Newtonia Capstone Project

A PROJECT REPORT

Submitted by

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in

Information & Communication Technology

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Project Definition and Scope

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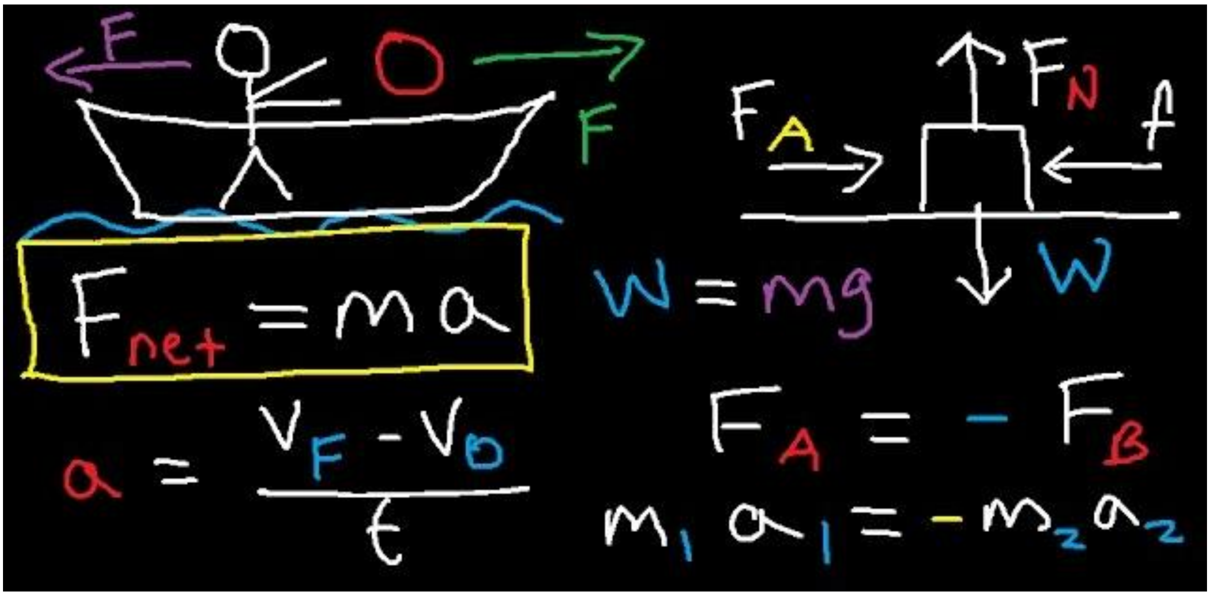
1. Introduction



The **Newton's Laws of Motion** were first introduced by **Sir Isaac Newton** and originally published in 1687. These three laws describe the relationship between **motion and force.** Students typically learn these concepts in classes from grades 8 to 12, especially in physics, where the subject is often taught in a theoretical way—teachers explain the concepts without practical demonstrations that make them easier to understand on the spot.

The **Newtonia Project** aims to bridge this gap by developing **Newtonia devices** that teachers can use to explain these laws, while allowing students to interact with them and gain hands-on experience. Through this approach, learners can engage with various physical quantities and observe them on **Real-time visual displays** while interacting with the Newtonia device. This also helps highlight the difference between ideal physics (theory) and real-world physical behavior.

By using **Embedded system design,** we can implement these concepts in everyday objects like toy cars, balls, or other items. Real-time data such as acceleration, velocity, position which can be measured and transmitted wirelessly from the **Newtonia device** to a computer, where it is shown on an interactive and visually engaging display.

2. Problem Statement

The fundamental concepts of **Newton's Laws of Motion** are often taught in a purely theoretical manner in schools, particularly between grades 8 and 12. While teachers explain the principles of motion and force, students rarely get the opportunity to observe or interact with real-world demonstrations of these concepts. This gap between theory and practice makes it difficult for learners to fully grasp the difference between idealized physics models and real physical behavior.

There is a lack of interactive, hands-on tools that allow students to visualize and experience physical quantities such as **acceleration, velocity, and force in real time**. Without practical exposure, students struggle to connect classroom learning with real-world applications, which limits both understanding and interest in the subject.

3. Objectives

- To help students understand Newton's Laws of Motion in a simple and practical way.
- To show the difference between theory taught in class and real-life physics.
- To create devices that can measure things like speed, force, and acceleration.
- To display these measurements on a screen wirelessly in real time.
- To develop small embedded systems to collect and send data wirelessly.
- To make physics more interesting and easier for students to learn.

4. Relevance to ICT domain

Newtonia Project is very relevance to ICT domain because it use ICT technology. The project applies embedded systems, sensors, and wireless communication to collect real-time data such as speed, force, and acceleration. This data is then sent to a computer or mobile and shown on the screen through a visual display.

In this way, ICT tools like data processing, wireless transfer, and visualization are used to make physics more practical and interactive for students. The project shows how ICT can be applied in the education field to create smart learning systems.

5. Feasibility Analysis

5.1 Technical Feasibility

The Newtonia Project can be built using Embedded System. For Hardware, we can use ESP32 Microcontroller with BLE & Wi-Fi, Accelerometer & Gyrometer MPU6050, Motor Encoder, Position Sensor, Inertia Sensor, 3.7V Battery & PCB. For Software, we can use HTML, CSS, Python or Node.js to display basic visualization frameworks.

5.2 Economica Feasibility

The overall cost of the project is a little bit expensive. Hardware like sensors, microcontrollers, and models can be purchased at a moderate price. Most of the software tools are open-source and free, so there is no extra cost for licenses. However, during testing and experimenting, the cost may increase slightly because of making new versions or new modules to get the result.

5.3 Ethical Feasibility

The project does not deal with sensitive personal data, so privacy risks are minimal. However, care must be taken to ensure the system is safe for students to use (no electrical hazards or unsafe devices). The project also promotes education and has a positive impact on society by making learning easier. To handle ethical concerns, safety testing of devices and responsible use of collected data will be followed.

