Low-Cost Airborne Thermal Sensors for Animal Monitoring

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Introduction

Background

Vertebrate pests are a major environmental and economic threat in New Zealand. One of the species that has high potential threat is possum (*Trichosurus vulpecula*). The direct environmental impacts of possum are in defoliation of native flora and predation of native birds (Montague 2000). The direct economic impact is a result of their role as vectors of bovine tuberculosis (Tb). New Zealand spends $70m annually on possum control, largely undertaken by the Animal Health Board (for Tb management), Regional Councils (for plant, animal and environmental protection) and Department of Conservation (for environmental protection).

Possums are notoriously difficult to control. Direct field-control methods such as trapping are expensive and can have limited success in remote, inaccessible terrain. Use of toxins e.g., 1080 and cyanide offer a more sustained control option, but their use needs to be well regulated because of risks to non-target species and public opposition.

Before and after possum a control operation the size of the pest population needs to be measured in some way to dictate when a scheduled control operation should be initiated, or to assess the effectiveness of a just-completed operation. Current national protocols describe how best to monitor pest populations (e.g., NPCA 2008a, 2008b). These monitoring methods themselves are costly, especially when they are an additional cost over and above the cost of the control operation.

One of the challenges with pest monitoring after a control operation is that the pest population will be at very low density if the operation has been successful. Being able to detect and measure the size of the very-small residual population is operationally difficult. Large areas need to be searched to accurately define the size and location of the residual population. A typical monitoring plan would be to survey 10,000ha where likely possums numbers are less than 1 per ha. The current protocol for monitoring would involve a minimum of 30 person-days of effort.

As pest managers improve in their ability to control vertebrate pests, population sizes are reducing. While this is good news for New Zealand, it makes the job of undertaking effective monitoring and residual population control even harder because there are fewer and fewer animals remaining. Those remaining are likely to be sparsely distributed over their habitat. Thus the marginal costs of pest management increase.

The possum control industry needs methods that can accurately detect animals. Methods need to be as cost-effective as current monitoring methods. One possible alternative method is to use remote sensing using infrared equipment (thermal imagers) to detect heat emitted by animals.

Thermal imagers have been trialed in NZ for possums, but industry uptake was limited because of the equipment was large and heavy, and the development of the technology was at a very early stage (Trotter 1999, Epro 2003).

While thermal imagers remain expensive, technological advances and increased demand from non-scientific markets has resulted in a new generation of moderately-priced thermal cameras. In some industries, thermal cameras are accessible as an everyday field tool rather than as oversubscribed, specialized equipment. For animal monitoring applications, this level of ubiquity relies on thermal cameras providing a capability or utility not currently available. When used correctly, thermal cameras should increase an observer's ability to differentiate a warm animal from an ambient background, particularly in low light or at night. If an animal's heat signature is strong enough it might be possible to use the thermal camera to see around or even through obstructions such as heavy dense bush, leaf cover or tree canopy.

If thermal image technology were to be successful for detecting small animals it could be used for monitoring a range of animals beyond possums including ferrets, rabbits, stoats, wallabies, deer, goats, chamois and thar.

In this report, two low-cost commercially-available thermal sensors are evaluated for imaging a brushtailed possum in different environmental conditions, and at increasing distances, with the goal of gathering practical information on the utility of such sensors for handheld field use. The sensors were also considered for use in low-level survey from unmanned aircraft.

Applications

Possum behavior makes visual detection difficult and inaccurate. Their size, coloration, nocturnal behavior and the potential to be anywhere from underground burrows to high in the forest canopy makes it difficult for human observers to count them with any certainty. Indirect methods, such as bait consumption, bait interference and fecal pellet counts have been shown to be effective but can be labor intensive to distribute and monitor (Fraser et al 2003).

Two potential applications have been proposed for thermal imagers. First, a hand-held thermal camera could be used to "augment" a human observers vision, allowing a human observer to perform a standard visual search with a much greater chance of spotting the possums. Second, a thermal camera could be used in either a static or moving automated detection system. For example, a thermal camera could be used as part of a camera trap, or could be mounted on a small (remote controlled) aircraft to effectively "thermally map" an area. This map could then be analyzed in post processing for the heat signatures of possums.

Both usages rely on the thermal sensors being an effective mechanism for detecting possums under normal field conditions. Possums are well insulated with thick under-fur as well as long guard hairs. This two-layer coverage reduces heat radiation and means the animal has relative stable temperature year round. As with many other mammals, the key heat-loss area is the head because the ears, eyes, mouth and nose do not have fur covering.

