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E-bike load demand estimation for transport using cartographic data

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Abstract:

In remote areas of Sub-Saharan Africa, as well as in Rwanda, communities face the problem of finding an affordable and suitable way of transport for their daily life. Currently, the short-range transportation of people and goods rely on manual traction (e.g., bicycles, handmade wooden bicycle, etc.) and on small combustion engines. However, this region has a large renewable energy source (solar) which can help to mitigate this problem. Electric bicycles may be used to tackle the problem, although their use is still not largely widespread despite its potential. In addition, the local society does not have an easy way to accurately estimate the amount of energy consumed for a certain itinerary to be sure of how the electric vehicles perform. Thus, characteristic analysis of consumed energy is very important to analyze the performance of electric vehicle storage systems, model charging infrastructure, size vehicles, planning for itineraries, etc. This paper presents a methodology to estimate the power consumed by electric bikes for specific itineraries. In order to accomplish so, the WebPlotDigitizer tool and Google Maps were used to produce driving profile patterns. The results are compared against experimental data, showing the accuracy of the methodology presented. The simulated results show that the consumed power value differs by only 1.68% from the experimental recorded value; the difference can be explained by traffic congestion, the density of traffic, and the intersection that occurred during the experiment. The presented method of driving energy requirement estimation using WebPlotDigitizer is attractive, affordable, and easy to use.

Keywords: *Driving Pattern, Electric vehicle, Itinerary, WebPlotDigitizer*

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1. INTRODUCTION

Rwanda as a hilly country (thousand hills country) may adapt the usage of green power to facilitate different types of transport. All over the country, people use small vehicles (like bicycles and motorcycles) for different tasks such as the transport of goods and people (taxi-driving). However, the use of small combustion engines for this purpose become expensive and the use of fossil fuels as a source of power contributes to global warming. On the other hand, electric vehicles have numerous advantages over conventional fossil fuel-powered vehicles such as zero emissions, higher tank-to-wheel efficiency, etc[1]. Nowadays electric vehicles have attracted a lot of attention among the researchers and stakeholders because of their remarkable attributes towards greener transport. The increase of electric vehicles can make significant changes to the community not only in terms of technology to move personally, but also to transfer our savings from dependence on fossil fuels and ultimately reducing the carbon footprint of the traditional mode of transport[2]. Adapting existing bicycles to become electric would help to promote the productive use of renewable energy purpose and assist to mitigate the issue of climate change[3]. The benefit of e-bikes in terms of conserving the user's energy is most significant in hilly regions to overcome terrains barriers, and they also play a good position as vital transportation strategies in low-profit fringe groups wherein the general public transportation system isn’t always well-built[4]. This paper describes a methodology for modelling and estimating the required energy for an electric bicycle for given specific routes. This model has been used to estimate load demand profiles, which in turn, can be used for sizing E-bikes charging stations. It is assumed that electric bicycles under consideration would have similar driving patterns as current existing vehicles. The WebPlotDigitizer[5], is used to generate data, which are in format of a Comma- Separated-Value (CSV) file where the first column is time and the second column is height. To do so, driving profiles are obtained from mapping tools[6], which contain cycling routes available in Rwanda. The length of the journey, the time that it takes to cover its distance and the elevation of the profile is expected to be extracted from a map captured from google maps[6], and all these information were used to guess the horizontal speed. Then, a tool developed in MatLab was used to call the CSV file data for simulation; to estimate the energy consumption by EV for the given profile. The results obtained with this methodology for the battery discharge were compared with the experimental data for validation. The weighted arithmetic mean method was used to Generate driving patterns to determine the energy consumption in battery packs, and it was found that this can help the E-bicycles customers to make more rational decisions, when choosing their new vehicles and to choose if they cannot install additional energy consuming functions or accessories on their vehicles[7]. Yuniarto et al. their paper concentrated on how to evolve a small electric vehicle model to analyze its performance, by focusing on its range estimation and consumed energy for a chosen range by means of ISO 13064-1:2012 drive cycle. the MATLAB/Simulink environment was used to model a longitudinal model of an electric scooter. It was concluded that the proposed methodology is valid and can be used as a starting point for the next research on any motorcycle that uses electricity as a source of energy[8]. Ilyès Miri et al. developed a computer-based model to estimate the consumed energy for a given driving cycle. The results have shown accuracy with a low error once compared with the test data[9]. Estimated the energy used for a chosen itinerary, here different variables intervening in the vehicle dynamics were considered by adding the effect of the driving behavior derived from smartphone sensors, captured using the Drivies app [10], The weighted arithmetic mean method was used to Generate driving patterns to determine the energy consumption in battery packs, and it was found that this can help the E-bicycles customers to make more rational decisions, when choosing their new vehicles and to choose if they cannot install additional energy-consuming functions or accessories on their vehicles[7]. By means of global positioning system (GPS), D. Penić et al describe the method for estimation of power and required energy of the vehicle, here the measured track (speed and altitude profile) was used and the drag model of the vehicle and it is found that , it is possible to calculate both powers that the vehicle develops, and energy consumed for a certain distance [11]. S. Hong and others proposed an algorithm that accurately predicts the SOC of an e-bike using a real-world driving cycle was executed, Where the route was extracted and drawn on the map using the Google application programming interfaces (API) with the GPS latitude and longitude information from the On-Board Diagnostics (OBD) data. it was confirmed that the results are more accurately compared to others[12]. A series of models with a polynomial combination structure were developed and analyzed, and were characterized by the explicit consideration of the e-bike mechanical dynamics and the electric machine system, as well as the ability to be applied easily. This method has shown the importance of electrical bicycle movement properties and powertrain characteristics on energy consumption estimation[3]. A routing approach which is a novel static energy model for electric bicycles, which allows to computing energy requirements for arbitrary street segments. it has found that the method can be used to compute the route with the lowest energy demand or farthest cruising range estimations[13].

