Matlab-based High-Performance Electric Motorbike Energy Model, Utilising Video Data.

Tudor Stincescu
Department of Electrical and Electronic Engineering
The University of Sheffield
Sir Frederick Mappin Building
Mappin St., Sheffield S1 3JD, UK
Email: tstincescu1@sheffield.ac.uk

Rui Zhao
Department of Electrical and Electronic Engineering
The University of Sheffield
Sir Frederick Mappin Building
Mappin St., Sheffield S1 3JD, UK
Email: r.zhao@sheffield.ac.uk

Erica E. F. Ballantyne
Sheffield University Management School
The University of Sheffield
Conduit Rd., Sheffield S10 1FL, UK
Email: e.e.ballantyne@sheffield.ac.uk

David A. Stone
Department of Electrical and Electronic Engineering
The University of Sheffield
Sir Frederick Mappin Building
Mappin St., Sheffield S10 1FL, UK
Email: d.a.stone@sheffield.ac.uk

Martin P. Foster
Department of Electrical and Electronic Engineering
The University of Sheffield
Sir Frederick Mappin Building
Mappin St., Sheffield S10 1FL, UK
Email: m.p.foster@sheffield.ac.uk

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Abstract — **This paper presents a novel approach towards modelling energy usage of a high-performance, motorsport-purposed electric motorcycle (eBike) under racing use conditions. While the energy usage is assessed, the simulation robustness is also considered as it will confirm that the chosen modelling approach has a high degree of versatility. The presented research work showcases the presented modelling approach applied as a software model, indicates the chosen methodology for acquiring the required telemetry data and finally presents the results and related conclusions and interpretations and their meaning to the field of expertise and the related project.**

Keywords* — *eBike, Electric Vehicle, Simulation, High-Performance Powertrains, Energy Usage Prediction

I. INTRODUCTION

Over the last decade, there has been a significant increase in the adoption of light Electric Vehicle (EV) powertrains. These are shown to be less polluting with a smaller carbon footprint when compared to their traditional internal combustion engine counterparts.[1]

The process of implementing electrified powertrains as fully developed consumer products has been significantly accelerated around the world by regulations regarding the reduction or net cancellation of greenhouse gases (GHGs) in a relatively short timescale. These policies aim to achieve the emission reduction through quick and reliable implementation of electrified powertrains as means of powering all categories of vehicles, including high-performance vehicles.[2][3]

II. JUSTIFICATION

Whilst plenty of electric powertrain solutions applied to light vehicles exist, research into applying this technology to high-performance vehicles, including racing electric motorbikes (eBikes) is underdeveloped. These, together with the rest of the motorsport sector, including its related logistic operations now form a significant contribution to total vehicle CO_2 emissions.[4]

Similarly, whilst the electric powertrain technology has been successfully trialled as a competitive means to power a motorsport vehicle in other series [5], such as Formula E, the concept has never been meaningfully applied to motorsport-grade motorbikes. Therefore, a clear conclusion regarding the feasibility of implementing the electrified powertrain concept in this field does not yet exist, as key performance characteristics such as the required torque, weight and power for such a powertrain to become competitive were not measured.

In order to benchmark such performance characteristics as well as to understand the design requirements and implications of swapping a traditional ICE for an e-Motorbike, more telemetry data is required. Whilst this can be acquired through real-life motorsport testing, acquiring data in this way implies expensive operations in terms of logistics and manufacturing, and motorsport companies may not deem these priority activities.

An alternative to real-life testing is represented by software modelling and simulation methods. These have greatly improved in terms of precision, performance, and usability in recent years [6], making it a cheap and viable alternative to other conventional methods. [6] Furthermore, the predictions generated by software modelling techniques

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can be extended to road-legal motorbike manufacturers, demonstrating the value and significance of the engineering and economic potential of such modelling solutions when considering the entirety of the market.

This project also serves as an extensive study that builds on previous research concerning the energy usage of electric refuse collection vehicles (eRCV) fleet under normal operation conditions throughout the week[7]. This "extension" of the project targets to understand the flexibility of the chosen mathematical approach and its software application when applied to various vehicles with different performance characteristics and driving styles.

