Omnidirectional Surveillance System Using Thermal Camera

Wai Kit Wong, Poi Ngee Tan, Chu Kiong Loo and Way Soong Lim

Abstract- Thermography, or thermal visualization is a type of infrared visualization. Thermographic cameras are used in many heavy factories like metal recycling factories, wafer production factories and etc for monitoring the temperature conditions of the machines. Besides, thermographic camera can be used to detect trespassers in environment with poor lighting condition, whereby, the conventional digital cameras are less applicable in. This paper proposed an efficient omnidirectional surveillance system using thermal camera. In this surveillance system, the omnidirectional scenes in a machine room, production plant, pump house, laboratory, etc within a factory site are first captured using a thermal camera attached to a custom made hyperbolic IR (infrared radiation) reflected mirror. The captured scenes with some machines to be monitored are then fed into a laptop computer for image processing and alarm purposes. Log-polar mapping is proposed to map the captured omnidirectional thermal image into panoramic image, hence providing the observer or image processing tools a complete wide angle of view. Two simple and fast detection algorithms are embedded into the thermal imaging surveillance system. This surveillance system is not only used for monitoring the functioning condition of different machines/items in a factory site, but can also use for detecting the trespassers in a poor lighting condition. The observed significances of this new proposed omnidirectional thermal imaging system include: it can cover a wide angle of view (360° omnidirectional), using minimum hardware, low cost and the output thermal images are with higher data compression. Experimental results show that the proposed surveillance system achieves high accuracy in monitoring machines conditions and detecting trespassers.

Keywords- Machine Vision, Thermal imaging system, Machine condition monitoring, Omnidirectional System, Image Processing & Understanding.

1. INTRODUCTION

THERMOGRAPHY, or thermal visualization is a type of infrared visualization [1]. Thermographic cameras or in short thermal cameras are used in many heavy factories like metal recycling factories, wafer production factories and etc for monitoring the temperature conditions of the machines. When there is any malfunctioning of machines, extra heat will be generated and it can be picked up by thermal camera. Thermal camera will generate an image to indicate the condition of the machine. This enables the operator to decide on the on/off switch. Any malfunctioned machines detected will proceed to further repairmen action. This is so-called thermal imaging monitoring.

The use of thermal imaging monitoring is much convenient compared to conventional maintenance method; the operator needs to perform some hands on job to measure the functioning machines frequently, which required more man power and longer maintenance time. With the aids of thermal imaging monitoring, the operator can maintain and monitor the machines by just observing the thermal images on the machines captured routinely and display on a monitor, even from a remote location. So, this can reduce hands on workload, man power, maintenance time and improve safety, since some overheat devices cannot see through eyes, but can be read from thermal images, hence the use of thermal imaging monitoring can prevent accident happen too [2].

One problem encountered in most surveillance systems is the change in ambient light, especially in an outdoor environment where the lighting condition is varies naturally. This makes the conventional digital color images analysis task in smart surveillance very difficult. One common approach to alleviate this problem is to train the system to compensate for any change in the illumination [3]. However, this is generally not enough for trespasser detection in dark. In recent time, thermal camera has been used for imaging objects in the dark. The camera uses infra-red (IR) sensors that captures IR radiation coming from different objects in the surrounding and forms IR image [1]. Since IR radiation from an object is due to the thermal radiation, and not the light reflected from the object, such camera can be conveniently used for trespasser detection in night vision too.

If a single thermal camera is to monitor a single machine/location, then for more machines/location in different angle of view, there required more thermal cameras. Hence, it will cost more, beside complicated the monitoring network. In this project we propose to build up an effective surveillance system. Our research is aimed to develop an omnidirectional surveillance system that includes four main features:

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1.) 360 degree viewing using a single thermal camera, surrounding machines/items can be monitored. This achieving wide area coverage using minimum hardware.
2.) Infra-red imaging for application even in poor lighting condition. Maintenanace staffs/ technician may need not to check and monitor every single machines/item by hand in dark place which is time consuming and quite risky.
3.) Effective automatic machine condition monitoring system that will raise alerts/alarm whenever any security threat (machines/items overheating) arises.
4.) Effective trespasser detection system able to detect trespassers in a poor lighting condition

In this paper, an omnidirectional thermal imaging system consists of thermal camera, custom made IR reflected hyperbolic mirror, camera mirror holder, and laptop/PC as image processing tool is proposed for effective machine condition monitoring and trespasser detection purposes. Thermal images captured from the custom made hyperbolic mirror are in omnidirectional view. Log-polar mapping technique is applied for unwarping the captured omnidirectional thermal images into panoramic form. Two simple and fast detection algorithms are embedded into the thermal imaging surveillance system for monitoring the functioning condition of different machines/items in a factory site and detecting the trespassers in a poor lighting condition. Experimental results show that the proposed surveillance system achieves high accuracy in monitoring machines conditions and detecting trespassers. The paper is organized in the following way: Section II will be briefly comments on the omnidirectional thermal imaging system. Section III presents the proposed log-polar mapping technique. Section IV presents the proposed algorithms for machine condition monitoring and trespasser detection, section V reports some experimental results. Finally in section VI, we draw some conclusion and envision future developments.