This set of field trials was intended to explore the functionality of two low cost sensors when imaging captive possums, and to point either towards further adaptations that could lead to field use of thermal imagers, or potential shortcomings which could be addressed with further research or careful camera selection.

Thermal Imaging

"Thermal imaging" is the use of a sensor to detect and measure infrared electromagnetic radiation with a wavelength of ~8-14 um. As all objects emit black body radiation in this wavelength in proportion to their temperature, a thermal imaging camera effectively "sees temperature" and can be used to see in the absence of visible light, or to detect objects which may be well camouflaged but are at a different temperature from their environment. Though originally developed for scientific and military purposes, thermal imaging has found a myriad of different uses in more commercial settings, including fire fighting, plant maintenance and energy auditing.

Thermal cameras can be divided into two families. Cooled cameras rely on sensor chemistry which must be cooled to near absolute zero to prevent the sensors' own heat from interfering with the image. Such sensors can be extremely sensitive, but require bulky and expensive cooling equipment. Un-cooled sensors, in comparison, operate at ambient or near-ambient temperatures, greatly reducing complexity and making handheld or portable thermal cameras a possibility. Unfortunately, the construction and fabrication methods used for un-cooled cameras limit their sensitivity and overall resolution.

Note that the thermal cameras described here should not be confused with the near-infrared "night vision" cameras available in the consumer security market. These cameras exploit the sensitivity of the CCD sensors used in digital still and video cameras to light in the 0.7-1 um wavelength, which is just outside the range of human vision. Since most black body radiation is not emitted in this wavelength, these cameras cannot "see heat" as in a proper thermal camera. Rather, most infrared night vision systems are "active" systems which include infrared LED illumination. These systems are completely analogous to a normal camera, with the near-infrared lights illuminating the scene for the camera, but since human eyes can't see in the near infrared, the lighting is "invisible" to humans.

Pixel Size and Field of View

The ability of a camera to resolve a visible feature is driven by its resolution, the field of view of its lens, and its distance from the target. Pixel size can be estimated as:

width of an one pixel (m) = distance (m) * tan(field of view (degrees)/pixels)

For example, an object 10cm square will appear one pixel wide by one pixel high at 79.7m on a camera with a 23 degree (horizontal) by 17 degree (vertical) field of view.

As with visual cameras, the individual sensor elements in a thermal camera can be assumed to be taking an average of emitted radiation over the whole pixel, so it might still be possible to "see" a sub-pixel object, but only if it's sufficiently distinct from the background to "pull up" the average emissivity of the pixel above the background value.

Methods

The Cameras

For this project, two low-cost un-cooled thermal cameras were evaluated, both of which are readily available in the New Zealand market: the PathFindIR and the TiR3. Due to the military origins of the technology, there are some export restrictions on thermal camera technologies, but both of these cameras avoid those restrictions by limiting their capabilities. For example, the PathFindIR operates at a 7Hz update rate, while licensed users within the US can purchase the same unit with a 25 or 30 Hz update rate.

The PathFindIR (Figure 1) is a low-cost IR sensor developed by FLIR Systems (USA) explicitly for the automotive market, either as an option supplied by the manufacturer, or for aftermarket installation. It is marketed as a supplement to normal headlights for nighttime driving, where the thermal camera will be able to see warm objects (animals on the road, warm engines of other cars) far beyond the range of the headlights. As a simplified consumer unit, it has no user-modifiable settings and outputs directly into analog video (NTSC or PAL). The PathFindIR has a resolution of 320 x 240 pixels and a field of view of 36 degrees horizontally by 27 degree vertically (2.0 mrad spatial resolution). The unit has a wide depth of field and is fixed focus at the middle- to long-distance, as befits it automotive application. The manufacturer suggested retail price (MSRP) is approx $5000 USD.

Figure 1. FLIR PathFindIR uncooled thermal imager for automotive applications (image from FLIR).

Unlike most thermal imagers that are targeted at scientific applications, the PathFindIR is non-radiometric. Rather than providing direct access to the individual pixel values, as would be appropriate for calculating surface temperatures, the PathFindIR internally generates an black-and-white analog video signal with intensity (brightness) proportional to the radiation received, but scaled by an automatic gain factor based on the warmest and coldest objects in view. As such, the video output from the camera will always present a usable black-and-white image in which the hottest items are white and the coldest black. However, there is no way to directly quantify the amount of infrared radiation detected by a given pixel, nor can the absolute temperature of a given surface be calculated. If the camera could see both the target of interest and calibration targets of known temperature it might be possible to make good estimates of surface temperature, however this would require rather severe assumptions on the behavior of the image processing occurring within the camera.

