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Original Research Article

Development of a Digital Twin Software Application for Performance Assessment on Electric Vehicles

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ABSTRACT

The application of a digital twin in automotive industry is a virtual replica of vehicle mechanics, electrics and physical behaviour involving internet, artificial intelligence, machine learning, predictive analysis, simulation tools, 5G, and virtual sensors. This research developed an application digital twin software (ADTS) for the performance assessment on linear to circular economic innovation in automotive industry. ADTS measured electric vehicle (EV) performance respect to time, distance, speed, and battery level utilizing computer program to replicate the processes. The attached ADTS measured data from the electric vehicle on testing at different stages of speed levels A and B. C++ computer language was employed to create simulations that predicted how a product and process performance enhance higher degree of control over memory. ADTS predicted the behaviour of the electric cars for an increase in time leading to increase in the speed but battery level depreciation. At low speed, results of EVs tests cemented the findings of battery voltage consumption level in test A higher than test B at high speed. EVs ran at low speed consumed more energy than that of high speed. As the EVs assumes appreciable speed, the momentum increases, and inertia decreases at less power. DTS drives innovation and predicted EVs against failure complex systems.

1. INTRODUCTION

Worldwide transportation accounts for 18% of global carbon dioxide emissions as of 2019 (Dimitrios and Antreas, 2022). Mitigating the impending threat of climate change, consumers and industries must adopt sustainable transport practices that comply with the United Nations Sustainable Development Goals of increased energy efficiency and reduced greenhouse gas emissions. In light of this, a new class of vehicles has recently emerged (smart electric vehicles) to reduce carbon dioxide emissions up to 40% compared to diesel engine vehicles (Ghanishtha *et al.,* 2021).

The act of bringing these vehicles to the mainstream, supporting architecture is needed to optimize a sustainable manner such as a novel architecture of digital twin technology. Digital Twin technology is used in a wide range of applications, including electric vehicle. The platform provides a virtual representation of a physical object in real-time and implementation on various aspect of EVs. The DT emulates the actual vehicle on the road to predict and optimize its performance and improve vehicle safety. The numbers of electric vehicle on the roads are increasing every year as people become more environmentally conscious and gasoline prices are becoming volatile (Leitman and Brant, 2013). Therefore, the need to build more robust, efficient and reliable EVs through the application or adaption of digital twin technology is necessary. DT is basically a virtual counterpart of a physical asset which increases operational efficiency of vehicle physical counterpart using real-time data (Yash and Seema, 2019).

The automobile sector uses digital twin for simulation of vehicles capturing the behavioral and operational data of the vehicle and analyze the overall vehicle performance, delivering a personalized service for customers. DT is used in the powertrain of electric vehicles, health monitoring, diagnosis, prediction, optimization, risk assessment, troubleshooting and testing to minimize rate of failure (Nureni et al, 2022). This is developed for a range of assets, including the system level, subsystem level, individual component level, and various others levels within the electric vehicle powertrain (Diwakar et al., 2019; Xiaokang et al, 2024).

Digital twin technology is a valuable tool in the electro-mobility field, facilitating the implementation of diagnostic and prognostic algorithms that provides various benefits, including increased vehicle lifespan and optimal performance, ensured health monitoring and maintenance, as well as optimized battery management and efficiency (Yassine *et al.,* 2023). A framework based on digital twin for real-time monitoring, intelligent management, and autonomous control of battery packs was designed. Deploying DT into the battery packs of electric vehicles improved the safety and service life of the battery packs (Suriyan et al., 2023). A performance comparison of different motor types via permanent magnet synchronous motor (PMSM), permanent magnet synchronous motor Brushless (PMSMB) and brushless direct current electric motor (BDCEM) of the ceryan brand vehicle model in terms of energy consumption and acceleration, utilizing real-time road data was tested and confirmed PMSM brushless motor as best (Abdurrahman *et al.*, 2024). Implementing digital twin technology helps organizations to get real-time on-road insights and prevent failure by predicting it, even before the user receives the products (Akshay and Abhijit, 2023).

In addition, digital twins can be used to effectively address the issues in electric vehicles services such as tracking, monitoring, battery and charge management, connectivity, security and privacy. This technology helps to overcome the constraints of real environmental factors affecting electric vehicle systems (Wasim *et al.,* 2023; Yao *et al.,* 2023). The use of digital twin in practice is based on sensors that gather real-time data and connect to a cloud-based system that receives and processes all through which a system can be replicated and its future is accurately predicted (Luke James, 2022). The paper concentrates on highlighting the potential for artificial intelligence (AI) integration to further enhance the capabilities of digital twin technology and drive innovation in various industries. It therefore developed a digital twins software representation and modeling capable of expanding and improving the lifecycle of complex systems and processes of electric vehicles.

