Millimeter-waves and object detection

Dr. Tushar Sandhan

Contents

- What is millimeter-wave (mm wave)?
  - mmW devises for gesture recognition, localization/tracking, and imaging
  - How mmW radios “see” the environment
- Concealed Object Detection for Millimeter-Wave Images With Normalized Accumulation Map
- Millimeter-wave in Biomedical
- Advantages, Disadvantages and Uses
- Trends in mmW

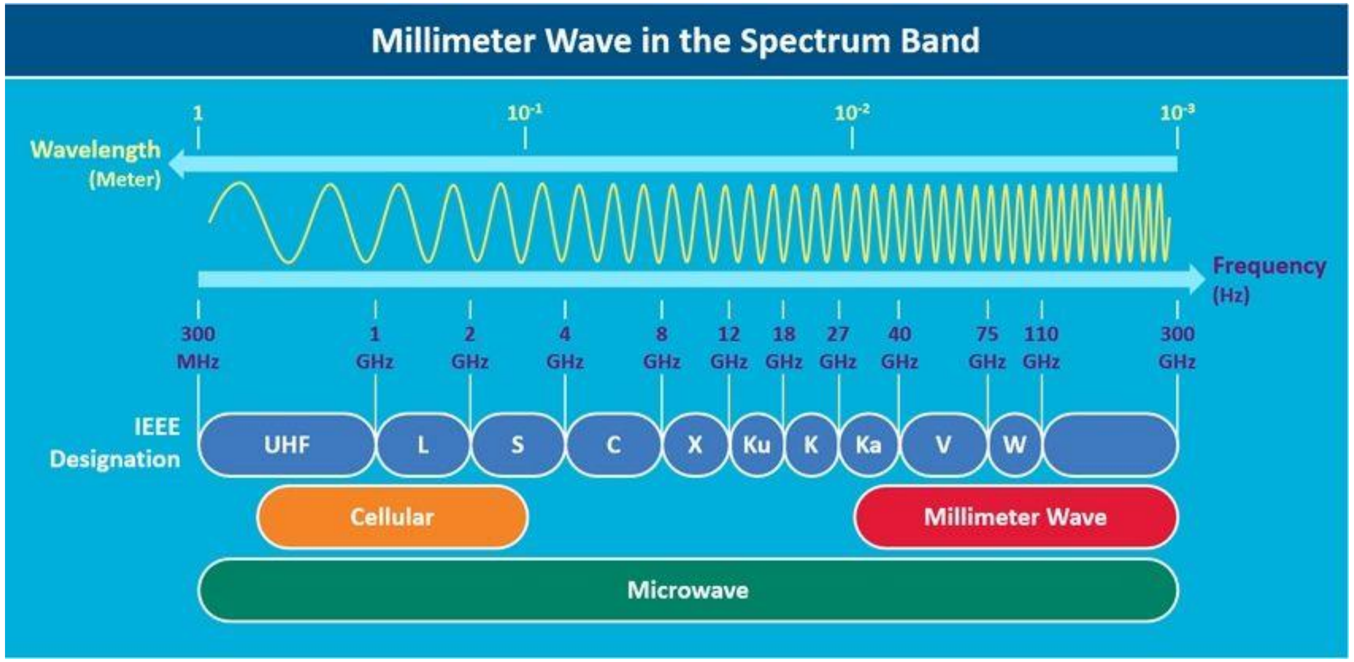
sandhan@iitk.ac.in

What is millimeter-wave (mm wave)?

- **What is millimeter-wave (mm wave)?**

- Millimeter wave (MM wave), also known as millimeter band, is the band of spectrum with wavelengths between 10 millimeters (30 GHz) and 1 millimeter (300 GHz) i.e., (1 cm to 1 mm) [. It is also known as the extremely high frequency (EHF) band by the International Telecommunication Union (ITU).

