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Key Technology Trends and Emerging Applications for Compact Thermal Imagers

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Abstract

The FLIR Lepton LWIR camera module, introduced in January 2014, has demonstrated that compact, cost-effective thermal imaging modules are achievable for consumer electronics applications. The FLIR ONE product family which turns a mobile phone into a complete thermal camera solution has further started the process of putting thermal imaging in the hands of many consumers. The open question is, "What is the killer application for consumer thermal imaging?" This paper presents an overview of some key technologies and technology trends that will dramatically advance consumer thermal imaging applications. This paper also discusses the range of potential future applications for thermal imaging and how the market and use cases might evolve over the next 3-5 years.

Key words: Microbolometer, LWIR, thermal imaging, smartphone, IoT

Introduction

Thermal imaging is poised to go mainstream. FLIR has developed a thermal infrared camera so tiny, low-power and inexpensive that it can be integrated into a cellphone or other mobile device. The cost point is achieved by using high-volume manufacturing processes and materials developed for mobile phone cameras, including packaging, calibration and assembly. Micro-miniature low-cost thermal cameras can be used in applications that were unthinkable even a few years ago: non-contact thermometers integrated in smartphones, new gestural and thermal touch user interfaces, wearable spectrometers, IoT climate control and care devices, and people counting.

Lepton Thermal Camera

The Lepton is a micro-miniature thermal imaging camera that produces a stream of longwave infrared (LWIR) images that are 80 by 60 pixels in size at a frame rate of <9 Hz. This frame rate was chosen because of current US export laws that make a 9 Hz thermal camera exportable with fewer restrictions. Realizing a mobile-phone sized thermal camera is the next step in a rapid evolution in infrared camera technology that has taken place over the last 15 years. The infrared industry has dramatically reduced the size, weight, power and cost of thermal imaging cameras. This trend is illustrated in Figure 1 which shows the reduction in the size of FLIR thermal camera cores that has taken place from 2010 to 2014. Lepton, shown on the right of Figure 1, is less than 10 mm on a side including the lens, weighs 0.55 grams, and consumes less than 150 mW of power.

Fig. 1. Thermal camera miniaturization.

Lepton is innovative in every aspect, and required a very significant investment in technology development. These are some of the key technology advances used in the design: very low cost lenses built in a novel high-volume wafer-level process, wafer-level packaging of sensors to reduce camera size and number of manufacturing steps, high-speed automated camera assembly and calibration with minimal touch labor, and single-chip camera electronics to reduce size, power requirements and number of interconnects.

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The control interface is similar to the I2C protocol, and the serial video interface is MIPI compatible, using a D-PHY transmitter to send serial video data and clocks to the host. The video is accessible either via the MIPI interface or as packetized video using SPI.

Emerging Thermal Sensor Applications

As a result of the recent reductions in size, power and cost of thermal sensors many never before possible high-volume applications are poised to emerge.

FLIR ONE Smartphone Accessory

The Lepton thermal imager converts a scene's heat pattern into digital image data, but it does not include a display or memory for image storage. FLIR has developed the Lepton-based FLIR ONE smartphone accessory family for iOS and Android devices in order to put a turnkey camera system into the hands of consumers, app developers and OEM customers. The FLIR ONE, shown in Figure 2, attaches to a smartphone and feeds video data to it from a Lepton and a visible camera mounted next to each other. High resolution edge details from the visible camera are overlaid on the Lepton images producing a blended visible and thermal image with good spatial features. The user controls the device via a phone app, enabling the capture of still images or video as well as temperature measurement with a temperature spotmeter.

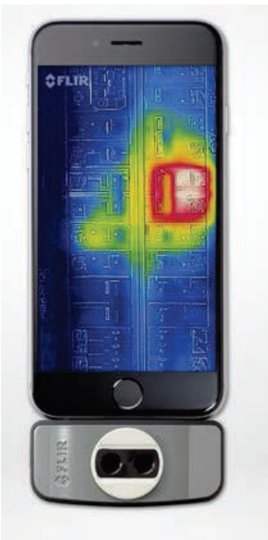

Fig. 2. FLIR ONE

Smartphone as non-contact thermometer

Today thermopile detectors are commonly used in a number of contact and non-contact thermometers. Recent advances in the miniaturization of thermal cameras make it likely that in the future thermal sensors capable of measuring human body temperatures will be available in smartphones. The smartphone will become the "thermometer that is always with you". The connectivity inherent in the smartphone may also enable novel and useful data aggregation such as traffic-map-like health reports for local schools and regions.