6. Market/ User Needs Analysis

- Smart Classrooms: How Sensors and AI Are Shaping Educational Paradigms
- NEWTON Virtual Labs: Introduction and Teacher Perspective | IEEE Conference Publication | IEEE Xplore
- AI meets physics: a comprehensive survey | Artificial Intelligence Review
- Frontiers | Use of wearable devices in the teaching-learning process: a systematic review of the literature
- Application of New Sensor Technology in the Field of Education in the Era of Internet of Things - Chen - 2021 - Journal of Sensors - Wiley Online Library

Supported by academic and professional sources, it is evident that students require more than lecture-based theory. They benefit greatly from hands-on interaction, visualization, experiments, and feedback to better understand physics concepts.

Similarly, teachers need tools that are easy to use, reliable, and maintainable, while also ensuring they clearly improve students' understanding. For long-term adoption, such tools must also integrate smoothly into existing class time and curriculum requirements.

7. Novelty

Many existing approaches in physics education rely on simulations, virtual labs, or traditional demonstrations, which are helpful but often lack real-world interaction. Similarly, sensor-based platforms have been explored in science education, but many are either too complex for teachers to manage or not affordable for schools.

The Newtonia Project introduces originality by combining embedded systems, real-time sensors, and wireless data transfer into simple physical models (such as toy cars or balls). Unlike virtual-only systems, this approach allows students to both play and experiment with real objects while simultaneously seeing real-time data visualization of physical quantities like velocity, acceleration, and force.

8. Conclusion

The Newtonia Project provides an innovative solution to make learning physics more interactive, practical, and engaging. By combining embedded systems, sensors, and real-time data visualization, students can see and experiment with physical quantities like acceleration, velocity, and force in real time. This bridges the gap between theory and real-world experience, helping students understand concepts more deeply.

The project is technically feasible, economically reasonable, and ethically safe, while also being relevant to the ICT domain through the use of technology for data collection, wireless communication, and visualization. Its novelty lies in offering hands-on experimentation combined with visual feedback, making it easier for teachers to explain concepts and for students to learn actively.

Ideation and Stakeholder need Analysis

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1. Stakeholder Analysis

1.1 Stakeholder Identification

- Students (especially grades 8-12, learning science/physics)
- Science/Physics Teachers
- School Management / Administrators
- Educational Policy Makers

1.2 Challenges of Stakeholders

- Students often get only theory without practical experiments, which makes it difficult for them to connect physics concepts to real life.
- They need clear, simple, and enjoyable ways to learn; otherwise, they may lose interest.
- Teachers face limited time in class, making it hard to set up and run complex experiments.
- School management has budget limitations, so they cannot afford expensive lab equipment.
- Management worry about maintenance, repairs, and the long-term sustainability of devices.
- Policy makers must ensure safety, standardization, and data privacy when introducing ICT devices in education.

1.3 Supporting Evidence from Studies

- https://www.researchgate.net/publication/371086747_Exploring_Students'_Perceived_Difficulties_of_Learning_Physics
- https://educatia21.reviste.ubbcluj.ro/data/uploads/article/2024/ed21-no28-art36.pdf
- https://infonomics-society.org/wp-content/uploads/ijcdse/published-papers/special-issue-volume-3-2013/How-Do-Students-Perceive-the-Difficulty-of-Physics-in-Secondary-School.pdf

This show that many physics students face serious challenges that go beyond just theory. These include things like difficulty connecting physics to real life, trouble with mathematical parts, lack of motivation, and missing lab resources.

Students need more than theory; they require hands-on interaction, real experiments, visualization, and feedback to truly understand physics. Teachers need tools that are easy to use, reliable, maintainable, and clearly improve student understanding.

These tools must also fit well into the class schedule and syllabus, so they can be used without disrupting teaching or needing too much extra preparation.

2. Problem Statement

The fundamental concepts of **Newton's Laws of Motion** are often taught in a purely theoretical manner in schools, particularly between grades 8 and 12. While teachers explain the principles of motion and force, students rarely get the opportunity to observe or interact with real-world demonstrations of these concepts. This gap between theory and practice makes it difficult for learners to fully grasp the difference between idealized physics models and real physical behaviour.

There is a lack of interactive, hands-on tools that allow students to visualize and experience physical quantities such as **acceleration, velocity, and force in real time**. Without practical exposure, students struggle to connect classroom learning with real-world applications, which limits both understanding and interest in the subject.

3. Creative Ideation

Based on the identified challenges and needs of stakeholders, we can propose two ideas:

Idea 1: Newtonia IoT-Enabled Physics Lab Kits

Description: Develop small, low-cost kits with sensors (accelerometer, gyroscope, force sensors) connected to a microcontroller (ESP32). Data is sent wirelessly to a computer or mobile app for real-time visualization of motion, velocity, and force.

ICT Domain: Internet of Things (IoT) and wireless data transfer.

Justification: Students get hands-on interaction and see physics concepts in action. Teachers can demonstrate quickly without setting up heavy lab equipment. Schools benefit from affordable and reusable kits.

Idea 2: Gamified Virtual + Physical Hybrid Platform

Description: Combine real-world experiments (with IoT kits) and a gamified virtual platform where students earn points, badges, or rewards by completing experiments or solving challenges.

ICT Domain: Gamification, cloud-based platforms, and mobile learning.

Justification: Students stay motivated and find learning fun. Parents see positive engagement without extra cost in tuition or private labs. Policy makers and schools' benefit from a solution that is scalable and attractive for modern classrooms.

4. Relevance to ICT domain

The problem of teaching Newton’s Laws of Motion only through theory can be solved effectively by applying modern ICT technologies. The proposed solutions align closely with current ICT trends and have direct benefits for both education and the ICT field.

