SMART TIRE SENSORS FOR VERIFYING ACCURACY OF CONTINUOUS FRICTION MEASURING EQUIPMENT (CFME)

RICHARD Y. JI, P.E., PH.D.
FEDERAL AVIATION ADMINISTRATION (FAA)
MURPHY FLYNN, MANAGER
AIRPORT PAVEMENTS R&D SECTION, FAA
HAO WANG PROFESSOR
RUTGERS UNIVERSITY

RPUG
Road Profile Users' Group

ACKNOWLEDGMENT

Jingang Yi Professor, Rutgers University

Xunjie Chen Graduate Student, Rutgers University

BACKGROUND

- Safety of runway is challenging due to high takeoff and landing speed of aircrafts, especially during wet weather conditions
- Continuous Friction Measuring Equipment (CFME) is used for monitoring airfield pavement friction as specified by FAA AC 150/5320-12
- There is a need for improving the accuracy of CFME, monitoring pavement condition and providing information for the pilot
- FAA Runway Friction Program

FAA OWNED SARSYS SFT

- FAA-Approved CFME (AC 150/5320-12C)
- SARSYS SFT Mounted in SAAB Vehicle
- 15% Fixed-Slip Ratio Maintained by Direct Mechanical Connection to Vehicle Drive
- Tractive Force Measured with Load Cells While Maintaining Constant Vertical Load on Measuring Wheel
- Self-Wetting System Maintains 1 mm of Water on Surface Ahead of Measuring Wheel (Water Flow and Pressure Adjusted By Operator for Travel Speed)
- Measuring Wheel Conforms to ASTM E1551

FAA OWNED DYNATEST RFT

- FAA-Approved CFME (AC 150/5320-12C)
- Dynatest RFT Mounted on Ford F-450 Truck
- 14% Fixed-Slip Ratio Controlled by Hydraulic System
- Two-Axis Force Transducer Measures Vertical Load and Tractive Force at Measuring Wheel
- Self-Wetting System Utilizes Positive Displacement Water Pump to Maintain 1 mm of Water on Surface Ahead of Measuring Wheel Independent of Travel Speed
- Measuring Wheel Conforms to ASTM E670, E1551, or E1844

FAA OWNED VIATECH FRICTION MK2

- ViaFriction MK2 Conforms to CEN TS 15901-14:2016: Procedure for determining the skid resistance of a pavement surface using a device with longitudinal controlled slip
- ViaFriction MK2 and Water Tank are Trailer Mounted
- ViaFriction MK2 Uses an Electric Braking System to Measure Friction Coefficient and Control Speed of Measuring Wheel
- ViaFriction MK2 can be Operated in Fixed Slip Mode, Variable Slip Mode, and Surveillance Mode
- In Fixed Mode Measuring Wheel Slip Can be Adjusted in the Range of 1% to 75% (Normal Range 15-20%)
- In Variable Slip Mode Braking is Applied to Measuring Wheel from Free Rolling Condition Decelerating to Approximately 6 MPH in 1 Second and Measuring Braking Force
- Surveillance Mode is Similar to Fixed Slip Mode Where Measurements are Taken Only When Friction is Below Prescribed Level Reducing Wear on Measuring Wheel and Apparatus
- Self-Wetting System for Maintaining 1 mm of water Ahead of Measuring Wheel Independent of Travel Speed
- Measuring Wheel Conforms to ASTM E1551
- Snow Tire Installed for Friction Measurements under Winter Weather Conditions

CONTINUOUS FRICTION MEASURING EQUIPMENT

The friction measurement accuracy of CFMEs can be affected by many factors

- Tire rubber deformation
- Slip ratio
- Pavement surface texture
- Water depth
- Surface contaminant
- Temperature
- Speed
- Equipment type

RESEARCH MOTIVATION AND OBJECTIVES

- Smart tire sensors have been used by the automotive industry and research labs to monitor tire pressure, measure tire rubber deformation, and estimate driving/braking condition

