Development and deployment of Infrared Fever Screening Systems

ABSTRACT
The Infrared Fever Screening System (IFss), conceptualised by Defence Science & Technology Agency and Singapore Technologies Electronics during the Severe Acute Respiratory Syndrome outbreak in 2003, is the first infrared-based system in the world to be used for fever screening of large groups of people. The IFss does not measure skin temperature but uses a two-point detection concept to screen for fever. The first decision point is to sieve out probable febrile persons using thermal imagers and the second decision point is the confirmation that the subject has an elevated body temperature using conventional clinical thermometers. Statistics, physics and human physiology were key inputs in the design of the IFss. Workflow and other operational considerations such as operator training are also important in ensuring the performance of the IFss. The authors relate their experience in the development and deployment of the IFss.

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1. INTRODUCTION

When Severe Acute Respiratory Syndrome (SARS) hit Singapore in March 2003, there was a need to efficiently screen large groups of people for fever as it is the only known symptom of SARS. This was especially critical at immigration checkpoints to control the spread of SARS. However, conventional means of taking temperature using ear and oral thermometers were too slow and inconvenienced everyone. On 3 April 2003, the Singapore Ministry of Health (MOH) approached DSTA for possible alternative solutions.

DSTA manages complex defence science and technology programmes and conducts research and development (R&D) in multi-disciplinary areas ranging from engineering, information technology to biomedical sciences. The Sensor Systems Division (SSD) in DSTA manages the acquisitions and development of sensors for the Singapore Armed Forces (SAF) and is experienced in the field of electro-optics and radar. Working with MOH to understand the requirements, DSTA quickly came up with a design concept using the SAF’s military thermal imager. Singapore Technologies (ST) Electronics, which designs and manufactures thermal imagers, was roped in to work together in this project. The idea was quickly turned into a prototype within a week.

The result is the Infrared Fever Screening System (IFss), a system that can screen large groups of people quickly, non-intrusively and with a high level of confidence in sieving out febrile persons. It is the first thermal-imager-based system in the world to be used solely for mass screening. The IFss requires a constant and stable temperature source called the thermal reference source (TRS). The TRS is located within the field of view of the thermal imager such that IR energy radiated from other objects within the field of view can be compared to the energy radiated from the TRS. The temperature of the TRS thus represents an adjustable threshold setting for temperature screening.

For the first decision point, the thermal imager was chosen to rapidly scan and screen a large group of people efficiently. The area of interest will be the facial region since facial skin is thin, with blood vessels close to the skin surface. Those found to have a higher-than-normal facial skin temperature are assumed to have a higher-than-normal body core temperature and subjected to the second test using conventional clinical thermometers.

A thermal imager can capture electromagnetic radiation in the infrared band. According to Planck’s Law, all objects that have temperatures above zero degrees Kelvin emit infrared (IR) radiation. IR radiation energy and temperature can be correlated. As can be seen in Figure 1, a greater amount of IR energy is radiated when an object has a higher temperature. Therefore by comparing total IR radiation energy emitted by objects across a specific wave band, relative temperature differentials can be obtained.

The IFss works in real-time by sampling the IR energy radiated from a scene, processing it using a computer and generating a pseudo colour video of relative temperature distribution.

It is important to note that the IFss is designed to provide relative temperature differences and not absolute temperatures. It is designed from a total system engineering perspective, i.e. taking into consideration thermal imager specifications, human body and skin temperature physiology, human traffic flow and environmental conditions. It should not be regarded as an absolute temperature measurement tool, but rather as a tool for fast mass screening.

2. DEVELOPMENT OF THE IFss

2.1 Design concept

The design aim of the IFss is to detect fever suspects with high confidence, relative ease and speed so that they can be sent for medical diagnosis. The World Health Organisation (WHO) and Communicable Disease Centre (CDC) guidelines relating to SARS identify a suspect case as one whose body temperature is greater than 38°C (Brum, et al, 2003). Therefore, the IFss must identify individuals with a body core temperature above 38°C. The requirements also dictate that the system be non-intrusive and have high throughput. In the ideal case, the system should be both fast and accurate. Unfortunately, as in most engineering problems, there is a tradeoff between speed and accuracy.

