White Paper

High Performance CMOS-Based Infrared Sensing Platform for Scalable Applications

Introduction

Thermal infrared (IR) imaging is a leading modality for detecting humans and heat signatures. Unlike visual cameras, where CMOS imagers capture reflected photons in the visible spectrum, thermal imaging detects infrared emission from objects. CMOS image sensors (CIS) are sensitive to visible wavelengths (400–700 nm) and near-infrared (700–1,100 nm), whereas thermal sensors operate in the long-wave infrared (LWIR) band (8–14 µm), where humans and most objects at room temperature exhibit peak radiative output.

Thermal imaging provides unique benefits, including robust visibility through smoke and fog and operation independent of ambient illumination, enabling performance in complete darkness. It is therefore well suited for human detection, as humans appear as warm emitters against a cooler background. Further thermal imaging allows to detect and visualize with spatial resolution small temperature changes and differences, which is relevant for industrial fixed asset monitoring, electrical and mechanical heat evolution monitoring (e.g. bearings, conveyor belts, batteries, data centers).

Thermal sensing technologies can be broadly classified into cooled photon detectors and uncooled detectors. Cooled detectors require cryogenic operation and are therefore prohibitively expensive for civil use. Uncooled detectors, which are more relevant for commercial applications, convert incident IR radiation through an indirect thermometer-like mechanism: absorbed photons induce a small temperature rise (ΔT), that modifies a temperature-dependent material property; which is then read out and converted into an electrical signal.

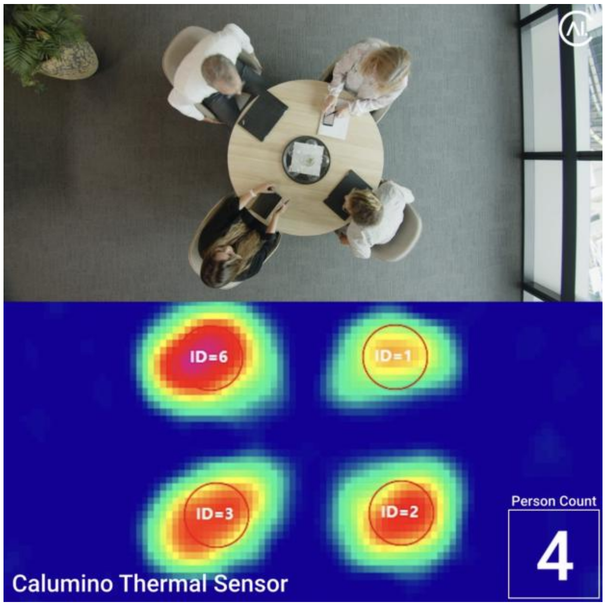

Figure 1: *Top:* Top-down visual image. *Bottom:* Corresponding thermal output from Calumino Thermal Sensor (CTS) with AI-based person-detection overlay.

However, today's uncooled detector landscape is constrained by cost or limited performance. Microbolometers, traditionally developed for military applications remain too expensive for human indoor detection in smart buildings or consumer applications. Thermopiles often lack sufficient sensitivity. In addition, for system level integration, factors such as cost, power, stability, privacy, and export controls are relevant and further limit applicability. Most importantly, existing thermal sensor component manufacturers do not provide a solution for data-analysis or interpretation for tangible outcomes, such as HVAC control through people counting and location detection.

The challenge in deploying thermal sensing at scale in buildings and consumer systems is not detection per se, but achieving sufficient sensitivity and stability at low resolution, low power, and low cost - while preserving privacy and offering on-edge AI, enabling actionable system-level decisions. Microbolometers fail at the cost ceiling and privacy. Thermopiles don't offer the right performance. PIR motion sensors lack spatial and temporal information.

Calumino's novel thermo-optical approach, leveraging CMOS imaging sensors and AI chips by Himax Technologies, Inc (Himax), closes this price-performance gap and offers a system level solution for a variety of different applications, such privacy non-intrusive people counting, location and activity detection (see Fig. 1) for HVAC, lighting, aged- and health-care and security, or temperature monitoring of assets.

Figures of Merit in Thermal Sensing

The world of "thermal" differs from visual imaging and different merits apply to evaluate and characterize the performance of thermal detectors.

