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COMPUTATIONAL MODEL FOR PREDICTING THE REMAINING BATTERY ENERGY OF AN UNMANNED AGRICULTURAL GROUND VEHICLE

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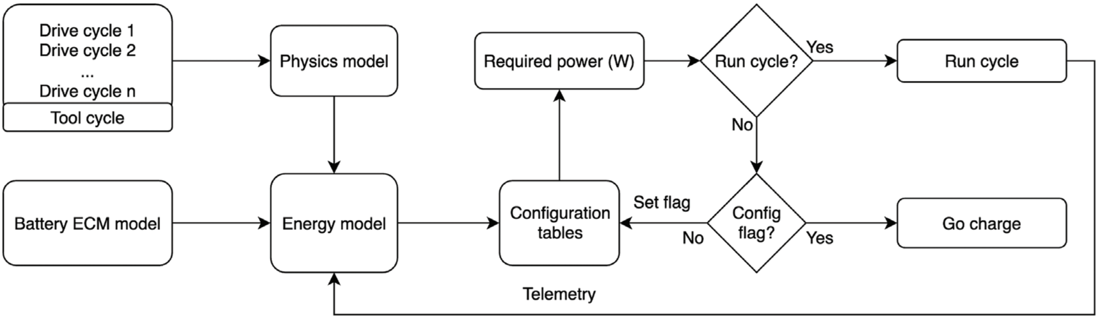
Abstract – This paper presents a computational model and an approach for predicting the remaining battery energy of an autonomous unmanned ground vehicle (UGV) used for fertilizer application in blueberry plantations under the soil conditions of drained peatlands. The primary objective of the study is to optimize battery operating modes by reducing non-productive energy consumption, justifying an appropriate depth of discharge, and extending the service life of the energy storage system. To achieve this, a computational model for energy consumption estimation and prediction is proposed, enabling an optimal for battery operating regime of the field UGV under operator defined constraints. The developed model supports dynamic adaptation of work cycles, minimizes non-productive motion, and maintains the state of charge within ranges that are optimal for the specific battery chemistry. The proposed approach combines a rolling resistance based vehicle motion model with a temperature dependent Thevenin equivalent circuit model (ECM) of the battery pack. Based on a set of typical duty cycles, the developed vehicle model determines the mechanical power required for the planned operation. Battery parameters are obtained from cell characterization data, including the open-circuit voltage-state of charge (OCV–SOC) relationship, ohmic resistance, and polarization dynamics. The state of charge and polarization effects are estimated using an extended Kalman filter (EKF), which is driven by measured current and corrected using voltage measurements with temperature dependent parameter scaling. To reconcile the calculated energy demand with measurement results, a drivetrain efficiency map dependent on speed and torque was developed. This map was identified using controller area network (CAN) bus, IMUs, and current measurement data by comparing the predicted mechanical power with the measured electrical power. The resulting efficiency map captures losses in the hub motors, power controllers, wiring, and auxiliary systems, and is used for mission simulation and real-time prediction of voltage, power, and remaining usable energy under alternative combinations of drive cycles. The approach was validated on an autonomous agricultural UGV developed by the Field Robotics Research Group of the Estonian University of Life Sciences. The platform is equipped with four 48 V, 1 kW hub motors, an onboard computing system based on two Raspberry Pi Zero 2W units, CAN communication, motion sensing via OpenLog Artemis IMUs, and a lithium-ion battery pack based on Samsung SDI 94 Ah cells.

Keywords – Autonomous agricultural robotics; equivalent circuit models; extended Kalman filter; mission-aware energy estimation; power consumption models; power management optimization



Flow diagram of computational model

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