IoT (Internet of Things): Using IoT-enabled devices such as sensors and microcontrollers makes it possible to measure real-time data like velocity, acceleration, and force. This matches the growing ICT trend of smart, connected devices that provide real-time feedback. It allows students to interact with physical objects while teachers and administrators can collect data for analysis.

Gamification and Cloud Platforms: By integrating gamification elements and storing data on cloud platforms, the project connects with ICT trends in e-learning, mobile learning, and cloud computing. This ensures scalability, easy access, and increased motivation for students.

Wireless Communication (5G/Wi-Fi): Real-time transfer of experimental data from devices to computers or mobile applications relies on wireless communication. This supports the ICT trend of fast, reliable connectivity, which is essential for real-time classroom applications.

System Design and Architecture

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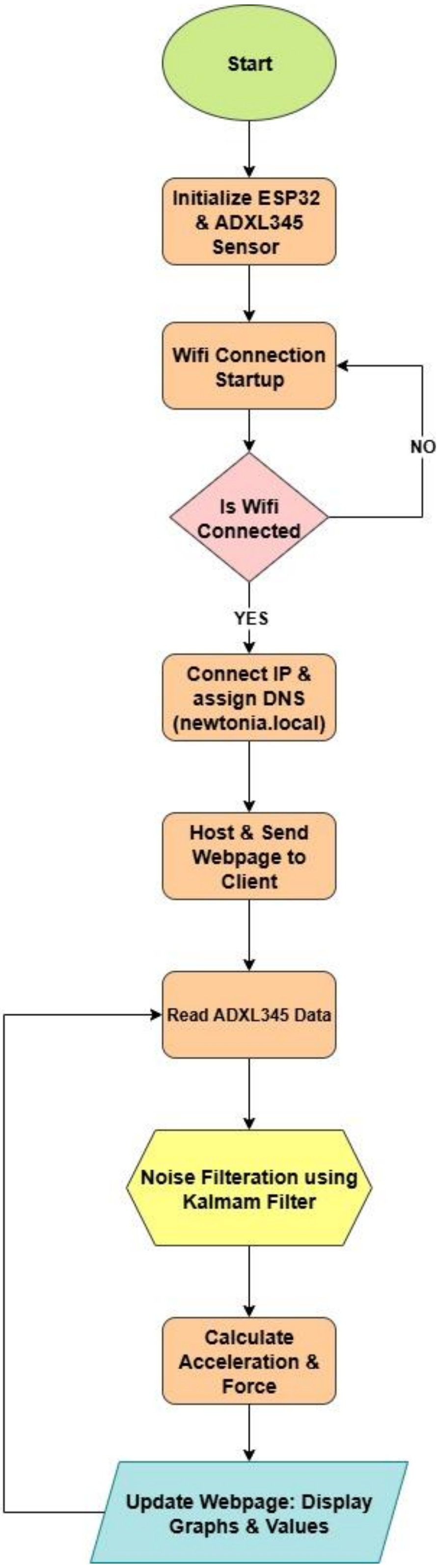
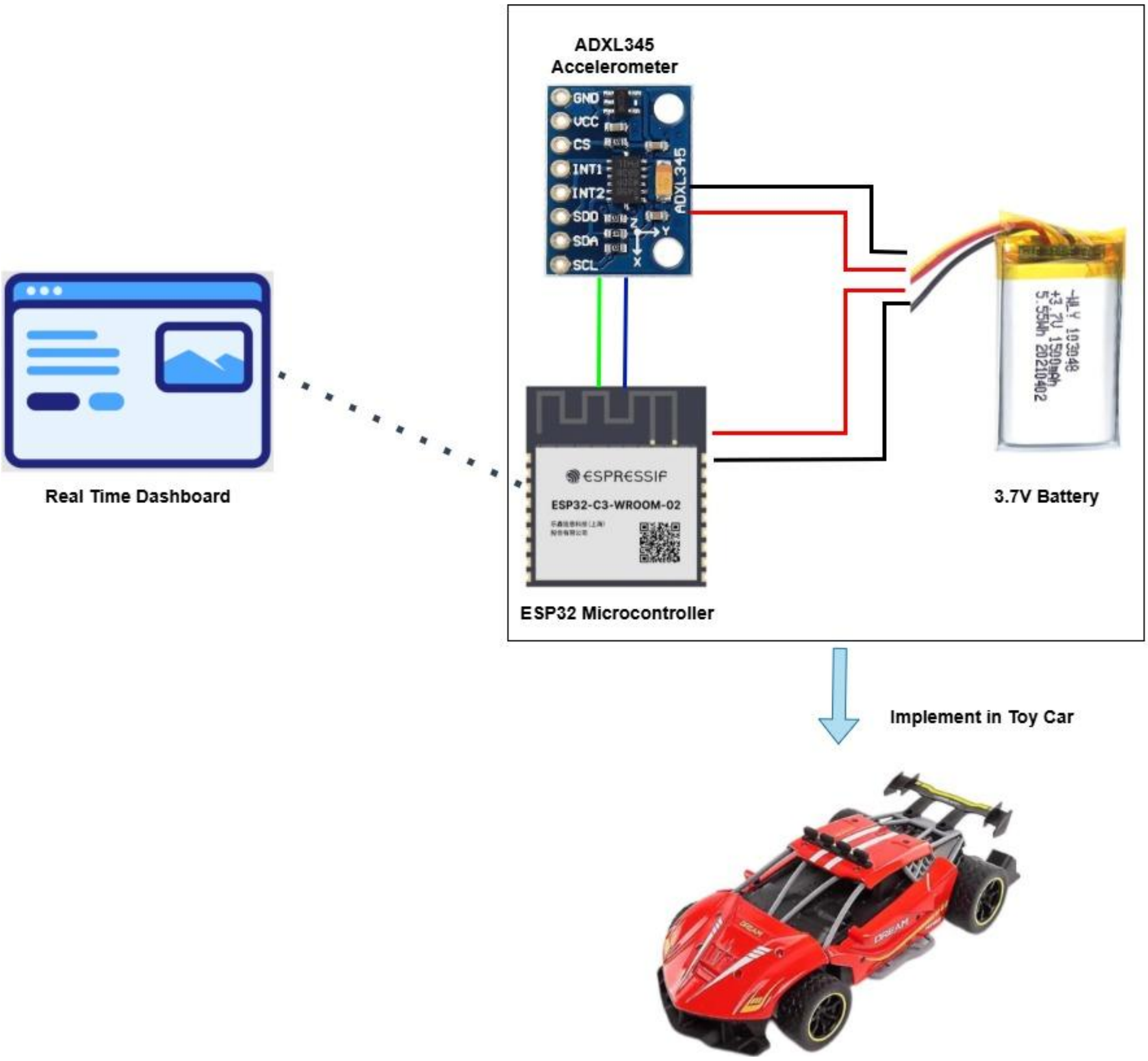
1. Flowchart


