Solar Bicycle Energy Management System Using HP48G Calculator

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Abstract

Energy of the solar bicycle is supplied by the battery, which is connected to the solar panels. The energy management of the solar bicycle is very important in order to optimize the limited energy available from the battery. HP48G calculator is used to handle the energy management of the solar bicycle due to its portability and computer-like capabilities. This paper describes how the HP48G calculator is used to prepare the solar bicycle team from the Universiti Tenaga Nasional, Malaysia (UNITEN) entering the Malaysia International Solar Cycle Challenge 1999. It covers the experiments carried out in the lab, and the test runs on the solar bicycle and the supporting vehicle that accompanies the bicycle during the race. It gives the details on how various data are collected, analyzed and tabulated by the HP48G calculator. With its powerful matrix based computation, and fine graphics display, HP48G could handily analyze the data, and display the results. The interface used to link the calculator and the sensors which measure the voltage and current is Portable Lab Data Logger 100 (PLDL100). The database built from the readings collected during the experiments and trial runs, serve as a basis for the overall energy management of the solar bicycle.

Keywords: Solar Bicycle, Energy Management, Solar Panels, HP48G Calculator, Data Analysis

Introduction

Energy management of the solar bicycle is very important due to the limited energy supplied by the battery. Optimizing the energy utilization is crucial especially when preparing a team for an international competition. A computer with appropriate software could be used to gather and analyze the data taken from the bicycle. However, HP48G calculator has been opted due to its portability and computer-like capabilities. Together with PLDL100 data logger, the data that have been extracted from the tests could easily be tabulated and presented in a form of graphs. HP48G has its own programming language, and all the calculations performed have been carried out using the language.
This paper first describes the components of the solar bicycle, and then it touches the various tests that have been carried out in the lab and on the road. Theoretical calculations are also included. Finally, UNITEN's solar bicycle team experiences during the Malaysia International Solar Cycle Challenge '99 held in June 1999 are highlighted.

General Descriptions

The UNITEN's solar bicycle consists of a dual motor system, a two-speed controller and throttle, a battery and battery containment system. Two motors were chosen due for lightness of power ratio, cost, balance and ease of control functions.

Motors

The main component of the solar bicycle is the motor. A pair of electric motors is positioned face-to-face with their shafts in coaxial alignment, and a drive roller is joined to both output shafts and disposed between the two motors. The drive roller engagement with the tire creates a reaction force that further pivots the motor mounting assembly toward the tire, so that frictional engagement of the drive roller on the tire increases automatically as torque increases.

Rollers

The rollers are made up of a machined aluminum shaft with a hardened steel sleeve pressed over it. The steel sleeve has a heavy diamond knurl cut into it to prevent tire slipping in damp conditions. The rollers slide over the two motor shafts, and torque is applied by the steel roll pins.

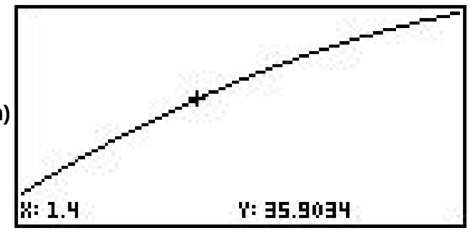
Speed	Diameter
31.1 km/h (19.2 mph)	3.3 cm (1.3 in)
25.3 km/h (15.6 mph)	2.7 cm (1.1 in)

Relationship between roller diameter and bike speed

The rollers that have been supplied with the motor are meant for speed in the range of 25 km/h to 32 km/h, which is not enough for a competition. Thus, the roller diameter needs to be modified so that further improvement in speed could be made. Various diameters of the rollers have been used and the speeds achieved are recorded. The time taken for the battery to be fully drained at various roller diameters are also recorded. When the diameter size is increased the speed will increase, but at the same time, the battery will drain faster.