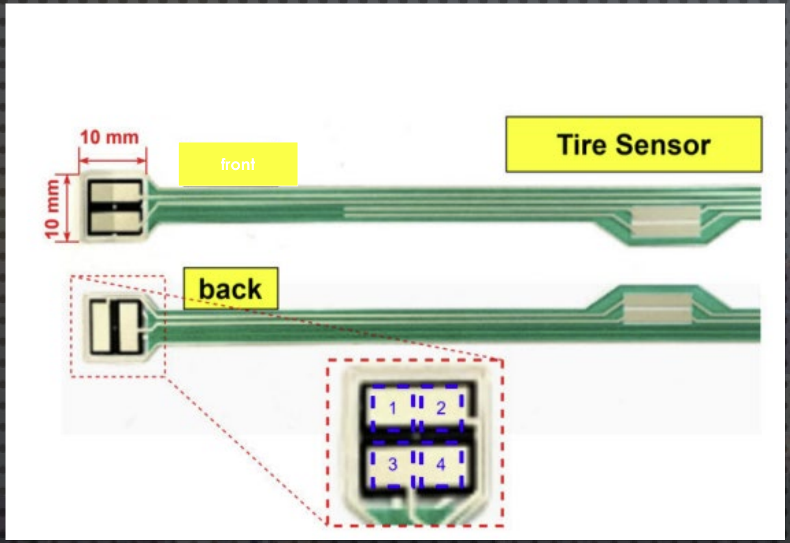
- **Research Objectives**
  - Determine feasibility of using smart tire sensor to measure friction coefficient
  - Access and compare the accuracy of smart tire sensors with CFME readings (Mu value)

SMART TIRE SENSOR TECHNOLOGIES

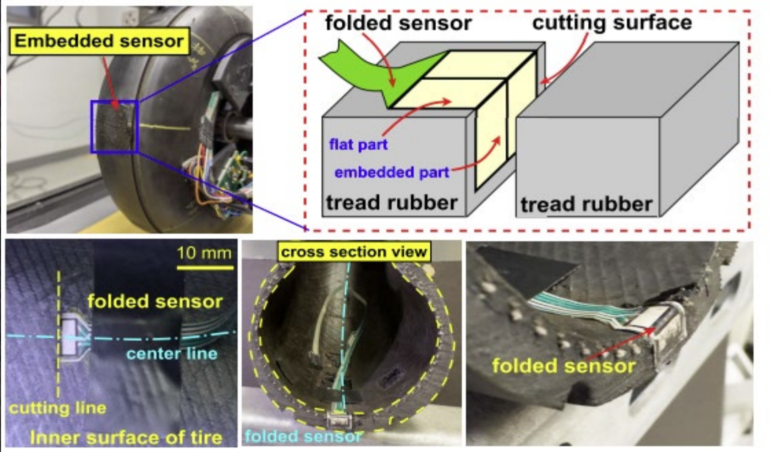
- SMART SENSORS WERE INSTALLED ON TIRES AND PROVIDE REAL-TIME INFORMATION ON VARIOUS TIRE-PAVEMENT CONTACT CHARACTERISTICS (APOLLO 2003)
- THIS INFORMATION CAN BE USED TO ASSESS PAVEMENT SURFACE CONDITION AND FACILITATE VEHICLE OR AIRCRAFT DYNAMIC CONTROL
- DIFFERENT TYPES OF SENSORS HAVE BEEN USED FOR DIFFERENT PURPOSES

Sensor types	Measurement variables	Estimated characteristics	Application purposes
• **Accelerometer** • **Piezoelectric** • **Piezoresistive** • **Optical** • **Capacitance** • **Magnetic** • **Infrared**	• Strain • Acceleration • Temperature • Pressure • Global deformation	• Contact patch • Normal force • Lateral force • Friction coefficient • Slip ratio • Slip angle	• Performance analysis and design of tire • Vehicle dynamic control • Pavement surface condition

PRESSURE-BASED SENSOR IN TIRE TREAD



- The force sensor we chose is RX-M0202S from RouXi Electronic Technology Company