2. E-BIKE DYNAMICS MODELLING

For the complete system model of a pedelec, the bicycle mechanical dynamics need to be described here. The different forces acting on a bicycle are represented in Figure 1[14] ; and to propel the bicycle, the EV must overcome concerned forces To calculate the horizontal total force, it is considered that the road is flat and the tractive force is supplied by the torque from a pedal-assisted by traction motor[7] [15].The total tractive force (the longitudinal dynamics of the e-bike) provided by the EV must be equal to:

$$M \times \frac{dv_{EV(t)}}{dt} = -F_{rr}(t) - F_{ad}(t) - F_{\alpha}(t) + F_{t\_h}(t) \qquad (1)$$

where M is the total mass of the pedelec (including the rider and passenger) and v is the pedelec longitudinal velocity.

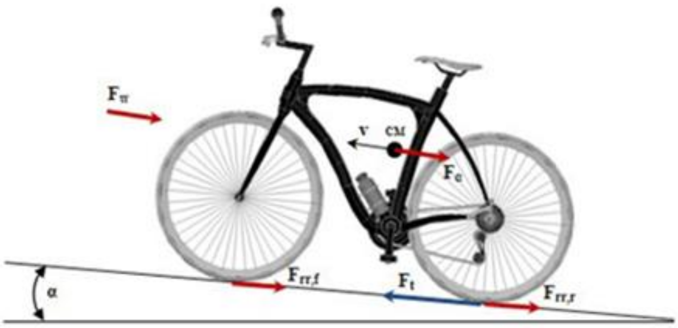

Fig. 1. Forces acting on the bicycle

Besides, the following definitions are required:

- $F_{rr}(t) = M \times g \times f_{rr} \times cos\,\alpha$ is the rolling resistance, "g" is the gravity constant and f_{rr} is the rolling resistance Coefficient between tires and road.
- $F_{\alpha} = M \times g \times \sin\alpha$ is the gradient resistance force (note that for horizontal direction, this force will be nearly zero)
- $F_{ad}(t) = \frac{1}{2}\rho_a C_{ad} A_f v_{EV}^2(t)$ is aerodynamic drag resistance, "ρ_a" is the air density, "C_{ad}" is the aerodynamic drag coefficient, and "A_f" is frontal area. The parameters for a typical e-bicycle are listed in Table 1.