Speed vs. Roller Diameter

Speed (kph)

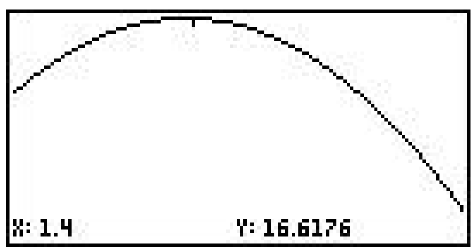


Diameter (in)

The above graph shows the speed of the bicycle versus various diameters of the roller. The speed increases when the diameter increases.
The following graph shows the total distance covered by the bicycle when different diameters of the rollers are used.

Distance vs. Roller Diameter

Distance (km)



Diameter (in)

Although an increase in the roller diameter increases the speed of the bicycle, the total distance covered tends to drop. This is because more energy from the battery is required to maintain the high speed, and the battery drains much faster.
Curve fitting the graph of distance vs. diameter gives the following equation:

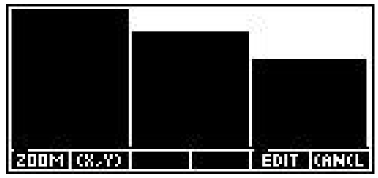
$$s = -18.04d^2 + 50.51d - 17.94$$

By taking the derivative, the diameter of 1.4 inch gives the farthest distance that could be traveled by the bicycle.

Power Source

The bicycle utilizes a 17 amp-hour (AH), sealed lead acid battery for its power. The battery weighs 5.4 kg. Weight is a major factor contributing to the performance of the bicycle and the team has decided to use only one unit of a 12-volt battery. A test has been carried out using three different weighs and the graph is plotted.

Average Speed vs. No. of Batteries



Batteries

The graph shows that the average speed drops when more weigh is put on the bicycle by having more batteries.

Solar Panel

The solar panel located at the back of the bicycle is a lightweight 5W panel. This panel is good for extra 1.9 amp-hours per day. The main power source for the 17 amp-hour battery is from the 75W solar panel, located on the roof of the supporting vehicle that follows the bicycle during the competition.

PLDL100: Portable Lab Data Logger

The data logger is used together with the HP48G calculator in order to take the data. The Portable Lab Data Logger 100 is a product by Firmware Systems, Inc. It can read data simultaneously from 4 ports and stores all 4 readings in one record at up to 350 records per second with storage capacity of 1000 records. The data logger can easily be used with Hewlett Packard HP48 graphing calculators. The software installed in the calculator is HP 48 PLDL Command Library, which provides an interface to the PLDL 100 data logger.

Calibration

Before the data logger can be used, some calibrations need to be carried out. The reading from the data logger gives 2.44V when the reading of the current is 0 amps. A linear interpolation formula is used to find the current.

For example if the data logger shows a reading of 2.013 V, the actual amps is:

Amps = 0 + (2.013 - 2.44)/(0 - 2.44) x (0.6 - 0)

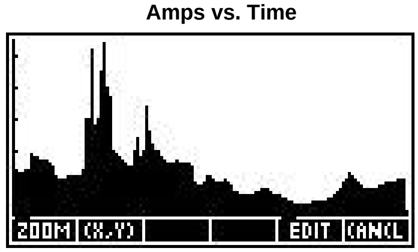
= 0.105 amps

Charging Through Solar Panel

A 75W BP Solar Panel is used to charge a drained battery. The PLDL 100 data logger takes the amps every two minutes. The data is kept in HP48G calculator. The graph for amps vs. time is tabulated.

Amps vs. Time

Amps (A)

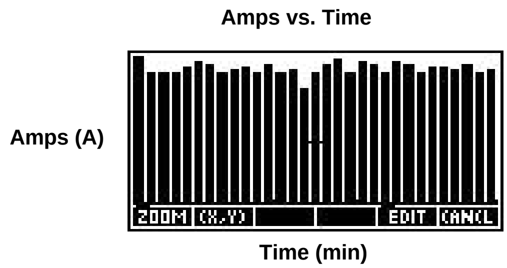


Time (min)

The duration for the test is 4 hours. The area under the graph gives the amount of energy collected by the battery. Using the HP48G the area under the graph is calculated using the Trapezoidal rule. The above gives energy collected as 11.97 amps-hour.