Fig.3. Non-contact smartphone thermometer

Thermal Enabled New User Interfaces

Pyroelectric thermal detectors are extremely low power devices that generate a transient electrical response to a thermal signal. Traditionally, PIR devices have been used to detect motion or room occupancy and control lighting or doors. With more sophisticated algorithms such as those demonstrated by Pyreos (Edinburgh, Scotland) a quad pyroelectric detector array enables basic gesture recognition (up, down, left and right) to be easily added to consumer devices which can enable natural, non-contact gestural control for applications such as turning pages for an e-reader.

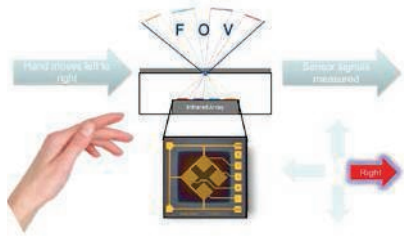

Fig. 4. Pyroelectric based gesture (Pyreos)

Another emerging user interface for wearables and augmented reality applications called "thermal touch" has been demonstrated by Metaio (Munich, Germany). The thermal sensor detects the surface temperature change caused by the user touching real-world objects and in effect turns any surface into a "thermal touch screen".

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Fig. 5. Thermal-based wearable UI (Metaio)

Spectroscopy

Many organic substances have unique, fundamental spectral responses in the MWIR and/or the LWIR region of the IR spectrum. Infrared detectors may soon enable compact, low-cost spectrometers that are integrated into handheld or wearables as suggested by Pyreos. A consumer spectrometer can be used to verify that milk and other foods are not contaminated with hazardous substances, for example.

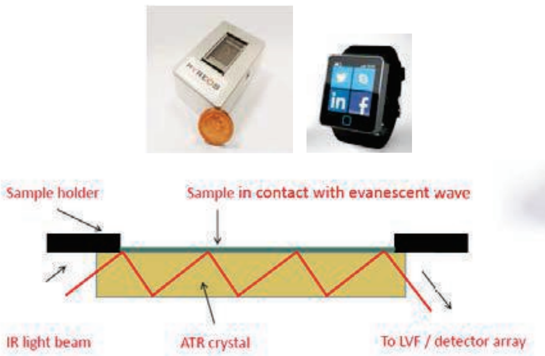

Fig. 6. Consumer spectroscopy (Pyreos)

Internet of Things (IoT)

The Internet of Things can be defined as the aggregation of all the sensing modules which are linked to the Cloud. Yole (Lyon, France) expects the total IoT market sensor volume to be 11.8 billion units by 2024.[1] Compact, low-power thermal sensors will be embedded in many IoT applications including: smart appliances, thermostats and other distributed environmental control systems as well as presence detection and elder care monitoring. Low power thermal sensor arrays will become key enablers of increased energy efficiency by allowing building and outdoor lighting to be adjusted based on the presence of people and further by allowing optimized and localized climate control. Energy will be allocated to lighting and heating dynamically on an as-needed basis. In elder care applications, compact thermal imagers allow for activity, presence and fall detection in critical and hazardous areas such as bathrooms while preserving privacy with their low spatial resolution.

People Counting

Thermal imaging is one of the leading methods of counting people in indoor and outdoor settings. People counting and tracking is a relatively new capability offered to retail locations to determine how many people are shopping and what their habits are while shopping. People counting is also used for managing lines and wait times, and making assessments of the total number of people and their movements in public areas like airports and large shopping malls. Using thermal imaging as the people counting method offers advantages over visible-light imaging systems because the technique does not depend on ambient light and works equally well regardless of the lighting conditions. Additionally, low-resolution thermal infrared does not generate personally identifiable video information and so allows for anonymous collection of statistics on people movement and presence detection.
Current people counting systems use low resolution sensors and are often referred to a “blob” detectors because people or other objects moving through the camera’s field of view show up as undifferentiated blobs. These ultra-low resolution sensors are often pyroelectric or thermopile detectors arranged into a small array of pixels, often 16x16. These sensors are very inexpensive compared to the traditional thermal imaging modules that often have resolutions of 320x240 pixels but can cost in excess of $1000.
The new generation of very small, low cost, low power microbolometer cameras offer cost advantages over traditional thermal imagers, while also delivering system and performance advantages over the ultra-low resolution systems deployed today. Lepton’s 80x60 image size provides almost 19 times the number of pixels for detection compared to a 16x16 array. Depending on lens configuration and location of the people counting device, this provides the potential to more accurately count people over an area that is substantially larger than the current system without sacrificing resolution compared to current systems. In a situation where multiple people-counting systems might be required, now one system could do the job for a substantially lower net cost. Additionally, the ASIC inside Lepton contains a signal processing engine that, depending on the complexity of the algorithm, could take the place of the external processor used in current people counting devices, further lowering the system cost. Finally, a higher resolution device like Lepton could be configured to perform

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certain types of discrimination functions that a 16x16 sensor could not do. These discrimination tasks could include determining if a person is carrying an object, making an assessment of whether or not objects are in a shopping cart and if they are at room temperature, or hot or cold. A higher resolution camera could also be used to distinguish between children and adults, and human beings and animals.