Then, we define $F_{t_h}(t)$as the total tractive horizontal force provided by the motor (see equation (2)) and this force is used to calculate the total horizontal power.

$$F_{t\_h}(t) = M \times g \times f_{rr} + \frac{1}{2}\rho_a C_{ad} A_f v_h^2(t) + M \times \frac{dv_{h(t)}}{dt} \quad (2)$$

Table 1. Mass of components considered for E-bicycle[16]

Bicycle part	Bicycle	Rider	Passenger	Battery	Gear and motor
Mass in kg	12	70	62	10	8

Table 2. Typical parameters of E-bicycle [14]

Symbol	ρ_{air}	A_f	f_{rr}	C_{ad}	η_{SYS}
Quantity	1.2 Kg/m^3	0.509m^2	0.0025	0.76	0.93

Where $v_h(t)$is the vehicle's horizontal speed and Table 1 shows the mass components considered to be propelled by e-bike. The average rider's weight under the study is suggested to be 70 kg, while the weight of 62 kg is added to account for passengers carried on the e-bicycle. Table 2 shows the maximum values of various system parameters. The vertical force (F_V) depends on the weight of the electrical bicycle system. From the horizontal and vertical power, the total power (P_t) was calculated. The propulsion power required to propel the bike at maximum speed is the product of the traction total force (F_t) and the travelling linear speed (v_{EV}). The total net electrical input power required is:

$$P_{t\_net} = \frac{P_t}{\eta_{SYS}} = \frac{F_t \times V_{EV}}{\eta_{SYS}} \quad (3)$$

where η_{SYS} is the system efficiency.

3. DRIVING PATTERN GENERATION OF ELECTRIC VEHICLE

This section describes the process to generate the data that can be used to estimate the loading of the battery, to predict battery power demand from any electrical bicycle, to estimate load profiles demand, the electrical vehicle must be simulated across a variety of actual operating circumstances. In order to simulate an electrical car, it is necessary to have both a detailed features of the vehicle and an understanding of the duty; the vehicle is intended to perform. The description of the vehicle comprises all information required for a dynamic simulation, such as the properties of the battery cells, battery modules, and battery packs, as well as the parameters of the motor, inverter, and drivetrain. For Electrical vehicles, the estimation of the state of charge and the driving range is typically done based on the worldwide standard driving cycles. The driving cycle is a speed-time profile that depicts the usual driving style in a certain city or region, and the driving cycles have numerous uses in the transportation industry, including the estimation of the state of charge, driving range calculations, and energy management optimization tactics. Research on electric vehicle driving cycles is, therefore essential[17][18]. Numerous researchers have created driving cycles that are suitable for real-world use[18]. Here four types of existing drive-cycle profiles that are typically used, are described; The urban dynamometer driving schedule (UDDS) profile is a good indicator of how people drive in cities. The Environmental Protection Agency (EPA) originally established it as a dynamometer test for internal combustion vehicles to verify city driving fuel efficiency; however, the EV community has now accepted it as a measure of electrical efficiency for urban driving as well. The other is the highway fuel-efficiency test (HW-FET), which was developed to analyze highway fuel economy but is now also utilized to assess how well electric vehicles perform on highways. The third one is The US06 drive-cycle profile is representative of mixed highway and urban driving[17]. The last one is the New York City cycle (NYCC) is representative of bus or taxicab driving in New York City and it has been developed to simulate low-speed urban driving with frequent stops[19]. In transportation research, the driving concept has been broadly utilized to characterize driving behaviors. Driving pattern formulations are typically represented by featuring vehicle states.

Driving designs characterized by speed and acceleration profiles had been utilized in emission assessments[20].