Draining through a Motor

The battery that has been fully charged with the solar panel is then drained through a small motor. The current reading is recorded via the PLDL 100 data logger. It takes 1 hour to drain the battery, and the energy that has been used is 10.34 amps-hour.



Calculations: Power

Followings are the formulas use to calculate the power required to move a bicycle at a certain speed.

$F_w = \frac{1}{2} A C_w \rho V^2$	*Wind Resistance*
$F_{rl} = 9.81 W_{kg} C_{rr}$	*Rolling Resistance*
$F_{sl} = 9.81 W_{kg} \Lambda$	*Gravity Forces*
$P = (F_w + F_{rl} + F_{sl})V$	*Power*
$V_p = C_d C_l 2\pi / (60 x 1000)$	*Speed of Pedal*
$F_{av} = P / V_p$	*Average Force on Pedal*
$F_{eff} = 360 F_{av} / (2 Eff)$	*Effective Pedaling Force*

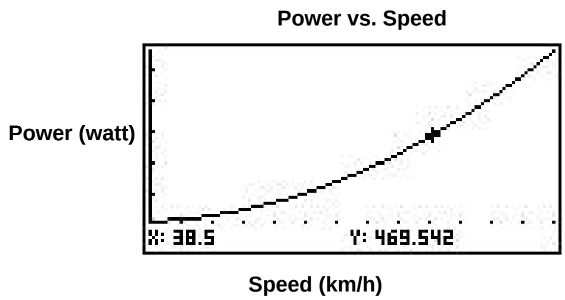
Parameters required for the formulas above are:

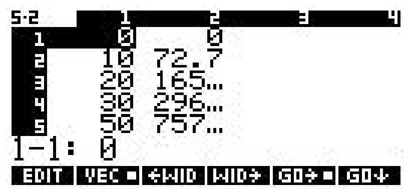
A	Effective Frontal Area of the Bike
C_w	Drag Coefficient
ρ	Air Density
V	Speed of the Bicycle
Δ	Gradient Hill. The slope of a hill is defined here as rise divided by horizontal run.
C_d	cadence
C_l	crank length

A program code has been written on HP48G for the formulas stated above. Various analyses can be made on the bicycle using the written code.

i) Power vs. Speed

One of the main aspects of the solar bicycle is in determining the power required for the bicycle at various speeds. Several parameters need to be considered which includes the wind resistance, rolling resistance, and gravity forces.
The following Power vs. Speed graph is for a bicycle with a total weight, including the rider, of 75 kg, runs on a flat road. The coefficient of rolling is taken as 0.004 and the coefficient of wind drag is 0.5. The power is solely coming from the rider energy input, meaning that the calculations do not yet take into account the energy coming from the battery.



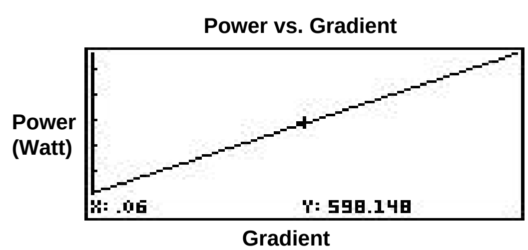


HP48G window screen shows data in a matrix form

The power needs to pedal the bicycle increases as the speed increases. For instance, to move at a speed of 38.5 km/h, the human power required is 470 W.
If the motor is switched on and the supply of energy is coming from the battery, the power from human input can greatly be reduced. For example if the amps is maintained at 30 A, the battery will supply a power of 360 W (P=VI=12x30=360W). Thus the cyclist only needs to cycle with a power input of (470-360)W = 110W. This is the main reason why the cyclist can ride very comfortably on the solar bicycle. The energy coming from the battery allows the rider to put 77% less effort to get the same speed.
To achieve a speed of 45 km/h, with the help of the motor, the cyclist needs to put a power input of 250 W. Still this is much less than the 470 W required to maintain at 38.5 km/h when the cyclist rides the bicycle without the motor.