2. Omnidirectional Thermal imaging system model

The omnidirectional thermal imaging system model proposed in this paper is shown in Fig.1. The system required a custom made IR reflected hyperbolic mirror, a camera mirror holder, a fine resolution thermal camera and a laptop/PC with Matlab ver 2007 programming.

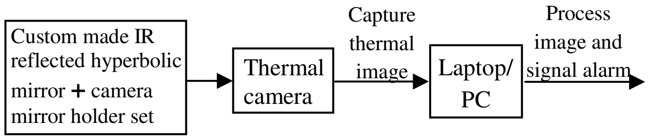

Fig. 1. Omnidirectional Thermal Imaging System Model

2.1 Custom made IR reflected hyperbolic mirror

The best shape of practical use omnidirectional mirror is hyperbolic. As derived by Chahl and Srinivasan in [4], all the polynomial mirror shapes (conical, spherical, parabolic, etc) do not provide a central perspective projection, except for the hyperbolic one. They also shown that the hyperbolic mirror guarantee a linear mapping between the angle of elevation θ and the radial distance from the center of the image plane ρ. Another advantage of hyperbolic mirror is when using it with a camera/imager of homogenous pixel density, the resolution in the omnidirectional image captured is also increasing with growing eccentricity and hence it will guarantee a uniform resolution for the panoramic image after unwarping.

The research group of OMNIVIEWS project from Czech Technical University further developed MATLAB software for designing omnidirectional mirror [5]. From the MATLAB software, we can design our own omnidirectional hyperbolic mirror by inputting some parameters specify the mirror dimension. The first parameter is the focal length of the camera f, in which for the thermal camera we use is 12.5 mm and the distance d (ρz-plane) from the origin is set to 2 m. The image plane height h is set to 20 cm. the radius of the mirror rim is chosen t_1=3.6cm as modified from Svoboda work in [6], with radius for fovea region 0.6 cm and retina region 3.0 cm. Fovea angle is set in between 0° to 45°, whereas retina angle is from 45° to 135°. The coordinates as well as the plot of the mirror shape is generated using MATLAB and shown in Fig. 2. We provide the coordinates as well as mechanical drawing using Autocad to precision engineering company to fabricate/custom made the hyperbolic mirror. The hyperbolic mirror is milling by using aluminum bar and then chrome plating with a chemical element named chromium. Chromium is regarded with great interest because of its lustrous (good in IR reflection), high corrosion resistance, high melting point and hardness. The fabricated mirror is shown in Fig. 3.

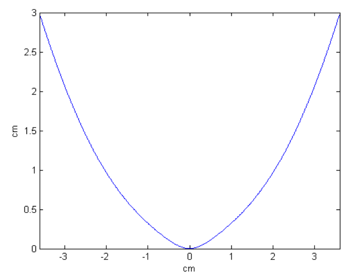

Fig. 2: Mirror coordinates plot in MATLAB

Fig.3: Fabricated mirror

2.2 Camera Mirror Holder

The camera mirror holder is self designed and custom made with aluminum material as shown in Fig. 4.

2.3 Thermal Camera

The thermal camera used in this paper is a affordable and accurate temperature measurement model: ThermoVision A-20M manufactured by FLIR SYSTEM [7]. The thermal camera has a temperature sensitivity of 0.10 in a range from -20ºC to 900ºC and it can capture thermal image with fine resolution up to 320 X 240 pixels offering more than 76,000 individual measurement points per image at a refresh rate of 50/60 Hz. The A-20M features a choice of connectivity options. For fast image and data transfer of real-time fully radiometric 16-bit images, an IEEE-1394 FireWire digital output can be chose. For network and/or multiple camera installations, Ethernet connectivity is also available. Each A-20M can be equipped with its own unique URL allowing it to be addressed independently via its Ethernet connection and it can be linked together with router to form a network. Therefore, it is best outfitted for machine condition monitoring system in a big factory site.

2.4 Laptop/PC

A laptop or PC can be used for image processor, either place on site or in a monitoring room. Matlab ver 7.0 programming is chosen to be used because it has user friendly software for performing log-polar mapping technique to unwrap the omnidirectional thermal image into panoramic form and it can partitioned the panoramic thermal images easily according to each single machine to be monitored, process them smoothly with the machine condition monitoring algorithm we programmed in, and alarm operator with self recorded sound (e.g. : "machine A overheat", "machine B and machine C overheat", "Trespasser intruding", etc). The overall fabricated system model is shown Fig. 4.

Fig.4: Overall fabricated omnidirectional imaging system model

3 Log Polar Mapping

Log-polar geometry or log-polar transform in short, is an example of foveated or space-variant image representation used in the active vision systems motivated by human visual system [8]. It is a spatially-variant image representation in which pixel separation increases linearly with distance from a central point [9]. It provides a way of concentrating computational resources on regions of interest, whilst retaining low-resolution information from a wider field of view. One advantage of this kind of sampling is data reduction. Foveal image representations like this are most useful in the context of active vision system where the densely sampled central region can be directed to pick up the most salient information. Human eyes are very roughly organized in this way.

