Title : **Real-Time Edge AI Analysis of Photoplethysmography Signals for Diabetic Vascular Health Assessment**

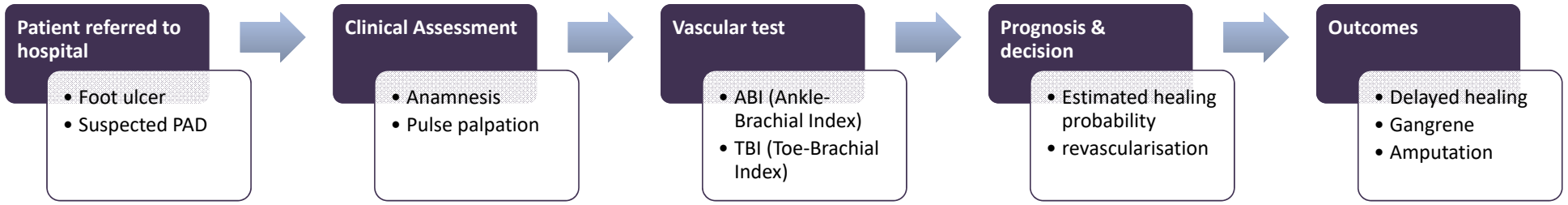
Full name of Speaker : Prof. Ir. Dr. Widad Ismail

Institution : Universiti Sains Malaysia

Project Title: **Real-Time Edge AI Analysis of Photoplethysmography Signals for Diabetic Vascular Health Assessment**

Background :

Diabetes is a leading NCD across ASEAN: adult prevalence is 21.1% in Malaysia, 11.3% in Indonesia and 10.2% in Thailand. Malaysia has about 4.8 million adults with diabetes, projected to reach 7.5 million by 2050 (IDF Diabetes Atlas, 11th ed., 2025). At 20–28% PAD prevalence in diabetes (IWGDF/ESVS/SVS, 2023), about 1.0–1.3 million may already have peripheral artery disease (PAD). The pathway below follows such a patient in hospital, where the system will be validated.



Pathway adapted from IWGDF/ESVS/SVS (2023) and Malaysian CPG (2018)

Clinical assessment of foot ulcers and suspected PAD typically involves checking the pulse in the leg, followed by ABI and TBI measurement to evaluate peripheral perfusion and guide treatment decisions. Conventional ABI and TBI assessment primarily rely on static pressure measurement. Singhania et al. (2024) reported a sensitivity of 35.3% for ABI, compared with 82.4% for TBI. While TBI is more sensitive in diabetes, neither characterises dynamic microvascular responses to stimulation, and glucose tests (HbA1c, CGM) do not show how diabetes affects the peripheral circulation. This project fills that gap with a functional PPG-based test of microvascular reactivity at the toe for point-of-care monitoring.

Project Title: **Real-Time Edge AI Analysis of Photoplethysmography Signals for Diabetic Vascular Health Assessment**

Targets:

Target 1 Wearable sensor node

- A PPG sensor uses four wavelengths that operate simultaneously to detect different depths and chromophores in the skin and underlying tissues, so a single recording gives depth-resolved results rather than just an estimate from a single channel.

