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THERMAL INFRARED VIDEO IMAGERY OF THE ROTORUA GEOTHERMAL FIELD

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ABSTRACT

The shallow ground temperature measurement surveys most commonly used to monitor for and characterise surface thermal changes are extremely time consuming, expensive, necessarily incomplete and, in some cases, impractical. Aerial thermal infrared investigations of New Zealand geothermal areas conducted from 1968 to 1975 illustrated their usefulness for identifying and locating thermal features as well as estimating heat flows. Unfortunately, these studies were not continued. The recent availability of advanced thermal IR instrumentation and powerful image processing facilities in New Zealand, and the continuing need for a comprehensive, economic geothermal surface activity monitoring technique, led to the present investigation of helicopter-borne thermal IR video scanner methods.

Thermal IR imagery of several thermal areas associated with the Rotorua geothermal field was obtained with an Inframetrics 525 thermal IR video scanner mounted in a helicopter. Simultaneous visible video imagery was also obtained to assist with interpretation. Preliminary visual examination of the imagery shows that several different thermal feature types, including hot seepages, hot streams and pools and warm ground, are easily identifiable. Manmade features such as roads, cars and buildings are also clearly visible.

An incorrect instrument phase adjustment produced an imagery banding problem, however, techniques for defining and correcting the data have been developed and are demonstrated. A methodology for obtaining, processing and analysing comprehensive thermal IR and visible video imagery for geothermal surface activity monitoring purposes has been developed. Use of the video data capture method avoids all the photographic processing problems and provides the ability to easily store vast quantities of data, examine it at a basic level as it is being collected and easily digitize and analyse data of specific interest using powerful computer image processing techniques. As a result of the success of this study, a comprehensive baseline survey of the surface thermal activity at Broadlands geothermal field is scheduled for late 1988.

INTRODUCTION

Geothermal fields typically have identified surface areas in excess of 10 km^2. Associated zones of surface and near-surface thermal activity, which range in size from <1 m up to ~1 km , may occur anywhere within the field area. The activity manifests itself in a variety of forms; warm/hot and steaming ground, fumaroles, warm/hot pools and springs, geysers, sinter terraces, hydrothermal eruption craters, mud pools and warm/hot streams and seepages.

As a result of natural changes in system heat source, alteration of permeability and variation in reservoir fluid pressure, the internal structure and near-surface properties of geothermal systems are modified, thus causing change in both the character and location of the associated surface manifestations. Generally, the changes occur slowly, and in existing areas of surface activity or their immediate environs, though new areas of activity can appear. Experience at Wairakei and Tauhara geothermal fields shows that the natural evolutionary processes can be significantly modified and accelerated by exploitation. For example, at Wairakei most of the boiling springs and all of the geysers ceased activity within a few years of the onset of exploitation for the Wairakei Geothermal Power Station. The major area of thermal activity also shifted location from Geyser Valley to Craters of the Moon, a distance of ~4 km. Several hydrothermal eruptions have since occurred at both Wairakei and Tauhara (Mongillo and Allis, 1988; Allis, 1984; Scott and Cody, 1982) and large areas of steam heated ground have appeared and are observably changing character on time scales of a few years (Mongillo and Allis,1988; **Allis,1979a;** b).

As implied above, change in geothermal surface activity can indicate the occurrence of important changes in the system below, hence the information provided by its monitoring can be useful in reservoir studies and field management. Where new geothermal developments are planned or proceeding, it is prudent to monitor as much of the surface thermal activity as possible, prior to commencement of exploitation. This allows determination of baseline characteristics to which future measurements can be compared for change monitoring. It is also especially important to monitor the natural activity during the early phases of field production, a period when major changes are known to occur (ibid.). The delineation and monitoring of surface activity in urban areas located near exploited, as well as unexploited, fields is also of considerable importance both for planning purposes and safety reasons (Dickinson, 1975; 1973).