In robotics, there has been a trend to design and use true retina-like sensors [10], [11] or simulate the log-polar images by software conversion [12], [13]. In the software conversion of log-polar images, practitioners in pattern recognition usually named it as log-polar mapping. The advantages of log-polar mapping is that it can unwarp an omnidirectional image into panoramic image, hence providing the observer and image processing tools a complete wide angle of view for the surveillance area's surroundings and preserving fine output image quality in a higher data compression manner. The spatially-variant grid that represents log-polar mapping is formed by *i* number of concentric circles with *N* samples over each concentric circle [8]. An example of a spatially-variant sampling grid is shown in Fig. 5.

The log-polar mapping use in this paper can be summarized as following: Initially, omnidirectional thermal image is captured using a thermal camera and a custom made IR reflected hyperbolic mirror. The geometry of the captured omnidirectional thermal image is in Cartesian form (x_1,y_1). Next, the Cartesian omnidirectional thermal image is sampled by the spatially-variant grid into a log-polar form (ρ,θ) omnidirectional thermal image. After that, the log-polar omnidirectional thermal image is unwarped into a panoramic thermal image (x_2,y_2), another Cartesian form. Since the panoramic thermal image is in Cartesian form, subsequent image processing task will become much easier.

The center of pixel for log-polar sampling is described by [8]:

$$\rho(x_1, y_1) = \ln_b\left(\frac{R}{\rho_o}\right) \quad (1)$$

$$\theta(x_1, y_1) = \frac{N}{2\pi}\tan^{-1}\left(\frac{y_1}{x_1}\right) \quad (2)$$

The center of pixel for log-polar mapping is described as:

$$x_2(\rho,\theta) = \rho\cos\left(\frac{2\pi\theta(x_1, y_1)}{N}\right) \quad (3)$$

$$y_2(\rho,\theta) = \rho\sin\left(\frac{2\pi\theta(x_1, y_1)}{N}\right) \quad (4)$$

where R is the distance between given point and the center of mapping $= \sqrt{x_1^2 + y_1^2}$,

ρ_o is the scaling factor which will define the size of the circle at $\rho(x_1,y_1) = 0$,

b is the base of the algorithm [8],

$$b = \frac{N+\pi}{N-\pi} \quad (5)$$

N is the number of angular samples over each concentric circle.

A graphical view illustrating the log-polar mapping is shown in Fig. 5 [8]. To sample the Cartesian pixels (x_1,y_1)

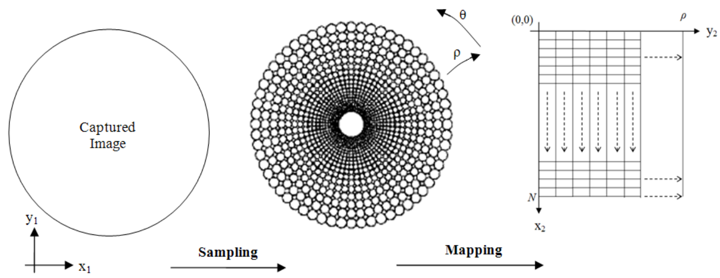

Fig. 5: A graphical view of log-polar mapping.

into log-polar pixel (ρ,θ), at each center point calculated using (1) and (2), the corresponding log-polar pixel (ρ_n,θ_n) covers a region of Cartesian pixels with radius:

$$r_n = br_{n-1} \quad (6)$$

where n = 1,2,3,…..,N-1. Fig. 6 shows the circle sampling method of log-polar mapping [8], [11], where A, A′, B and B′ points are the centre of pixel for log-polar sampling.

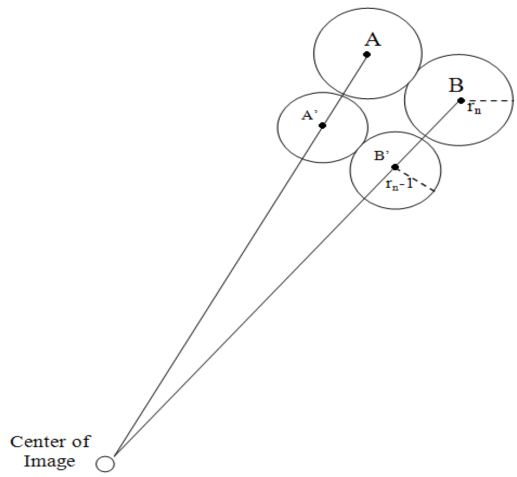

Fig. 6: Circular Sampling Structure in Log-Polar Mapping.