Screening a large group of people for fever is similar to the radar detection problem. In the case of the radar, it has to scan a large surveillance space for very few targets. The radar must be able to distinguish RF echoes of real targets from clutter noise. One way is to narrow down probable targets in two steps. Like the Radar Double Threshold Detection Scheme, the IFss uses a two-tier detection concept to screen a large group of people for fever. The first decision point is the detection of individuals with high skin temperatures and the second decision point is the confirmation that the subject has an elevated body temperature using conventional clinical thermometers.

2.2 Key Considerations

2.2.1 Physics

Thermal imager

A key component of the IFss is the thermal imager. When the IFss was first conceptualised, there was an operational need to produce and deploy these systems quickly. Cooled military thermal imagers operating in the 3-5μm waveband were used as they could be made available by the SAF. Optimised for military
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When the IFss was introduced, it generated immense international interest in the use of thermal imagers for human temperature of Clinical Thermology (ACCT) (Ronald Brum, et al, 2003) proposes that the most effective point-of-contact screening of individuals in public places is clinical digital infrared thermal imaging.

This paper shares our experience in the development and deployment of the IFss, especially the important considerations that have gone into the system design.

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scenarios, they have very high gain and the advantages of better spatial resolution and sensitivity. However, compared to commercial uncooled thermal imagers, they have a smaller field of view, higher power consumption, longer start-up time and higher cost. The peak wavelength (Wien’s Law) for human body temperatures, which is around 10μm, falls outside the cooled thermal imager wavelength. As such, uncooled thermal imagers were chosen to replace these military thermal imagers for long-term operation.

Developed by ST Electronics, the 8-12μm wavelength uncooled thermal imagers in use now are based on microbolometer technology. Microbolometers are thermoelectric in nature, which means that when the detector senses IR energy, it reacts by changing resistance. Changes in resistance are converted to electrical signals to form a video image.

With help from various organisations including DSTA, SPRING Singapore (Standards, Productivity and Innovation Board) created a technical reference that specifies the technical and implementation requirements for thermal-imager-based systems used for human temperature screening. The important technical parameters include uniformity, drift, minimum detectable temperature difference (affected by number of quantisation levels, uniformity, and maximum drift between self-corrections), distance effect, and accuracy and stability of TRS. These key parameters will affect the performance of all thermal-imager-based screening systems.

Other considerations

Besides emitting IR radiation, objects can also reflect IR radiation. As such, ambient lighting condition becomes an important consideration when situating the IFss for reliable results. Stray light and reflections, which may change throughout the day (such as sunlight from a nearby window), must thus be minimised when operating the IFss.

The performance of the IFss is dependent on the stability and accuracy of the TRS, since it is used as a reference to which objects are compared. Besides using a high performance TRS, the external environment, namely the ambient temperature and air flow, also has to be stable. Trials were conducted to see if the IFss was suitable for use in uncontrolled ambient conditions, but the performance was found to be inconsistent in such environments.

2.2.2 Human Physiology

Some knowledge of human physiology, in the areas of body temperature regulation and the characteristics of fever, is needed to understand the considerations and limitations of using skin temperature to detect fever.

Characteristics of body temperature

Core or internal body temperature is generally considered to be the temperature of blood in the heart and the brain. However, this is not easily accessed, except with the insertion of an invasive catheter. Therefore, other body sites are used as proxies to assess human core temperature. The offset from the “core temperature” increases from rectal, oral, ear, axillary (under armpit) to skin (in the head and neck region) (American Society for Testing and Materials, 2003).

The relation between one’s core temperature and skin temperature varies from person to person, and is dependent on skin blood perfusion and environment conditions. In addition, skin temperature cannot be independently correlated with internal body temperature. However, we have found through our trials that areas in the face region, namely, the temples, neck and a small patch of skin between the eyes and nose, are the closest to core temperature due to the proximity of blood perfusion. These are the areas focussed on when examining the IFss images on the video display.

The offset from core temperature is factored into the design of the IFss as the threshold. This will be discussed in detail in the following section on statistics.

Another consideration affecting core temperature is the Circadian Variation. The core temperatures of human beings follow a 24-hour cycle, with the following points in the cycle:

- Zenith (highest, approx. 37.5°C) at 4-6pm
- Nadir (lowest, approx. 35.5°C) in the early morning

However, someone with fever is probably unaffected by this Circadian Variation, so the performance of the IFss with the set threshold should not be affected. The Circadian Variation, does imply that the false alarm rate (percentage of people who have no fever but are deemed feverish) is probably lower in the morning.