Since anomalous surface and near-surface heat discharges are generally associated with the presence of geothermal systems, measurement of individual feature temperatures and comprehensive shallow (15 cm-1 m depth) ground temperature surveys are often used to monitor and characterize their changes. Unfortunately, these methods are extremely time consuming, expensive, necessarily incomplete, and in some cases, impractical (Allis and Webber, 1984; Dawson and Dickinson, 1970). As a result, important surface feature monitoring is often neglected.

The development of a reliable, effective, low-cost technique for mapping and monitoring surface and near-surface geothermal activity would be very useful. Early (1968-1975) aerial thermal IR investigations of geothermal areas in New Zealand showed that thermal features could be identified and located, and that heat flows could be estimated (Dickinson, 1973; 1975; 1976; Hochstein and Dickinson, 1970). Though these results were very promising, the investigations were not continued. The recent availability of advanced infrared instrumentation and powerful image processing facilities in New Zealand and the continuing need for a comprehensive geothermal monitoring technique rekindled interest in the use of thermal infrared remote sensing techniques for geothermal surface feature monitoring. Consequently, a survey of several geothermal areas was conducted to examine the suitability of a helicopter-borne thermal IR video scanner for geothermal surface feature study and investigate the utility of digital image processing techniques for analyzing the imagery.

THE SURVEY AREA

A helicopter-borne thermal IR survey was performed over several thermal areas associated with the Rotorua geothermal field on 6 February 1988. The areas covered by this study were chosen to examine the instrument's ability to detect and distinguish among a variety of thermal features. The locations investigated included the lake edge and shore zones of Lake Rotorua extending from Rotorua Airport to Ohinemutu, a portion of Arikikapakapa, most of Whakarewarewa and the length of the Puarenga Stream from Whakarewarewa to its mouth at Ngapuna (Figure 1). A non-thermal background control area at Arawa Park was also covered as were two other ground truth sites located on known anomalous ground (Figure 1). The imagery was flown at an airspeed of -25 km/hr and covered a total distance of -16 km. Navigation was performed visually, assisted by the real-time monitoring of the IR imagery as it was being collected and recorded.

The survey was conducted in the late afternoon, from 8.05 pm to 8.45 pm local time (local sunset was -8.30 pm). Though the weather had been very promising throughout the day, it quickly degenerated by the time the survey commenced. The moderate on-shore winds did not pose problems and it did not rain. However, the low cloud cover restricted flight altitudes to -500 m (above ground level) for the entire survey.

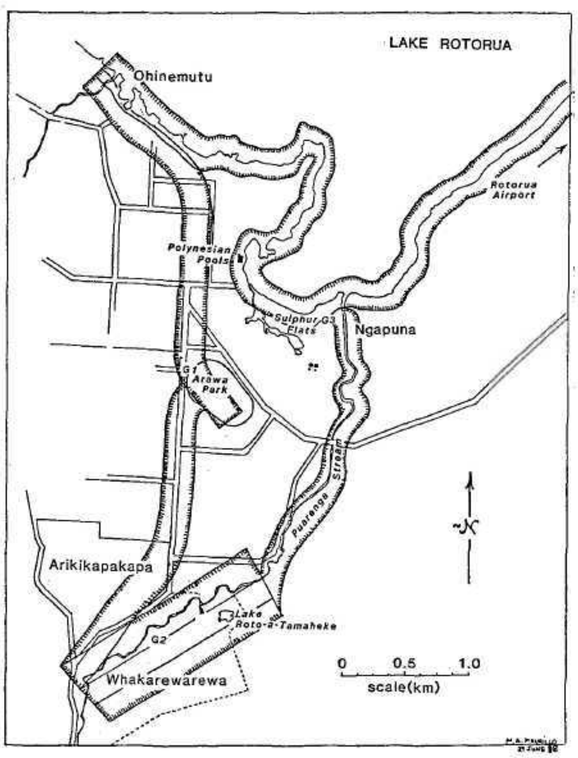

Figure 1: Sketch of the Rotorua thermal IR survey flight path with thermal areas identified. Stippled lines approximate the imagery swath width. GI, G2 and G3 are the ground truth locations.