- **Noise-Equivalent Temperature Difference (NETD):** A measure of sensitivity, representing the smallest resolvable temperature contrast. For indoor human detection, NETD <200 mK is required, with <100 mK preferred for detecting subjects at distance or resolving edge features.

- **Frame rate:** Limited by the thermal time constant of IR pixels. Many imagers are restricted to <9 Hz to comply with defense-related export controls, though 4–8 Hz is generally sufficient for indoor human sensing.

- **Resolution:** Defined by the number of IR pixels. Systems range from <100 pixels (e.g., 8×8 arrays) to several thousand pixels. As resolution increases beyond ~50x50 IR pixels, privacy diminishes, and individuals become not only detectable but potentially classifiable and identifiable. Calumino has deliberately chosen a low resolution to protect privacy.

- **Field of view (FOV):** For indoor sensing, wide horizontal FOV (>100°) is preferred to maximize coverage.

- **Stability:** Bolometers exhibit short-term drift and require shutter-based flat-field correction. Thermopiles and bolometers are inherently sensitive to ambient temperature fluctuations due to thermoelectric conversion, resulting in baseline instability. Similarly to NETD this parameter is critical for reliable people detection algorithms, ensuring a stable signal input.

- **Accuracy:** Refers to radiometric accuracy. True temperature accuracy depends on object emissivity, size, viewing angle, distance, environmental conditions, sensor operating point, and equilibrium effects. This metric is often stated as a simple value such as "±2 K accuracy" without specifying the measurement conditions under which it applies. Such values typically refer to accuracy under controlled calibration conditions, whereas determining accuracy in real-world scenarios is substantially more complex.

- **Power consumption:** Critical for battery-powered systems. For portable or low-power applications, thermal sensors should consume ideally less than 50 mW. Because the Calumino Thermal Sensor's

(CTS) main power consumption comes from the CMOS, Himax plays an essential role with their leading low-power platforms on a system-level.

These parameters collectively guide sensor selection for human-detection applications. Figure 2 illustrates the importance of NETD and signal stability.

NETD represents the standard deviation of temporal noise, meaning each pixel fluctuates within approximately ±3×NETD for 99.7% of time. In the bottom row of Figure 2, a human thermal signal appears for several consecutive frames around the 30- and 140-frame marks at roughly 4 K above the background. Although the human core temperature is ~37 °C, the effective skin- or clothing-surface temperature is typically <30 °C, and the thermal contrast relative to the scene decreases with distance and other conditions. In many scenarios, a human may present less than 1 K contrast; for example when entering from a cold outdoor environment into a warm indoor space before thermal equilibration, or when sunlight heats up the background, or when only a few peripheral pixels fall within the field of view, or at distances exceeding ~3 m. In these cases, the importance of NETD becomes evident: NETD <100 mK enables detection of thermal signatures on the order of ~300 mK above or below background, as demonstrated by CTS performance. At such sensitivity levels, resolution becomes less critical. Furthermore, the bottom row of Figure 2 shows that the thermopile exhibits baseline drift (dotted line), whereas the CTS maintains a stable, low-noise baseline — an essential requirement for reliable people detection algorithms.

For system integrators, NETD and stability directly determine algorithm confidence and false-positive rates, often more than pixel count. If the sensor drifts or exhibits a hysteresis behavior with operating temperature fluctuations, a mechanical shutter or some flat field correction procedure has to be performed to reset the imagery. These countermeasures can impact cost, complexity and usability of the entire system.