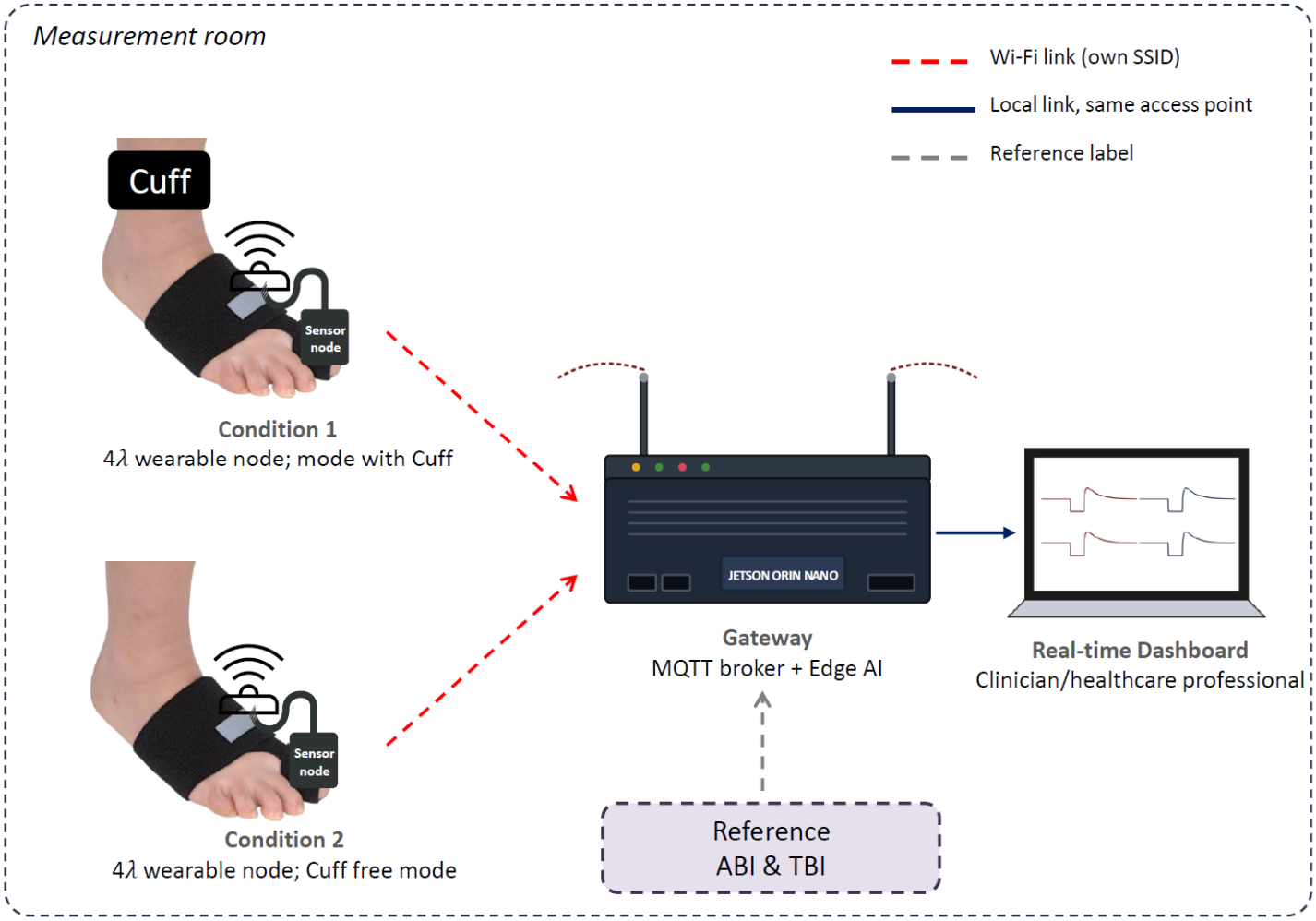
Target 2 Real time edge AI gateway & dashboard

- An edge-computing platform serves as the central IoMT gateway: it ingests data in real time, checks integrity, filters the signal and runs the detection algorithms locally, without high-latency cloud processing.
- Display real-time profiles on the dashboard, allowing healthcare professionals to monitor the condition of patients' vascular health.

Target 3 Clinical vascular profiling & ASEAN database

- Record vascular responses from healthy adults, people with diabetes without PAD and people with diabetes with PAD at partner sites in Malaysia, Thailand and Indonesia; compare the response metrics with clinical reference (ABI and TBI) to build a synchronised ASEAN physiological database.

Proposed Method (1): Scientific & Technology



What is measured

- Four wavelength reflectance PPG at the hallux. One site, four tissue depth.

One node with two conditions

- PPG is continuously recorded to assess the pattern and rate of perfusion recovery after cuff release relative to the pre-occlusion baseline, with all phases systematically measured.

Edge AI

- Jetson Orin serves as an offline edge computing gateway, locally processing all collected data into clinical profiles and displaying results on real time dashboard for medical assessment.

Proposed Method (2): Technical Implementation

Layer 1 **Physical Devices & Controllers**
Wearable sensor node

- PPG sensor with 4 wavelength at big toe via wearable holder.
- **MCU** – Control LED sequencing, First In, First Out & timestamp per sample.