Start
Initialize ESP32 & ADXL345 Sensor
Wifi Connection Startup
NO
Is Wifi Connected
YES
Connect IP & assign DNS (newtonia.local)
Host & Send Webpage to Client
Read ADXL345 Data
Noise Filteration using Kalmam Filter
Calculate Acceleration & Force
Update Webpage: Display Graphs & Values

2. Circuit Diagram



3. Technology Stack

To implement the Newtonia Project, a balanced mix of hardware and software is selected. The chosen stack ensures **real-time data collection, wireless transfer, visualization, and user-friendly interaction**.

Hardware

- **Microcontroller ESP32C3WROOM02**
  - Chosen for low cost, wide community support, and built-in sensor compatibility.
  - ESP32 additionally offers **Wi-Fi and Bluetooth** support for wireless communication.
- **Accelerometer ADXL345**
  - Used to measure motion, force, and acceleration in real time.
  - Chosen because it is lightweight, reliable, and widely used in physics-related IoT experiments.
- **3.7V 1500mAh Battery**
  - Powers the system, enabling portability and continuous operation without dependency on wired connections.
  - Chosen for being compact, rechargeable, and having sufficient capacity for classroom experiments.

Software

- **Programming Languages: C/C++ (Arduino IDE)**
  - C/C++ is used for microcontroller programming because it is **lightweight and fast**.
- **Frameworks and Libraries**
  - WebSocket & Node.js: For real-time communication between the microcontroller and the web server, ensuring smooth and fast data transfer.
  - HTML,CSS & JavaScript: Used to build a web-based dashboard for interactive visualization of acceleration, velocity, and force data.
    - HTML provides structure,
    - CSS ensures styling and a clean layout
    - JavaScript manages dynamic updates and interactivity, allowing real-time display of acceleration, velocity, and force.

4. Scalability

The Newtonia Project is designed to remain simple and efficient while still being scalable for classroom or laboratory use.

Support for Multiple Devices

- A single Node.js server with WebSocket can handle multiple ESP32 devices at once.
- Each device can send data streams independently, allowing several students to run experiments at the same time.

Optimized Data Transfer

- Sensor data (acceleration, velocity, force) is processed and reduced on the ESP32 before being sent.
- This minimizes network traffic, reduces packet loss, and ensures smooth graph updates in the web dashboard.

Real-Time Graph Updates

- The dashboard is designed with JSON-based chart libraries to efficiently update only the latest data points instead of re-rendering the entire graph.
- This reduces CPU load on student computers and ensures a responsive user experience.

Performance Tuning

- The sampling rate of the accelerometer (ADXL345) can be adjusted to balance data accuracy and system load.
- The system avoids overload and ensures smooth operation.

Scalable Classroom Use

- Teachers can project the web dashboard on a big screen to display experiments for the entire class.
- Alternatively, each student group can connect their ESP32 device to the same server, making it scalable for large classrooms without extra infrastructure.

Cost and Reliability

- The system uses open-source tools (Arduino IDE, Node.js, WebSocket, HTML/CSS), which keeps costs low.
- No dependency on cloud subscriptions.

