Image Processing Method for Automatic Threat Detection using Millimeter-Wave Images

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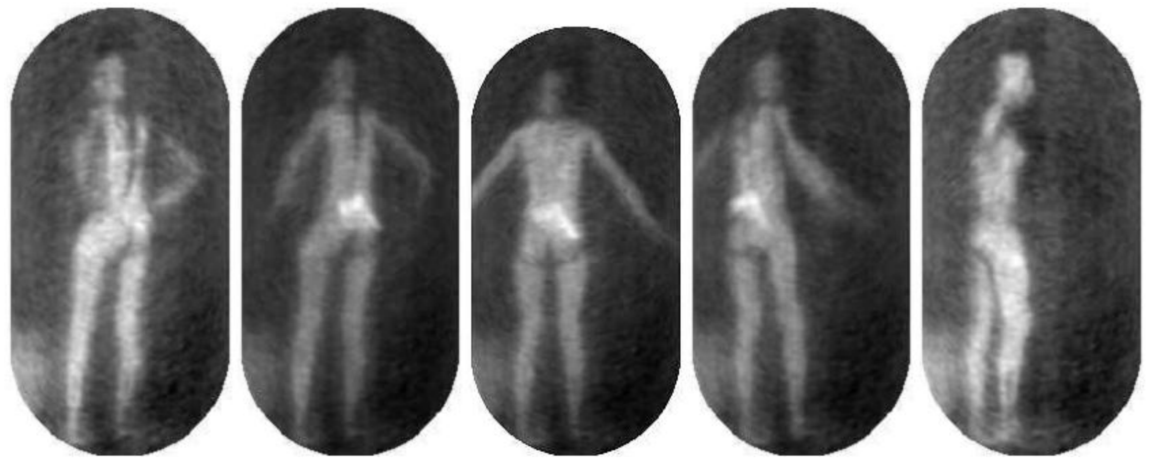
Introduction

Safety scanning has become a critical issue in security management of public buildings such as airports, post offices, banks, stations. Pioneer methods of scanning were based on X-rays which have characteristic to penetrate through different environments. X-rays produce harmful ionizing radiation and can't be implemented in real-time system due to slow acquisition. To resolve this problems, Millimeter-Waves (MMW) are used. MMW bounce radio waves off people making it possible to create an image in short time which is specificity of real time system. The original method presented uses real-time MMW image processing for automatic threat object detection.

Features of the MMW images

Our method performs using MMW images. Forming of the MMW image is based on reflective behavior of the scene (background, human body, metallic object). MMW sensors measure the reflectivity of the objects. Metal objects have higher reflectivity compared with the human body or background, therefore they appear brighter in the image.



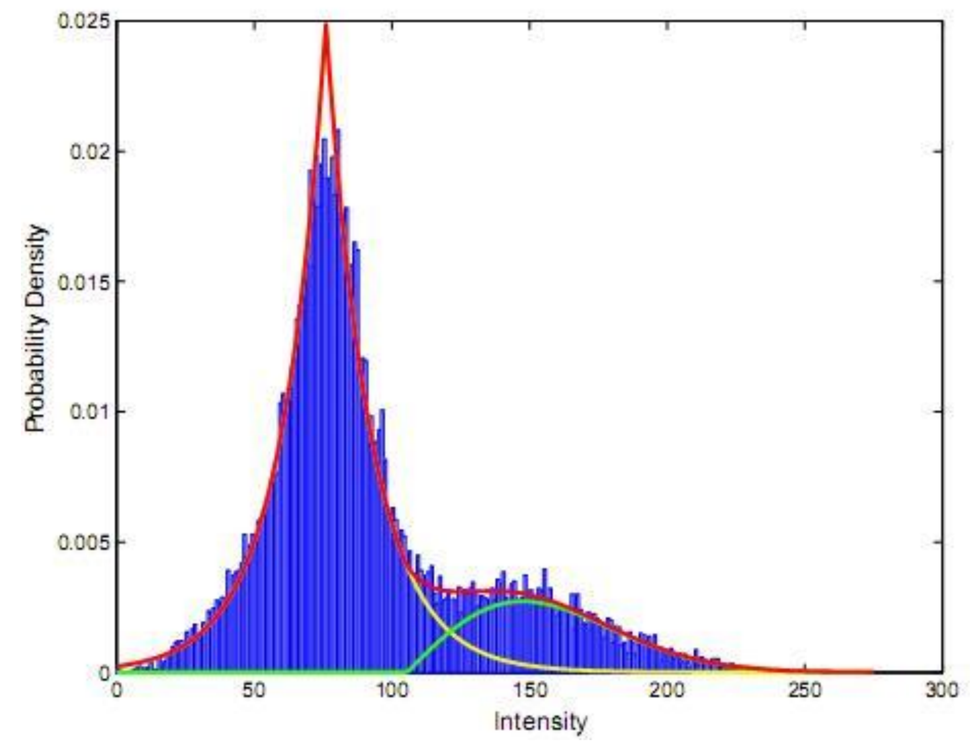
MMW images appearance used for processing