For our field evaluation, the PathFindIR was coupled with a portable battery back, a small LCD screen and a digital video recorder which allowed capture of its video output.

The TiR3 (Figure 2) is a handheld "thermal imager" sold by Fluke Instruments (USA). It is targeted at a variety of engineering applications, such as thermal auditing of buildings or plants, and preventative electrical maintenance.

In contrast to the PathFindIR, the TiR3 is a complete unit out-of-the-box, with a built-in LCD display, rechargeable batteries and the capacity to store images to a memory card. It also has a resolution of 320 x 240 pixels, and has a retail price of approx $18,000USD.

Unlike the PathFindIR, the TiR3 is radiometric, in that it directly measures and records the infrared radiation collected by each pixel in the sensor. This allows the user to go back and re-process the data, perhaps with different assumptions about the emissivity of surfaces in view. In this way, the TiR3's collected images are analogous to the "raw" settings available on many high-end digital cameras.

Figure 2. Fluke TiR3 un-cooled thermal camera (images from Fluke)

The color maps displayed on the screen and in the images below are generated from the raw emissivity data using user-defined temperature endpoints and a selected color map. The colors used and the range of temperatures displayed can easily be modified either in real-time or in post processing either for aesthetic reasons or to increase contrast across a temperature gradient.

The TiR3 comes stock with 20mm lens which gives a 23deg horizontal by 17 degree vertical field of field (1.3mrad spatial resolution). Fluke sells a 54mm telephoto lens (9 degrees horizontal by 6 degree vertical field of view) which could not be obtained for this trial. The effects of this longer lens on usable distance are included in the discussion below. As it is designed for the analysis of relatively static scenes (buildings) the TiR3 has a very shallow depth of field and manual focus, which proved difficult to use under field conditions.

These thermal imaging cameras were trialed with a caged possum in May 2008, in three different habitats near Christchurch – an urban area (Cashmere), forest cover and tussock grassland (Victoria Park).

Results

Field trial with PathFindIR

The preliminary tests of the PathFindIR were conducted in the urban environment. The possum was imaged from distances of 1, 5 and 10 m (Figure 3). The images in the figure were taken directly from the video captured with the digital video recorder and accurately reflects the black-and-white imagery coming out of the PathFindIR and presented to the operator on the LCD screen in realtime. Images were contrast enhanced to improve possum detection (see below).