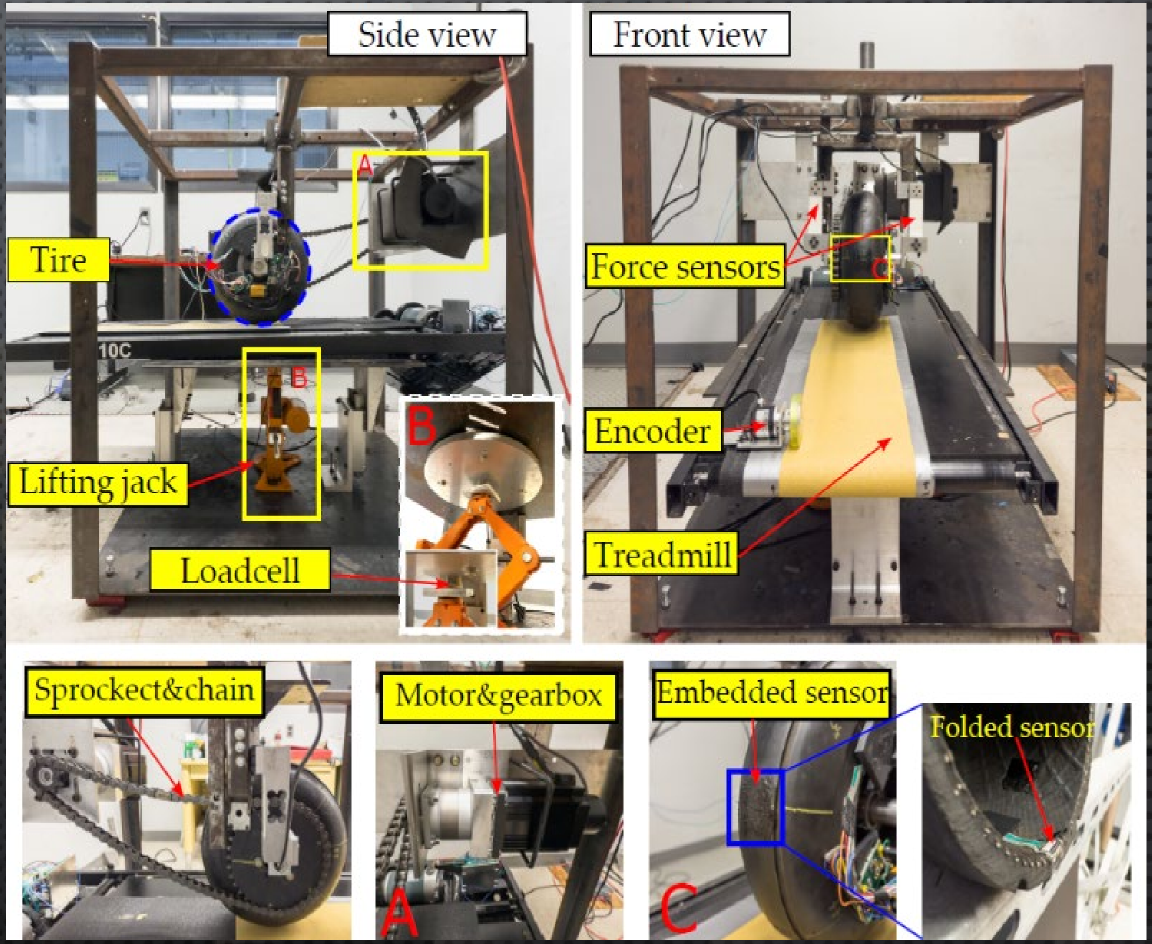


- The sensor film was first folded, dividing two rows of sensing units, and embedded inside the tire tread rubber layer