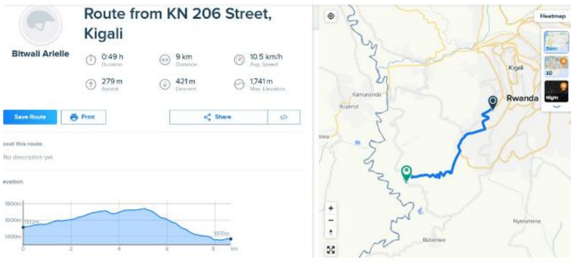

Figure 2. Route from KN 206 Street, Kigali [6]

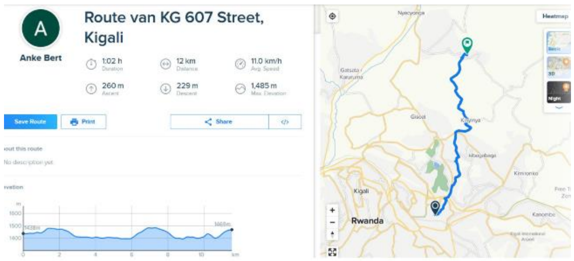

Figure 3. Cycling Route van KG 607 Street, Kigali [6]

The driving pattern analysis focuses on getting accurate energy usage as a function of trip length and it assesses the impact of driving patterns on the vehicle performance, to ensure the e-bike users' driving requirements[21] , As an example, cycling routes available in Rwanda are considered[6]. Here, two cycling routes were chosen; Figure 2 shows the itinerary of a route from KN 206 Street Kigali via KN256 street, the total distance travelled is available on the map and the time required to accomplish this trip was 49 minutes. The other route selected is KG 607 Street Kigali, (see figure3). The total horizontal travelled distance is 12km; while the vertical distance varies between 1438m and 1469m. The time to cover the itinerary is 1 hour and 2 minutes. The same weight (*bike+rider+cargo*) has been considered for both itineraries. The itinerary profiles are uploaded in "WebPlotDigitizer", to be able to generate the driving data from the height profile. For this paper, it is assumed the bike is running at a fixed linear speed (v_{EV}).

$$v_{EV} = \frac{Traveled\ ditance}{used\ time\ (t)} \tag{4}$$

The parameters regarding the vertical motion were obtained by differentiating the vertical position *(H)* in equation (5) and (6). The horizontal component of the speed can be estimated from the constant linear speed (v_{EV}) and the vertical speed v_t.

$$vt = \frac{dH}{dt} \tag{5}$$

$$at = \frac{dv}{dt} \tag{6}$$

$$V_h = \sqrt{v_{EV}^2 - v_t^2} \tag{7}$$

The current profile can be obtained considering the power required for the itinerary (assuming that the traction force of the bike comes from an electric system) and battery voltage [22]as follows:

$$P_b = \frac{Q \times V}{t} = I \times V \tag{8}$$

Combining (3) and (8);

$$I_b = \frac{F_{tot} \times v_{EV}}{V \times \eta_{SYS}} \tag{9}$$

where: V is the battery voltage, I_b is the current discharged from the battery and η_{SYS} is the system efficiency.

4. RESULTS AND ANALYSIS

After generating data using WebPlotDigitizer**,** a program has been developed in MatLab to generate the profiles shown as follows. First, figure 4 shows the variation of vertical speed (v_t) and the vertical acceleration (a_v) with respect to the variation of height for the route KN 206 Street (City of Kigali)

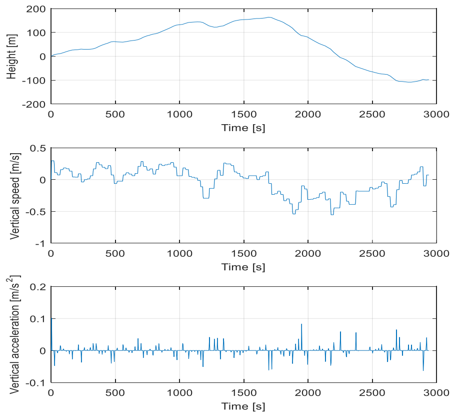

Figure 4. Variation of vertical velocity and acceleration with respect to the height for route KN 206 Street Kigali