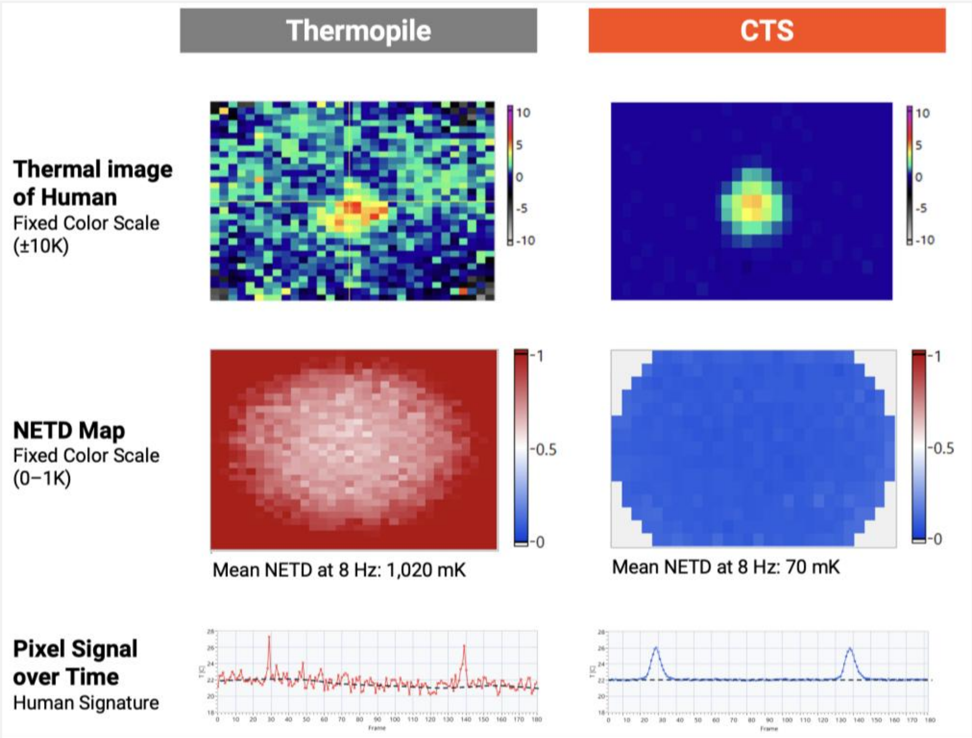

Figure 2: Comparison of thermopile performance (left) versus the Calumino Thermal Sensor (CTS) (right). *Top row:* Thermal images of a human shown on a fixed ±10 K color scale. *Middle row:* NETD maps displayed on a fixed 0–1 K scale. The thermopile shows a mean NETD of 1,020 mK at 8 Hz, while the CTS achieves a mean NETD of ~70 mK at 8 Hz. *Bottom row:* Center-pixel temporal signal with a human crossing the field of view at approximately the 30- and 140-frame marks.

Operating Principle of the Calumino Thermal Sensor

The Calumino Thermal Sensor (CTS) operates on a novel, patented thermo-optical principle that enables high performance at scalable cost. The core element is a zero-power MOMS (micro-opto-mechanical system) chip comprising an array of micro-mirrors. Each micro-mirror functions as an IR pixel and consists of an absorption paddle connected to a bi-material actuator, implemented as a free-standing structure anchored to a substrate.

The paddle absorbs IR radiation, producing a small temperature increase (ΔT) that induces angular deflection ($\Delta\alpha$) of the micro-mirror through the bi-material actuator, which exploits the differential thermal expansion of its constituent materials (aluminum and silicon oxide which have a high coefficient of thermal expansion (CTE) mismatch). The paddle also incorporates a reflective surface illuminated with visible light (e.g., blue light from a standard LED, with e.g. 450nm), projecting a spot onto a CIS. When the micro-mirror tilts, the reflected spot shifts accordingly. Because the micro-mirrors are entirely passive and require no electronics, they behave analogously to miniature bimetallic springs. The behavior is proportional and linear: the spot, or "dot" moves proportionally to the angular deflection, as it is in the 10^{-4} degree range, which in turn is proportional to the absorbed influx infrared power density.

The design further incorporates a temperature-compensating structure that suppresses response to ambient operating-temperature changes. Only IR-absorption-induced ΔT drives mirror deflection, providing exceptional signal stability of the detector. This is a major advantage over thermo-electrical converters which do not have an intrinsic operating temperature offset, and some, such as diodes have a non-linear signal transfer function behavior with ambient temperature conditions.

The MOMS chip converts IR radiation into micro-mirror motion, and the CMOS imager translates that motion into electrical output via spot-tracking. Figure 3 illustrates a schematic of the CTS architecture, and Figure 4 shows the reflected micro-mirror dot pattern captured by the CIS. The CIS is monochrome.