It should be noted that children tend to have higher body temperatures than adults. Therefore, the false alarm rate for children is probably higher compared to adults.

Detection and regulation of temperature

Human beings belong to a group of animals named Homeotherms. Homeotherms regulate and maintain a constant body temperature using a variety of regulation mechanisms. There exists a gradient between core and surface temperature to minimise heat loss and permit cooling. Radiation, conduction, convection and evaporation (sweating) are the regulation mechanisms used to exchange heat with the environment (Figure 3). Of these mechanisms, only the radiation of IR energy is used by the IFss to detect fever.

The part of the brain that controls this regulation is the hypothalamus. Its inputs are the peripheral detectors such as cold and warm thermoreceptors in the skin as well as the central detectors like the hypothalamic sensor and tissue receptors. The hypothalamus, a key node of the temperature regulation feedback loop (Figure 2), controls the regulation mechanism using hormones (like thyroxine and epinephrine) and via the nervous system (through muscular activity, vasodilation and vasoconstriction).

The thermoreceptors in the skin are more sensitive to rapid change than steady change so subjects should be acclimatised in a stable environment before being screened (for example, they should not be checked immediately after they enter a cold room from a hot environment). Otherwise, their skin temperature may not be representative of the actual core temperature.

For consistency, the IFss requires subjects to be at or close to resting metabolic rate. The performance of the IFss is affected if the subject is subjected to activity that may affect the regulation of his body temperature, such as

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Characteristics of Fever

The use of skin temperature as a proxy to the core temperature may be inaccurate at certain stages of fever and thus it is possible that some individuals with fever may not be picked out by the IFss. For body temperature regulation, the body determines a temperature as its “set-point” at any one time. Fever occurs when the hypothalamus detects pyrogens and raises the set point. As can be seen in Figure 4, fever can be broken into different stages. The IFss is designed to detect people at the plateau of the fever (when his core temperature is high) and not at the rising slope (immediately after fever starts) or falling slope (after fever breaks). When the fever begins, the body attempts to raise its temperature and vasoconstriction occurs to prevent heat loss through the skin. The skin temperature will thus be cold and IR radiation may not cross the set threshold. As can be seen in Figure 4, fever can be broken into different stages. The IFss is designed to detect people at the plateau of the fever (when his core temperature is high) and not at the rising slope (immediately after fever starts) or falling slope (after fever breaks). When the fever begins, the body attempts to raise its temperature and vasoconstriction occurs to prevent heat loss through the skin. The skin temperature will thus be cold and IR radiation may not cross the set threshold. Therefore individuals at this stage of fever will not be picked out.

Statistics have to be considered due to the nature of human skin temperature. As explained earlier in the human physiology section, skin temperature cannot be independently correlated with internal body temperature. A statistical method must be employed such that skin temperature is looked at from a macro (populations) instead of a microscopic (individuals) point of view. An analogy can be drawn to human height versus foot size. While we cannot independently correlate an individual’s foot size to his height, the trend of a taller person having a larger foot allows us to statistically examine the relationship between height and foot size in a population. Similarly, we can use statistics to correlate skin temperatures with core temperatures for a population.

The average skin temperature of the population of normal healthy people is well researched and documented. According to medical research on human body thermography, at resting metabolic rate and with normal clothing in a room temperature of 15 to 20°C, the skin temperature of an individual from a healthy population is between 32°C to 35°C. The probability distribution function (PDF) of skin temperatures for a population is expected to look like a normal Gaussian distribution.

Even though there is an absence of similar research and documentation on the skin temperature distribution of a febrile population, the skin temperature of a febrile population is expected to also follow a normal distribution, but with a higher mean than the one for a healthy population (Figure 5). It is also expected to have a lower variance compared to that of the healthy population.

When a threshold is set, it cuts the upper tail of the PDF curve for the healthy population and lower tail of the curve for the febrile population. For the healthy population, the area under the curve to the left of the threshold is the probability of true negative (no fever classified as no fever). The area under the curve to the right of the threshold is the probability of false positive (no fever identified as having fever), also known as the false alarm rate. For the febrile population, the area under the curve to the left of the threshold is the probability of false negative (fever classified as no fever) and the area under the curve to the right of the threshold is the probability of true positive (fever identified as having fever).