INSTRUMENTATION

The infrared imagery was obtained with an Inframetrics 525 thermal IR video scanner (owned and operated by ASEA-Brown-Boveri Services, Hamilton) mounted in a Bell Jet Ranger helicopter (Figure 2). The instrument consists of a small (13 cm x 11 cm x 16 cm) scanner head containing an optical-mechanical scanning system which collects the IR radiation from the target scene, focusses and sweeps it across a liquid nitrogen (LN_2) cooled mercury-cadmium-telluride detector sensitive in the 8-12 ym wavelength band. The electrical signals from the detector are processed by the controller electronics to produce DC-restored TV-type black and white imagery of the scene temperature pattern which can be recorded on a standard video cassette recorder (VCR) and simultaneously observed on a portable TV-monitor.

The instrument has an instantaneous field of view of 2 millirians and a total frame field of view (H x V) of 18° x 14°. At an altitude of 500 m, the nadir ground resolution element is -1 m and the total field of view covers an area of -158 m x 123 m (i.e. -1.94 x 10^4 m^2). The imagery produced consists of 240 interlaced lines with 157 elements per line. It is black and white, with a 64 tone (6-bit) grey scale range. Each image has a temperature range scale identification bar located on its left edge and an intensity wedge superimposed along the bottom. The central 40 of the 64 grey levels of the intensity wedge (and imagery) are calibrated for each temperature range. For the most sensitive range, 10°C, each tone corresponds to 0.25°C.

Though it was planned to obtain mostly vertical imagery, concern that the instrument would be damaged by the spillage of the LN_2 coolant during vertical operation resulted in the collection of mostly oblique imagery. Simultaneous visible wavelength video imagery was also collected using a JVC Portapack visible video camera. The objective here was to test the viability of using visible video imagery, rather than conventional aerial photography, to assist with the location and identification of features on the thermal imagery.

IMAGE PROCESSING AND ANALYSIS

Visual examination of the thermal IR imagery in its "raw" video format can be conducted on any standard TV-VCR system. This procedure allows areas of interest to be identified and provides a means for basic level interpretation by the educated eye. However, one of the most important advantages of video imagery data is the ability to easily transfer it to a computer for processing and analysis by powerful digital image processing techniques.

Computer digital acquisition, processing and analysis of the thermal IR and visible video imagery was performed using the Division of Information Technology (DSIR) image processing system which utilises the EPIC image processing software (McDonnell, 1986) implemented on a MICROVAX2 computer system. An interactive frame grabber facility was used to digitally capture 32 thermal IR and four visible images from their respective video tapes. A video camera linked to the frame grabber was also used to digitize portions of aerial photographs covering three of the survey areas. The digitized images thus obtained consist of 512 lines x 512 pixels and are re-scaled to have an 8-bit intensity range (i.e. 256 grey levels with: 0 = black, 255 = white).