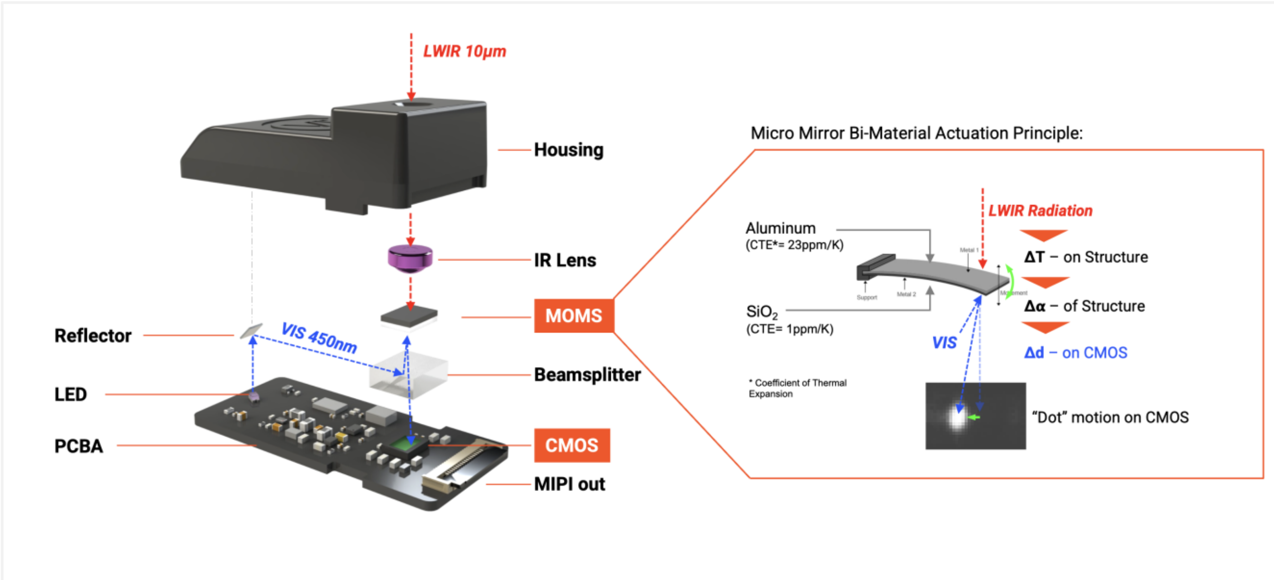

Figure 3: System architecture of the Calumino Thermal Sensor (CTS). *Left:* Exploded schematic of the CTS module showing the LWIR optical path and readout chain. *Right:* Detail of the bi-material micro-mirror actuation principle. Absorbed LWIR radiation produces a temperature rise (ΔT) in the structure, causing angular deflection due to the differential thermal expansion. This angular deflection results in a lateral displacement (Δd) of the reflected visible "dot" on the CMOS sensor, which is measured to infer the incident thermal signal.

Centroid algorithms determine the reflected-spot position. Averaging multiple CMOS frames improves positional accuracy with a square-root dependence, thereby enhancing system sensitivity.

Calumino and Himax have partnered up to enable a scalable and low-power thermal sensor with on-edge AI solution. For the CTS3001, Calumino is leveraging Himax's HM0360 CMOS image sensor, because of its low-noise, 60 Hz frame rate and low-power capability. In standard mode, the CTS operates with 60 Hz CMOS sampling and 8× averaging, yielding a native 7.5 Hz output and approximately 2.8× NETD improvement relative to unaveraged raw-frame operation – all while being low-power.

The CTS module integrates a 140° FOV IR lens and outputs MIPI data directly from the CMOS sensor. Owing to the efficiency and capability of the HM0360, typical power consumption is <30 mW (7.5 Hz output, 60 Hz sampling) and can be reduced to single-digit milliwatt levels at lower sampling frequencies, providing flexibility for a wide range of application requirements.

The CTS3001 interfaces directly with the low-cost, low-power Himax WiseEye 2 AI processor via MIPI, a tightly coupled optical–CMOS–AI pipeline with no intermediate ADC or DSP stages. This solution allows on-edge AI with standard MIPI interface and existing toolchain support, enabling direct deployment of pre-trained people-counting models.

For smart building applications, the total power consumption of the solution (thermal sensor + AI processor) is often capped and critical for system design. For example, some bus-systems can have power supply restrictions which impact the sensor and system-level selection. Further battery-operated devices typically need to last for over 1 year, and the thermal sensor + on-edge AI processor can be woken up by e.g. a motion sensor. Event based system wake up, or event dependent sampling rate is also an option for power constrained system designs.

