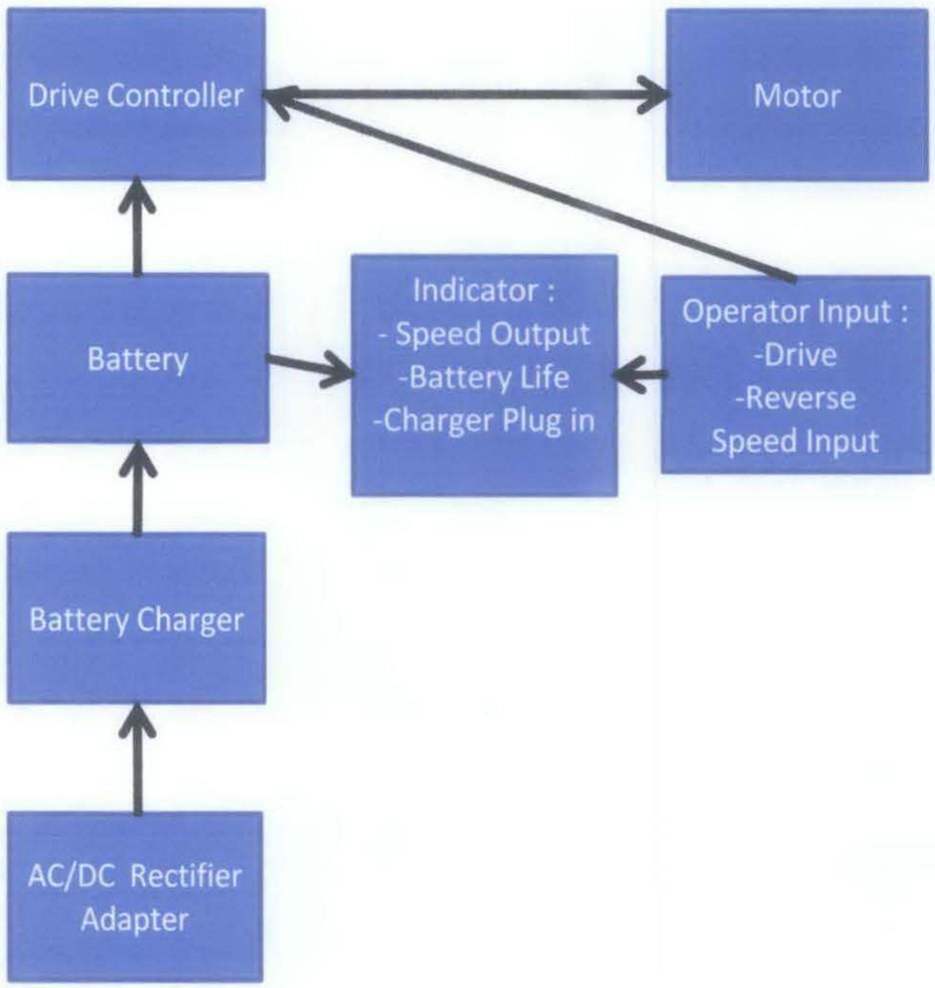
APPENDIXES

Appendix 1: Force variation in difference transporter velocity

Velocity, v (m/s)	Angular velocity (Rad/s)	RPM	Air density, ρ (kg/m3)	Gravity, G (m/s2)	Drag Coefficient, CD	Acceleration	Body + Segway area (m)	Total Mass (kg)	Human Mass (kg)	Rolling Coefficient, CR	Inclination		Air resistance (N)	Rolling resistance (N)	Inclination Force (N)	Acceleration force (N)	Total force (N)	Tyre torque (N.m)	Power (W)
											Degree(°)	Radian							
0.0	0	0	1.225	9.81	1.5	0.93	1.6	165	113	0.01360	0	0.0000	0	22	0	153	175	42	0
0.5	2	20	1.225	9.81	1.5	0.88	1.6	165	113	0.01360	1	0.0175	0	22	28	146	168	40	84
1.0	4	40	1.225	9.81	1.5	0.84	1.6	165	113	0.01360	2	0.0349	1	22	56	138	162	39	162
1.5	6	60	1.225	9.81	1.5	0.79	1.6	165	113	0.01360	3	0.0524	3	22	85	130	156	37	234
2.0	8	80	1.225	9.81	1.5	0.74	1.6	165	113	0.01360	4	0.0698	6	22	113	123	151	36	301
2.5	10	99	1.225	9.81	1.5	0.70	1.6	165	113	0.01360	5	0.0873	9	22	141	115	146	35	366
3.0	13	119	1.225	9.81	1.5	0.65	1.6	165	113	0.01360	6	0.1047	13	22	169	107	143	34	428
3.5	15	139	1.225	9.81	1.5	0.60	1.6	165	113	0.01361	7	0.1222	18	22	197	100	140	34	489
4.0	17	159	1.225	9.81	1.5	0.56	1.6	165	113	0.01361	8	0.1396	24	22	225	92	138	33	550
4.5	19	179	1.225	9.81	1.5	0.51	1.6	165	113	0.01361	9	0.1571	30	22	253	84	136	33	613
5.0	21	199	1.225	9.81	1.5	0.46	1.6	165	113	0.01361	10	0.1745	37	22	281	77	136	33	678