The intensity value in each individual log-polar pixel equals the mean intensity value of all pixels inside the sampling circle on the original Cartesian image (x_1,y_1):

$$mean = \frac{total \ (x_1,y_1) \ pixel \ value}{total \ number \ of \ (x_1,y_1) \ pixel} \quad (7)$$

The region of Cartesian pixels on the panoramic image (x_2,y_2) is covered by an individual log-polar pixel on the log-polar (ρ,θ) omnidirectional image. Therefore, the pixels in that specific region on the panoramic image (x_2,y_2) will have the same intensity with respect to the corresponding individual log-polar pixel. Fig. 7 shows the mapping or unwarping of log-polar pixel onto its corresponding Cartesian pixel (x_2,y_2), as described by (3) and (4).

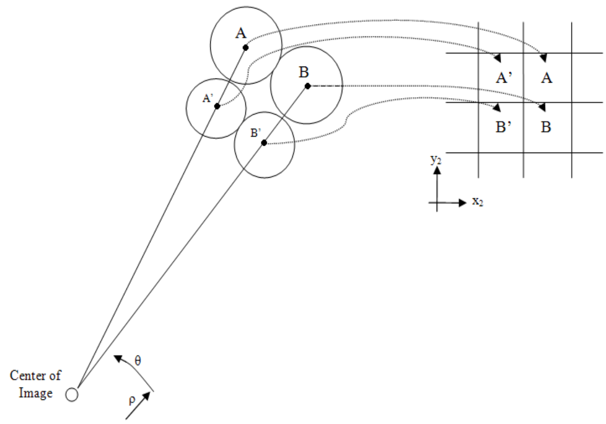

Fig. 7. Unwarping Process.

4 Algorithm For Machine Condition Monitoring And Trespasser Detection

In this section, we propose two simple and effective algorithms for machine condition monitoring and trespasser detection for the omnidirectional thermal imaging system.

4.1 Algorithm for machine condition monitoring

The algorithm for machine condition monitoring is summarized as below:

Step 1: Acquire omnidirectional image from thermal camera into laptop.

Step 2: Unwarp the omnidirectional thermal image into panoramic thermal image using log-polar mapping technique.

Step 3: Partition the region of interest (ROI) of the unwarped panoramic image into n sections horizontally where n = number of machines.

Step 4: Define $m_n = (x_{\min(n)} : x_{\max(n)}, y_{\min(n)} : y_{\max(n)})$ be the range of the partition, separate the ROI of the image into

$$m_n = (x_{\max(n-1)} : 1\frac{(n)x_{\max}}{n_{\max}}, y_{\min} : y_{\max}) \quad (8)$$

An example of partitioning of ROI for machine condition monitoring system is shown in Fig. 8 with $m_1 = (1:107,1:60)$, $m_2 = (108:214,1:60)$, $m_3 = (215:320,1:60)$

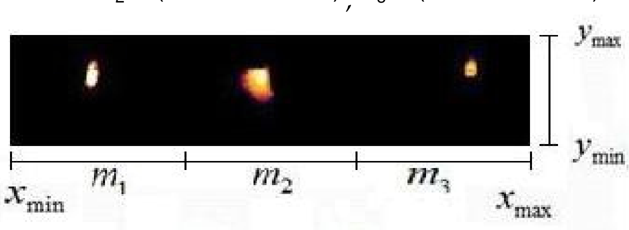

Fig. 8: Partitioning of ROI for machine condition monitoring system.

Step 5: Calculate the sum of RGB elements for each pixel (x, y) using:

$$T_{(x,y)} = R_{(x,y)} + G_{(x,y)} + B_{(x,y)} \quad (9)$$

where $R_{(x,y)}$ is the value of red element of pixel (x,y); $G_{(x,y)}$ is the value of green element of pixel (x,y) and $B_{(x,y)}$ is the value of blue element of pixel(x,y). Pixel with higher temperature will give higher $T_{(x,y)}$ value. For example, at a reference point as shown in Fig. 9, $T_{(197,88)} = 243 + 113 + 0 = 256$.

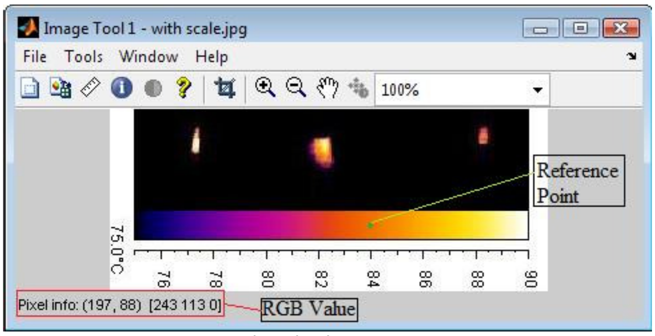

Fig. 9: Calculating value of T of reference point

Step 6: Define an overheat threshold value, $T_{(x_r,y_r)}$. $T_{(x_r,y_r)}$ is a value with sum of $R_{(x,y)}$, $G_{(x,y)}$ and $B_{(x,y)}$ equal to a predefined overheat color tone value, For example, if machines exceed 87°C is consider overheat, then $T_{(x_r,y_r)}$ is the total sum of $R_{(x,y)}$, $G_{(x,y)}$ and $B_{(x,y)}$ for the color tone value as shown in reference point in Fig. 9.