2. MATERIALS AND METHODS

2.1. Digital Twin Description and Methodology

An esp32 microcontroller embedded Wi-Fi client connected to internet was used to perform a wireless transaction between a system and user. The hardware includes the real-time clock (RTC), hall motor speed sensor and battery level sensor connected to the esp32 microcontroller. RTC has time stamp of the test-running time and the hall motor speed sensor measures the revolution per minute of shaft output from the electric vehicle engine. An android application was developed to initiate test-run data capturing process. Initiating a test run process on the android application, the esp32 module capture the signal sent by the application internet. When the signal sent initiates a test-run process, the digital twin system initiates the RTC, hall motor speed sensor and battery level sensor to start capturing. respectively. The digital system was programmed to capture and send data to the cloud server at an interval of 1 minute. The data sent to server by the digital system is RPM, speed, battery level in voltage and time stamp in minute. The data collected was simulated and used for prediction purpose. The digital twin hardware consists of the following elements:

i. ESP32: It is a series of low-cost, low-power system microcontroller with integrated Wi-Fi and dual-mode Bluetooth. It includes built-in antenna switches, RF balun, power amplifier, low-noise receiver amplifier, filters and power-management modules. This microcontroller was adopted for its ability to access internet on its own when programmed. It also has the ability to read and write digital signals.

ii. Hall motor speed sensor (HMSS): The speed sensor is a linear magnetic hall sensor that reacts to magnetic field. The analog output measures the polarity and relative strength of the magnetic field. While the digital output of the sensor was implemented in the digital to count the rpm generated by the engine.

iii. Real-time clock (RTC): The DS1307 with an inbuilt temperature compensated crystal oscillator (TCXO) and crystal is both low-cost and exceptionally precise. It keeps track of seconds, minutes, hours, days, dates, months, and years. The clock has an AM/PM indication and works in either a 24-hour or 12-hour mode. Two programmable time-of- day alarms are included, as well as a programmable square-wave output. An I2C bidirectional bus is used to transport address and data serially.

iv. Battery level sensor (BLS): This module comprises of resistors which act as a voltage divider that breaks the voltage from high to a lower voltage. Sensor communicates with an analog output pin, and it is a real time battery level monitoring sensor.

C^{++} is the language adopted in programming DT on the Arduino platform. In the developed digital twin program, all electronic components used were soldiered together. Each component was tested for functionality and the code was uploaded to the ESP board through USB cord from the PC. A frontend and backend web program were written to take in the information sent from the ESP board and display it on the mobile application through the means of internet. Since the battery level determines the longevity of the system, the digital twin system (DTS) helps to monitor the battery level of the system while running, to keep the record of the voltage drop in relation to the speed of the system. Therefore, obtained data can be used to optimize the battery capacity or upgrade the battery capacity

3. RESULTS AND DISCUSSION

On road testing undertaken for 10 minutes each at different experimental stages within Federal University Oye-Ekiti premises, Ikole-Ekiti campus, the digital twin system adapted with the electric vehicle measured output data from the android application developed. Figure 1 and 2 show the results of drive tests conducted with the digital twin system for performance assessment in respect of distance, speed, battery level and time (minute). Figure 1 shows the relationship in respect of time, distance, speed, and battery level when the electric vehicle runs at high speed. As distance covered and speed increase, the battery level depreciates. But as the car gains a certain level of speed, the momentum increases while inertia decreases and the car move at uniform motion with less battery consumption.

Figure 2 represents speed, distance and battery level relationship. An increase in speed implies corresponding increase in distance covered with decrease in battery level in consonant to Moh'd *et al.*, (2015) assertion. Figure 3 indicates an increase in battery consumption as the car spent more time in motion. An increase in speed implies more battery consumption as stated in Naseri *et al.*, (2023). Figure 4 shows the behaviour of time, speed, distance and battery level when the car is at high-speed Naseri *et al.*, (2023). As the vehicle gain certain level of motion, the momentum increases while inertial decreases; at this point, speed remain constant and battery consumption is less. The Figure 5 indicates an increase in distance with increase in speed while battery consumption is constant when the car is in constant motion as reported by Mohsen and Bilge (2023).