5.5	23	219	1.225	9.81	1.5	0.42	1.6	165	113	0.01362	11	0.1920	44	22	309	69	136	33	746
6.0	25	239	1.225	9.81	1.5	0.37	1.6	165	113	0.01362	12	0.2094	53	22	337	61	136	33	818
6.5	27	259	1.225	9.81	1.5	0.33	1.6	165	113	0.01362	13	0.2269	62	22	364	54	138	33	896
7.0	29	279	1.225	9.81	1.5	0.28	1.6	165	113	0.01363	14	0.2443	72	22	392	46	140	34	981
7.5	31	298	1.225	9.81	1.5	0.23	1.6	165	113	0.01363	15	0.2618	83	22	419	38	143	34	1073
8.0	33	318	1.225	9.81	1.5	0.19	1.6	165	113	0.01363	16	0.2793	94	22	446	31	147	35	1175
8.5	35	338	1.225	9.81	1.5	0.14	1.6	165	113	0.01364	17	0.2967	106	22	473	23	151	36	1286
9.0	38	358	1.225	9.81	1.5	0.09	1.6	165	113	0.01364	18	0.3142	119	22	500	15	156	38	1408
9.5	40	378	1.225	9.81	1.5	0.05	1.6	165	113	0.01365	19	0.3316	133	22	527	8	162	39	1543
10.0	42	398	1.225	9.81	1.5	0.00	1.6	165	113	0.01365	20	0.3491	147	22	554	0	169	41	1691

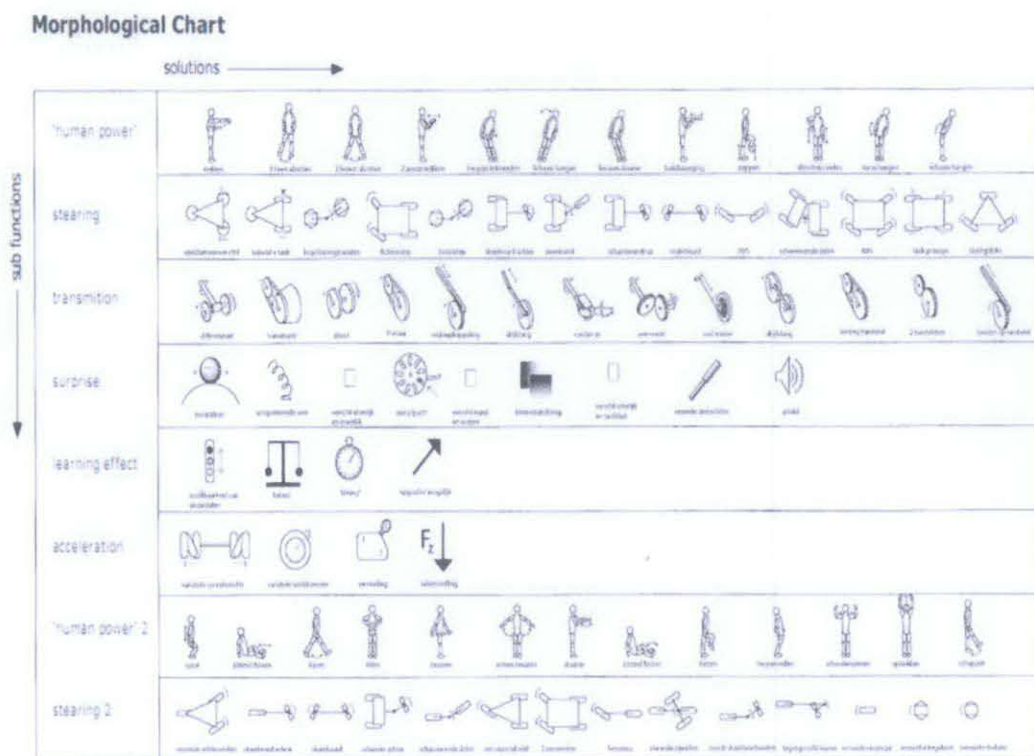


Appendix 2: Total System Description with Block Diagram

Lithium-ion Battery Pack Specifications at a Glance:

	NiMH	Saphion Lithium-Ion
Battery Capacity:	220 watt hours (Wh)	400 watt hours (Wh)
Range: Gentle, level riding	12 miles (approx.)	24 miles (approx.)
Range: Aggressive, hilly riding	8 miles (approx.)	15 miles (approx.)
Charge Time:	5 hours (approx.)	8 hours (approx.)
Temperature Range*:	41-120°F	14-120°F

Appendix 3: Specification of two types of batteries



Appendix 4: Morphology Chart on PT