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Implementation

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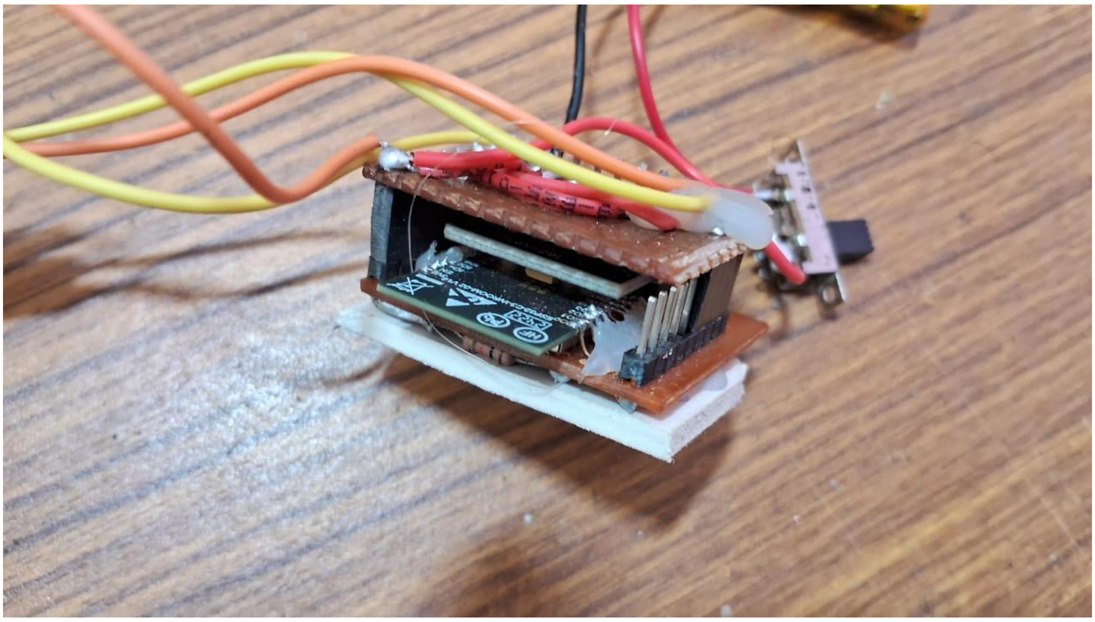
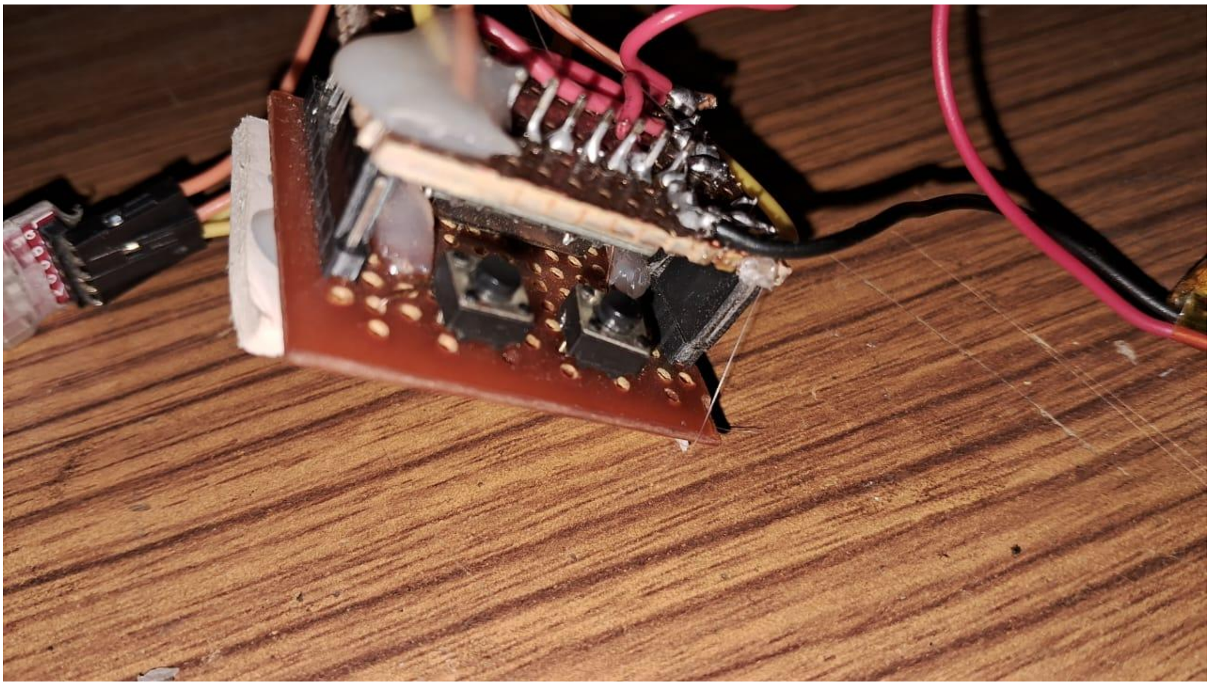
1. Project Objectives

- Design and develop a low-cost prototype using ESP32/ESP8266 and sensors to demonstrate Newton's Laws of Motion in real-time.
- Enable real-time data collection and visualization of motion parameters (e.g., acceleration, velocity, and force).
- Provide hands-on learning experiences for students, making physics concepts easier to understand compared to only theoretical teaching.
- Integrate IoT and web technologies (WiFi, WebSocket, Node.js, HTML, and Chart.js) to build an interactive system.
- Support teachers with easy-to-use tools that allow classroom demonstrations without expensive laboratory equipment.
- Improve learning engagement by making experiments interactive, visual, and accessible through any web browser.