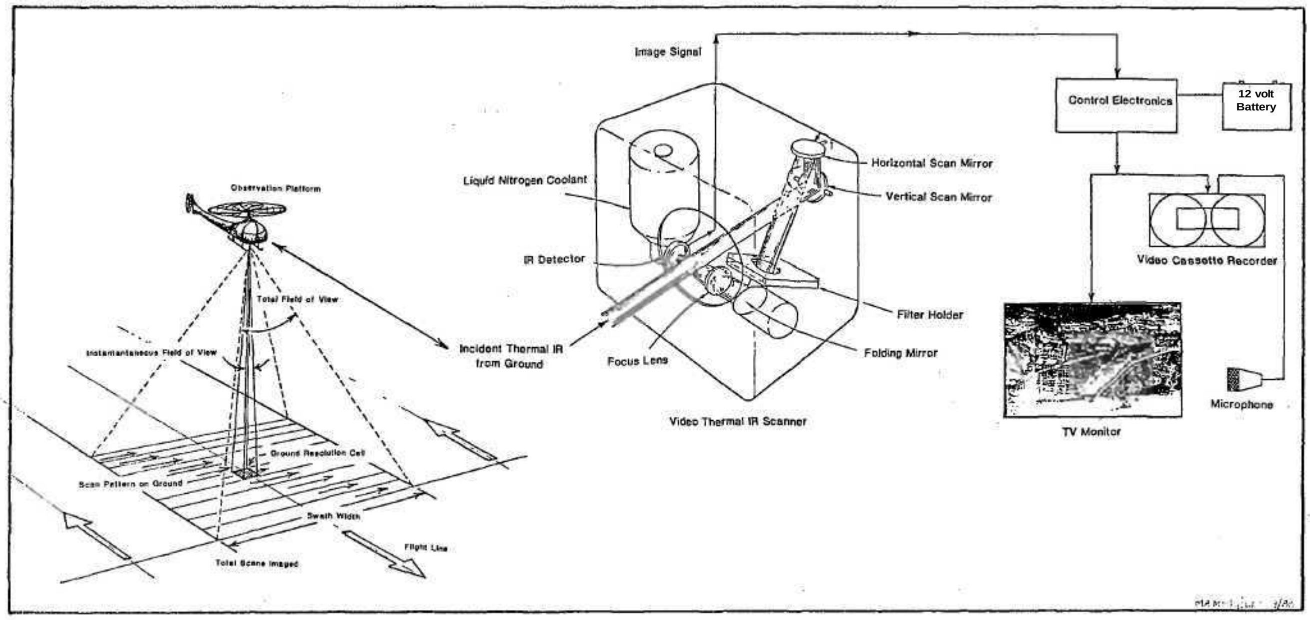

Figure 2: Sketch of thermal IR survey parameters and scanner system.

Initial visual examination of the IR imagery indicated the presence of a periodic horizontal banding problem. Closer scrutiny of 11 of the digitized images showed that the banding was the result of a periodic intensity variation in alternating groups of four lines and a periodic relative shift in their horizontal locations (Figure 3a). The latter problem appears to have been caused by an incorrect instrument phase adjustment (Inframetrics Operations Manual, p 5-4; J. Hansberry, Inframetrics, pers. comm. 1988).

The first stage of the image processing was directed at characterizing the detailed form of the banding problem and making corrections for it. The best correction procedure developed consisted of destriping the image to remedy the periodic intensity variations, then "unlacing" it into two subimages which were then re-interlaced with an appropriate relative shift to correct for the periodic horizontal displacement. Smoothing the resultant image with a low pass 4 x 3 uniformally weighted spatial filter (which roughly corresponds to the theoretical instrument resolution element size) was found to be very effective in reducing noise without producing significant loss of detail. The result of these correction/filtering procedures is illustrated in Figure 3b.

Various processing and analysis techniques were applied to several of the images which had been corrected as described above. Quantitative correlation of the imagery with the measured ground temperatures of the calibration sites has not yet been attempted. Representative examples illustrating the results of the most useful image processing methods are presented in Figures 3 and 4. Note that the images in these two figures were obtained from a laser printer, hence do not demonstrate the true quality of the results obtained.

Figure 3 presents imagery of Lake Roto-a-Tamaheke and its vicinity. Figure 3a shows an almost entire "raw" (i.e. unprocessed) frame grabbed image. The banding problem is clearly illustrated. Figure 3b presents the results after processing and filtering the image to correct the banding. Lake Roto-a-Tamaheke has a temperature -50°C. Many of the bright features on the imagery correspond to hot pools whose temperatures range from 50-100°C.

Figure 3c illustrates the results of density slicing of the image into 2°C steps (instrument temperature scale). Note the clear definition of the higher temperature (brighter) areas both around the lake's edge and nearby. Details in the higher temperature areas of the image are enhanced in Figure 3d by setting the areas corresponding to the cooler 80% of the image to black and contrast stretching the remaining (20%) higher temperature areas so they range in appearance from black to white. The structure in the lake's surface temperature becomes quite apparent.