As height increases the vertical acceleration decreases and vice versa, for this case the battery energy assists the rider to overcome the inclined plane. Figure 5s shows the horizontal speed (v_h) and the horizontal acceleration (a_h) for the route from KN 206 Street Kigali, where the height increases the horizontal speed decreases as well as the acceleration. In figure 5, the elevation varies by 142m while in Figure 6 the difference between the lowest and highest point is 31m. These conditions affect power consumption.

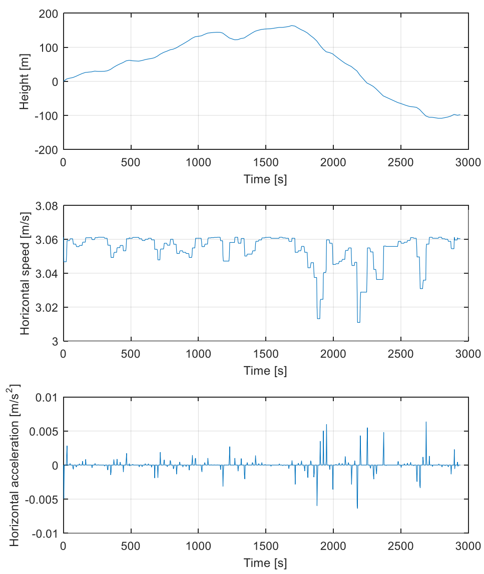

Figure 5. variation of horizontal speed with respect to height for Route from KN 206 Street Kigali

The total extracted power was estimated based on both horizontal and vertical power profiles. Figure 7 shows the net power required by the motor for the Route from KN 206 Street Kigali. The integration of the net total traction power over the whole trip done that the bike requires is 100.4321 Wh for this specific itinerary. The cycling Route van KG 607 Street has a length of 12 km with a low inclination and the maximum required power is 420w (see figure 8). Compared to the one from route KN 206 Street Kigali whose length is 9km and the maximum power is 505.38w, it is clear the more the high vertical speed the more the higher power is needed.

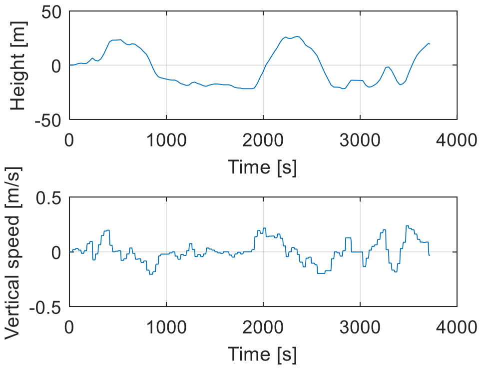

Figure 6. Variation of vertical velocity with respect to the height for route van KG 607 Street

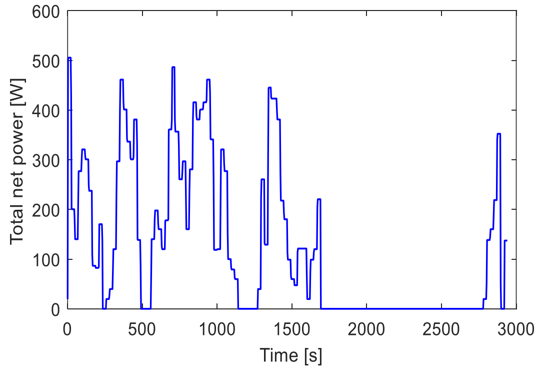

Figure 7. Net total power for Route from KN 206 Street Kigali

An electric bike travelling the Itinerary of Route van KG 607 Street, consumes 78.781Wh. On the other hand, the one for the route KN 206 Street Kigali requires 100.430wh. The power spending depends on the specific elevation profiles of the itinerary. To validate the method used to create the discharging load profiles, the experimental data were compared with the results found using the proposed method. The proposed methodology was used to analyze the consumed energy for the route of queen's Parks, and the data were compared against real data collected in the same route. The total average energy and under peak power respectively obtained from the proposed methodology were 7.60Wh and 393.28W and figure9 shows the compared consumed power for the first four minutes; for both the estimated and the actual values. The total average energy recorded experimentally in [23] was 8.48Wh and the peak power was 400W.