Mixture Models for MMW images

Each material from the scene is described with certain type of probability density function (PDF), f_i , which follows Rayleigh, Laplacian or Uniform distribution. Each distribution type is defined with set of parameters θ. Since the scene consists of several objects, weighted combination of the PDFs is used for expressing the histogram of the scene image. α_i coefficients represent the weight factors. These combinations of PDFs are called mixture models and can be mathematically formalized as :

$$f_{mix} = \sum_{i=1}^{N} \alpha_i f_i(\theta)$$

Maximum Likelihood (ML) method is used for estimating the parameters of the distributions and Chi-Square test to choose the best combination of distributions.



Example of the best-fitting distribution pair for image containing human body, metal object and the background. The result is obtained using ML and Chi-Square test.

Classification Strategy

Classification of MMW images is divided into three stages:

- recognition of sequences containing threats
- recognition of particular frames containing threats
- recognition of concrete threat areas within selected frames

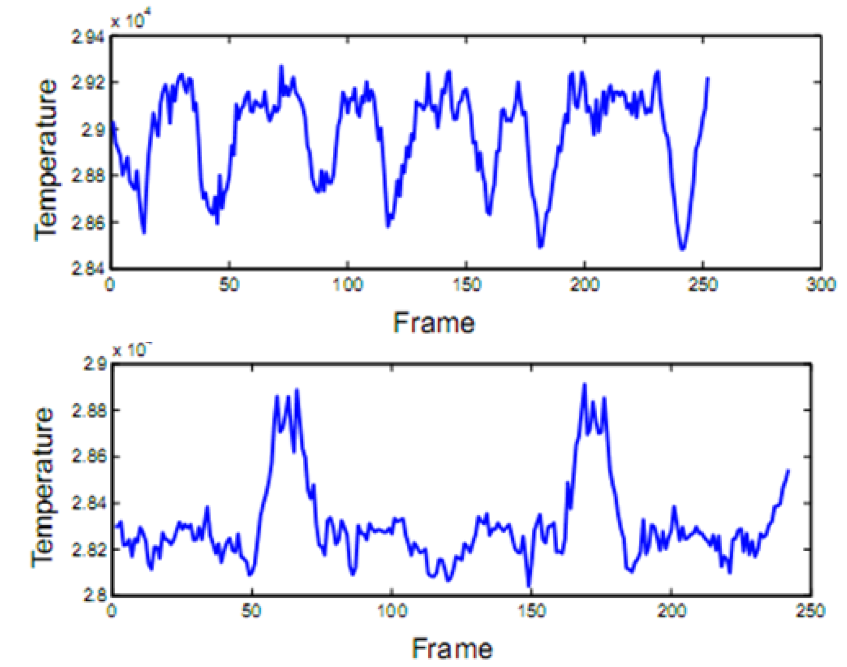
Recognition of sequences containing threats

To identify metallic object in sequence t, we examine the variation of the maximum intensity, I^{max}_t. If a threat shows up in the scene, the range of variation tends to be high. Empirically, we defined that a threat is into the scene if:

$$\frac{(\mathrm{MAX}(I_t^{max}) - \mathrm{MIN}(I_t^{max}))}{\mathrm{MAX}(I_t^{max})} < 0.03$$