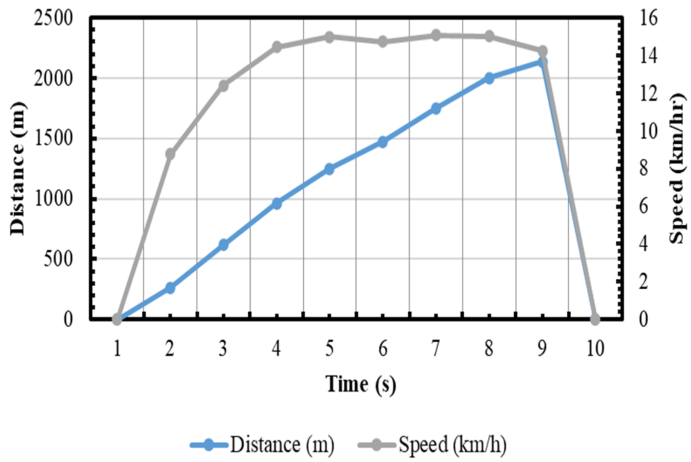

Figure 1: Effect of time on speed and distance for drive test A

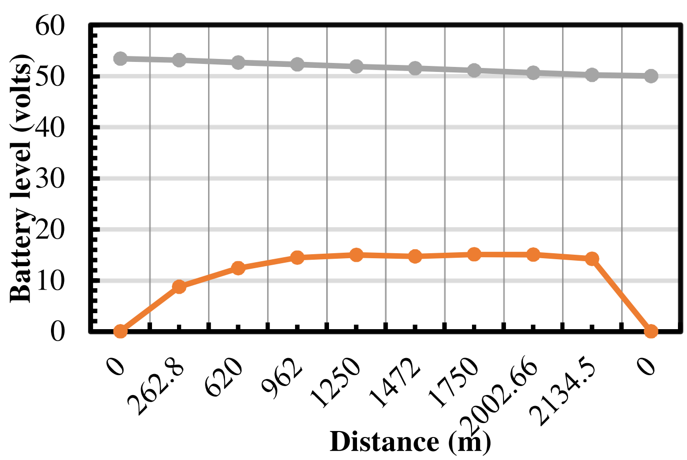

Figure 2: Effect of distance on battery level for drive test A

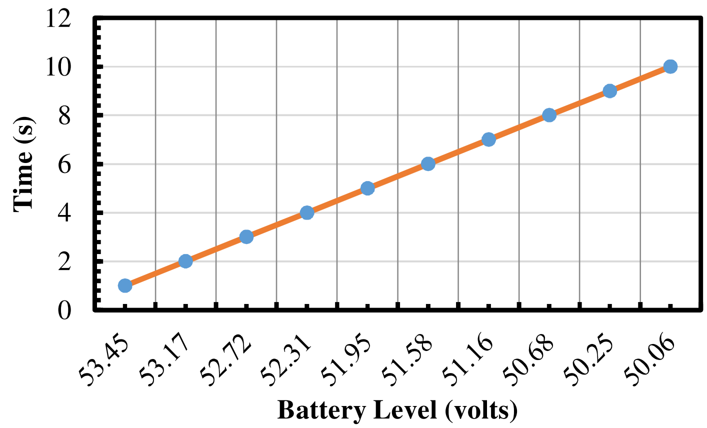

Figure 3: Relationship between time and battery level for drive test A

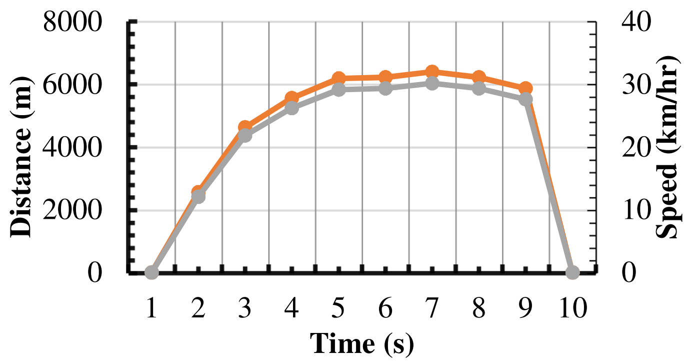

Figure 4 Effect of time on speed and distance level for drive test B

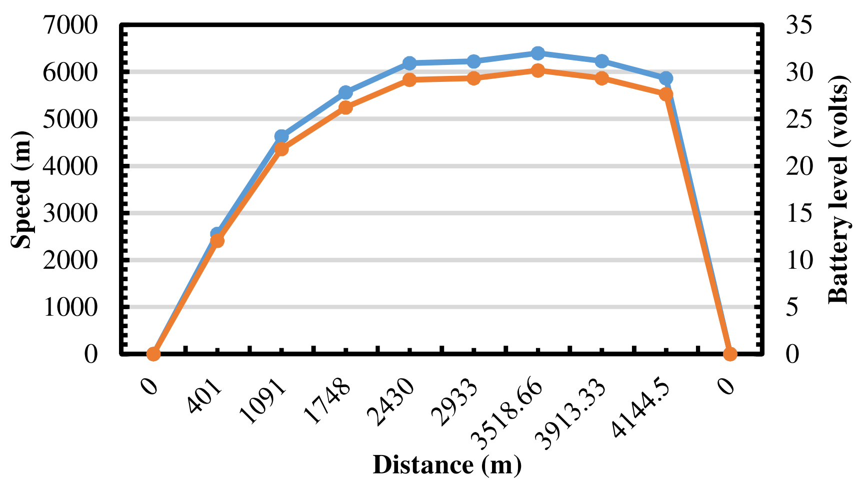

Figure 5: Effect of distance on speed and battery level for drive test B

At two different experimental runs for ten minutes on road testing within Fuoye's premises Ikole-Ekiti Campus, the digital twin system measured the output data on driving. Figures 1and 2 show test result for distance covered (rpm), speed in km/h, and battery's level in voltage and time stamp in minute. In tests A and B conducted, the behaviors of speed, time, distance and battery level relationships were presented in agreement to Diwakar et al., (2019). As time increases, the speed also increases and battery level depreciates as contained in Besselink et al., (2010). This explains the relationship between times, speed and distance cover under the usual conventional vehicle for which fuel level decreases as all these parameters increases. In addition, the speed increases in both revolution per minute and km/h. The battery voltage consumption in test A is higher than the voltage consumption for test B making it better than Abdurrahman *et al.*, (2024) report. This implies that, as car run at low speed, more energy is consumed than in high speed. It is a justification that as vehicle assumes some certain appreciable speed, the momentum increases and the inertial decreases with less power in the vehicle's speed at constant motion.

4. CONCLUSION

A digital twin software for electric vehicle performance assessment and prediction has successfully been developed. The application of the software is powered by a traction of 48v, 115A, and 5.5kw series wound DC motor powered by 28.8 kWhr capacity while computing and simulating data. Physical system and behaviour of the vehicle are identified and modified in its real-time behavior in respect of distance, speed, and battery consumption by the software. ADTS allows the simulation to precisely mirror the real-world condition of the electric vehicle for performance evaluations. The outcomes help in the realization of the true cyber-physical system through the digital twin that has a dynamic interconnected nature with the physical model through real-time sensory data. The DTS data in simulation is used to predict electric vehicle performance, enhancing safety, and optimized battery management and efficiency.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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Appendix