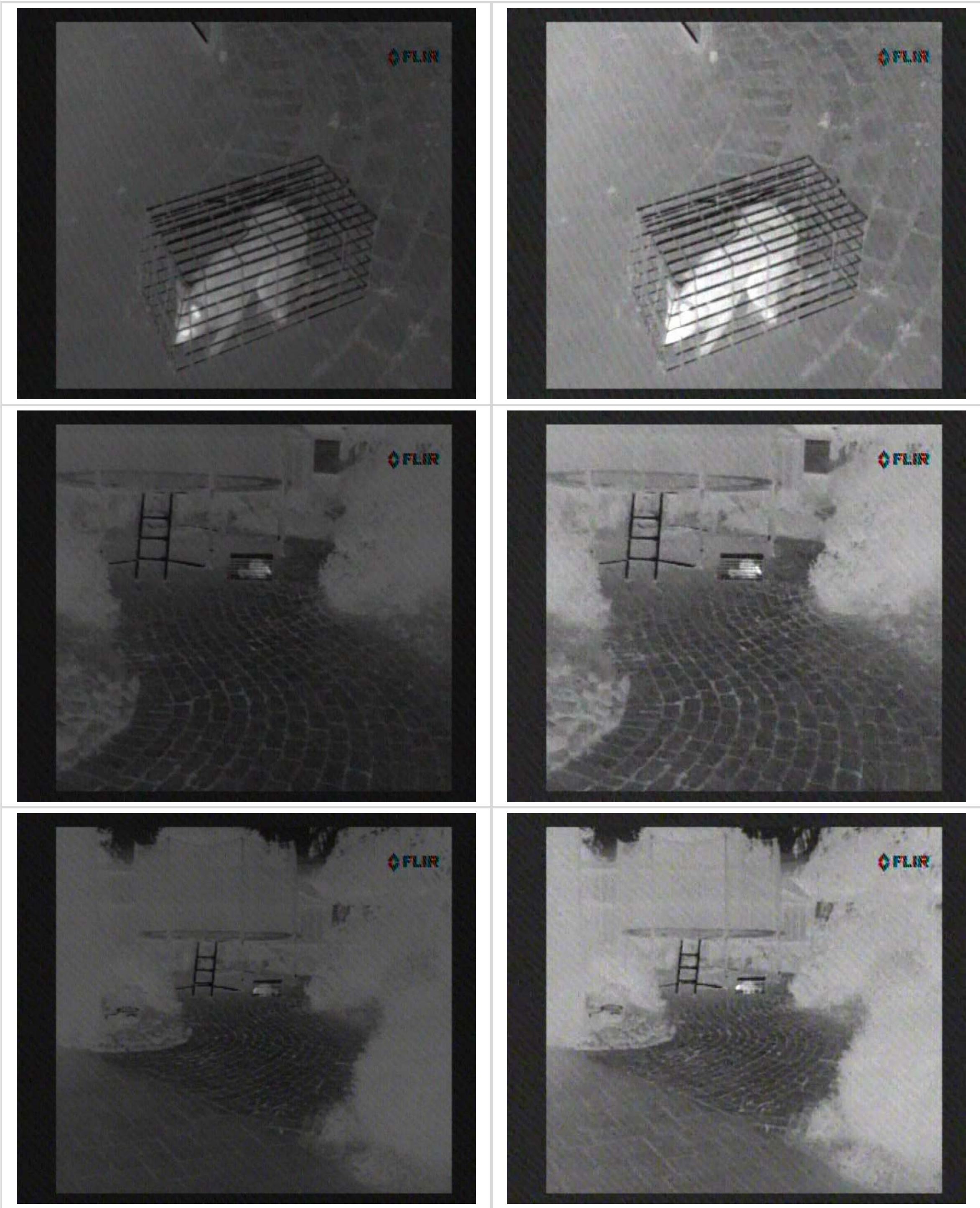

Figure 3. Images of a caged possum using PathFindIr at 1, 5 and 10 m (from top to bottom). Images on the right at contrast enhanced.

Trial with enhanced PathfindIR images

As a further trial of the PathFindIR, the captured video was run through a number of simple video manipulation algorithms, exploring the possibility that such manipulations could make the resulting output easier to interpret by a human operator, either in real-time or in post-processing. The method is similar to the computer analyzing method used by Trotter (1999).

The first enhancement attempt was a simple contrast filter which increases the brightness on portions of the video greater than the mean brightness, and decreases those portions darker than the mean brightness (Figure 3). This method does make the overall shape of the animal "brighter" in the image, and easier to pick out, however the contrast map also greatly increases the "brightness" of the surrounding vegetation. If the animal were directly in front of the vegetation instead of on the cooler hard surface, it would be very difficult to pick out.

The second filter was a simple color map whereby a given brightness value is mapped to a color (Figure 4). This is analogous to the processing occurring in the TiR3's color maps, with the distinction that the TiR3 is working directly with the IR levels measured by the camera, while this algorithm is working with video brightness's that have been generated from emissivity measurements internal to the PathFindIR. This additional uncontrolled processing step introduces an unknown amount of degradation to the data.

As with the TiR3, the color map used can be essentially arbitrary. For this example, a color map was generated which mimicked that color map use in the TiR3 imagery above, with blue for the coldest parts of the images and red for the warmest, passing through green at the midpoint. This color map was applied to both the normal and high contrast (Figure 4).