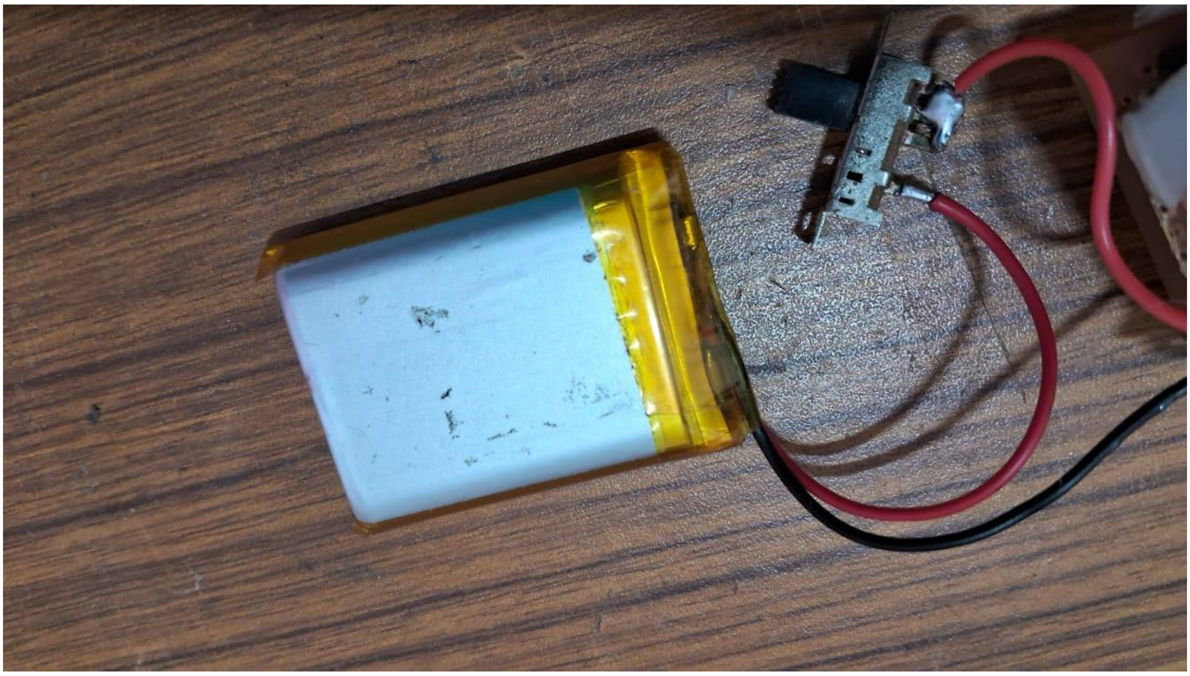
2. Hardware Implementation



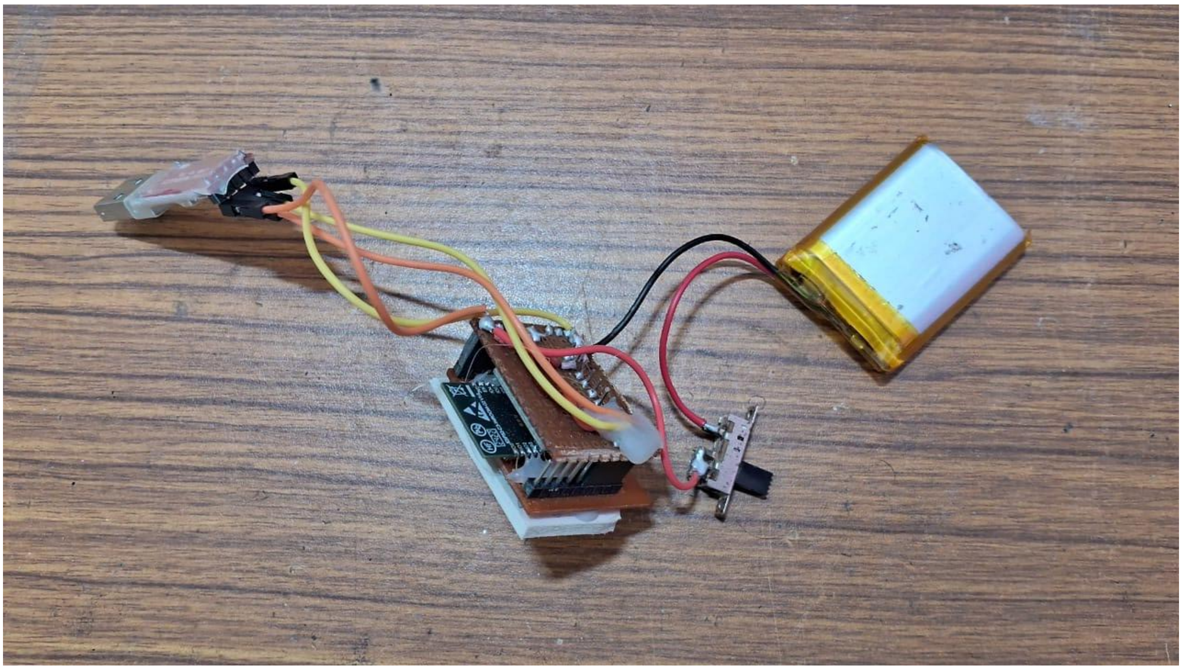
Using ESP32C3WROOM02 & ADXL345 Accelerometer, we developed a very compact size of circuit module from scratch without using any development board like NodeMCU etc..



Implemented 2 switch for Program FLASH configuration in ESP32C3WROOM02.



3.7V LiPo Battery & Switch

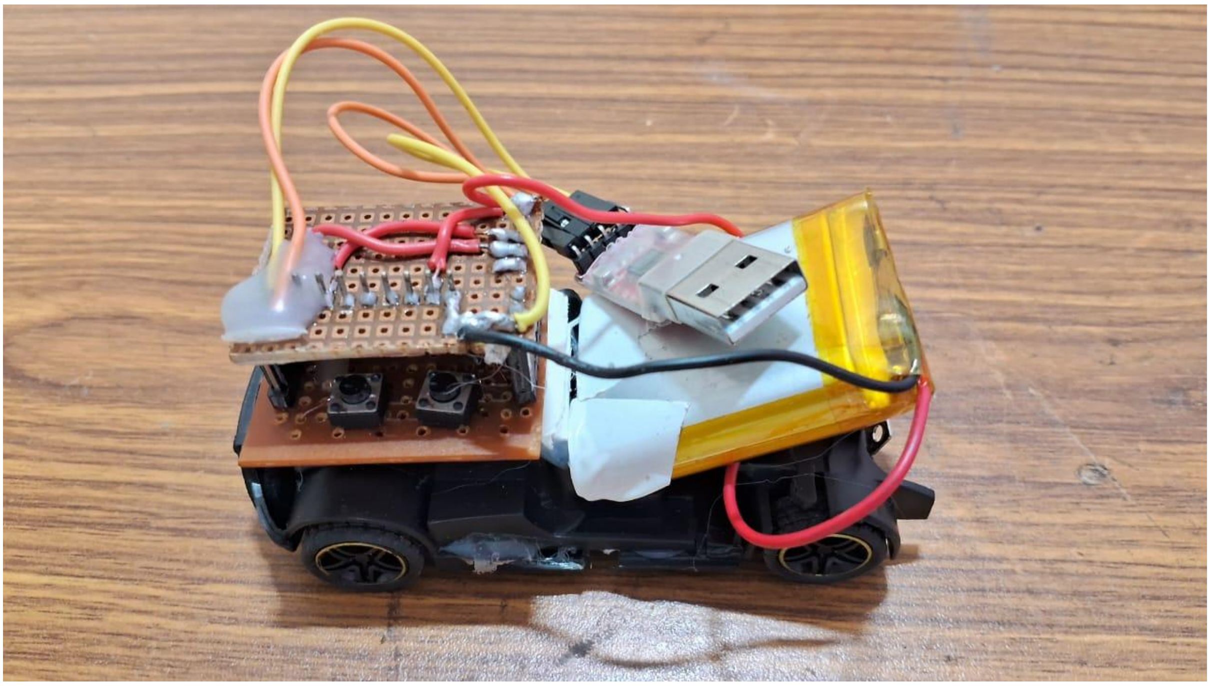


Overall Circuit with excluding USB to TTL for Flash Program.