The developed digital twin software using C++ language programming is as stated.

```
#include <EEPROM.h>
    #include "soc/soc.h" // Disable brownour problems
    #include "soc/rtc_cntl_reg.h" // Disable brownour problems
    #define EEPROM_SIZE 64
    #include <WiFi.h>
#include <HTTPClient.h>
#include <Wire.h>
#include <ErriezDS1307.h>
// Create RTC object
ErriezDS1307 rtc;
#define TACH_PIN 2 // пин тахометра (желательна внешняя подтяжка 4.7к к VCC)
#include <Tachometer.h>
Tachometer tacho;
volatile byte pulseCount;
//const char* ssid = "TECNO CAMON 12";
//const char* ssid = "itel P36";
const char* ssid = "Infinix HOT 9";
const char* password = "Adejumosam.01?1";
//const char* password = "olasuccess";
//const char* serverName1 = "http://http://sensor.energymata.com/api/submit";
const char* serverName1 = "http://nocktin.scienceontheweb.net/postdata.php";
//const char* serverName2 = "http://jentrygo.000webhostapp.com/postdata2.php";
String apiKeyValue = "tPmAT5Ab3j7F9";
int BLpin = 34;
float BL;
int BLval;
int pulse = 15;
int pVal = 0;
float unit;
String state;
int counter;
int counter1;
int conu;
int Count = 0;
int check = 0;
String file;
float Speed;
float diameter = 2.5;
int speedVal;
int rpm;
int ss;
int interval;
long previousMillis = 0;
int check1 = 0;
```

```
int s1;
int s2;
int m;
int mm;
void IRAM_ATTR pulseCounter
{tacho.tick;}
void setup
 {
WRITE_PERI_REG(RTC_CNTL_BROWN_OUT_REG, 0); //disable brownout detector
Serial.begin(115200);
EEPROM.begin(EEPROM_SIZE);
// pinMode(BLpin, OUTPUT);
pinMode(pulse, INPUT);
pinMode(0, INPUT);
WiFi.begin(ssid, password);
Wire.begin();
Wire.setClock(100000);
// Initialize RTC
while (!rtc.begin()) {
Serial.println(F("RTC not found"));
delay(3000);}
// Set square wave out pin
// SquareWaveDisable, SquareWave1Hz, SquareWave4096Hz, SquareWave8192Hz,
SquareWave32768Hz
rtc.setSquareWave(SquareWaveDisable);
pinMode(TACH_PIN, INPUT_PULLUP);
// настраиваем прерывание
attachInterrupt(digitalPinToInterrupt(TACH_PIN), pulseCounter, FALLING);
while (WiFi.status() != WL_CONNECTED) {
delay  (500);
int counter = Count++;
Serial.print("Connecting to WiFi..");
Serial.println(counter);
if ( counter == 2)
{ESP.restart;}}
Serial.println("Connected to the WiFi network");
Serial.println(WiFi.localIP;
check = 1;
check1 = 1;}
void loop
{
Serial.println(" ");
Serial.println(" ");
Serial.print("speed: ");
Serial.println(Speed);
BLval = analogRead(BLpin);
```

```
BL = ((BLval/1240.0)*12) +0.9; //219
Serial.print("battery level: ");
Serial.println(BL);
Serial.print("ss: ");
Serial.println(ss);
Serial.print("check: ");
Serial.println(check);
static uint32_t tmr;
if (millis() - tmr > 100) {
Serial.print("RPM: ");
tmr = millis();
// RPM
rpm = tacho.getRPM() / 2;
Speed = diameter * rpm * 0.001885;
Serial.println(rpm);
}
static uint8_t secondLast = 0xff;
uint8_t hour;
uint8_t minute;
uint8_t second;
if ((WiFi.status() == WL_CONNECTED)) { //Check the current connection status
HTTPClient http;
http.begin("http://nocktin.scienceontheweb.net/update.php"); //Specify the URL
int httpCode = http.GET();
if (httpCode > 0) { //Check for the returning code
state = http.getString();
ss = state.toInt();
Serial.println("online captured state");
Serial.println(state);
Serial.println(ss);
} else {
Serial.println("Error on HTTP request");
}
http.end(); //Free the resources
}
if ( ss == 1 && check == 1) {
Serial.println("working");
}
unsigned long currentMillis = millis();
if ( ss == 1 && check == 1 && currentMillis - previousMillis > 1 * 1000) {
if(check1 == 1) {
if (!rtc.getTime(&hour, &minute, &second)) {
Serial.println(F("Error: DS1307 read failed"));
} else {
// Print RTC time every second
if (second != secondLast) {
```

```
secondLast = second;
s1 = second;
}
}
//delay(1000);
check1 = 2;
}
if (!rtc.getTime(&hour, &minute, &second)) {
Serial.println(F("Error: DS1307 read failed"));
} else {
// Print RTC time every second
if (second != secondLast) {
secondLast = second;
s2 = second;
mm = minute;
// if ( s2 >= s1) {
// m = s2 - s1;
// }else if (s2 <= s1) {
// m = ((s2 + 60) - s1);
// }
//
// if (m == 0) {
// counter1 = conu++;
// mm = counter1;
// }
Serial.print("first second = ");
Serial.println(s1);
Serial.println("");
Serial.print(" 2 second = ");
Serial.println(s2);
Serial.println("");
Serial.print("second = ");
Serial.println(second);
Serial.println("");
Serial.print(" current interval = ");
Serial.println(mm);
Serial.println("");
Serial.print("mintue = ");
Serial.println(m);
Serial.println("");
}}
if(WiFi.status()== WL_CONNECTED){
HTTPClient http;
// Your Domain name with URL path or IP address with path
http.begin(serverName1);
// Specify content-type header
```

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```
http.addHeader("Content-Type", "application/x-www-form-urlencoded");
// Prepare your HTTP POST request data
String httpRequestData = "&rpm=" + String(rpm) + "&speed=" + String(Speed) +
"&batterylevel=" + String(BL) + "&time=" + String(mm) + "";
Serial.print("httpRequestData: ");
Serial.println(httpRequestData);
int httpResponseCode = http.POST(httpRequestData);
// Serial.println("recharge comfirmed");
if (httpResponseCode>0) {
Serial.print("HTTP Response code: ");
Serial.println(httpResponseCode);
String state2;
state2= http.getString();
Serial.println(state2);
}
else {
Serial.print("Error code: ");
Serial.println(httpResponseCode);
}
// Free resources
http.end();
}
else {
Serial.println("WiFi Disconnected");
}
// }
previousMillis = currentMillis;}
}
```