Step 7: Compare $T_{(x,y)}$ with $T_{(x_r,y_r)}$ in each machine's section. If $T_{(x,y)} \geq T_{(x_r,y_r)}$, then overheat take place at pixel (*x,y*), else if $T_{(x,y)} < T_{(x_r,y_r)}$, then no overheat take place at pixel (*x,y*). A variable *h* is used to gather the number of pixels in concern:

$$for \begin{cases} T_{(x,y)} \geq T_{(x_r,y_r)} \rightarrow h_i = 1 \\ T_{(x,y)} < T_{(x_r,y_r)} \rightarrow h_i = 0 \end{cases} \quad (10)$$

where *i* as the sequence number of scanned pixel.

Step 8: Define the minimum overheat size of a machine, *S*. If total overheated pixels in a section are more than *S*, then the machine in that particular section is said to be overheated, else the machine in that section is consider function in normal condition.

$$for \begin{cases} \sum_{i=1}^{total\_pixel} h_i \geq S \rightarrow Machine \ overheat \\ \sum_{i=1}^{total\_pixel} h_i < S \rightarrow Machine \ not \ overheat \end{cases} \quad (11)$$

4.2 Algorithm for trespasser detection

The algorithm for trespasser detection is summarized as below:

Step 1: Adjust the thermal camera detection range to 30°C to 40°C so that object with human body temperature range can be detected.

Step 2: Unwarp the omnidirectional thermal image into panoramic thermal image using log-polar mapping technique.

Step 3: Capture images continuously from thermal camera into laptop and names it as *Px* where *x* = 1, 2, 3…is the discrete time instant.

Step 4: Divide each image captured from thermal camera into (m x n) regions. Each region consists of equal number of pixels.

Step 5: Define a matrix, *M* with size of (m x n) to represent the characteristic of each corresponding region.

Step 6: Define a threshold value *Q*. *Q* is the threshold value of the difference between sum of R, G, B value for a particular current image pixel to previous image pixel.

Step 7: Define a variable, *h* for counting the number of pixels exceeding *Q*. Initially, *h* is set to 0.

Step 8: Define *H as* a minimum number of pixels with difference exceeding *Q*.

Step 9: Compare current taken image *Px* with previous taken image $Px-1$. For each corresponding region, find out the difference between a particular current image and previous image pixels' sum of R, G, B value. If the difference between sum of R, G, B value for a particular current image pixel to previous image pixel ≥ *Q*, then *h* = *h* + *1*. If h ≥ *H*, mark a "1" into the corresponding element of *M*, else if *h* < *H*, mark a "0" into the corresponding element of *M*. An example is shown in Fig. 10.

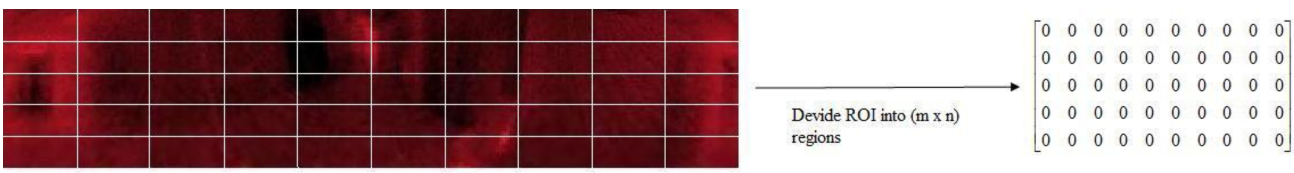

Fig.10: An example for partitioning of ROI for trespasser detection surveillance system.

Step 10: Let F be the number of different elements which align vertically and continuously. Some examples of calculation of F are shown below.

Examples:

E.g. (1)

$$\text{Compare}\begin{bmatrix}0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\end{bmatrix}\text{with}\begin{bmatrix}0&0&0&0&0\\0&1&0&0&0\\0&1&0&0&0\\0&1&0&0&0\\0&1&0&0&0\end{bmatrix}$$

$F = 4$ in this example.

E.g. (2)

$$\text{Compare}\begin{bmatrix}0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\end{bmatrix}\text{with}\begin{bmatrix}0&0&0&0&0\\0&1&0&0&0\\0&0&0&1&0\\0&0&0&1&0\\0&0&0&1&0\end{bmatrix}$$

$F = 3$ in this example because only 3 different elements are aligned vertically and continuously.

E.g. (3)

$$\text{Compare}\begin{bmatrix}0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\end{bmatrix}\text{with}\begin{bmatrix}0&0&0&0&0\\0&1&0&0&0\\0&1&0&1&0\\0&0&0&1&0\\0&0&0&1&0\end{bmatrix}$$

If there are more than 2 groups of vertically and continuously different elements, then we will take the largest number. In this case, $F = 3$

Step 11: Define G as minimum regions that a human being will appear on screen. If $F \geq G$, then alarm unknown trespasser detected.