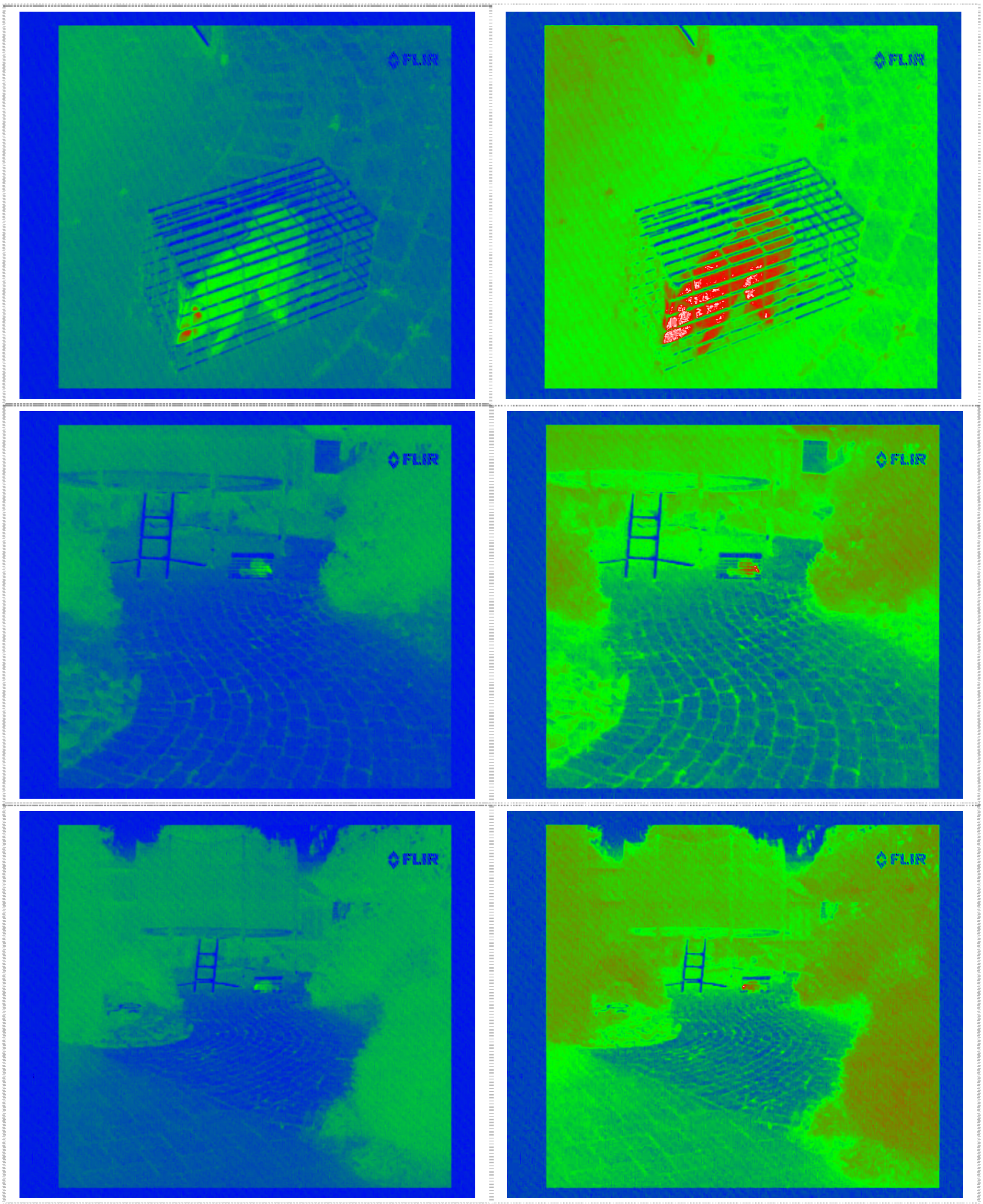

Figure 4. Enhanced images of a caged possum using PathFindIr by color mapping (left), and by enhanced contrast and color mapping (right). See figure 3 for reference images.

From these images it is clear that the simple color mapping increases the ability to pick out slight color/temperature contrasts in the image, and the possum is quite easy to pick out from any of the color mapped images. At the longer distances, the color difference between the possum and the surrounding vegetation start to diminish and it would be quite easy to lose the image of the possum against the background if it were located at a greater distance. This emphasizes the importance of being able to pick out and highlight small temperature gradients, which could depend on the ambient conditions and the temperature of the surroundings.

Although the video manipulations presented here were performed on a desktop computer in post-processing, it would be relatively simple to build a small embedded device, perhaps as part of a more ruggedized packaging of the PathFindIR, which could perform these transforms in realtime. Careful analysis would be required to demonstrate that the additional packaging and processing equipment needed for the PathFindIR would not significantly shrink its price advantage over something like the TiR3.

Field trial with TiR3

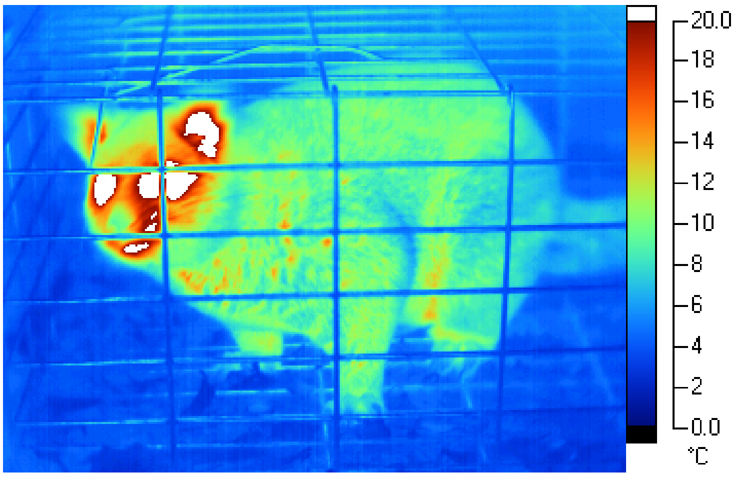

Figure 5 Caged possum. As noted above, the color map is applied in post-processing and can easily be changed. The white areas are "off the scale," in this case warmer than 20 degrees C.