Recognition of particular frames containing threats

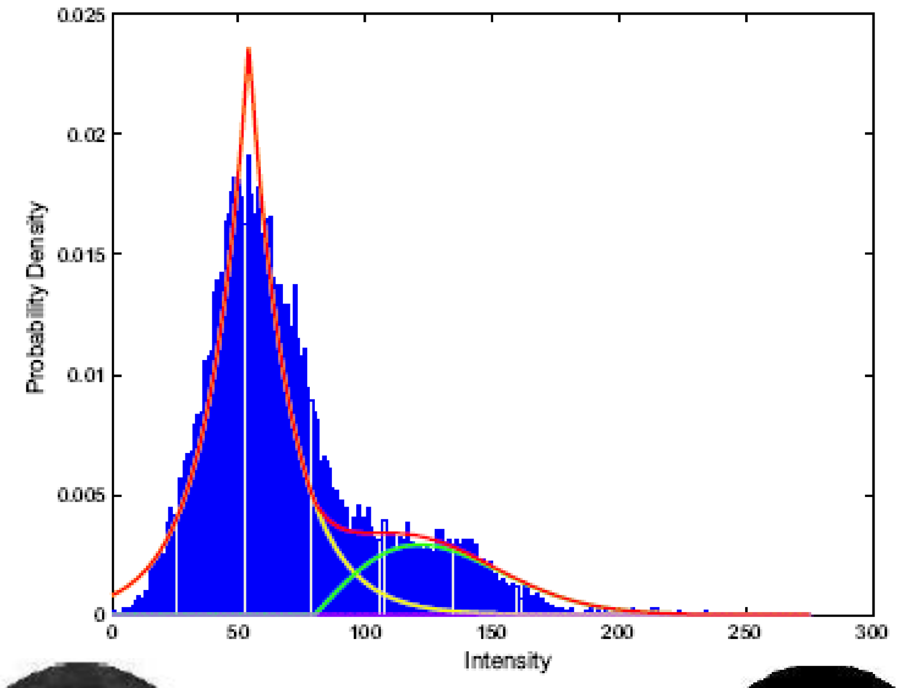
To identify presence of a threat in a frame, Hidden Markov Model (HMM) taught to recognize noticeable temperature variation is used. This model is composed of two states: "threat" and "not threat". HMM shows more flexibility compared to empirical methods using threshold values in terms that it can be easily taught again to adapt at the new environment with different reflectivity.

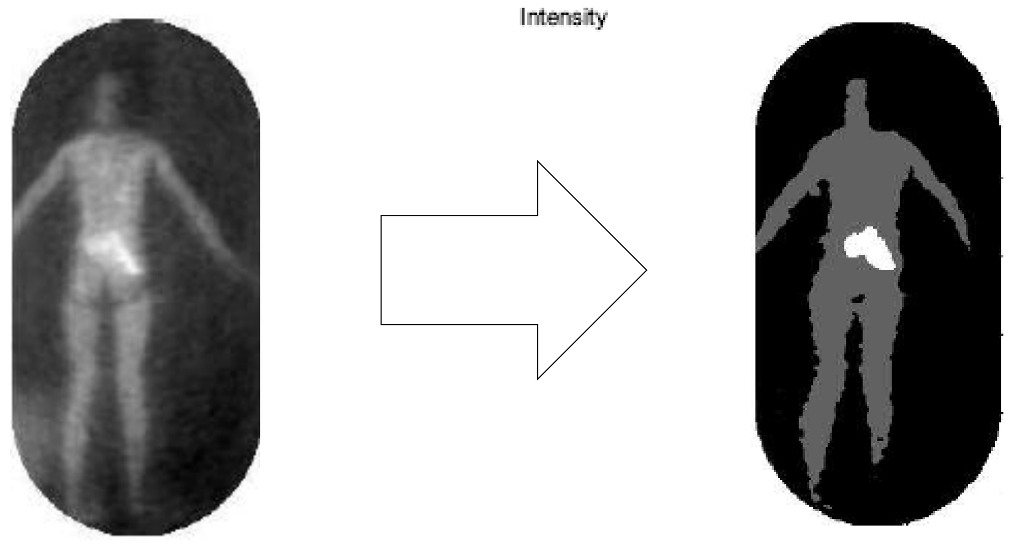


Signals of temperature variation provided for HMM to perform classification. Signal at the top corresponds to "no threat" state while signal at the bottom corresponds to "threat" state. Each signal was classified in the correct state.

Recognition of concrete threat areas within selected frames

The aim is to locate area where threat is positioned. Furthermore, this step must be accomplished in "real-time". Two methods can be implemented as a solution, k-Means and Estimation Maximization (EM). k-Means is faster but less accurate than EM. Choosing between these two methods requires compromise. Results are obtained using EM algorithm classification.