5. Experimental Result

In this section, we briefly illustrate the application of the proposed omnidirectional thermal imaging system for machine condition monitoring. and trespasser detection. As for machine condition monitoring part, we select a three machines case for studies. The omnidirectional thermal images for the functioning machines are collected at the Applied Mechanics Lab in Faculty of Engineering and Technology, Multimedia University.

An omnidirectional image captured by using digital camera on the site is shown in Fig. 11. An omnidirectional thermal image is also captured by using thermal camera on the site based on three machines are functioning in overheat condition, as shown in Fig. 12. The unwarped form of Fig. 11 (digital color panoramic form) is shown in Fig. 13 whereas the unwarp form of Fig.12 (thermal image panoramic form) is shown in Fig. 14 respectively. In Fig. 14, the log-polar mapping process is by 4 : 1 reduction mapping scale, which means that 320 X 240 omnidirectional thermal image's Cartesian pixels are mapped to one fourth of the thermal image Cartesian pixels (320 X 60) in panoramic view, with four fold data compression compare to original omnidirectional thermal image as in Fig. 12. In Fig. 14, Machine A (leftmost) and Machine C (rightmost) are vibro test machines with same model and same specs, where as Machine B (center) is a fatigue test machine with cooling

Fig. 11: Case studies of machines for monitoring captured in Applied Mechanical Lab (Digital Color Form).

Fig. 12: Case studies for machines for monitoring captured in Applied Mechanics Lab (Thermal image, all machines are functioning in overheat condition)

Fig. 13: Unwarp form of Fig.11 (digital color panoramic form)

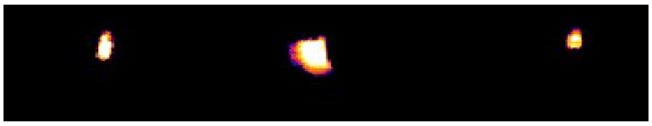

Fig. 14: Unwarp form of Fig.12 (thermal image panoramic form)

system. The motors of machine A, B and C are considered to be overheated when it reaches 90˚C. Hence we set the temperature measurement range on thermal camera from 80˚C to 90˚C. The temperature level display on captured thermal images are with different color tones ranging from black, blue, magenta, orange, yellow, light yellow to white represents each step size of temperature range display on the thermal camera. The actual size of the machines appear in the thermal image is approximately 105 pixels for machine A, 288 pixels for machine B, 60 pixels for machine C. *S* is the minimum size of the machines appear in the image. By running test on 1000 samples thermal images for different *S* varying from 10%, 20% … 100% of actual size of the machines appear in the thermal image, the results is plot in Fig. 15. The optimum value of *S* is at 50% of actual machine size, i.e with higher accuracy. Hence, we set *S* = 53 pixels for machine A, *S* = 144 pixels for machine B and *S* = 30 pixels for machine C.

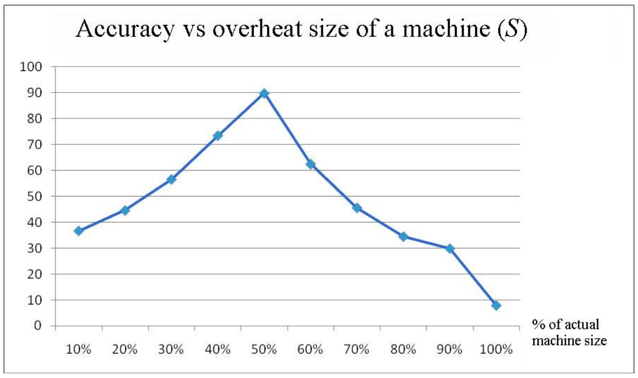

Fig. 15: Accuracy vs. overheat size of a machine (*S*).

The possible machines condition can be divided into 8 major classes, namely: All the machines function properly (none of the machines overheat); Machine A overheat; Machine B overheat; Machine C overheat; Machine A and B overheat; Machine B and C overheat; Machine A and C overheat; Machine A, B and C overheat.

The algorithm for machine condition monitoring was evaluated with respect to the thermal images captured live, unwarped into panoramic view and displayed on monitor screen as interpreted by an operator (human observer) the overall description of which could be called the "Operator Perceived Activity" (OPA) [14]. The operator will comments on the images captured by the thermal camera, whether the observed particular machine is overheated or not and compare with that detected by the omnidirectional thermal imaging system. From the total of 10,000 captured and unwarped images, 9633 images were tracked perfectly (machines conditions agreed by both observer and omnidirectional thermal imaging system), that is an accuracy of 96.33%.