The TiR3 trials were performed outdoors in the early evening with a caged possum. The ambient air temperature was approximately 2 - 3^{o} C. The possum was placed on the ground on a track under tree cover, and the possum was imaged from a range of distances from < 1 m to 45m at 5 m intervals. This allowed evaluation of the visibility of the possum in the image at a range of distances (Figure 6). At the time, the camera was allowed to automatically scale the color map on the TiR3's display for maximum sensitivity. In post-processing, the color maps were fixed to either 0-20^{o} C or 0-10^{o} C as noted.

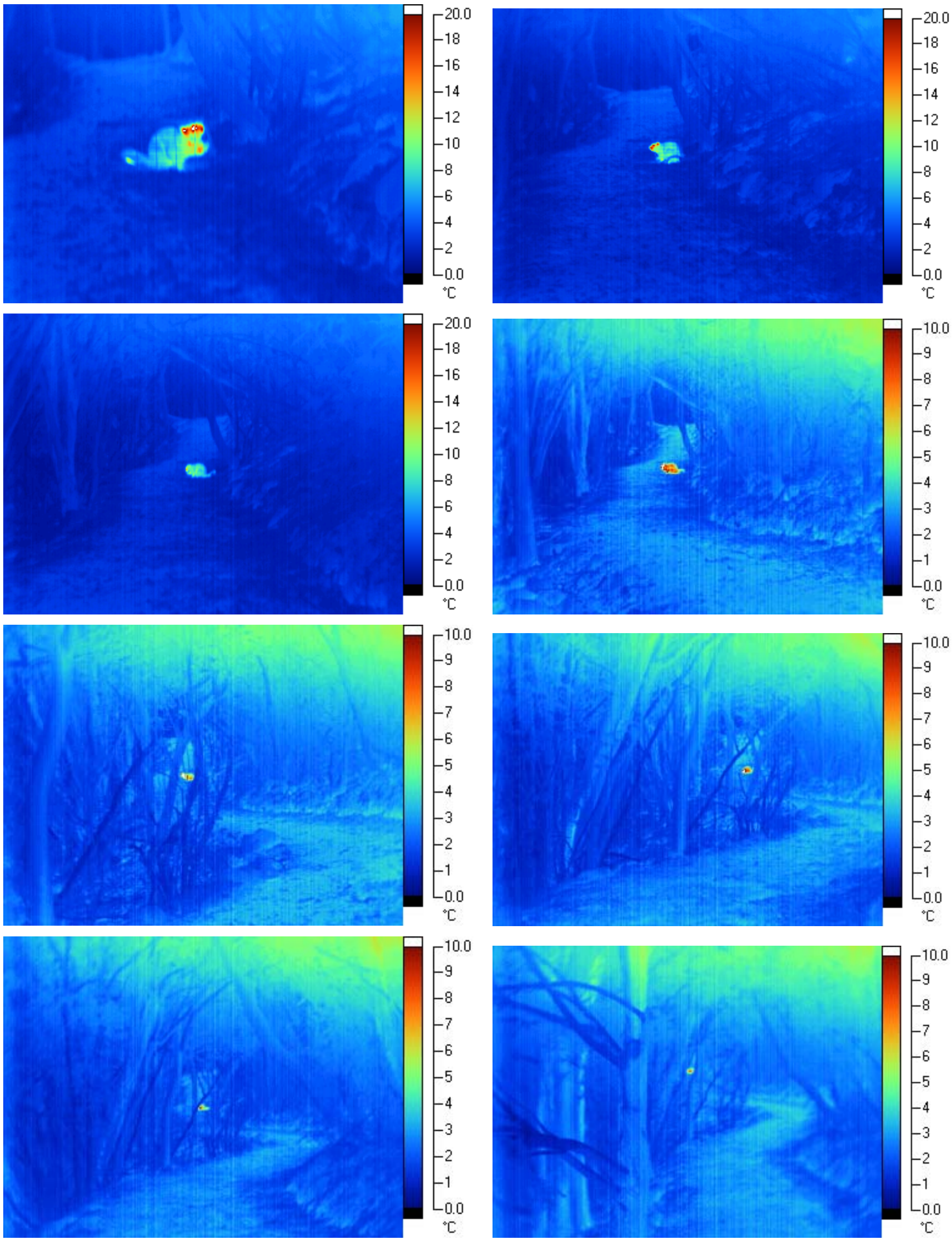

Figure 6. Images of caged possum using the TiR3 at increasing distance, reading from left to right and top to bottom: 5, 10, 15, 20 25, 30, 25, 40 m.