Proper threshold setting is thus very crucial to the robustness of IFss operation. Too low a threshold setting will result in a lower percentage of missed detections, but will also mean more false alarms. Too high a threshold will mean less false alarms, but will also increase the percentage of missed detections.

In other words, if the priority is to make sure that very few febrile people are missed, the threshold must be set lower. This may be at the expense of a higher false alarm rate. If the priority is to minimise the number of people pulled out to be checked with a conventional clinical thermometer, the threshold must be set higher. This, however, will mean that a higher percentage of febrile people will be missed.

This concept is similar to the Receiver Operating Characteristic (ROC) curve analysis developed in signal processing and used in clinical medicine to judge the ability of a test to discriminate diseased cases from normal cases (Zweig & Campbell, 1993; National Committee for Clinical Laboratory Standards, 1995). Similar to the problem of separating feverish people from healthy people, when one considers the results of a particular test for disease in two populations, one population with the disease, the other population without the disease, there is rarely a perfect separation between the two groups. ROC plots can be used to help select optimum decision thresholds by finding the best (lowest) combination of false negatives and false positives.

However, this optimal threshold obtained may not give an acceptable (low enough) false negative fraction (proportion of febrile population that will not be detected) if the priority is to minimise false negatives. Therefore, the initial approach to our trials is to characterise the febrile population facial skin temperature and use the data to find an acceptable threshold with a low enough false negative fraction.

2.3 Trials

A series of trials was conducted to verify the IFss design, obtain a suitable threshold setting and validate the performance of the IFss.

2.3.1 Prototype Trial

Using the IFss prototype, a trial was conducted at the Accidents & Emergency Department of Singapore General Hospital on 4 April 2003 to calibrate the thermal imager, characterise the skin temperatures for febrile population and establish the acceptable initial threshold to be used.

Very few cases of high fever patients (seven cases) were presented for testing due to the threat of infection. Given the small sample size, the chi-squared distribution was used for the population variance. The small population of febrile patients was further narrowed down to those with body core temperature of 38°C and above. The corresponding skin temperature characteristics were found:

Mean skin temperature, \( T_{m/F} = 36.16°C \)

Standard deviation, \( m/F = 0.40°C \)
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Mean skin temperature, \( T_{m/F} = 36.16°C \)
Standard deviation, \( \sigma_{m/F} = 0.40°C \)
14

**2.3.2 Validation at Changi Airport**

The IFss prototype, with this initial threshold set at 35.1°C, was chosen. As more time became available, more tests were subsequently conducted to further characterise and validate the skin temperature distribution of both healthy and febrile populations. Using the IFss, a trial was conducted to obtain data on the forehead skin temperatures of healthy people. Thirty-six healthy adults, aged 18 to 45 years, were screened using the IFss. Their thermographs were recorded and analysed to determine their forehead skin temperatures. The mean skin temperature was found to be 32.85°C, with a standard deviation of 0.95°C. In other words, the probability of a healthy person having a skin temperature below 34.75°C (2σ above mean) is 97.5%. Since the sample was representative of a healthy population, this result gave us confidence that the threshold setting of 35.1°C will have a low false alarm rate.

Another test was conducted at Singapore’s Alexandra Hospital on patients with fever to validate the effectiveness of the IFss with the threshold set at 35.1°C. Patients with body temperatures above 38°C were scanned using the IFss to determine if they would be picked out using the threshold setting. The results showed a 100% probability of true positive and 96.1% specificity. In other words, we would have a very high confidence of picking out febrile people with the trade-off being an approximately 16% false alarm rate. The final threshold setting of 35.0°C was chosen.

The results showed that if the threshold was set at 35.0°C, we could expect close to 100% sensitivity and 83.9% specificity. In other words, we would have a very high confidence of picking out febrile people with the trade-off being an approximately 16% false alarm rate. The final threshold setting of 35.0°C was chosen.