Thermal areas near the mouth of the Puarenga Stream (Ngapuna area) are shown in the images in Figures 4a and 4b; Figure 4a illustrates the results of contrast sketching the cooler 50% of the image while setting the rest (hotter parts) of the image to white. Details in the cooler areas are enhanced. The black areas in the lower right of the image are vegetation and the grey areas are warm barren ground. Many of the brightest areas are hot ground. Hot springs can be seen located along the lower edge of the stream which runs diagonally across the image. Density slicing of the corrected image at 2°C levels is illustrated in Figure 4b. The possible presence of a hot spring in the stream bed is indicated by the cone-shaped feature in the lower left hand section of the image.

The Polynesian Pools area and nearby Lake Rotorua are presented in figures 4c (raw image) and 4d. Contrast sketching the 10-60% brightness range was performed to enhance the middle-brightness areas. The brightest rectangular feature is actually two large cooling vats containing water used by part of the complex and the other four bright rectangular features are hot pools. The two rectangular features which appear to have "crosses" in them (just left of image centre) are two groups of four pools (-3-4 m across) which are built over top the Radium and Priest Pools (T. Lloyd, pers. comm. 1988). Also note the hot streams flowing into the lake (left and right of the image) and the drain of hot water from the pools complex (centre left of image).

Imagery of the Ohinemutu area is shown in corrected/filtered image form in Figure 4e. The flow pattern of hot water discharging into Ruapeka Bay (above and left of centre) from the smaller hot embayment (lower right) is clearly discernable. The