The CTS + Himax enabling platform, provides key advantages of high sensitivity, low cost, on edge AI, low power and privacy protection which are requirements by most indoor human sensing needs. Such attributes are not achievable with conventional consumer CIS or general-purpose AI MCUs.

Himax Low Power Platform

Several years ago, Himax recognized that many commercial and consumer type "smart sensing" applications require battery-powered operation, especially in scenarios where existing buildings or infrastructure were not designed to accommodate new device installations. Battery power greatly enhances installation flexibility, but traditional technologies limited such devices to basic detection functions, making vision-based detection nearly impossible due to power constraints. To address this, Himax invested in the development of ultra-low power CMOS image sensors, enabling a broader range of battery-powered, vision-based detection applications.

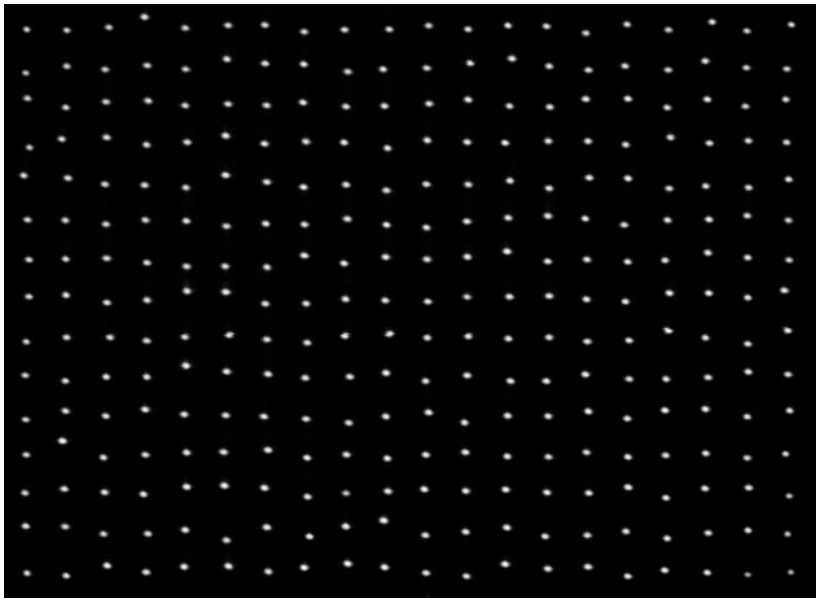

Figure 4: CMOS image sensor capture of the reflected visible light "dot" pattern generated by the CTS MOMS micro-mirror array. Each dot corresponds to an individual micro-mirror (IR pixel).

Himax's low-power CIS designs deliver outstanding energy efficiency without sacrificing image quality. The focus extends beyond sensor power consumption to minimizing overall system latency and overhead. For example, the HM0360 achieves less than 9 mW at VGA 30 fps, and under 1 mW with 2fps auto wake-up and sleep. In deep sleep mode, power drops below 20 µW, allowing instant image capture upon host trigger and immediate return to sleep after data transfer. Many scenarios require only a few activations per second or even less, making this architecture effective for maximizing battery life. The HM0360 also features premetering for optimal exposure on every wake-up, independent motion detection, and fast context switching for efficient mode transitions.

Traditional IoT systems often transmit sensor data to the cloud for analysis, resulting in high computational demands, increased energy consumption, and data security risks. Advanced edge AI applications still face challenges in compute, memory, and power. The Himax WiseEye ultra-low power AI processor is engineered to overcome these barriers. It features an efficient neural network processing unit (NPU), multi-level power management for always-on scenarios, and supports model optimization and pruning for real-time inference with compact models. Deep integration with Himax's ultra-low power CIS enables an end-to-end sensing and inference solution, ideal for applications such as human presence detection, access control, biometrics, and AI PCs.

Summary

Calumino's thermal sensor uses an optical approach to amplify thermal signals, decoupling temperature signal noise from other electronic noise. When combined with Himax's low-power CIS and WiseEye AI processor, Calumino's sensor delivers precise temperature information and supports long-term, battery-powered intelligent analytics. This makes it well-suited for occupancy sensing, people counting in smart buildings, and a wide range of consumer and industrial applications.

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