DYNAMIC FRICTION TEST PLATFORM

Dynamic friction test platform

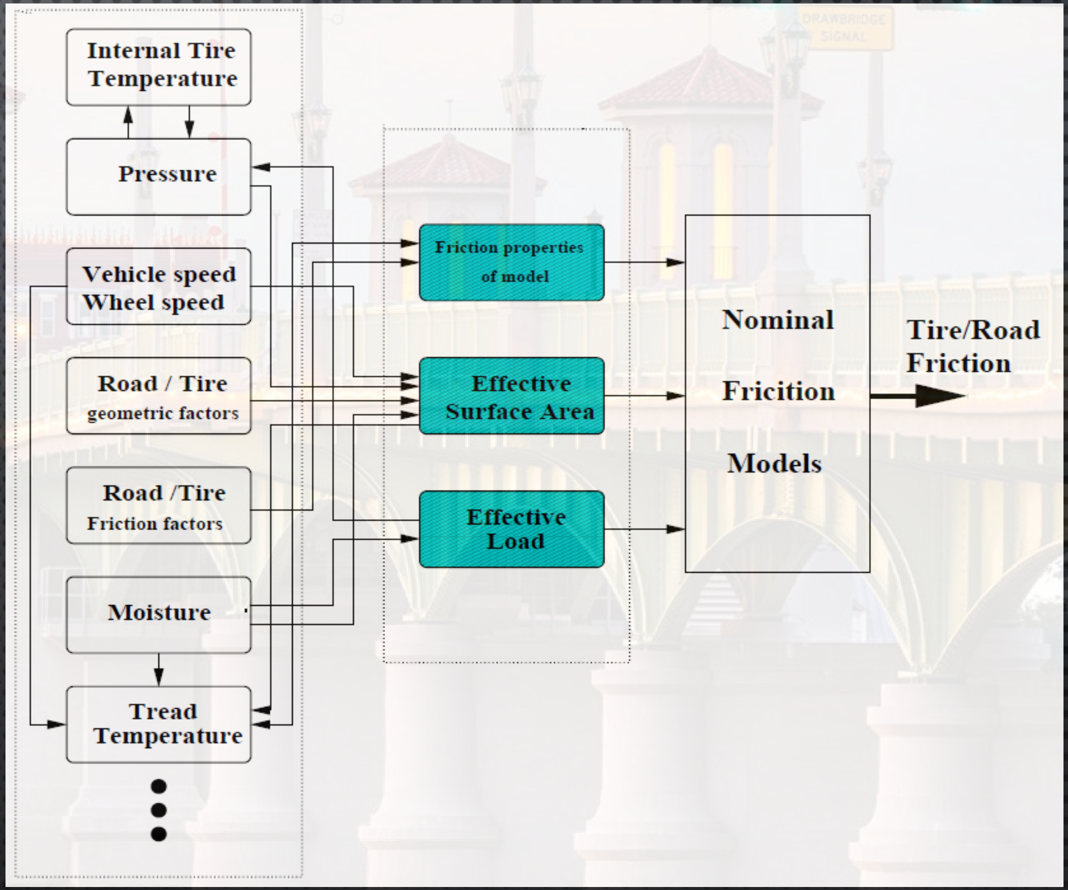
- **Lifting jack** is used for control of tire-belt contact and normal load
- **Driving motors** are used to control tire rotation and belt movement to create different slip ratios
- **Force sensors** for reference measurement of friction force
- **Flexible pressure sensors** are embedded in the tire rubber tread
- **An instrumented plate** is installed on the side of the wheel for wireless data transmission



FRICTION MEASUREMENT WITH SMART TIRE SENSORS

INVESTIGATE THE FEASIBILITY AND FURTHER DEVELOP THE METHOD OR ALGORITHM FOR MEASURING FRICTION COEFFICIENT

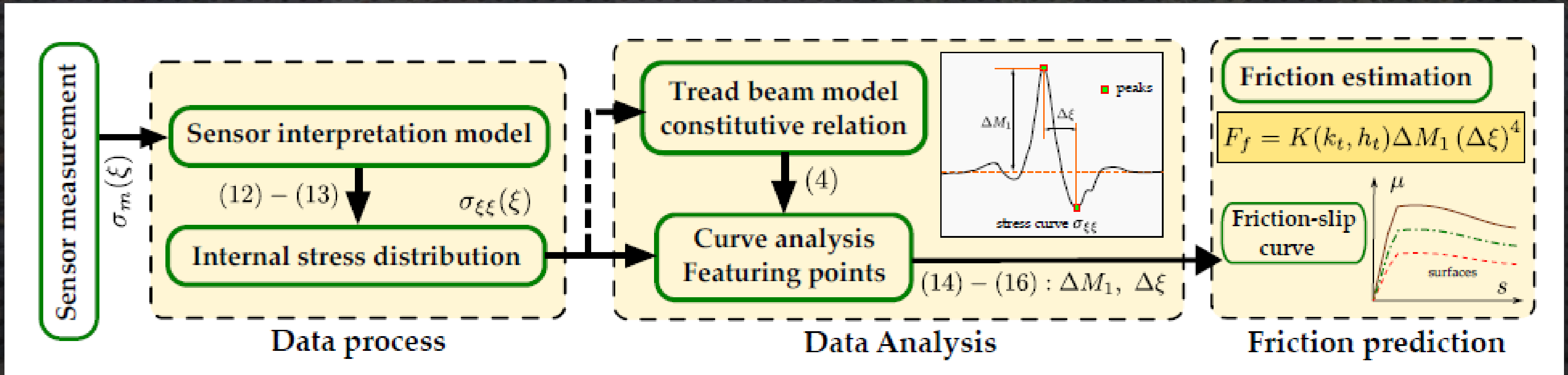
- EMPIRICAL APPROACH BASED ON EXPERIMENTAL AND SIMULATION DATA (REGRESSION MODELS; MACHINE LEARNING)
- PHYSICS-BASED APPROACH RELYING ON TIRE (OR TIRE TREAD) MODELS AND TIRE-PAVEMENT INTERACTION MODELS