III. AIMS

The aim of the project is to deliver a white box turn-key simulation solution, able to deliver meaningful predictions on energy consumption and power losses alongside vehicle behaviour and other important parameters relevant in estimating vehicle wear and vehicle diagnosis at a subsystem-level.

This paper proposes a novel approach to software modelling of an eBike using the Matlab / Simulink [8] platform, employing state of the art model-based programming through SimScape [9]. The approach demonstrates how a novel interval modelling methodology, based on speed mapping against time, can be applied to the problem of understanding vehicle energy usage for engineering design purposes through simulation rather than real-life testing. Traditional modelling approaches based on speed profiling may result in completely unreliable predictions for motorsport vehicles such as eBikes, as under normal circumstances these are subject to more aggressive driving, represented by full-throttle, maximum braking cycles and therefore require a highly-responsive system and simulation environment.

IV. METHODOLOGY

The proposed methodology for achieving the presented solution is based on a 2-stage process.

The first stage is concerned with acquiring the required telemetry data. In order for the model to perform a simulation, an input dataset is required, consisting of a speed-time and slope-time value pairs. Due to lack of publicly available telemetry data, a traditional, commonly used route emulation solution cannot be used since there is little to no data upon which speed-time datasets can be formed.

A potentially good source for acquiring this data has been found in publicly available videos that show replays of different competitors lapping around the Isle of Man racecourse, together with graphical interfaces that show the speed of the vehicle in real-time. By using OCR (optical character recognition) and image colour filtering technologies, and applying them to one of these videos via Python language-based, software-coded algorithms, a pseudo-telemetry, speed-time dataset can be extracted that is usable as input data for the Matlab software model. The low-level methodology employed in the software-based algorithm, together with its usage sub-definitions go beyond the scope of this paper.

Several videos have been trialled as potential candidates for harvesting the required data. One of the main challenges posed by this approach consists of image contrasts. To ensure a high degree of accuracy, the OCR technology requires a high contrast between the background image video, and the image from which the values need to be extracted (the foreground image). Since the background image will not be static as it consists of an onboard camera recording, the contrast can be improved by filtering the image colours so that low contrast colours intensity is minimised, and high contrast colours intensity maximised.

Unfortunately, no reliable onboard recordings of EV motorbikes were found in the public domain, therefore the only video selection criterion was higher value harvesting accuracy. While a good ICE-powered motorbike recording candidate was found and a high-accuracy speed-time telemetry has been harvested from the recording, the onboard speeds achieved in the video were significantly higher than the performance capabilities of a typical EV motorbike, however, linear mapping of the ICE-based data onto the performance envelope of a typical high powered electric motorbike allowed a proof of concept simulation

Finally, this acquired telemetry data is used as input information for the electric motorbike model and consists of approximately 4 laps of data. There is no clear delimitation between all the laps that can be derived from the speed-time information alone, but a clear one-lap telemetry has been identified by visually inspecting the speed-time telemetry value-pairs and looking for longer periods of zero speed idling.

The second process stage consists of the actual simulation environment and its related model-based vehicle. This employs the Matlab / Simulink programming environment, together with the SimScape Simulink library to help with building the eBike model.

The vehicle model used for this study is currently set up to simulate the physical parameters and physics of an eBike but can simulate any battery electric vehicle (BEV) by changing the default physical parameters. The drivetrain topology is a simple single pipeline consisting of Battery-DC Motor-Gearbox-Aerodynamic model, as seen in figure 1.

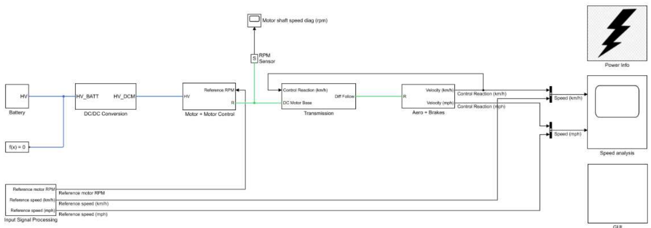

Figure 1. eBike software model.

