Sensor Fusion using Machine Learning: Smart Forehead Temperature Sensing
Agenda

• Background
• Introduction on PixArt Smart forehead temperature detection
• Challenges in this solution
• Benefits from TinyML on Smart forehead temperature detection
• Demo Video
• Summary
Data Analytics on Edge

• Machine Learning on the edge has the benefits of:
  • Saving cost
  • Saving power
  • Fast response
  • Saving Bandwidth
  • Data privacy reinforcement

• Ultra-low power sensors are essential.
• How about data from different sensors, can they help each other?

Low power CMOS image sensor

Low power Thermal Array sensor

Low power ML processing chip

Can they help each other?

Forehead Temperature
Face info
Mask info
Real face or not:
## Comparing Solutions on the Market

<table>
<thead>
<tr>
<th>Solution</th>
<th>Thermal image (Bolometer)</th>
<th>Forehead thermometer</th>
<th>PixArt Smart Forehead solution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Price</strong></td>
<td>Very high</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Thermal Image resolution</strong></td>
<td>&gt; 80x60</td>
<td>Single pixel</td>
<td>8x8</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Sensing distance</strong></td>
<td>Long (5M)</td>
<td>Very short (&lt;50mm)</td>
<td>&lt;1M</td>
</tr>
<tr>
<td><strong>System complexity</strong></td>
<td>Complex</td>
<td>Simple</td>
<td>Simple</td>
</tr>
<tr>
<td><strong>Mask information</strong></td>
<td>NA</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Face detection</strong></td>
<td>NA</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Auto–forehead Temp measurement-avoid error</strong></td>
<td>NA</td>
<td>NA</td>
<td>Yes</td>
</tr>
</tbody>
</table>

PixArt’s Target Solution:
- Similar cost to traditional forehead thermometer
- Longer measure distance than traditional forehead thermometer
- Provide more smart functions
- Small form factor
- Lower power consumption
Smart forehead Temperature Sensing

**Key Features**

- Combine temperature sensor with object detection to get more accurate result
- Real-time output face position, size and with Mask or not.
- Real-time report forehead maximum temperature
- Built-in Temperature compensation algorithm
- High temperature accuracy: $37 \pm 0.5 ^\circ C$
- Temperature report rate: 10Hz
- Sensing distance: up to 1m
- Sensor FOV(H/V)=60°
- Object Temperature: human temperature range.
- Ambient temperature sensing range: -40 °C to 85 °C

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Output data:
- Forehead temperature
- Face number, position & size
- Mask face or not
Components of Evaluation Board

a. **PAF9701C1 : 8x8 Thermal array sensor module**
   - Sensor FOV=600
   - Output data rate: 10Hz
   - Wide object temperature sensing range: -20°C to 150°C
   - Low power operation: 5mW
   - Suspend mode: < 10uW

b. **PAG7920J1 : Ultra-Low power QVGA CMOS image sensor module**
   - HW Auto Exposure and Auto Gain Control
   - Built-in Low power motion detection function
   - Lens FOV(H) = 72°
   - Ultra-low power consumption
     - < 100uW @motion detection Mode
     - 0.79mW @image mode @15fps

a. **PAG7681LS : Low-power object detection chip**
   - HW simplified Deep Learning engine embedded
   - Support color ISP function
   - JPEG encode output
   - Low Power consumption (QVGA sensor + PAG7681)
     - Human sensing(classification) : 1mW per fps
     - Human tracking(detection) : 6mW per fps
Possible Applications

- Can easily integrated with access control system or applied to smart doorbell
- Small form factor, can be used on hand-held device.
- The target detection object instead of Face can be changed through machine learning to apply to variety of applications, such as:
  - Animal temperature monitoring
  - People counting
  - Abnormal object temperature monitoring for Industrial application
  - Temperature sensing in the kitchen (Oven, pot...etc)
Extend 8x8 Detection Range by Face info

- **Challenge:** 8x8 resolution is not enough to detect forehead at 1 meter
  - Assuming Forehead area need larger than 2x2 pixel area, for 100cm detecting distance, FOV 60°, it needs 30 x 30 pixel thermal array to get enough resolution.

- **Overcome:** QVGA image can provide ~1.5 meter face detection range
  - Face position and size info helps to locate the most possible pixel and compensate the thermal calculation.
Forehead Temperature result (1)
non-compensate v.s compensated

No Face info compensate

30cm

50cm

Compensated by face info

30cm

50cm

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Forehead Temperature result (1)
non-compensate v.s compensated

No Face info compensate

Compensated by face info

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Low power consumption to reduce Heat influence

Challenge: Heat influence

- In general, MCU normal operation temperature will be around 45~50 deg.
- The heat induced by the MCU will affect the accuracy of thermal sensor

Overcome:

- PixArt PAG7620J1 + PAG7681LS operation temperature is around 35 deg
- Temperature error will be half comparing to general MCU solution.
Low Power Consumption to reduce Heat influence

- Image sensor always-on to detect motion
- When motion detected, start to detect face and wake up thermal sensor as well.
Benefits from TinyML architecture on Smart forehead temperature detection

• Performance upgrade
  • Extend 8x8 array measure range to 1 meter by using Face info
  • Accurately locate face position to avoid undesired heat object

• Cost Reduction
  • Low power consumption on the image sensor and ML chip allows to integrate in a small form factor pcb.

• Bandwidth saving and Data Value Added
  • Provide Forehead temperature
  • Provide additional detection information (Mask detection)
  • Possibility for other application (Human body, animal body...)
Demo Video (TBD)

- Will re-shoot the demo video, will be updated,
Summary

• Different sensor’s data through Machine Learning will help to upgrade performance and reduce cost.
• Ultra-low power sensor reduce the heat influence issue on the PCB.
• Can only output meta data, which greatly save transmitting bandwidth and improve data privacy
• Image sensor data and Thermal sensor data fused through machine learning, provides more value added information.
  • Forehead temperature
  • Mask information
  • Rule out undesired heat source
• With the sensor fusion platform, many possible application will be enable