Layer 2 **Connectivity**
Wireless link

- **Jetson as Access Point** – To avoid relying on the hospital network.
- **Mosquitto MQTT** – Data transmission protocol.
- **Frame Format:** Sequence number | Timestamp | λ_1 λ_2 λ_3 λ_4 | CRC

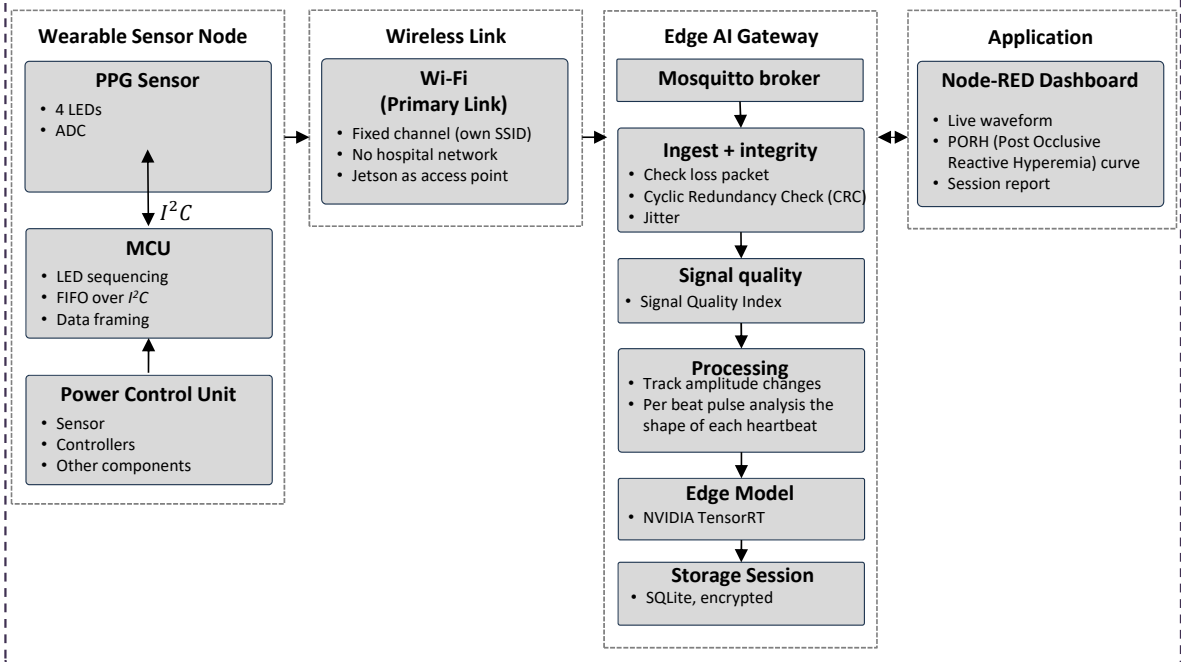
Layer 3-5 **Edge AI Gateway**
Jetson Orin Nano

- **L3 Edge Computing :** Raw data is processed into information (integrity check, signal quality index & waveform analysis of each pulse).
- **L4 Data Accumulation :** Location where processed data is stored before abstraction (Mosquitto MQTT broker)
- **L5 Data Abstraction** : The processed data is aggregated into meaningful information (profiling data & served to dashboard).

Layer 6 **Application**
Clinician dashboard

- **Node-RED** – Real time dashboard onsite with detail profiling view.

Overall System Architecture



IoT Layer: IoT World Forum Architecture Committee reference model (2014)

Proposed Method (3): Experiments & Field Testing

1 Bench validation
Optical calibration, contact-pressure control and signal-quality index at USM labs

2 Healthy volunteers
PORH protocol and repeatability; cuff and cuff-free modes

3 Clinical study, Malaysia
Healthy adults, diabetes without PAD and with PAD; ABI & TBI as reference

4 ASEAN field testing
Same protocol at partner clinics in Thailand and Indonesia, offline gateway on site

Evaluation

- ❑**Agreement with clinical reference**
  PORH features against ABI and TBI: sensitivity, specificity and ROC-AUC.
- ❑**Single vs four wavelengths**
  Both analyses on the same recording from the same patient.
- ❑**Repeatability**
  Between sessions and operators, with contact pressure held steady.
- ❑**System performance**
  On-device latency, packet loss and data integrity (CRC, jitter).