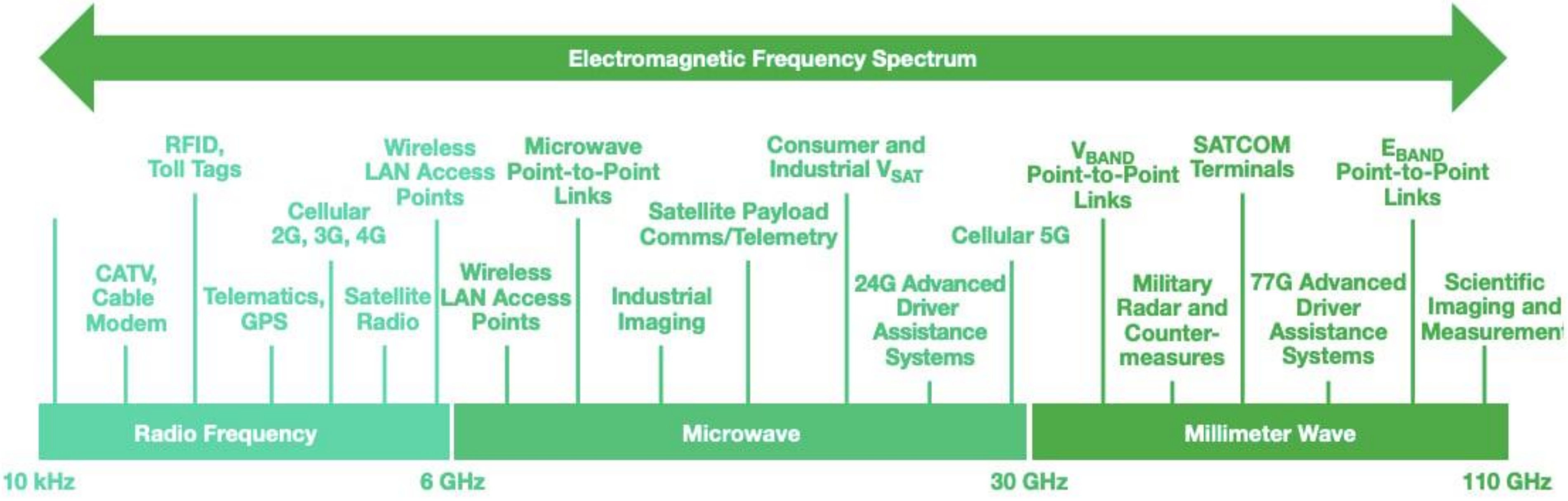
- Millimeter wave is a band of electromagnetic spectrum that can be used in a broad range of products and services, such as high-speed, point-to-point wireless local area networks (WLANs) and broadband access.



sandhan@iitk.ac.in

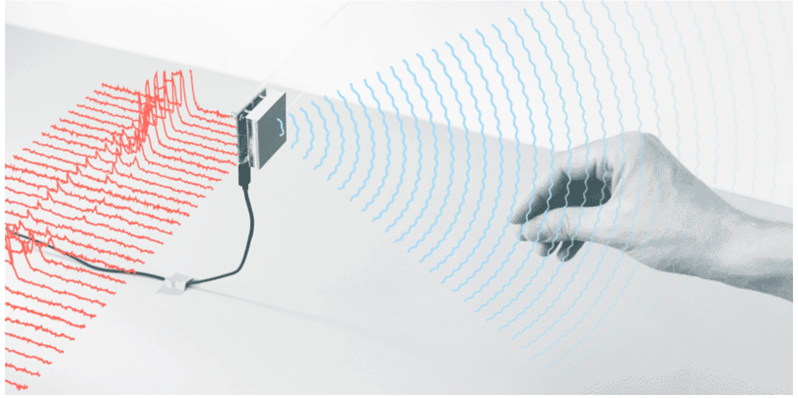
What is millimeter-wave (mmW)?