As for trespasser detection part, Fig. 16 shows the omnidirectional digital color image on the site to be measured. The corresponding unwrap panoramic form is shows in Fig. 17. As for thermal imaging, the temperature range of the thermal camera is switched to human body temperature range, i.e. from 30°C to 40°C. Temperature level display on the captured thermal images is with different color tones ranging from black, brown, dark red, red, orange, yellow, light yellow to white represents each step size of temperature range. The reason that we select 30°C to 40°C range and not a smaller range (35°C to 40°C) is because sometimes the trespasser is wearing thick cover (e.g. cap, thick jacket and thick jean) so that temperature released is a little bit lower than normal. So, we extend the range to 5°C more below normal range, which is 30°C to 40°C. However, if a bigger temperature range is used, let say, 20°C to 40°C, then more noise and distortion are included into the captured thermal images. This is because the temperature range (20°C to 40°C) is fall into the room temperature range, in which undesired IR signals (sunlight, fluorescent tube light, etc) are also absorbed into the thermal images. The performance can be seen and by comparing Fig. 18 and Fig. 19.

We can see that there are a lot of noise and distortions appears in Fig. 19 due to undesired IR signals. Therefore, we can conclude that the optimal temperature range to measure human being trespasser in the surveillance system is 30°C to 40°C. The unwarp panoramic form of Fig. 18 is shown in Fig. 20 respectively.

In algorithm for trespasser detection, there are three parameters need to be optimized which are *Q*, *H* and *G*, where *Q* is the threshold value of the difference between sum of R, G, B value for a particular current image pixel to previous image pixel, *H* is minimum number of pixels with difference exceeding *Q*, and *G* is minimum regions that a human being will appear on screen.

Since the image captured by thermal camera is in RGB form therefore the difference of sum of RGB values between a particular current image pixel to previous image pixel is in between 0 to 765. For *Q* parameter, 1000 sample images (with or without human being) are used to test for every difference point with step size of 15. The accuracy vs difference of sum of RGB values is plotted as Fig. 21. From the plot, the optimum *Q* value is 345 with highest accuracy of 95.30%.

Fig. 16: Omnidirectional digital color image on the site for trespasser detection.

Fig. 17: Unwarp form of Fig. 16 (digital color panoramic form)

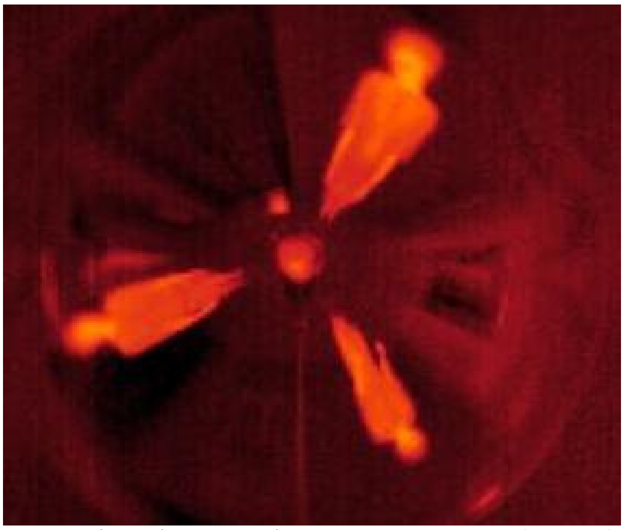

Fig. 18: Thermal image with temperature range 30°C to 40°C used for detecting trespasser.

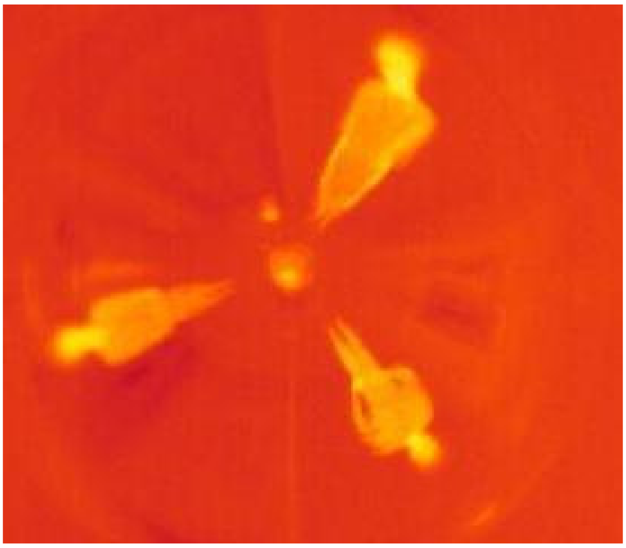

Fig. 19: Thermal image with temperature range 20°C to 40°C used for detecting trespasser.

Fig. 20: Unwarp form of Fig. 18 (thermal image panoramic form)