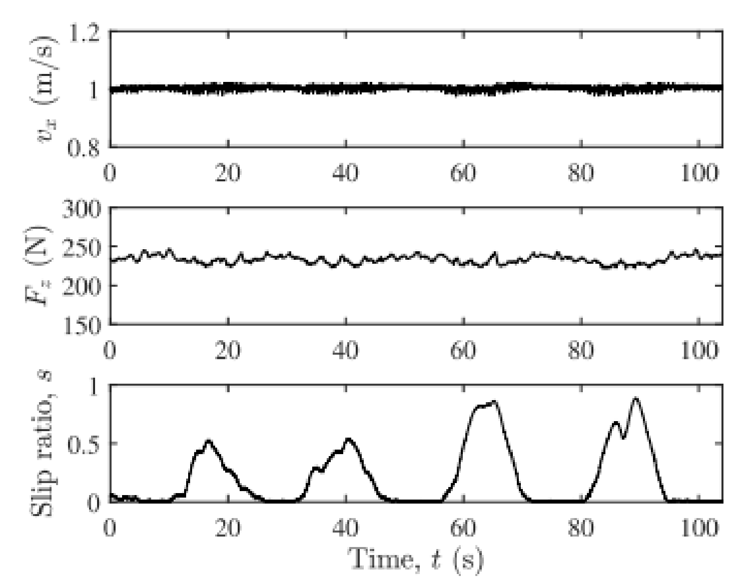
PREDICTION OF FRICTION FROM TIRE SENSOR

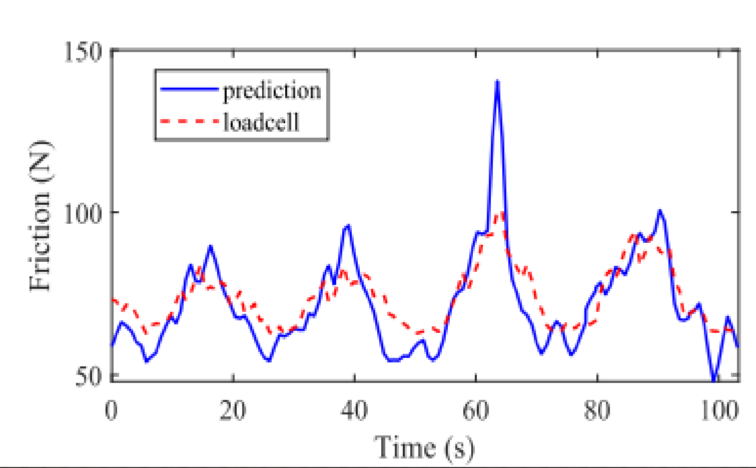
PHYSICS-BASED MODELS ARE DEVELOPED TO PREDICT FRICTION FORCE FROM SENSOR READINGS

