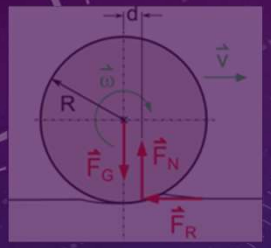


VIRTUAL FRICTION SENSOR

Predictive **μ** estimation using empirical models, sensor fusion and AI

Prototype implemented on Toyota C-HR

Project goal

current situation

- Tire-road friction (μ) is critical for vehicle safety: ESP, ACC, AEB, ADAS
- Today μ is estimated indirectly → often conservative or delayed. Empirical μ only available in extreme cases (full braking, strong acceleration)
- Dedicated μ sensors are expensive and fragile

virtual sensor concept

- Software approach using existing vehicle signals + AI correction

Goal: Reliable, fast, adaptive μ estimation without additional hardware

Add-on: Real-vehicle testing and μ-validation results will follow.

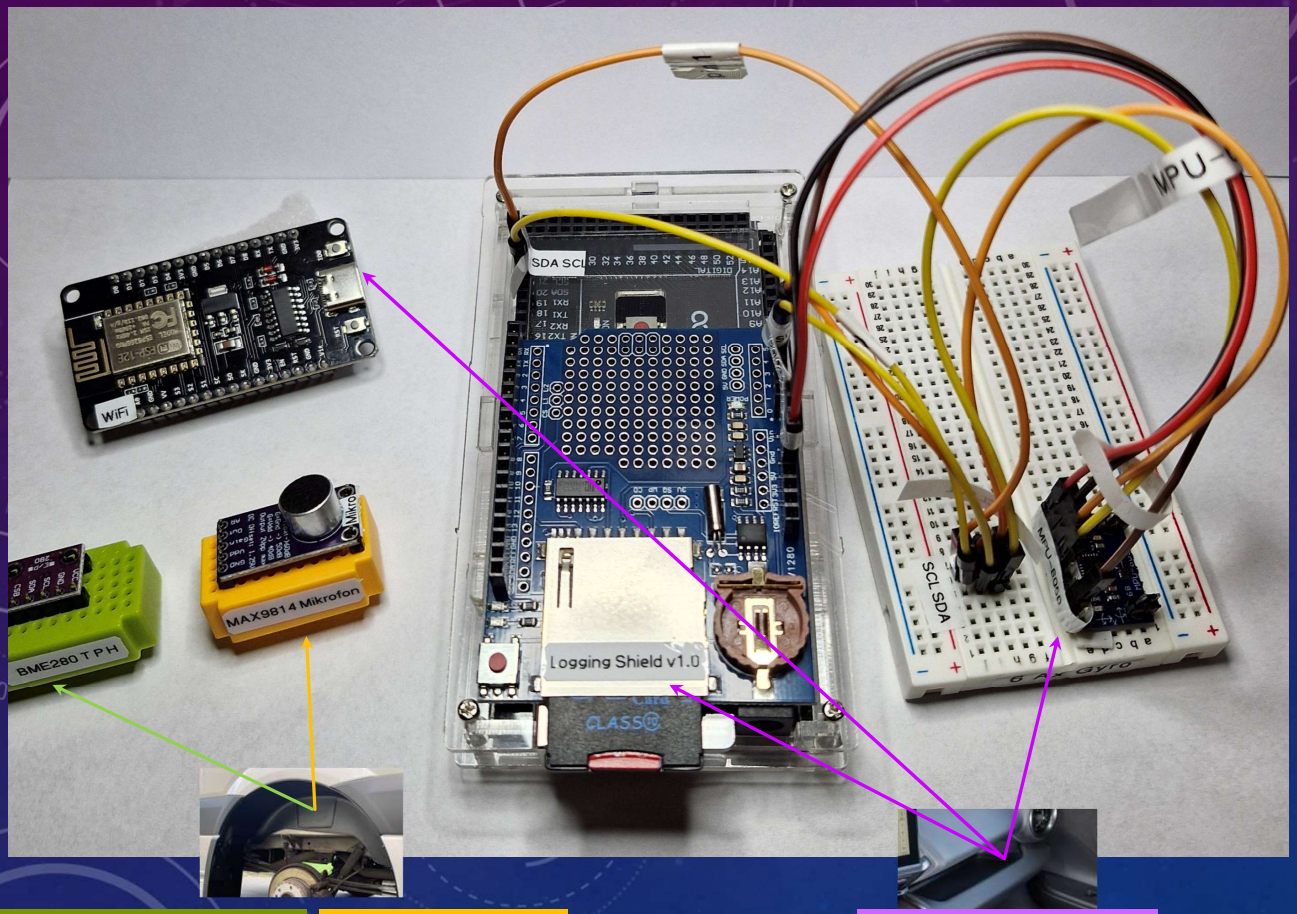
Calculation principle

1. Empirical model: μ_{truth} from a_{long} (IMU) vs. dv/dt (OBD-II)
2. Sensor fusion: combined climate (temperature, humidity, air pressure) and dynamic data (acceleration, yaw rate, vehicle speed)
3. Model training:
   - Classic AI model: supervised learning for μ_{pred} (μ_{truth} as label)
   - GenAI: Audio based training (tire/road sound)
5. Final fusion of AI + GenAI models
6. Model testing: μ_{truth} from unseen data
5. Validation: compare and validation of μ_{pred} vs. μ_{truth}

Sensors, communication and storage modules

1. MPU6050 (IMU, acceleration + gyroskop)
2. OBD-II Adapter (vehicle speed, engine data)
3. BME280 (humidity, air pressure, temperature)
4. MAX9814 (microphone for tire-/road noise)
5. SD-Logger Shield (local CSV-data storage)
6. ESP8266 WiFi module – wireless data transmission/ cloud connection

Vehicle installation and sensor placement (Toyota CH-R)



Bumper or Wheel arch

Wheel arch

Passenger dashboard

Driver footwell

Summary

project overview

- Development of Virtual Friction Sensor for predictive μ estimation
- Software only approach using empirical models, sensor fusion and AI
- Prototype implementation on Arduino Mega 2560 (Toyota CH-R)

key achievments

- Fusion of dynamic (IMU, OBD) and climate data (BME280)
- AI and GenAI models trained and validated with empirical μ_{truth}
- Reliable estimation without additional hardware

next steps

- Collect real-vehicle measurement data under different road conditions
- Evaluate model performance and optimize fusion accuracy
- Extend dataset for wet, icy and low-friction surfaces