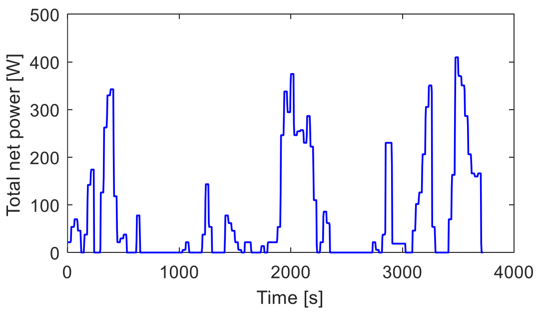

Figure 8. Net total power for Route van KG 607 Street

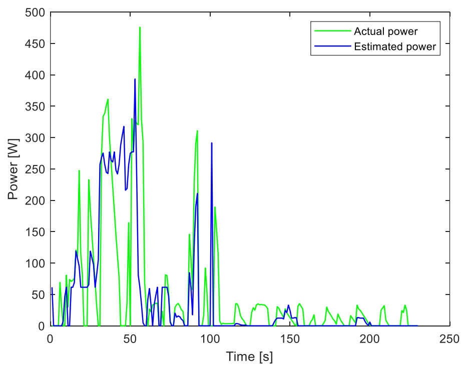

Figure 9. Graph showing both the estimated and the actual power

Considering the quantity of energy for both methods, it is evident the difference is negligible. In case the existing methods to measure consumed energy is not available, the used methodology should be used. The difference observed is due to the speed; the rider will not ride at the same speed rate and the weight of the considered systems are not the same As in[24][23], it is clear that when the vertical height increases the consumed power also increases and vice-versa. When the power is decreasing, it means the slop is tending to zero. For the case where power is null the bicycle is moving without using energy from the battery; it may be on downhill or on zero slop.

Both Figure10 and Figure11 are the curves of the discharged current from the battery for the respective itineraries. For the flat surface, the rider uses his forces and for the hill region, battery energy assists to climb. In descending part, the motor does not provide the power, it is where regenerating happens but, in this research, this case was not considered. These current profiles may be used for further analysis of battery storage system performance.