- INTEGRATED TREAD BEAM/LUGRE TIRE-PAVEMENT FRICTION MODEL
- TIRE SENSOR INTERPRETATION MODEL

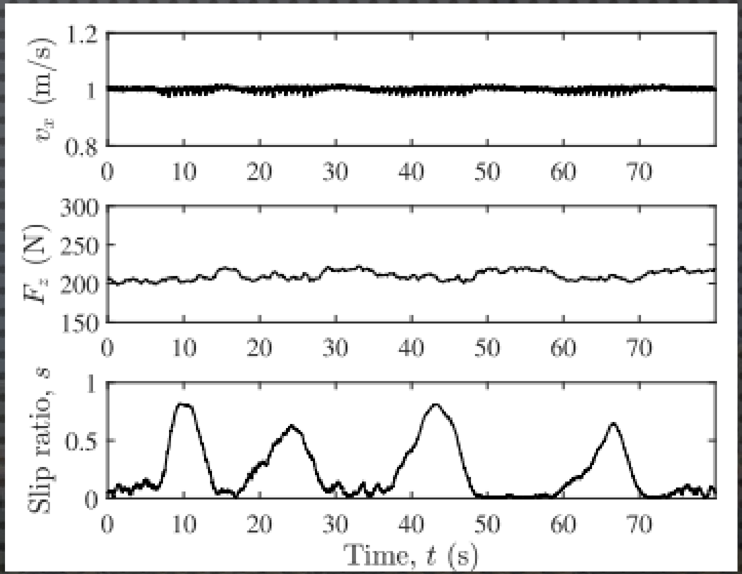


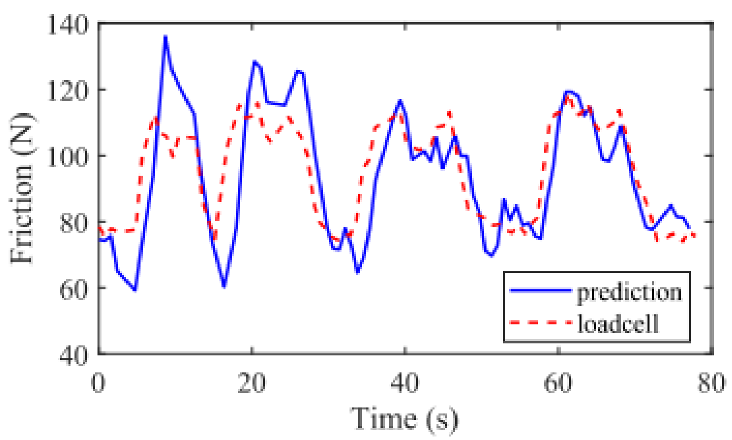
Smooth vs. Rough Belt Surface





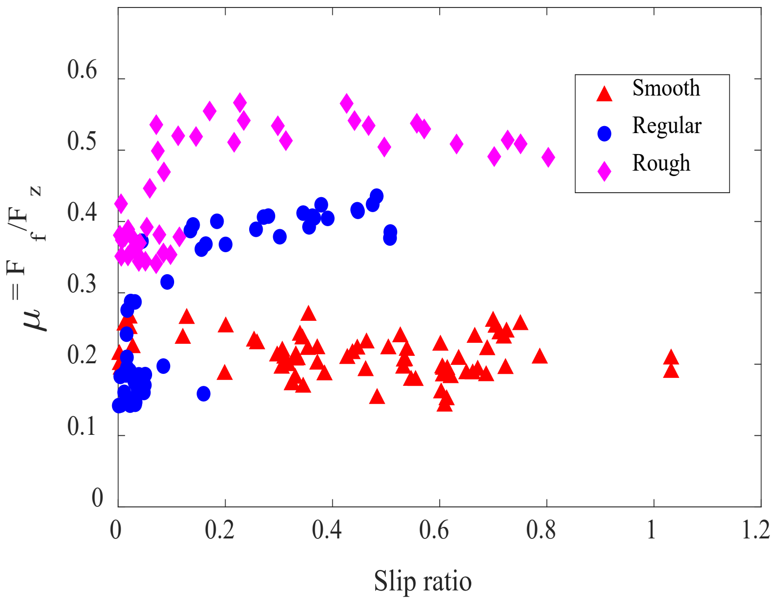
Smooth surface



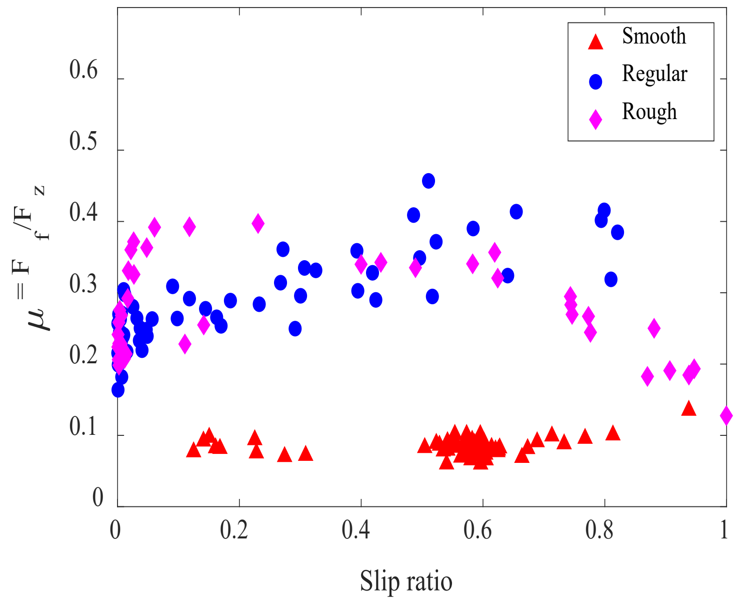


Rough surface

Dry vs. Wet Belt Surface



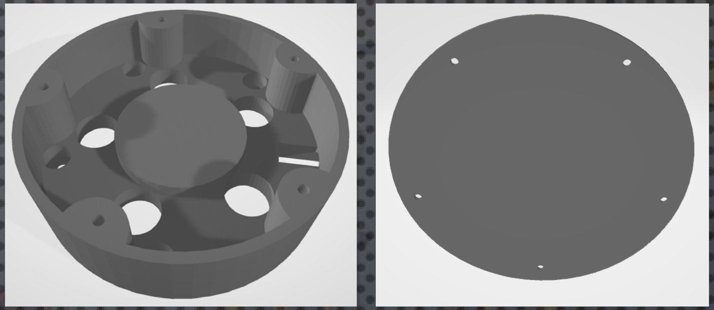
Friction coefficients at dry condition



Friction coefficients at wet condition

Instrumented Tire for Field Trial Test

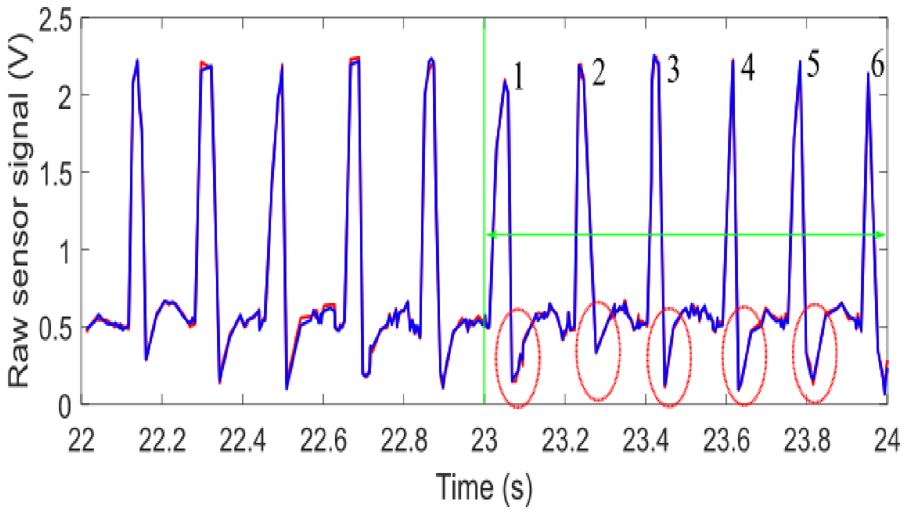
- Setup of the smart tire sensor system on CFME rim/tire.
- New wireless transmission module design.
- Check functionality of the sensor and corresponding data transmission module.