3. **OPERATION AND DEPLOYMENT**

A typical setup of the IFss, consisting of a thermal imager, thermal reference source (TRS), central processing unit (CPU) and display monitors is shown in Figure 6. Modularity is a feature of this setup. The thermal imager, TRS, and computer can be upgraded with minor changes in the software. It also facilitates maintenance and replacement.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>+LR</th>
<th>-LR</th>
</tr>
</thead>
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<tr>
<td>&gt;=32.71</td>
<td>100.0</td>
<td>0.0</td>
<td>1.00</td>
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<tr>
<td>&gt; 35.02</td>
<td>100.0</td>
<td>83.9</td>
<td>6.20</td>
<td>0.00</td>
</tr>
<tr>
<td>&gt; 35.5</td>
<td>93.5</td>
<td>83.9</td>
<td>5.80</td>
<td>0.08</td>
</tr>
<tr>
<td>&gt; 35.61</td>
<td>93.5</td>
<td>87.1</td>
<td>7.24</td>
<td>0.07</td>
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<tr>
<td>&gt; 35.63</td>
<td>91.3</td>
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<td>&gt; 35.65</td>
<td>91.3</td>
<td>90.3</td>
<td>9.43</td>
<td>0.10</td>
</tr>
<tr>
<td>&gt; 35.79</td>
<td>82.6</td>
<td>90.3</td>
<td>8.54</td>
<td>0.19</td>
</tr>
<tr>
<td>&gt; 35.81</td>
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<td>93.5</td>
<td>12.80</td>
<td>0.19</td>
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<tr>
<td>&gt; 37.01</td>
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<td>0.63</td>
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<tr>
<td>&gt; 37.4</td>
<td>96.4</td>
<td>96.8</td>
<td>9.43</td>
<td>0.72</td>
</tr>
<tr>
<td>&gt; 37.5</td>
<td>28.3</td>
<td>100.0</td>
<td>-</td>
<td>0.72</td>
</tr>
<tr>
<td>&gt; 38.13</td>
<td>0.0</td>
<td>100.0</td>
<td>-</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**KEY**

- Sensitivity: Probability that a test result will be positive when the disease is present
- Specificity: Probability that a test result will be negative when the disease is not present
- +LR: Positive likelihood ratio (ratio between the probability of a positive test result given the presence of the disease and the probability of a positive test result given the absence of the disease)
- -LR: Negative likelihood ratio (ratio between the probability of a negative test result given the presence of the disease and the probability of a negative test result given the absence of the disease)
The probability of a febrile person (>38°C body core temperature) having skin temperature above 35.36°C is 97.5%. To confidently sieve out potential febrile persons with elevated body core temperature of 38°C and above, the threshold could be set at 35.36°C. The IFss was declared operational at Changi Airport on 11 April 2003.

2.3.2 Validation at Changi Airport

The IFss prototype, with this initial threshold setting of 35.1°C, was chosen. As more time became available, more tests were subsequently conducted to further characterise and validate the skin temperature distribution of both healthy and febrile populations.

Using the IFss, a trial was conducted to obtain data on the forehead skin temperatures of healthy people. Thirty-six healthy adults, aged 18 to 45 years, were screened using the IFss. Their thermographs were recorded and analysed to determine their forehead skin temperatures. The mean skin temperature was found to be 32.85°C, with a standard deviation of 0.95°C. In other words, the probability of a healthy person having a skin temperature below 34.75°C (2σ above mean) is 97.5%. Since the sample was representative of a healthy population, this result gave us confidence that the threshold setting of 35.1°C will have a low false alarm rate.

Another test was conducted at Singapore’s Alexandra Hospital on patients with fever to validate the effectiveness of the IFss with the threshold set at 35.1°C. Patients with body temperatures above 38°C were scanned using the IFss to determine if they would be picked out using the threshold setting. The results showed a 100% probability of true positive for patients tested with body core temperatures above 38°C. In other words, there was confidence that the IFss was effective in picking out patients with core temperatures above 38°C.

Lastly, a trial was conducted at Singapore’s Tan Tock Seng Hospital (TTSH) using the IFss with a total sample of 46 patients, out of which 31 were non-febrile and 15 were febrile. Thermographs from the IFss were recorded and analysed. The maximum facial temperature was used as the criterion value. The results were analysed using the ROC methodology and the results are shown in Table 1.

The results showed that if the threshold was set at 35.0°C, we could expect close to 100% sensitivity and 83.9% specificity. In other words, we would have a very high confidence of picking out febrile people with the trade-off being an approximately 16% false alarm rate. The final threshold setting of 35.0°C was chosen.