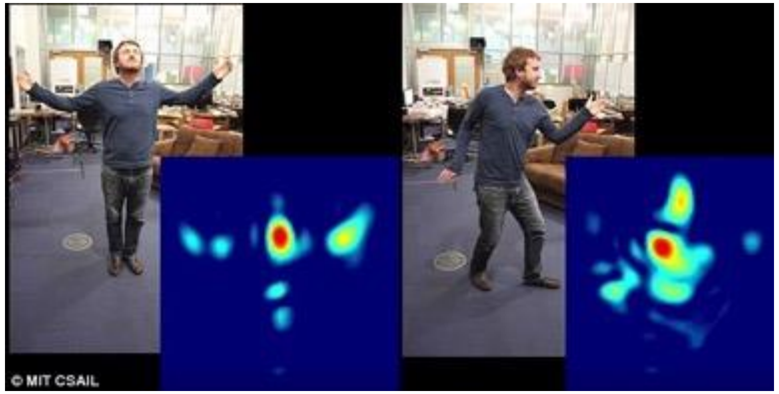
- Millimeter waves used for penetration into many optically opaque mediums such as living tissues, wood, ceramics, plastics, clothing, concrete, soil, fog, foliage, etc.
- More recently, microwave and millimeter-wave systems have been deployed for a variety of short-range applications, most notably in concealed weapon detection, through-the wall imaging, and nondestructive testing for structural integrity.



sandhan@iitk.ac.in

mmW devises for gesture recognition, localization/tracking, and imaging

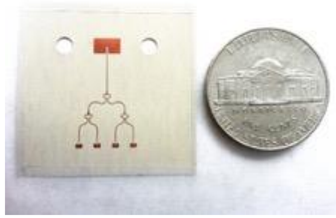




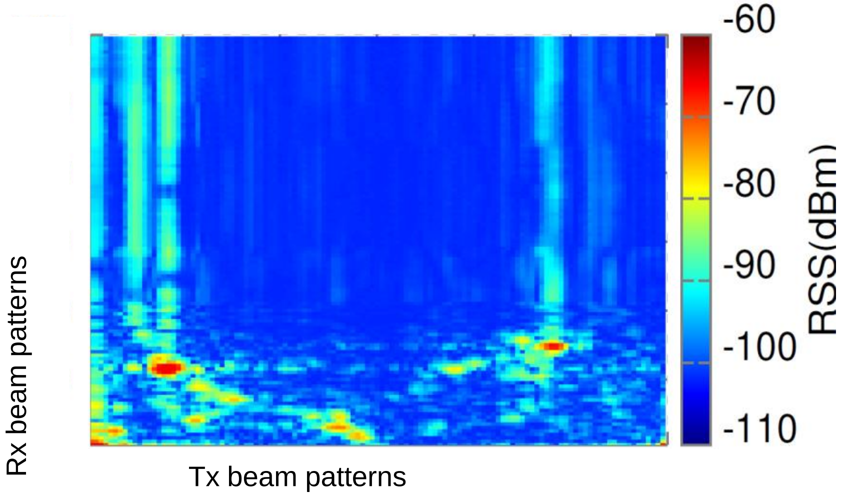
sandhan@iitk.ac.in

How mmW radios “see” the environment

- Radios: extremely low resolution sensors
  - Only a few “pixel sensors” (antenna elements)



From a mmWave radio’s eyes



From a camera’s eyes

sandhan@iitk.ac.in

Object recognition in millimeter-wave images

- Locating critical objects is crucial in various security applications and industries. For example, in security applications, such as in airports, these objects might be hidden or covered under shields or secret sheaths Millimeter-wave images can be utilized to discover and recognize the critical objects out of the hidden cases without any health risk due to their non-ionizing features.

- millimeter-wave images usually have waves in and around the detected objects, making object recognition difficult. Thus, regular image processing and classification methods cannot be used for these images and additional pre-processings and classification methods should be introduced.

- This technique consists of four steps, i.e., 1. preprocessing, 2. canceling rotation, 3. resizing objects (canceling scale), and 4. classification.
  - Pre-processing, itself, includes resampling images and background removal. Canceling rotation and resizing objects make the method robust to rotation and scale, respectively. In the classification section, the proposed layered classification frameworks, which are specialized for mmW images.