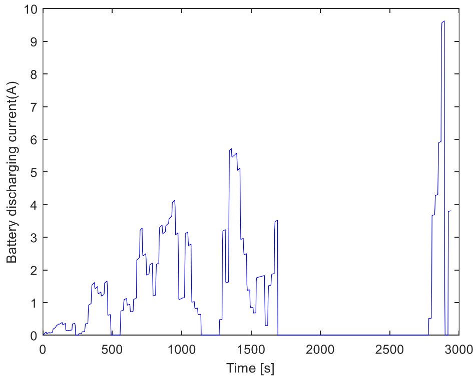

Figure10. Discharged current for Route from KN 206 Street Kigali

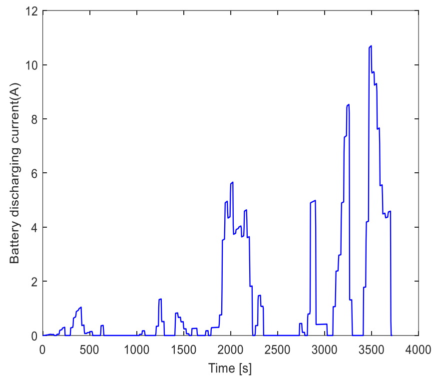

Figure 11. Discharged current for Cycling Route van KG 607 Street, Kigali

Converting the bicycle into an electric one requires choosing the right motor. For the case of e-bicycle, brushless DC motors (BLDC) are found to be most suitable due to their longer life (due to no brushes), high beginning torque, high no-load speed, small energy loss and energy utilization, less space and high volume to weight ratio, reduced estimate and higher proficiency[2], Choosing the appropriate motor will help to design the e-bike system, based on the results of traction power obtained for both itineraries, market availability, the chosen motor is a brushless DC motor (BLDC) with a 36V 500W Rear Hub Motor. It can typically be located in three different places on a bike: Bottom bracket (Mid-drive motor), the front wheel, and the back wheel. Because they take over the wheel hub, the front and rear wheel motors are referred to as hub motors. These motors' main benefit is that they are quite easy to use and uncomplicated[25]. The lithium-ion battery (Kokam cells) module has 36V with 36 cells, where 4 cells are in parallel and 9 in series. This battery has a capacity of 10.8 Ah.

5. DISCUSSION

The methodology presented in this article allows to generate journey data for assessing the power consumed by a small electric vehicle, for a given itinerary. The results show that when the route's elevation is increasing vertically; the vertical power and the higher power from the storage system are needed. This is supported by the findings found by Berntsen et al. where the article shows that the E-bike is faster than a conventional bicycle on the hilly route and the gradient influences the speed and trip duration[26], in the research of Amr Mohamed and Alexander Bigazzi, The focus was on examining systematic differences in speed and road grade dynamics between electric and conventional bicycle trips showed that the direction of grades and speeds matches; the more the grades increase the more the speed increases[27]. For most previous results, the consumed energy for a given route was conducted by using the already established[9], Speed profiles elaborated by considering the specific location; however, for this presented paper; this methodology is easy and applicable to any location. in addition, both the auxiliary devices and regenerative were not considered in this paper, here the effect of auxiliary devices was ignored because the targeted community (Bicycle riders) normally works during the day and their considered small electrical vehicles normally don't need these side-consuming devices. This is just one possible way of calculating the needed power; if the needed data for a very specific path wanted to be defined. The estimated energy to be used for the chosen itinerary was done by using various factors such as the distance of the route, the weight of the rider plus the one for the passenger, the weight of the bike, the terrain, and the speed. These data were used in the dynamic modelling of the small e-bike which is a good part to start with for analyzing the performance of the small electrical vehicle in the hilly region like Rwanda. Future research will concentrate on the effect of the regenerative and side devices that may help to perform the assigned task in a way which is improved.

6. CONCLUSION

An electric bicycle is an equipment that can help to enhance the productive use of electricity in rural areas through transport. To use E-bike system have different requirements, one of the main is the estimation of the energy required for a given itinerary which helps in proper planning. Methodology for modelling the required energy for an electric bicycle was described, by using the online cycling routes available in Rwanda. On the google map, travelled distance, the elevation of the route as well as the time used to complete the route are shown and these data are the ones used as input to the WebPlotDigitizer, which were used to extract the characteristic of the itinerary profile data. These data are saved in a CSV file. E-bike Dynamic equations were developed for the real system and the MATLAB was used to call CSV files data for simulation. Two cycling routes were chosen to be analyzed and it was found that the itinerary with a hillier region, the e-bike consumes much energy compared to the one with few hilly regions; An electric bike travelling the Itinerary of Route van KG 607 Street, consumes 78.781Wh, while the one for the route KN 206 Street Kigali requires 100.430wh. The used methods were validated by comparing the results with the ones found experimentally using sensors and GPS; during the experiment, the consumed power was 400w while the one found using the developed methodology is 393.28W. It was found the difference in both data of 1.68% is small, this difference is explained by the way riders speed, traffic congestion, the density of traffic lights and intersections. This used method of driving energy requirement estimation using WebPlotDigitizer is attractive and easy to apply, it was found its output is similar to the existing method. This methodology is a good method that can be used in place of expensive physical experiments. The found results will be used for sizing the charging station load to be developed based on the average data found during the simulation.

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