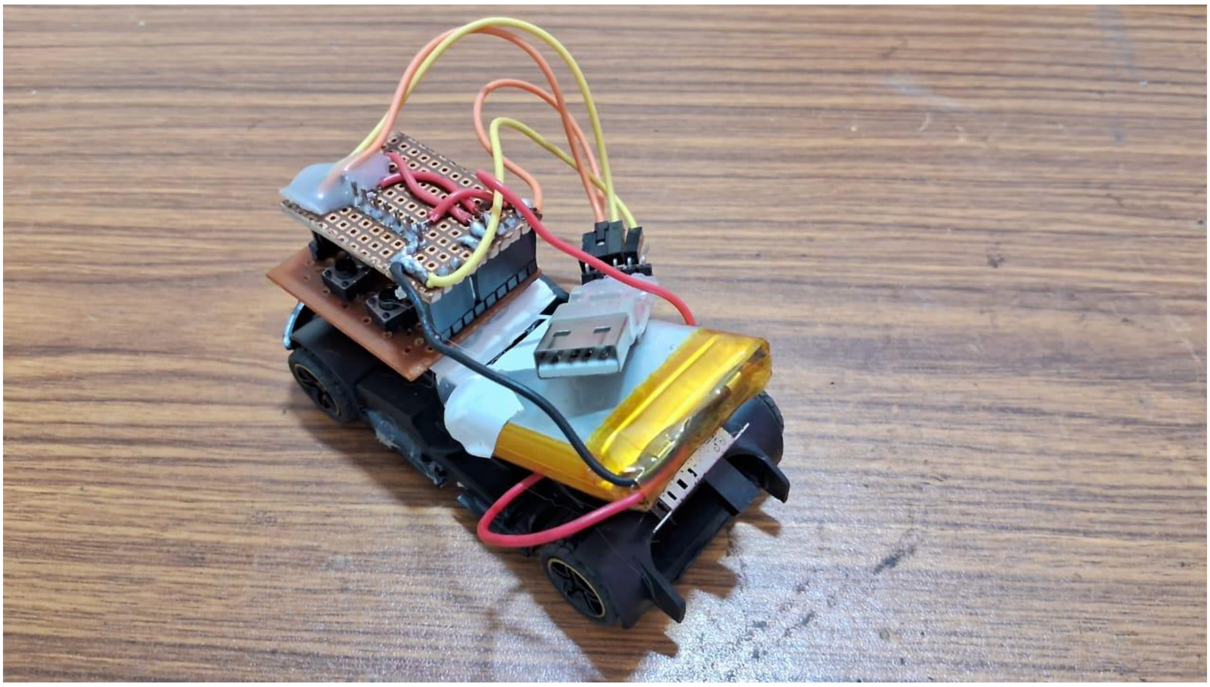
Simple Small Toys Car.

Remove upper body part of Toy Car.

Grinded & Cut the upper part for fitting Circuit Module.



Mount the Circuit module in this toy car lower body.



Final project of Real time Acceleration Newtonia Project.

3. Firmware Implementation

Code Source (Github) : https://github.com/MayankBaldania/Newtonia-Project/blob/2729bc8352da9520848a1cacf3cf3b27a72bb21f/Final_Code.ino

4. Functionality

4.1 Key Technology

- ESP32-C3: A microcontroller with integrated WiFi, used to read accelerometer data, & host a web server.
- WiFi.h Library: Manages WiFi connectivity for the ESP32-C3.
- WebServer Library: Runs an HTTP server on port 80 to serve a dynamic HTML webpage with a real-time graph.
- WebSocketsServer Library: Operates a WebSocket server on port 81 for low-latency, real-time data streaming to the client.
- ESPmDNS Library: Enables mDNS (multicast DNS) to access the ESP32-C3 via a local hostname (http://newtonia.local).
- Wire.h Library: Facilitates I2C communication with the ADXL345 accelerometer to read acceleration data.
- ADXL345 Accelerometer: A 3-axis accelerometer used to measure acceleration along the X-axis.
- Chart.js: A JavaScript library on the client side to render a real-time line graph of acceleration data.
- HTML/CSS/JavaScript: Provides a responsive webpage with a graph, control buttons, and a force calculation section based on Newton's second law.

4.2 Key Algorithms and Logic

- ADXL345 Data Acquisition:
  - The function reads 6 bytes from the ADXL345's register (X, Y, Z axes, though only X is used).
  - Converts raw X-axis data (16-bit, two's complement) to acceleration in m/s^2 using the formula: (x / 256.0) * 9.81, where 256 LSB/g is the sensitivity for ±2g range, and 9.81 m/s^2 is the gravitational constant.

- Moving Average Filter:
    - A circular buffer (movingAvgBuffer) of size 2 stores recent X-axis readings.
    - The movingAvgSum tracks the sum of buffer values, updated by subtracting the oldest value and adding the new one.
    - The average is computed (movingAvgSum / MOVING_AVG_SIZE) once the buffer is full, smoothing out short-term noise.
- Exponential Moving Average (EMA) Filter:
    - Applies EMA to the moving average output: X_filtered = (EMA_ALPHA * X_out) + ((1.0 - EMA_ALPHA) * X_filtered), where EMA_ALPHA = 0.1 controls smoothing (lower alpha = smoother output).
    - This further reduces noise for a stable graph display.
- Real-Time Graphing:
    - The client-side JavaScript parses JSON WebSocket messages ({"x": value}) and updates a Chart.js line graph.
    - Maintains a sliding window of 300 data points, removing the oldest point when the limit is reached to optimize performance.
- Force Calculation:
    - On the client side, Newton's second law (F = m * a) is applied with a fixed mass of 0.07 kg (70g).
    - The acceleration input (accelInput) allows manual entry, and the force is computed and displayed (force = massKg * accel).