ii) Power vs. Gradient

In the solar bicycle competition, the journey involves several legs that are hilly. Thus, it is very important to determine the power required at different gradients. The gradient is defined as the rise of the hill divided by its horizontal. Actually, this is the sinθ of the angle of the hill. The following graph shows the amount of power required when the gradient changes from 0 to 0.1 and the speed is maintained at 35 km/h.

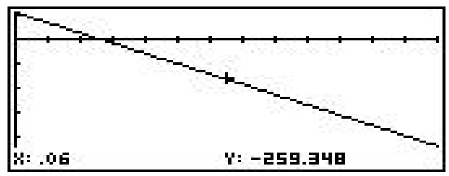


A linear relationship develops between the gradient and the power requirement. The limitation of the motor amps is 50 A which will give a power output of 600 W. To conserve the energy, when climbing a steep hill the rider is instructed to off the motor. This will avoid the battery from being drained off quickly.

When moving down the hill, the gravity forces give an advantage to the bicycle. The weight of the bicycle itself is enough to propel the bicycle forward.

Power vs. Gradient

Power (Watt)



Gradient

The graph shows the power requirement when the bicycle is cruising down the hill with a speed of 35 km/h. A negative power means that the cyclist does not need to pedal the bicycle in order to achieve that speed. Actually, at 0.6 gradient, solely on the weight of the bicycle, the speed can reach 28 km/h. But, this value assumes that the initial velocity of the bicycle is zero. It can go up much higher when the bicycle is moving at a certain speed right before going down the hill.

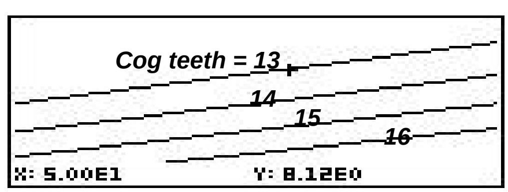
The approach taken by the team is to turn off the motor when attacking the hill. Although the speed is reduced greatly when moving up the hill, this is compensated with higher speed when the bicycle is moving down the hill

iii) Gear Chart

Gear chart gives a relationship between the forward motion of a bike and the revolution of the pedals. HP48G calculator has been used to curve-fit the chart, and produces the following graph which shows the distance in meters the bike will travel in one revolution of the pedals for a given chainring, cog, and wheel diameter of 671 mm.

Distance Traveled vs. Chainring & Cog Teeth

Distance traveled (m)

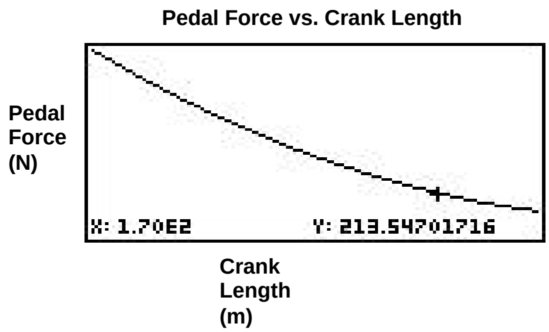


Chainring Teeth (in)

The team has tried various combinations during the road test, and finally has come up with chainring teeth of 57 in. and cog teeth of 13 in. With this selection, the bike travels 9.243 m for one revolution of the pedal. The chainring teeth of 57 in. is the largest the team could secure.

iv) Force on Pedals vs. Crank Length

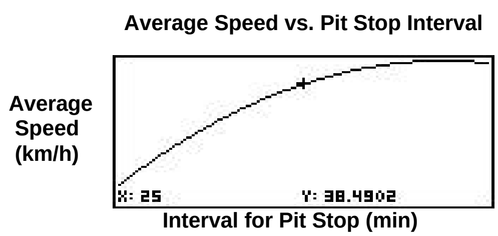
One of the changes that have been made on the solar bike is the size of the crank length. Incorrect selection of the crank length will result in more force required to do the pedaling. The graph shows that the force exerted on the pedal reduces with the increases of the crank length.