Object recognition in millimeter-wave images

- **Technique:**
- This method is categorized into three major parts. The first section is pre-processing, in which the images are resampled and backgrounds are removed. The second part is for making the method robust to rotation and scale, and includes canceling rotation and resizing objects. The last part is classification, which consists of K -means, first layer (SVM or LDA), and second layer (LDA).

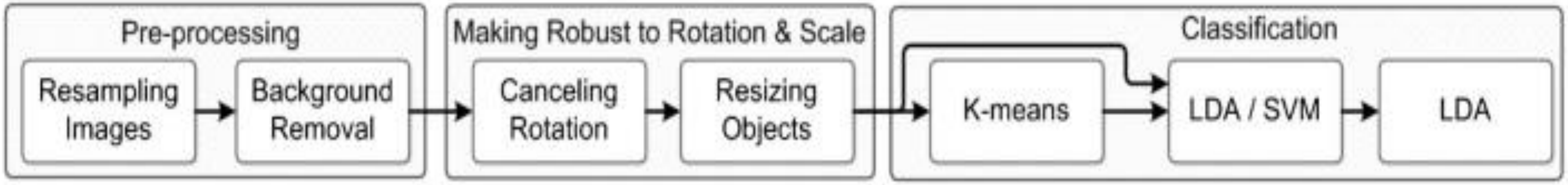


Fig : Overall structure of the mmWave analysis framework

Object recognition in millimeter-wave images

- **1. Pre-Processing:** Pre-processing includes resampling images and removing background,

- **2. Canceling Rotation:** The input images may have different rotations that make the variance of each class bigger and thus decrease the rate of recognition. The rotation of objects can be removed by first finding the principle orientation of them as follows.

  - The covariance matrix of the coordinates of non-zero pixels (i.e., object pixels) is formed as

$$C = \sum_{i=1}^{n} (X - \overline{X})(X - \overline{X})^T,$$

where n is the number of non-zero pixels and

$$X = \begin{bmatrix} x_1 & x_2 & x_3 & \cdots & x_n \\ y_1 & y_2 & y_3 & \cdots & y_n \end{bmatrix}$$

$$\overline{X} = \left[\frac{1}{n}\sum_{j=1}^{n} x_j, \frac{1}{n}\sum_{j=1}^{n} y_j\right]^T.$$

  - Also, $\bar{X}$ is the average of X formulated as

Object recognition in millimeter-wave images

- In mmW images, the target object is bright and the background is dark, and therefore the background can be removed by a simple thresholding technique. Suppose that I denotes the maximum intensity. Background can be removed by setting the intensities of pixels with intensity less than 0.5 × I to be zero, where half the maximum intensity was found to be a good threshold as shown in fig 1.

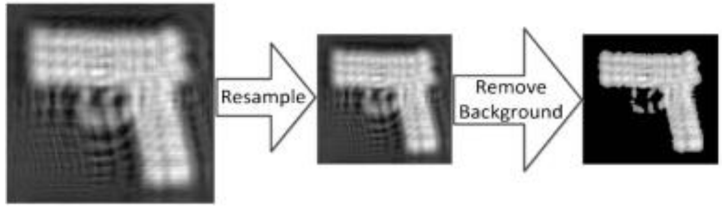


Fig 1: Pre-processing including resampling image and background removal.

- The two eigenvectors of C are the principle components (PCs) of bright pixels. These two vectors are depicted in Fig. 2. In the second column of this figure, the first eigenvector, which has the bigger eigenvalue, is depicted with blue color, and the second one is shown with red vector.