The proposed software model has been developed employing a modular software development approach, taking full advantage of the SimScape and Simulink simulation environments and capabilities. This offers a high degree of simulation versatility and energy prediction results usability, while ensuring minimal error when compared to real-life data.

Thanks to the optimised integration of SimScape within the Simulink environment and the modular approach developed, complex systems can be interfaced with relative ease by separating the physical contexts within the simulation and using special blocks to link these together. Therefore, the mechanical environment of the simulation is separated from the electrical side, one having the ability to model system-level constraints (such as efficiency) individually, at block-level.

System response and control is achieved by employing the use of a custom-designed control module, including a proportional-integral-derivative (PID) controller. Its output is fed through a response limiter to the DC Motor block, that emulates a DC Motor in torque/current-control mode. The P, I and D values of the controller have been tuned using the built-in Simulink control tuning software. Some fine tuning has been carried since to prevent any potential minor control loss issues.

The aerodynamic & brake block model includes a basic vehicle aerodynamic model as well as the braking force generators required for braking, which are controlled by the previously presented control module.

The transmission block includes the gearbox and the overall final drive gearing models.

The battery model block includes the battery model together with some measurement blocks. The modelling takes into account battery internal resistance, which can be observed under figure 2b, bottom left.

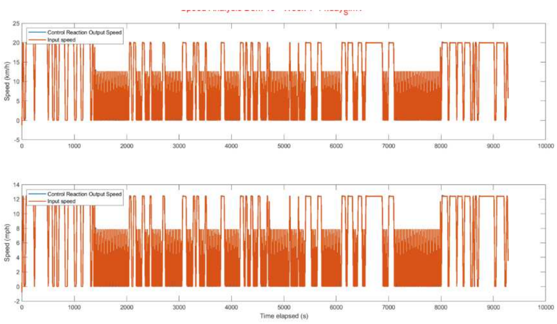

Figure 2a. Example of speed analysis based on input telemetry.

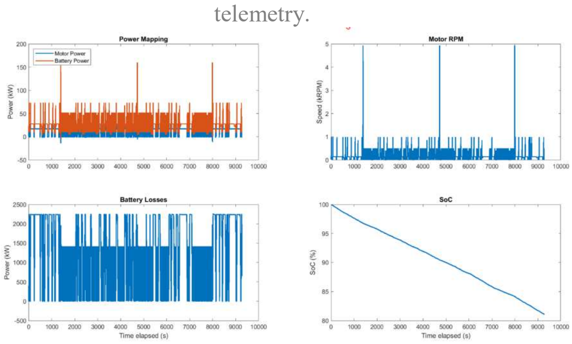

Figure 2b. Example of power prediction info based on input telemetry.

The model's main capabilities include the ability to monitor the predicted speed at a second-by-second level, as well as showing predicted energy usage and other information related to vehicle power delivery, as seen in figures 2a and 2b.

Results obtained when running simulations in previous validation and testing project phases indicate that the model has an average error rate of 8-10% in energy usage prediction when compared with real-life logged data. The error rate variability is dependent on the accuracy of the real-life data logs, the vehicle and powertrain topology as well as the usage context.

Finally, the high-level proposed solution's system workflow is represented in broad steps in figure 3.

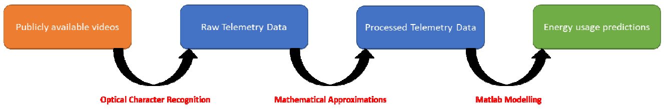

Figure 3. Proposed simulation approach high-level diagram.

V. RESULTS

Simulating the video-harvested, pseudo-telemetry data took, on average, 278.4 seconds, with a relative simulation environment solver tolerance of 1e-4. Some minor control issues have been observed, similar to the ones exhibited by the model when simulating other types of powertrains, where the control module fails to adjust the system response so that the model can accurately match the speed in the input data. This could be due to a lack of finer tuning of the proportional and integral values of the PID controller, however, the speed delta between the input and the system response is small, hence it does not make a significant difference in energy usage.

