

# NON INVASIVE HAEMOGLOBIN TESTING

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# PROBLEM STATEMENT

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## Current Challenges in Haemoglobin Testing

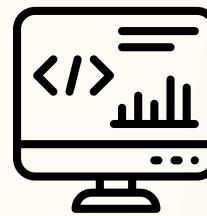
1. **Invasive**: Requires blood draws, causing discomfort and infection risk.
2. **Time-Consuming**: Lab processing delays results, especially in remote areas.
3. **Costly**: Equipment and reagents are unaffordable in low-resource settings.

## Need of the Hour

A **portable, non-invasive, and real-time solution** for haemoglobin estimation to enable accessible tests for all sections of society.

# OUR SOLUTION

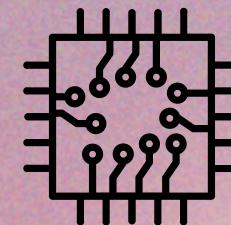
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## Non-Invasive Estimation

Uses palm/finger video frames to **capture hemoglobin-related skin color shifts** under controlled occlusion (cuff)

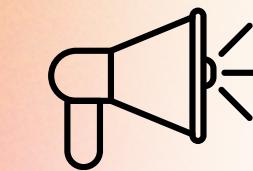
ML models **learn color features** to accurately predict hemoglobin (Hb) levels



## Embedded Deployment

ML model optimized and converted from **Python → C++ → RTL (Vitis HLS) → Verilog (Vivado)**

Deployed on **Zynq ZCU-104 FPGA** for real-time, hardware-accelerated inference.

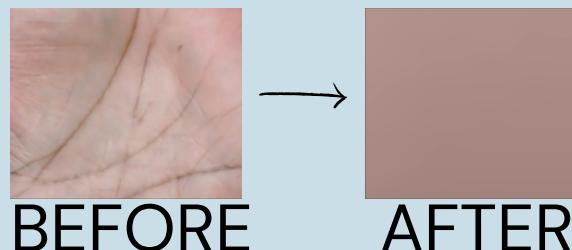


## Impact

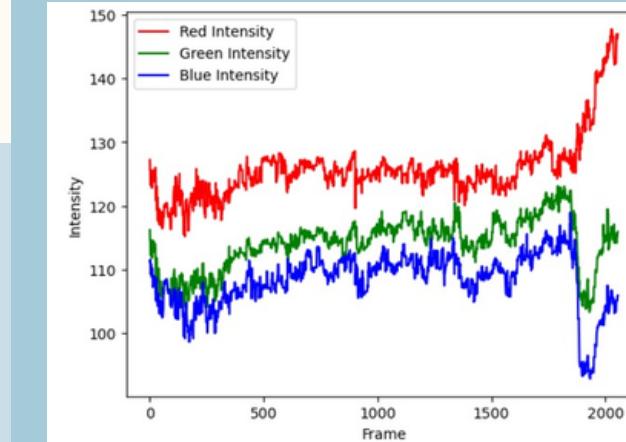
The solution enables **affordable, scalable** and **rapid point-of-care screening** for anemia and related conditions