3. OPERATION AND DEPLOYMENT

Table 1. Results of TTSH Test

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Sensitivity</th>
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<th>+LR</th>
<th>-LR</th>
</tr>
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<tr>
<td>&gt;32.71</td>
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Relative temperature is represented on a colour scale in the increasing order: black, blue, green, yellow and red. Any object above the threshold temperature set on the TRS will appear reddish. Two screen captures from the IFss are shown in Figure 8. The person on the top is cool (facial region is bluish or greenish) while the person on the bottom is considered feverish (patches of red on the forehead).

The placement of IFss is critical for its effectiveness. The IFss should be installed in a controlled environment with stable ambient temperature. Where possible, the IFss should not be set up facing glass panels or placed directly under air-con outlets or near halogen lamps.

Guideposts can be installed to regulate and control the flow of the people so that each subject stays in the field of view for at least two seconds. This will give the operator enough reaction time to determine whether a subject should be picked out. A controlled flow also allows the operator to correlate the thermograph on the video display to the corresponding individual.

As the IFss may be required to operate between 18 to 24 hours continuously, responsive technical support, as well as logistics package including spares, preventive maintenance and corrective maintenance, will have to be devised to ensure high equipment serviceability and availability.

Adequate training of operators is important for successful deployment of the IFss. Since the video images are in real time and there is a spread of possible scenarios (such as size and intensity of red patches on the head regions) the operators must be trained to confidently distinguish between feverish cases and non-feverish cases. They will need to make judgement calls on borderline cases and that will depend largely on the experience and confidence of operators. Ideally, there should be an automatic detection and alarm system within the IFss. However, due to the variety of factors that cannot be controlled (i.e. small changes in environment, speed of movement, human height) any alarm systems will probably involve some uncertainty.

In the absence of an alarm system, operators must work in shifts to reduce errors due to fatigue or even boredom.

4. CONCLUSION

The IFss is designed to detect relative temperature differences and should not be regarded as an absolute temperature measurement tool, but rather as a tool for fast mass screening. It will be extremely difficult to measure absolute temperatures without strict control of the environment and long dwell time on each individual. Integrating these requirements would compromise the ease of use and speed of screening.

In the development of the IFss, considerations in statistics, physics and human physiology were key inputs. Though human physiology limits any system that uses skin temperature to detect fever from having flawless performance, the use of thermal-imager-based systems is still the only effective solution for fast and efficient fever screening.

As the threshold setting is statistically determined, a very small percentage of false alarms or missed detections may be inevitable. The setting of the threshold is a trade-off between the false negative fraction and the level of false alarm. During periods of high SARS risk, very high confidence in picking out febrile individuals is more important than a low false alarm rate. Therefore, a threshold setting of 35.0°C is chosen. Using this threshold, the sensitivity is close to 100%, with a false alarm rate of about 16%. This threshold temperature may be adjusted up during low risk periods to reduce the workload of IFss operators by reducing the false alarm rate.

Future work in this area will develop on two fronts. Firstly, the medical fraternity will need to be involved to conduct more comprehensive trials to characterise the distribution of human skin temperatures under various scenarios. Secondly, the scientific community will need to develop or adapt thermal imagers that are optimised for the human body temperature range.

In operation (see Figure 7), a stream of people will walk a predetermined path past the TRS. One operator monitors the display while another controls the flow of people. The thermal imager is pre-adjusted such that it focuses on the face and neck regions as well as the TRS. Radiation energy captured by the thermal imager is continuously processed by the CPU and displayed on the IFss display monitor. The operator in front of the display will need to determine who needs to be picked out based on the percentage and size of red patches on their faces and necks. Anyone identified is led away by the other operator to have their temperature checked using a conventional clinical thermometer (such as an oral thermometer).
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Development and deployment of
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- ASEAN Outstanding Engineering Achievement Award
- IES Prestigious Engineering Achievement Award
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- Laureate of the 2004 US San Jose Tech Museum Award (Health Category).

BIOGRAPHY

Tan Yang How is a Deputy Director (Systems Architect). He received his MSc (Management of Technology) in 1994. He is a leading radar system expert in Singapore and has vast experience in sensor programme definition and development management. For his effort in the IFss project, he was awarded the National Day Public Administration Medal (Silver) in 2003.

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