Fig. 7. Image produced by a typical 16x16 pixel thermal imaging sensor used in people counting contrasted with a 80x60 Lepton image

Firefighting

One of the early non-military applications for thermal imagers was as a handheld firefighting camera. These cameras have enabled firefighters to perform their missions with greater effectiveness and safety by allowing the user to see through incredibly dense smoke or to see the temperature of walls, doors, and ceilings as a way to assess the spread of a fire when a direct view is not possible. These firefighting cameras initially enabled by uncooled microbolometers allowed for new low price points. Additionally, these devices provided wider operating temperature ranges and had lower power dissipation that enabled longer battery powered operation.

Incremental improvements in thermal cameras have proceeded steadily over the past 15 years to lower the price, decrease the size and power, and improve the image quality. However, in spite of these improvements, the cost and size of today's thermal cameras still limit how they are used. Not every firefighter has a thermal imager. Today firefighters still often rely on decades old methods of navigating in a smoke-filled building by feel. One other key limiter is that almost all firefighting cameras are handheld devices that force the firefighter to choose between seeing clearly or having both hands free. Many of the barriers to more universal use and hands free operation can be removed as a new generation of firefighting cameras are designed around the latest wave of small size, low power, low cost thermal imaging modules.

When the Lepton thermal imager was first introduced as a component in the FLIR ONE iPhone accessory, it helped establish a new low price point that reduced the cost of such technology to end users by roughly a factor of three, from $1100 to $349 (now $249). Because the cost of the thermal imaging module traditionally has been a key driver in the overall cost of the firefighting camera, similar reductions in end user cost seem achievable in the near future. These large anticipated reductions in cost should result in significantly more firefighters having thermal cameras as standard equipment.

Another area where technology advances are expected to improve firefighting cameras is in how these cameras are carried. Hands-free operation via helmet mounting or self-contained breathing apparatus (SCBA) mask mounting would be a significant improvement in usability compared to the present day bulky cameras that are either hand held or clipped to a utility belt when not in use. However, a typical thermal imaging module in today's firefighting cameras has dimensions of approximately 4 cm x 4 cm x 5 cm and has a power dissipation of about one watt. Water, shock, and thermal protection of the camera module as well as batteries add weight and volume in proportion to the protected volume. New camera modules such as Lepton make use of next generation sensors and custom-designed system-on-a-chip electronics that reduce power dissipation from around one watt to less than 200 mW, and reduce the enclosed volume by more than 2 orders of magnitude. Even if display power remains constant there is an opportunity to reduce battery size and weight by almost 50%. Further, with the mainstream introduction of consumer near eye displays built into smart glasses, such as Google Glass or Vuzix, the opportunity to dramatically reduce display size and power is achievable today. Existing near-eye displays can fit inside the SCBA mask and could bring power reduction to the display comparable to the power reduction of the thermal camera module.

Fig. 8. A typical firefighting camera whose size and weight is driven by the size and power dissipation of

the thermal imaging module packaged (left) and smart eyewear/near-eye display (right)

UAVs

Thermal imagers are used in UAVs to improve both nighttime and daytime situational awareness, survey buildings for energy efficiency and enhance crop and terrain surveys. They can also greatly enhance the ability to land a UAV in low light conditions. Compact thermal imagers are an ideal solution, especially for nano-UAVs, where every gram of additional weight negatively impacts system performance.

Fig. 9. Prox Dynamics Black Hornet PD-100T with Lepton imagery

Animal Care

It is well understood that measurement of surface temperature of an animal indicates where there is an abnormality due to inflammation, typically associated with an injury or infection. Temperature anomalies can also indicate reduced blood flow or the presence of cancerous growths. Animals cannot effectively communicate with the people responsible for their care, and in many cases survival instincts will induce animals to mask pain and discomfort. For those responsible for animal care, thermal imaging provides a quick, non-invasive means of identifying problems, making it a very effective complement to traditional diagnostic tools. Zoos and large veterinary practices have been employing thermal imagers in increasing numbers over the last decade. Further, because thermal images are easily stored and managed, they provide an effective means of tracking treatment and recovery. This practice has been limited to large training and racing facilities due to the high cost of the equipment as well as limited understanding of the technology.[1] The advent of compact, low-cost thermal imagers with intuitive user interfaces has changed this situation.

In recent years, thermal imaging has been used for diagnosis of tendon, hoof and saddle-related injuries in horses. A recent user experience illustrates the evolving use of thermal imaging in animal care. A horse and rider suffered a fall in an area removed from professional trainers or veterinarians. Shortly after the accident, a companion with a FLIR One used the compact thermal imager to help the rider determine that the horse had no major inflammation of the legs or hooves.