When applying the procedure described at the end of section IV, the telemetry of one lap can be identified between simulation time 2277s and 3388s in Figure 4a, highlighted by the blue oval.

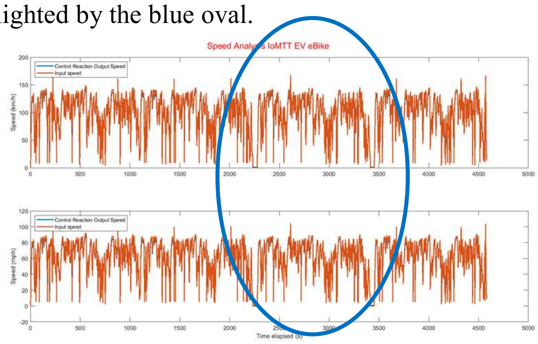

Figure 4a. Isle of Man TT telemetry. Top – speed(kph) v time elapsed(s), Bottom – speed(mph) v time elapsed(s)

From the simulation data, it can be estimated that the energy usage for a given track lap is between a minimum of 20.8 kWh and an estimated maximum of

22.2kWh.

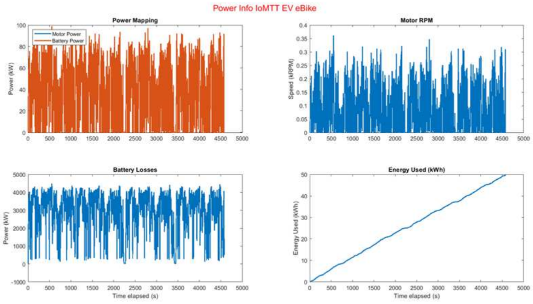

Figure 4b. Isle of Man TT telemetry, power prediction info. TL – Power Measurements (kW - battery & motor), TR – Motor RPM, BL – Battery Losses (kW), BR – Energy Usage (kWh)

It is worth noting that whilst some regenerative braking energy has been observed in the simulation, it is relatively small and within the simulation tolerance, so it cannot be considered meaningful energy saving in this application. One possible reason for this could be the aggressive acceleration-braking schedule which does not allow braking through motor inertia and consequentially energy generation. This factor is intrinsic to the performance of the vehicle and therefore it cannot be significantly changed. Another potential reason may lie with the technical parameters of the vehicle and the approximations considered for the missing parameters, as these might describe a vehicle incapable of performing energy generation through motor braking.

The presented software solution has been used to measure energy usage of a high-performance, race-ready, Isle of Man TT specification electric motorbike with telemetry representing several qualifying pace laps around the Isle of Man TT racecourse. From the available data, an average energy usage figure of 20-22 kWh per lap can be observed.

When comparing the energy use with other figures present in literature [10], although lack of data and lack of correlation regarding vehicle use, context, and type of powertrain is significant, the simulation results are on average within 10% of literature benchmarks. This is in keeping with the percentage errors observed when testing the model adapted for other powertrains and use contexts. A further factor that influences the increased energy usage lies with the lap times – the telemetry data points to a significantly lower lap time than those achieved in literature.

However, it can be seen that the model simulation is robust and did not fail or exhibited major errors in simulation, showing a solid proof that the presented approach is flexible and can be successfully employed to simulate a plethora of powertrain types, with much better accuracy if highly representative technical parameters and input data is available.

Although the available data for this project has been limited to publicly available high-level technical data and live recorded on-board videos, it has been possible to examine energy usage. The results are in line and can be successfully associated with other conclusions present in similar literature [10], supporting the argument towards validating the presented solution from a performance perspective.

VI. Conclusions

The results illustrate that the model described in this paper is robust and did not exhibit calculation or convergence failures during simulation. This presented approach is demonstrated to be highly flexible in simulating such high-performance electric powertrains, with the potential of significantly increased precision if representative technical parameters and input data are to be available.

The proposed solution has the potential to present itself as a viable, cheap and productive alternative for designing optimised high-performance motorsport eBike vehicles through understanding energy usage and system component sizing, but also in offering predictions concerning their CO_2 footprint as well as the expected lifetime of certain powertrain components, such as the battery and the electric motor.

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