As noted above, images taken at 20 m and beyond have a compressed color map to better emphasize the exposed portions of the possum, which ranges from 5 to over 20^{o} C. Examination of the color maps shows only a few lightly insulated areas of the possum (head, underside) are over 10^{o}, while most of the animal body is 8 - 10^{o} C. At greater distances, the "hot" portion of the animal shrinks to sub-pixel size and it is necessary to compress the temperature range to increase the color contrast between the animal and the background.

All of the images show a ghosting or hazing gradient coming from the top of the image, though it is much more apparent in the images with the compressed temperature range. This was not resolved though it is believed to be temperature contamination from moving the camera from the relatively warm interior of a car to the cold ambient air. It did not seem to fade or abate over the approximately 45 minutes spent testing.

It was not possible to get a clear line of sight to the possum at distances greater than 45 m in the first test site. However, even at 45 m the possum remains 4 -5 pixels wide, indicating it should be possible to resolve the animal from much greater distances. To test the maximum range of detection, the possum was moved to an open tussock pasture/tussock area and was again imaged at 70 m (Figure 7).

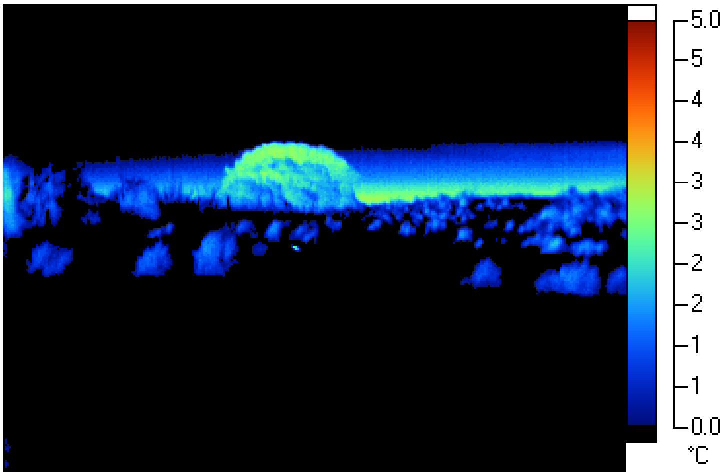

Figure 7. Thermal image of caged possum in tussock grassland using TiR3 at 70 m. The small dot in the middle of the image is the possum.

Note the environment has changed significantly. The pasture landscape, open to the sky, has cooled much faster than the wooded path, with only the tussock and bushes retaining any heat. Heat on the horizon is from Christchurch city, reflected off low clouds. While the possum can still be discerned in the center of the image, it has shrunk to just a few pixels in width and it would be quite difficult to pick it out on a cursory scan, let alone identify it as a possum.

This field testing did reveal a few operational difficulties with the TiR3. The shallow depth of field and manual focus required significant user input to find and focus on targets, even when the targets was known to be there. At long distances it would be quite easy for small objects in the distance (such as the possum at >40m) to simply get "blurred out" unless the instrument is sharply focused. The TiR3 also has a relatively slow shutter speed (perhaps due to the export restrictions above), and had a noticeable amount of motion blur. This tended not to be a factor in real-time use as human visual processing is adept at handling motion-related blurring, but made it quite difficult to take clear pictures, and would certainly affect the TiR3's ability to capture data for post-processing.

Conclusions

The field trials allowed us to make the following conclusions regarding thermal imaging for possums.

Field of View.
Both cameras evaluated have quite wide fields of view, with the warm head and face of the possum becoming sub-pixel in the range of 50-80 meters. For easy detection it would be best if the most prominent features of the possum were several pixel in size, particularly against a background of similar temperature. Even at the very short distances used, the possum was detectable because of its temperature differential from the background, not because of its shape. It was only at the very close ranges (< 20 m) that the image became clearly "possum shaped", including a large amount of body area which had at a small temperature difference from the background.