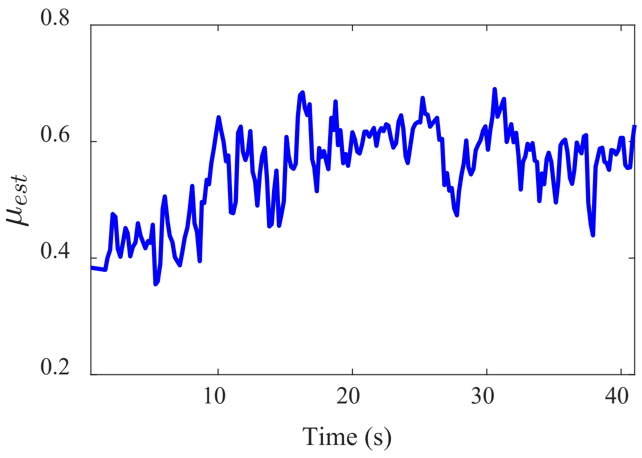


3D view of the new instrument plate

Tire assembly with the new instrument plate attached

Friction Estimation From Field Trial Test At National Airport Pavement Test Facility (NAPTF)





The overall friction coefficient is 0.57.

The maximum (instantaneous) friction coefficient is 0.69 and the minimum is 0.37.

Ongoing Work

- Incorporate temperature measurement of tire for more accurate friction estimation.
- Conduct field tests and compare the friction estimation results with the CFME results to validate the application of smart tire sensor.

Questions?

Contact the FAA Project Manager

Richard Y. Ji, P.E., Ph.D.

Airport Technology R & D
William J. Hughes Technical Center, ANG- E262
Richard.Ji@faa.gov