Considering this analysis, the team has decided to opt for a higher crank length than the normal one installed on the bicycle. The 170-mm crank length chosen by team replaces the original size of 100-mm.

v) Pit Stop

During the pit stop a team can change the battery and check the overall condition of the bicycle. Replacement of the rider can be made during the pit stop. The decision on how often to have a pit stop and battery replacement is very crucial because it affects the overall time taken for the team to finish the race.
The graph shows how the average speed varies with the interval for pit stop.



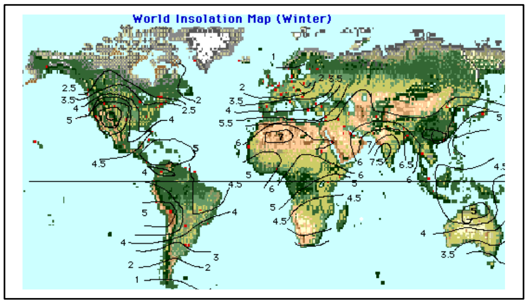
Prolonging the interval for pit stop can improve the average speed. For example, if the pit stop is done every 10 minutes, the average speed is 36.36 km/h. But, if it is done every 40 minutes, the average speed will improve to 39.04 km/h.
The approach that has been taken by the team is to monitor the volts of the battery. A voltmeter is attached on the bicycle. When the battery is fully charged the voltmeter registers a reading of 12.9 V. The battery loses its power to supply energy when the voltage drops down to 11 V. At this stage, the cyclist has been instructed to stop cycling in order to have a battery replacement. Average interval

time for a pit stop has been recorded at 25 minutes. This gives the average speed for the team as 38.5 km/h.

vi) Battery Charging Through Solar Panels

The solar bicycle is equipped with a small solar panel at the back of the bicycle. This solar panel is only rated at 5 W and is not enough to charge the battery. During the competition, the team is allowed to carry a supporting vehicle that has solar panels on its roof.

Our team carries six solar panels with each one rated at 75 W. Two solar panels are used to charge a battery, so at any one time, three batteries will be charged simultaneously.



World Insolation Map

The World Insolation Map above gives the amount of energy received at various locations around the globe. From the map, it can be seen that Malaysia receives 6.0 kWh/m^2 of energy. Cedar City, Utah (USA), which receives 6.2 kWh/m^2 collects data on the total amount of energy accumulated throughout the year in that city. The average accumulated amps gathered by the city is 15 A using a 55 W solar panel. From this information, the amount of energy received by Kuala Lumpur, Malaysia can be calculated. It takes about 3 hours to fully charge a battery. Over a 6 hours period, the team can charge about 6 batteries from the solar panels.

The Competition

The team participated in the Malaysian International Solar Cycle Challenge '99 held in June 1999. The race covered a distance of 875 km across the Malaysian peninsular and was divided into 4 stages. The team had a huge success by winning all the stages with a commanding average lead of about 45 minutes on each stage.

Champion … The UNITEN's Solar Bicycle Team

Efficient … rider and battery changed during the pit stop

With an average speed of 38.5 km/h, the UNITEN's Solar Cycle Team had been declared as the Outright Winner in the competition, leaving the runner up team by 3 hours and 3 minutes, a distance of more than 100 km. The victory reflected a good electrical and mechanical bicycle design. It also reflected excellent logistic and energy management. Credit was also due to the cyclists who were an integral part of the victory.

Conclusion

The HP48G calculator helps tremendously during the design and racing stages. It allows clear visualization of important parameters and helps engineers making swift decision on the best options to take. The energy management system carried out by the HP48G calculator helps the team to optimize the energy usage of the battery.

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