Edge AI & Secure Data Sharing (connected projects)

- ❑**1D CNN and LSTM models**
  Learn vascular signatures from time-series PPG; optimised with TensorRT on the Jetson gateway.
- ❑**Federated learning**
  Partners train one shared vascular-health model; raw patient data never leaves the site.
- ❑**Lightweight, encrypted telemetry**
  MQTT with a common data format keeps all sites synchronised.
- ❑**Ethics and data-sharing agreements**
  In place at each site before recruitment begins.

Impact (1): Scientific & Technological

Scientific Impact

❑**First reference values of toe blood-flow recovery for people with diabetes in Southeast Asia.**
The study measures how toe blood flow returns to normal after a brief cuff occlusion. Almost all such data come from Europe and North America; recordings from diabetic patients in Malaysia, Thailand and Indonesia fill this regional gap.

❑**A test of whether reading several skin depths at once tells us more.**
Light of different colours reaches different depths below the skin, so single-colour PPG sees only one layer. Reading four wavelengths together shows whether deeper and shallower vessels in the diabetic foot behave differently.

❑**A fair side-by-side test of single- and multi-wavelength PPG at the toe.**
Both analyses run on the same recording from the same patient, so any difference in the result comes from the number of wavelengths, not from patient or equipment differences.

Technology Impact

❑**Optical sensing of blood-flow recovery at the toe, without laboratory equipment.**
This measurement usually needs costly laser Doppler or NIRS systems. If a small optical sensor captures the same recovery pattern, clinicians gain a tool for places where such equipment is unavailable, and other researchers can build on it.

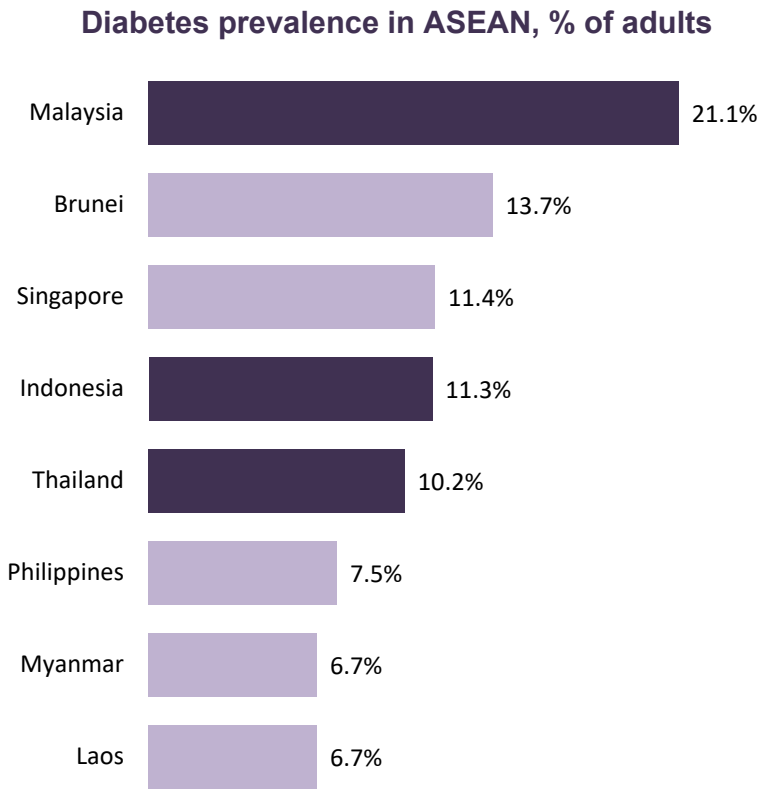
❑**A device that works fully offline.**
All processing, including the Edge AI models, runs on the gateway with no internet or outside server. Results are read on the spot, which suits low-connectivity settings and keeps patient data on site.

❑**A sensor probe that controls contact pressure by design.**
PPG signals change strongly with probe pressure, a main reason readings are hard to repeat. A small force sensor behind the optics lets the operator hold pressure steady, a design idea other PPG devices can adopt.

Impact (2): Societal

Societal Impact

- **Catching vascular failure before it leads to amputation.**
  Vascular disease in the foot progresses quietly until the skin breaks down. A simple test that can be repeated at every routine visit gives the chance to catch failing blood supply before surgery is needed.
- **Easing the economic burden through early screening.**
  Diabetes costs Malaysia about RM4.38 billion a year in direct healthcare, more than cancer or cardiovascular disease, mostly for ongoing outpatient care. Low-cost early screening helps this overstretched system find vascular problems before they become the most expensive to treat.
- **Bringing vascular screening to primary care across ASEAN.**
  The device works offline and needs no specialist laboratory, so clinics in rural or low-connectivity areas of Malaysia, Thailand and Indonesia can run the test on the spot.