Result of EM algorithm classification representing satisfactory fitting

Tracking Strategy

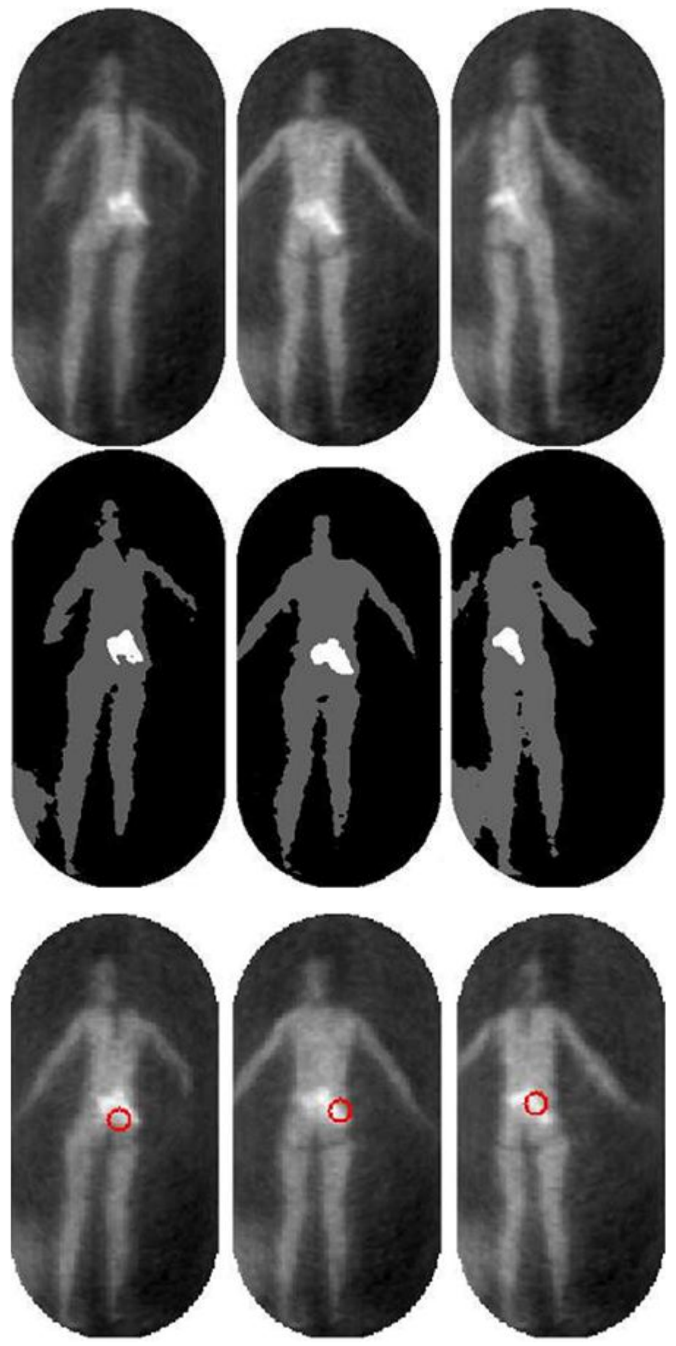
Tracking is supplementary algorithm which improves accuracy and stability of metal object recognition as long as the object is visible. Area where the threat is located is described by position, the number of images and size of the object surface. Tracking is implemented using Regularised Particle Filter (RPF). Usage of the RPF assumes that two models have already been defined, a *system model* and a *measurement model* [1]. System model expresses how states depend on time, while measurement model refers to measurement-state dependency. "State space vector" consists of position (x, y coordinates), velocity (dx/dt, dy/dt) and area of the target (Φ).

$$x_t = \left(x_t \; \dot{x}_t \; y_t \; \dot{y}_t \; \Phi_t \right)^T$$

Results

Sequence	Frames	Threat ?	No. Threat Frames	Error	E_{false}	E_{miss}
Plain01	211	No	-	-	-	-
Plain02	252	No	-	-	-	-
Plain03	218	No	-	-	-	-
Plain04	236	No	-	-	-	-
Threat01	242	Yes	24	8%	0%	100%
Threat02	155	Yes	27	3%	0%	100%
Threat03	179	Yes	56	5%	22%	78%
Threat04	136	Yes	30	8%	0%	100\%

Detection results of eight sequences of images taken during the testing. Frames column represents how many frames each sequence had. Threat column shows which state was selected by HMM. No. threat frames column has the number of frames containing metal object. Last three columns contain information about accuracy of the detection. Error column gives percentage of wrong classified frames while E_{false} column contains percentage of false alarms and E_{miss} column has percentage of missed frames.



Automatic detection and tracking results. Original MMW images containing threat (top row). Detection results (middle row). Tracking results (bottom row).

Conclusions

Research presented showcases real-time image processing intended for implementation in security systems with obtained results tend to be trustworthy, with EM algorithm yet to be optimized for fast application. Possibilities to upgrade the system so that it detects several metallic objects exist. Additional hardware, stability and performance tests need to be done in practice. Future improvements could upgrade algorithm making it possible to detect different material objects, increase number of possible tracking events or apply human body models.

References

[1] C. D. Haworth, Y. Petillot, E. Trucco, "Image Processing Techniques for Metallic Object Detection with Millimetre-wave Images", Pattern Recognition Letters,Volume 27, Issue 15 , Pages 1843-1851. Special issue on Vision for Crime Detection and Prevention, November 2006.
[2] B. Grafulla-Gonzalez , C.D. Haworth , A.R. Harvey , K. Lebart , Y. Petillot , Y. de Saint Pern , M. Tomsin , E. Trucco , "Millimetre-wave personnel scanners for automated weapon detection", Pattern Recognition and Image Analysis, Part 2, Proceedings of the lecture notes in computer Science 3687:48-57, 2005.