Thermal imagery uses specialized crystals to pass the longwave infrared spectrum. This contributes to the cost of thermal camera lenses, and as a result lens changing is non-trivial. The PathFindIR has a fixed lens, and its field of view cannot be improved. A telephoto lens is available for the TiR3 which provides approx 2.5 x the usable range. Unfortunately, a sample of this lens could not be found in Australasia for evaluation.

Cover.
The vegetation cover was a major impediment for imaging the possum. As with visible light, long wavelength infrared is easily blocked by physical objects. This is particularly true of objects with high thermal mass and which might be otherwise regulating their own temperature (living things, branches, leaves, etc). A very warm, poorly insulated creature (lightly clothed human) might heat up their surroundings enough to be seen through a thin layer of leaf litter or equivalent, but even in that case, the animal would have to be touching the leaves and warming them through conduction.

Sensitivity, Contrast and Discernment.
One of the key capabilities determined from the trials was the ability for the operator to quickly and easily discern relatively small temperature gradients in the image. With both systems we could exploit the human eye's sensitivity to color variation by color mapping the image. However it was clear the success of this technique relies on the ability to carefully tune the color map to ambient conditions.

Ambient Conditions.
Our trials demonstrated that thermal sensing is highly sensitive to ambient conditions. We conducted our trials were conducted in winter, in three different ambient conditions: open space at night which cooled quite rapidly; a wooded area at night which had retained some heat from the day; and an urban scene at dusk which was clearly still warm from the day. In the latter two cases the ability of the camera to pick the possum out from the background relied on the animal being at least a few degrees warmer than the ambient temperature. If the background were warmer (e.g., summer conditions) the animal may be near-impossible to discern. This differential in detection would confound attempts to use this methodology for a standardized index of possum numbers that is comparable among seasons and sites.

Features.

Field testing provided the opportunity to reveal some of the details of camera operation which could affect their use in the field. For example, the manual focus on the TiR3 proved to be frustrating and could seriously impede a survey at a variety of sighting distances and with moving targets. Also, while the TiR3 had a stronger real-time visual processing system, and a color display, the mechanisms for adjusting the color map were slow and somewhat clumsy. Again, they may be appropriate for static building analysis but would quickly become cumbersome in the bush. The TiR3 has also been configured as a digital camera, with a manual trigger press required for each image captured. There is no provision for recording video on-board, although it does have an analog output which could be connected to a recorder (as is done with the PathFindIR). On the other hand, the TiR3 was a far more ergonomic and robust packaging.

The PathFindIR suffers because it is a product manufactured to be attached to vehicles. It has no configuration options and requires separate packaging for power, viewing, and recording. Surprisingly, the non-radiometric nature of the PathFindIR does not appear to be a serious handicap. The task of spotting animals relies far more on the ability of the camera to discern and display small relative differences in temperature. The ability to compute absolute temperatures does not appear to be an advantage.

Cost.
Costs remain quite high, with the TiR3 at near $30,000 NZD. The PathFindIR is perhaps a quarter of that, but requires additional packaging to be useful, possibly including some relatively sophisticated video processing and recording equipment.

Airborne use.
Much of the research thus far (Trotter 1999) has focused on the use of thermal cameras or other sensors for aerial survey from helicopters. The relatively wide field of view, and resulting short detection range of the two thermal imagers tested means aircraft would need to fly dangerously low. With a narrower lens, a camera like the TiR3 might be appropriate for flight in a smaller unmanned aircraft, for example a UAV or kite/balloon, which can reliably operate within 50-100m of the ground. However, given the strong possibility of interference from branches, thick bush, or tree cover, even this survey method might only be useful in very limited situations, for example open pasture or deciduous forests in autumn/winter.

Summary

It was not clear that thermal imaging cameras would provide a significant advantage for in-the-field monitoring of small mammals. First, the correct camera must be selected, carefully balancing cost, field of view/range, display or color mapping functions and features. If such an optimal camera existed, it would give the user the ability to spot possums at night without disturbing the animal. It would easily be confounded by leaf or bush cover or high ambient temperatures. These restrictions may cover such a broad spectrum of the possible scenarios as to give no advantage to having a thermal sensor in the field.

That said, thermal sensing may have strong advantages when performing nocturnal field surveys on larger animals (deer, pigs, etc). First, larger animals can be imaged from much greater distances. They are more lightly insulated, leading to a much greater overall body temperature, and they tend to be ground based, so there is no question of hiding in burrows or in the tree canopy. They would also tend to be larger than any branch or leaf cover, meaning that some portion of the animal might be visible, despite some cover being in the way.

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