Dark bars: partner countries. Source: IDF Diabetes Atlas (2024 estimates).

Impact (3): Collaborative

Malaysia

- **Universiti Sains Malaysia (lead)**
  Auto-ID Lab & INOR (engineering); Family Medicine, Microbiology, Pharmacology, Dental Sciences (clinical)
- **Ministry of Health**
  Northern Region Blood Center (ICT)

Thailand

- **KMITL, Bangkok**
  Engineering partner
- **Chiang Mai University**
  Family Medicine, clinical site

Indonesia

- **Telkom University**
  Electrical engineering partner
- **Universitas Syiah Kuala, Banda Aceh**
  Family Medicine, clinical site

Collaborative Impact

- An engineering partner and a clinical partner in every country, so the device and the clinical protocol are developed together.
- One shared measurement protocol and a synchronised ASEAN physiological database for diabetic vascular health.
- Federated learning lets institutions build a shared model without moving patient data across borders.
- Joint supervision, researcher exchange and joint grant applications build regional capacity in IoMT and Edge AI.

Output/Outcome (1): Scientific & Technological

New Technology

- **Measurement system for depth-weighted reactive hyperaemia profiling at the toe**
  Four-wavelength sensing with contact pressure held steady, built to capture PORH recovery in the diabetic foot.
- **On-device PPG analysis and result generation**
  An integrated hardware–software prototype that processes raw PPG, extracts wavelength-specific PORH features and produces results on the device, with no external server.
- **Edge AI models for vascular risk profiling**
  1D CNN and LSTM models running on the gateway to flag PAD and diabetic-foot risk for clinical follow-up.

New Scientific Knowledge

- **Whether four wavelengths outperform one for toe-based vascular screening in diabetes**
  Both analyses use the same recording from the same patient, so the comparison is fair and the finding is useful either way.
- **Whether vessels at different depths recover differently during PORH**
  No study has yet asked whether tissue depths recover differently, or whether that pattern changes in diabetes. The project is built to answer this.
- **First toe-PORH reference values for people with diabetes in Southeast Asia**
  Regional data to set against the European and North American literature.

Output/Outcome (2): Societal & Collaborative

Societal

- **ASEAN diabetic vascular PPG dataset**
  De-identified multi-wavelength PORH recordings labelled with ABI and TBI; a subset released for public research use where ethics approvals allow.
- **Technology transfer**
  The point-of-care prototype as the basis for a commercial diagnostic kit, through industry licensing or a university spin-off.
- **Clinical measurement protocol**
  A documented toe PPG-PORH procedure for primary care, offered to clinical guideline and standards bodies.

Collaborative

- **ASEAN IVO consortium**
  Six organisations in Malaysia, Thailand and Indonesia, pairing engineering and clinical teams.
- **Joint outputs**
  Co-authored journal papers, a shared dataset, and joint PhD and Master's supervision.
- **Follow-on projects and new partners**
  Extend the framework to more ASEAN member states and pursue joint international grants.

Conclusion

Target

- Find out whether a portable four-wavelength PPG sensor at the big toe can capture post-occlusive reactive hyperaemia (PORH) in the diabetic foot, and whether this dynamic test adds to the static ABI and TBI used in clinics today, within a cross-border ASEAN framework.

Method

- Four-wavelength PPG at the big toe, contact pressure held steady
- Brief cuff occlusion; recovery recorded at every wavelength (several tissue depths)
- Offline Edge AI gateway with a real-time clinician dashboard
- Clinical study in Malaysia, field testing in Thailand and Indonesia

What is new

- Multi-wavelength depth reading, contact-pressure control and PPG-based PORH at the big toe, in people with diabetes, processed fully on the device. This combination is the project's contribution.

Scientific & societal impact

- Wearable IoMT prototype ready to develop into a commercial diagnostic kit
- ASEAN diabetic vascular database and a federated Edge AI model
- Three findings: four wavelengths vs one; depth-dependent recovery; first toe-PORH reference values in Southeast Asia