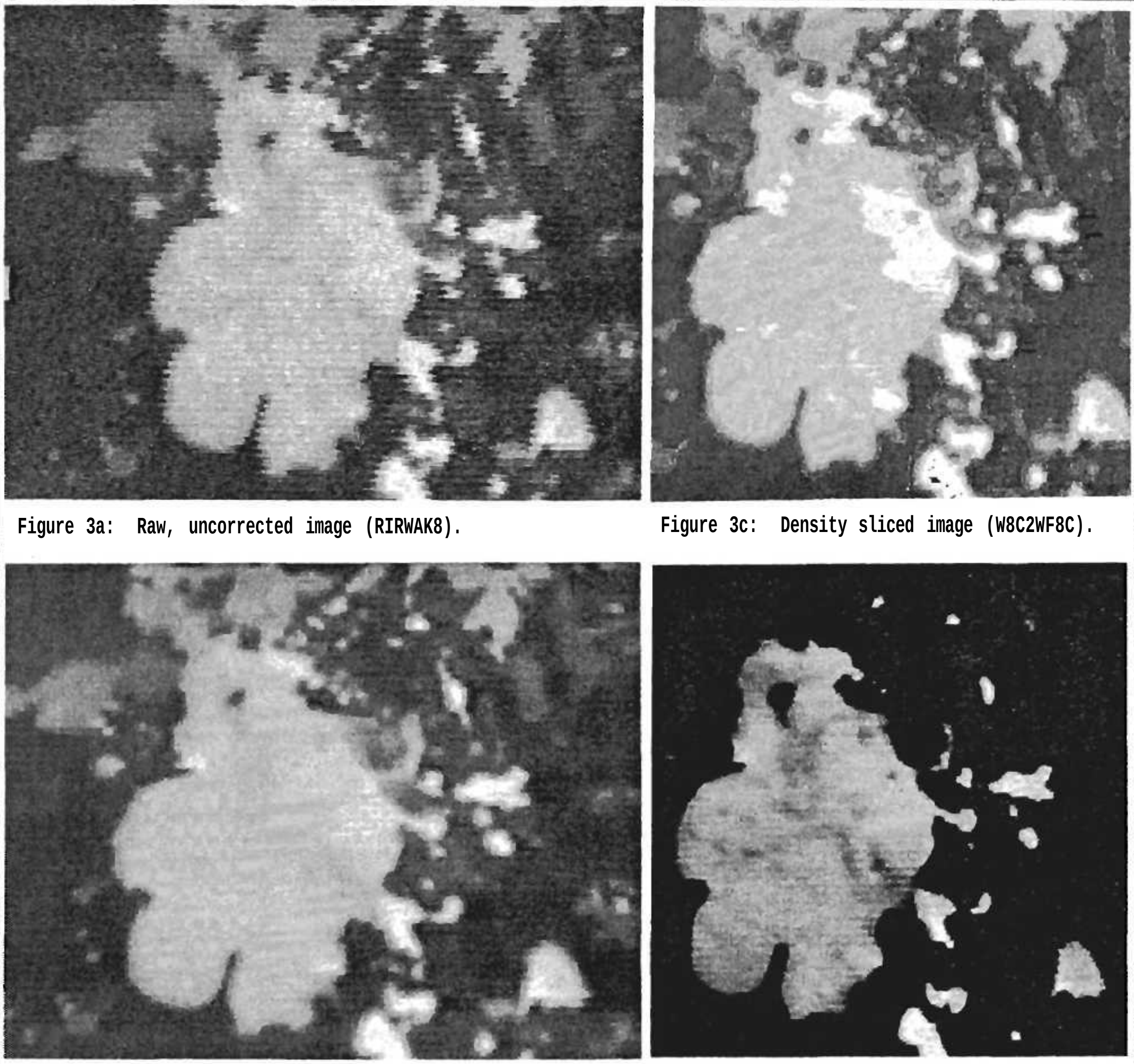

Figure 3a: Raw, uncorrected image (RIRWAK8).

Figure 3c: Density sliced image (W8C2WF8C).

Figure 3b: Corrected, filtered image (WQ8C2WF).

Figure 3d: High temperature stretched image (W8CS205T255).

Figure 3: Thermal infrared imagery of the Lake Roto-a-Tamaheke area, Whakarewarewa.

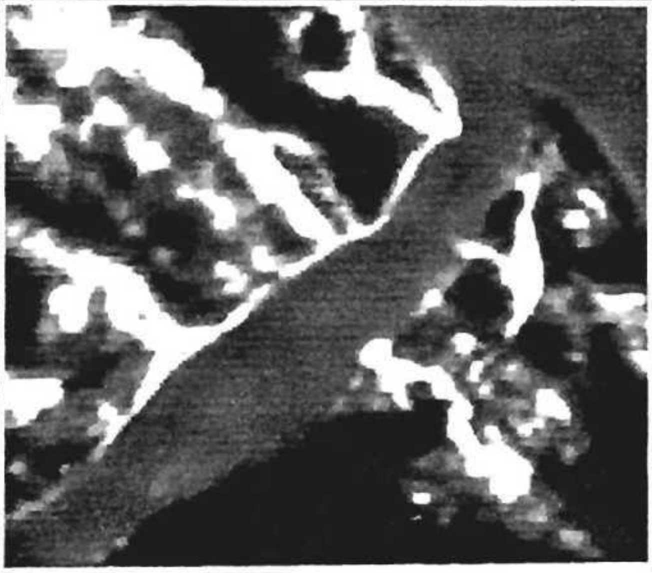

Figure 4a: Puarenga Stream mouth, stretched (P6CAS60T115).

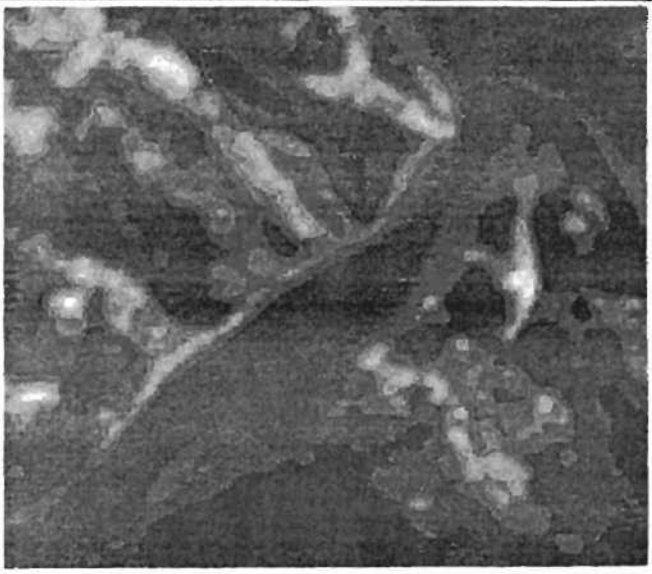

Figure 4b: Puarenga Stream mouth, density sliced (P6C2W8C).