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Deployment and Operations

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1. Deployment Process

1.1 Hardware Setup

- ESP32-C3 microcontroller connected with ADXL345 accelerometer via I²C pins (SDA = GPIO4, SCL = GPIO5).
- Power supplied using a 3.7V Li-ion battery.
- Onboard Wi-Fi enabled for device-to-network connection.

1.2 Firmware Flash

- Firmware written in C/C++ using Arduino IDE.
- Code uploaded to ESP32 via USB to TTL.

1.3 DNS and Network Integration

- Users on the same Wi-Fi can access the system by typing http://newtonia.local
- instead of a numeric IP.
- Tested on laptops, Android phones, and iOS devices: DNS resolved consistently without errors.

2.4 Dashboard Deployment

- ESP32 serves the HTML/CSS/JavaScript dashboard directly.
- Control buttons (pause, reset) and force calculator included.
- Accessible on Chrome, Firefox, and Safari.

2. Operation

1. Teacher powers ESP32 device.
2. Students connect their devices (laptops/phones) to the same Wi-Fi.
3. Students open browser → enter http://newtonia.local.
4. Dashboard loads instantly and displays live acceleration graph.
5. Students or teacher can move the toy car and observe:
    - Real-time motion data.
    - Calculated force values.
    - Multiple clients (up to 5 tested) receive synchronized data simultaneously.

3. Monitoring

3.1 Hardware Monitoring

- Periodic battery level check.
- Sensor wiring inspected before use (loose wires cause errors).

3.2 Software Monitoring

- Verify that the Wi-Fi is connected by LED blinking in Newtonia Device.
- Dashboard graphs visually confirm correct data flow.

4. Maintenance Plan

- Recharge Li-ion battery after each session.
- Store ESP32 and sensor in protective case.
- Replace worn cables or loose connectors.
- Backup firmware stored in GitHub repository

Testing and Validation

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1. Testing Strategy

Testing and validation were carried out to ensure that the Newtonia Project prototype meets its functional, performance, and usability objectives. The main focus was on verifying:

- Accurate sensor data collection.
- Proper Filtration of Noise Data
- Reliable WiFi connectivity and WebSocket communication.
- Correct real-time graph updates on the web dashboard.
- Smooth integration of hardware and software components.
- Alignment with the project objectives defined earlier.

2. Unit Testing

2.1 Wi-Fi Connectivity

The ESP32 was tested by connecting to a local Wi-Fi router. Several SSIDs and incorrect passwords were entered to check error handling. The device was successfully connected within 5–7 seconds under correct SSID & password.

2.2 Noise Data Filtration

ADXL345 accelerometer was placed in static positions. Expected values: ~0 m/s^2 on X/Y, ~9.81 m/s^2 on Z. Readings were within ±0.60 m/s^2 error margin with data fluctuation. After applying the moving average and EMA filter, noise was reduced by ±0.10 m/s^2.

2.3 ESP32 DNS

The EPS32 is registered with the hostname "newtonia.local". This means that instead of typing the device's IP address, users can simply enter "http://newtonia.local" in their browser to access the system. During testing, the DNS worked seamlessly, and no errors such as Error 404 – Page Not Found occurred.

2.4 Dynamic Website

Newtonia Project are connected to a device (laptop + smartphone) which accessed the dashboard simultaneously. Both clients received synchronized updates within 50 ms without any disconnection during a 30 min stress test or any lagging. Real-time reliability confirmed.

2.5 Hardware + Software Integration

Tested end-to-end flow. System successfully plotted real-time acceleration in graph after every 100ms update. Force calculation ($F = m \times a$) matched manual calculation. Integration fully aligned with project objectives.

3. Validation

- Graph updates after 100ms.
- ESP32 + WebSocket + Chart.js dashboard integrated successfully.
- 30 min stress test without disconnected.
- 4-5 device can connect without lag.
- Proper Noise Data Filtration
- Newtonia device connected instantly with Wi-Fi Router within 4-5 seconds.
- Newtonia device can run around 2-4 hours on single charge battery
- Force Calculation accuracy

4. Limitation

- Limited to local Wi-Fi; no cloud access yet.
- Can not applied in incline or decline surface.
- Still not filtered the noise data with 100 percent accuracy.
- Only X-axis tested; Y/Z axis can be added for 3D visualization.
- Performance may degrade if more than 5 clients connect simultaneously.

Innovation and Originality

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1. Innovation

Newtonia Project is innovative because it changes the normal way of learning physics. In schools, students mostly learn Newton's Laws only by theory from books or teachers' explanations. Sometimes they may see small demonstrations, but they do not get full real-time experience. Newtonia gives a new method where students can actually do experiments with small models and at the same time see the results on screen.

The innovation is in combining real experiments with technology. A toy car or ball is not just a toy anymore; it becomes a smart device with sensors inside it. These sensors measure speed, force, acceleration & other physical quantities. The microcontroller sends this data wirelessly to a computer or mobile, where students can watch graphs and values changing live.

This is different from virtual labs because it gives practical touch and real data. Students can push the car, roll the ball, and directly see how Newton's laws are working in real life. This way, the project makes learning interactive, playful, and easier to understand.

2. Contribution to ICT domain

- Uses Embedded Systems (ESP32, MPU6050, sensors) for collecting real-world data.
- Uses Wireless Communication (Wi-Fi) to connect devices without wires.
- Uses Data Processing and Visualization (Python, Node.js, HTML, CSS) to show results in graphs and visuals.
- Applies EdTech for making classrooms smart and interactive.
- Works on IoT concepts with real-time data transfer.
- Provides a low-cost solution with affordable sensors and open-source software.
- Supports interactive learning with real experiments and live data.
- Can be expanded to subjects like robotics, mechanics, or remote labs.