# Non Invasive Estimation Overview

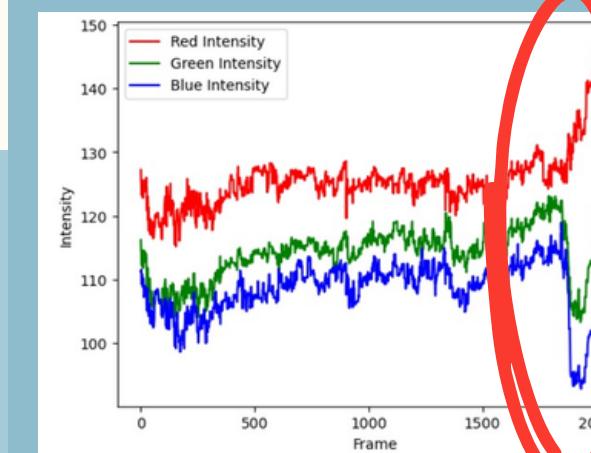
## SALIENT PATCH DETECTION



## INTENSITY OF COLOUR CHANNELS



## FIND RELEASE POINT

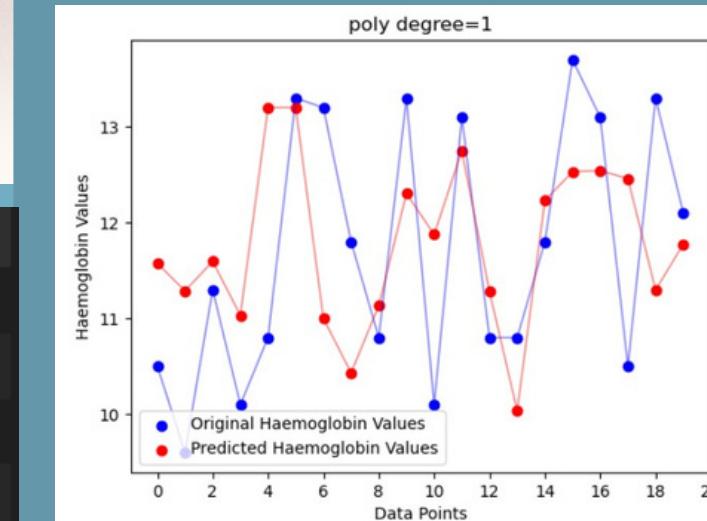


## AUC OF INTENSITY CHANNELS

	redArea	greenArea	blueArea
0	10766.0	8978.0	9510.5
1	11704.0	9503.0	9405.5
2	12002.0	9378.5	9479.0
3	10168.0	9125.5	9513.0
4	10231.5	8567.0	8620.0
5	9802.0	8835.0	8612.0

Linear Regression: 90.69%

## MODEL TRAINING



# Why FPGA-based Linear Regression for Haemoglobin Estimation?

[Input: Sensor/optical readings] → [FPGA Linear Regression] →  
[Output: Haemoglobin level prediction]

## Why FPGA (ZCU-104)?

- Low power, no need for internet.
- Real-time inference (predict hemoglobin from optical/sensor data instantly).
- Easy to embed into medical edge devices (eg: oxymeter).

# Vitis HLS Configuration & RTL Generation

## Project Setup

Created a Vitis HLS project for Zynq ZCU104, added C++ source files (main.cpp, main.h)

## Synthesis

Defined the top function (entry point) and ran C synthesis at 10ns clock period

## RTL Export

Generated synthesizable RTL from the C++ code and exported it as an IP core for Vivado

Successfully converted the ML classifier into hardware-accelerated RTL for FPGA deployment

# Hardware Acceleration: From ML to FPGA Deployment

## RTL Conversion

Transformed optimized C++ ML model into synthesizable Verilog via Vitis HLS

## FPGA Integration

Designed Zynq system in Vivado

- Custom IP core (Verilog) + Zynq PS (ARM)
- AXI-interconnected for hardware-software co-design.

## Deployment Ready

Generated bitstream (.bit) for FPGA configuration

ML classifier now runs on dedicated hardware (FPGA) for low-latency inference

# FPGA Deployment & Performance Evaluation

## Board Configuration

Connected ZCU104 via Ethernet, loaded bitstream (design\_1.bit) and hardware metadata (.hwh) via Jupyter Notebook

## Hardware Execution

Used PYNQ to

- Allocate buffers for input (palm RGB values) and weights
- Trigger FPGA IP (linear\_regression\_0) for accelerated predictions

# Results

## Root Mean Squared Error (RMSE)

- Measures the average deviation between predicted and lab-measured hemoglobin values.

$$\text{RMSE} = \sqrt{\frac{1}{m} \sum_{i=1}^m (\hat{h}_i - h_i)^2}$$

## Haemoglobin Estimation Accuracy

- % of predictions within acceptable error bounds, weighted by true values

$$\text{Accuracy} = \left( \frac{1}{m} \sum_{i=1}^m \frac{|h_i - \hat{h}_i|}{h_i} \right) \times 100\%$$

## Pearson Correlation (r)

- Quantifies linear relationship between predictions and ground truth (range: -1 to 1)

- RMSE: 1.3041
- Accuracy: 90.05%
- Correlation (r): 0.1112



# Next Steps

Now that the pipeline is set up, we can explore **sequential models** like RNNs or LSTMs to track the changes in red intensity more meaningfully and make the classifier more robust.

The FPGA design can also now be integrated with

- Camera module (for palm imaging)
- Micro-occlusion cuff (for blood flow modulation)
- Display(instant results)

to create a portable haemoglobin detection device!

# Thank You

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