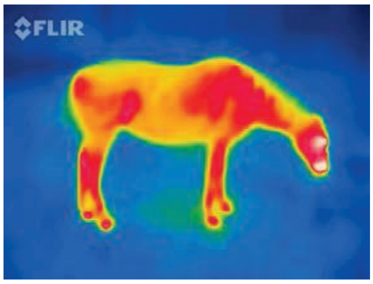

Fig. 10. This mare suffered an unexpected fall. After a short recovery time, the FLIR One indicated that the horse's legs showed no apparent injuries

In addition to detecting injuries, thermal imaging has been effectively used in veterinary practice with common household pets. It has been used on dogs to detect snakebites and to locate skeletal problems, as well as being used to monitor treatment of osteoarthritis in cats.[2] By making this means of information collection affordable and easy to use, the technology is moving out of the major clinics and into the hands of a much larger number of field vets and animal enthusiasts. As a result, needless animal suffering is reduced and animal health is improved.

Electronic System Troubleshooting

Electronic systems are increasingly complex and detecting faulty components on a printed circuit board is often a frustrating or fruitless task. In business settings, entire boards are routinely replaced due to the failure of a single component. For specialty boards in industrial setting, board replacement can lead to thousands of dollars of expense due to the failure of a single component. To avoid such expenditures, maintenance professionals use thermal imaging to detect hot (or cold) components on operating circuit boards. This allows them to isolate anomalies and quickly repair defective boards.

For hobbyists and home electronics enthusiasts, circuit repair has remained time consuming and difficult, particularly for those interested in vintage electronics. Many systems such as electronic keyboards, music synthesizers, and very early computers include boards that are no longer manufactured and are difficult to troubleshoot. Until the advent of compact, low-cost thermal imagers, hobbyists could frequently damage a circuit further while trying to isolate the problem.

Figure 11 depicts a Prophet 600 synthesizer circuit board, built around 1983 (the keys are visible at the bottom of the image). While the board functions correctly, the owner was concerned over possible issues with the voltage regulators. Using the FLIR One, he examined the board and identified that the diode rectifier and voltage regulators, located in the upper left, appeared to be functioning within normal operating ranges. Further, he noted that among the five ICs located along the lower edge of the image, two chips are appreciably hotter than their neighbors, and one is at a median temperature. The owner concluded that a replaced CPU is overdriving the timer and serial-to-parallel converter, causing those two chips to operate at higher temperatures.

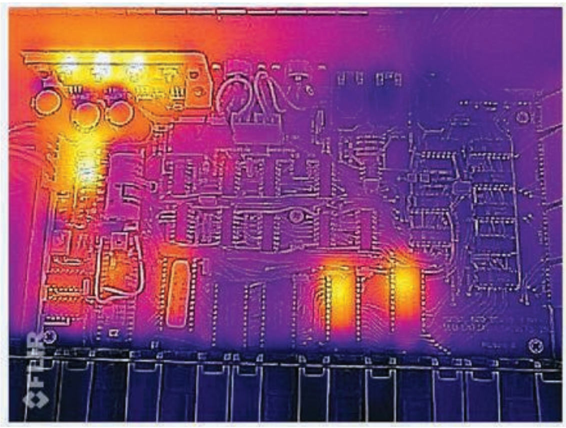

Figure 11. This vintage Sequential Circuits Prophet 600 circuit board has a healthy power supply, but unusual heat dissipation among the 5 large IC chips.

Thermal imaging is sometimes called a “sixth sense” because it enables a user to detect changes in their environment that they would be unaware of under normal circumstances. At the right price point, demand for that additional sense will become pervasive among consumers. Many institutional applications of thermal sensing have consumer-level counterparts. Health monitors, smart thermostats, medical screening, safety tests and equipment repair are all industrially-proven applications of thermal imaging which point to consumer-level applications enabled by small, low-cost thermal cameras like Lepton. If you provide any enthusiast a sixth sense, they will find ways to use it to improve whatever it is they are passionate about.

Fun Applications

The importance of play and fun as an enabler and driver of new technologies should not be underestimated. The plethora of social media applications such as SnapChat, Instagram and many others enabled by the integration of cameras in smartphones is one example of this effect. Similarly, it can be expected that many unforeseen and fun applications will be developed around thermal imagers as well. Fun applications may include thermal decoration of visible images, using the thermal data to extract people from the visible image and create a “thermal green screen” and thermal-enhanced night games such as scavenger hunts and laser tag.

Conclusions

Recent advances in thermal imaging have led to dramatic size, cost and power reductions for thermal cameras. While it is impossible to predict the “killer app” and ultimate volume drivers in advance, the rich array of thermal application possibilities discussed in this paper show that the future of thermal sensors and imagers is very bright indeed.

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