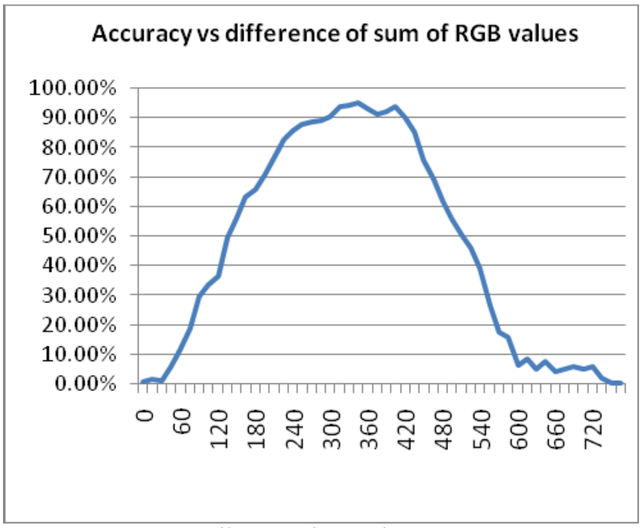

Fig. 21: Accuracy vs difference of sum of RGB values

We partition the unwarp panoramic thermal image into 50 regions (m =10, n = 5) with each region consists of equal number of pixels (384). As for *H* value, we tried the algorithm with pets (hamster, cat, and dog) and human, moving toward and away from the captured region. 1000 sample images are captured. By using the sample images, we repeated the simulation with *H* = 10, 20, 30 …100% of number of pixels difference to total pixels in one region ratio. The graph Accuracy vs. Number of Pixel Difference to Total Pixels in One Region Ratio is plotted in Fig. 22. From the plot, the optimum *H* value is 50% of total pixels in a region, with the highest accuracy of 97%.

As for *G* value, we tested the algorithm with human moving toward and away from the captured region with minimum regions that a human being will appear on screen, *G* = 1, 2, 3, 4 and 5. The graph of accuracy vs minimum regions that a human being will appear on screen *G* is shown in Fig. 23. From the graph, the optimum *G* value is 3 with highest accuracy of 93.5%.

For testing the trespasser detection performance of our surveillance system, a total of 1000 thermal images are captured as samples. This includes thermal images with a single trespasser, more than one trespasser, without trespasser and animals (cats, birds etc which are not counted as trespasser). The OPA [14] is used and the operator will comments on the images captured, whether there is any trespasser or not and compare with that detected result of the surveillance system.

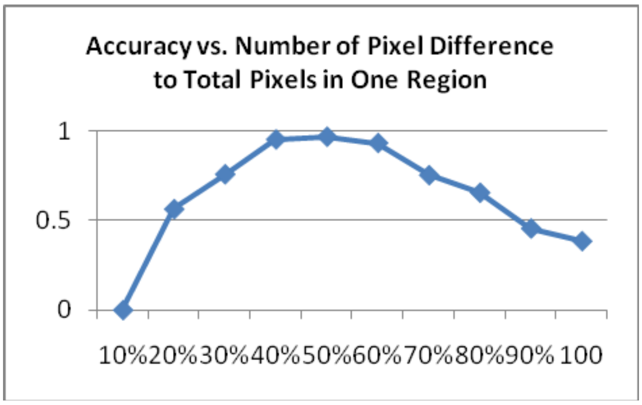

Fig. 22: Accuracy vs. Number of Pixel Difference to Total Pixels in One Region.

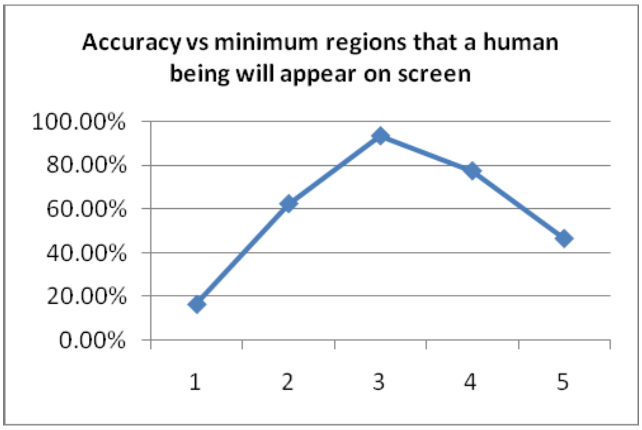

Fig. 23: Accuracy vs minimum regions that a human being will appear on screen

From the total of 1000 samples images for evaluation, 838 were tracked perfectly (trespasser-or-not condition agree by both observer and surveillance system), that is with an accuracy of 83.8%.

The omnidirectional surveillance system is also function in a fast way whereby the routine time required capturing in a thermal image, unwarped it into panoramic form and detect the machines condition/trespasser until the signal alarm or not is only 3 seconds.

6. CONCLUSION

In this paper, an omnidirectional thermal imaging system is proposed for surveillance purposes (machine condition monitoring and/or trespasser detection). A specific designed and custom made IR reflected hyperbolic mirror set (mirror + holder) is fabricated for obtaining 360 degree viewing of a location to be monitored. Log-polar mapping technique is applied in the imaging system for unwarping the captured omnidirectional thermal image into panoramic form. Two simple and fast algorithms: machine condition monitoring algorithm and trespasser detection algorithm had been developed that can be used for monitoring the functioning condition of different machines in a factory site and detecting trespasser, even in dark. The experimental results show that the proposed omidirectional thermal imaging system achieves high accuracy both in monitoring machines conditions and detecting trespassers. In future, an automatic power supply control system will be added to the machine condition monitoring system. When the monitoring system detected any of the machines overheated, the automatic power supply control system will cut off the power supply of the respective machine(s). This enhancement can reduce hands on workload, man power and maintenance time.

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