Figure 4c: Polynesian Pools area, raw, uncorrected (RIRPOLY1).

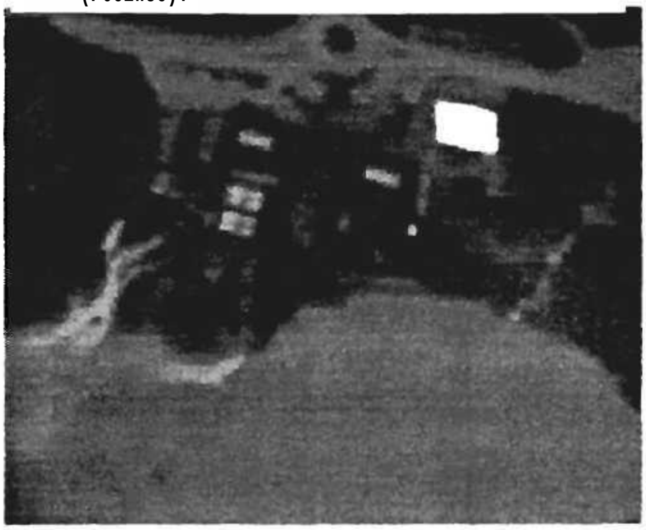

Figure 4d: Polynesian Pools area, corrected, filtered (P1C540T165).

Figure 4e: Ohinemutu area, corrected, filtered (04C1WF).

Figure 4f: Ohinemutu area, histogram-equalized (04C1WFHE).

Figure 4: Various imagery processes techniques are illustrated above for the Puarenga Stream mouth (4a, 4b), Polynesian Pools complex (4c, 4d) and Ohinemutu (4e, 4f) areas.

individual bright spots along the top edge of Ruapeku Bay correspond to hot springs having temperatures of -92-98°C. A warm stream flowing into the bay can also be seen at the lower left of the imagery. Figure 4f illustrates the results of the histogram-equilization process which redistributes image brightness levels on the basis of their frequency of occurrence, thus stretching the group that occurs most often over a greater brightness range. hence providing greater detail. Note that the cooler areas located along the bottom and right side of the image show much more detail than does the unenhanced image (Figure 4e). The brighter grey areas in the lower right of the image correspond to patches of hot barren ground.

RESULTS AND CONCLUSIONS

Preliminary visual examination of the thermal IR imagery using a TV-VCR system followed up by detailed image processing methods showed that several different types of thermal features were easily identifiable. From Ngapuna to Ohinemutu, hot seepages located along the lake edge and several hot streams flowing into the lake were easily discernable. In the Ngapuna and Whakarewarewa areas, hot pools and warm streams issuing from them were clearly defined, as was warm/hot barren thermal ground. Several hot springs and seepages were also located along the banks of the Ngapuna-end of the Puarenga Stream. Two hot springs submerged in the Puarenga Stream were detected at Ngapuna and possible identification was made of one hot spring located beneath Lake Rotorua itself. Water surface temperature structure was apparent on the image of that part of Lake Rotorua where very hot water flows into Ruapeka Bay (Ohinemutu) and on that of thermal Lake Roto-a-Tamaheke (Whakarewarewa). Manmade features such as roads, cars, buildings, and the Polynesian Pools area were also identified.

The results obtained from this study show that the Inframetrics 525 thermal IR video scanner, operating from a helicopter platform, is capable of producing useful imagery for the identification and location of geothermal surface features. A methodology for correcting, processing and analysing the thermal IR video imagery was developed and proven. The ability to digitally correct the imagery proved extremely valuable because the scanning phase of the instrument was not properly adjusted.

Though not illustrated here, comparison of the thermal IR imagery with the simultaneously obtained visible video imagery and corresponding digitized aerial photographs allow reasonably accurate IR feature location. Geometric rectification of the Lake Roto-a-Tamaheke image indicated that the process will allow quite accurate locations of features on thermal IR imagery.

ACKNOWLEDGEMENTS

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