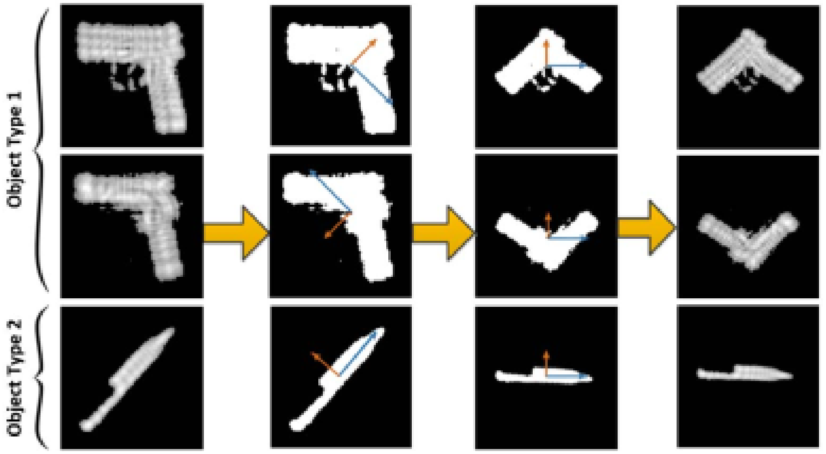


Fig 2: Canceling rotation without noting the density of bright pixels around the second eigenvector

sandhan@iitk.ac.in

Object recognition in millimeter-wave images

- **3. Resizing Objects:**

- At the first step of this phase, the rectangular region of the image that contains the object is cropped from the rotated image (see third column of Fig. 3)

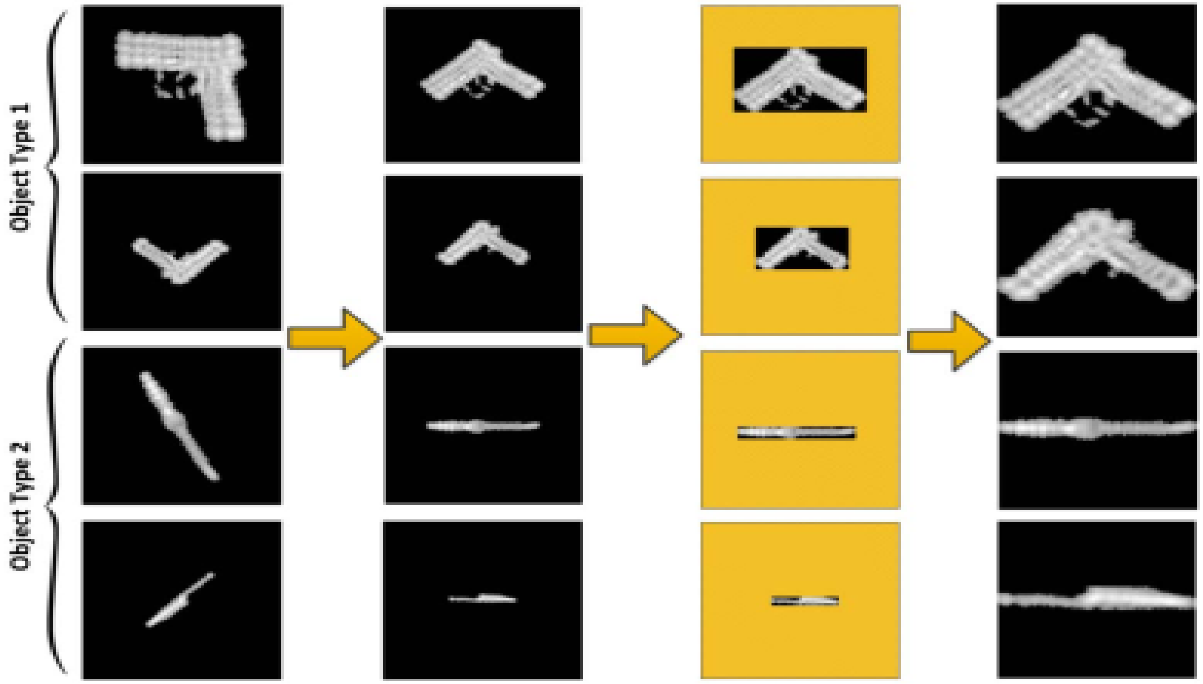


Fig. 3. Resizing objects

Object recognition in millimeter-wave images

- The dataset contains two different types of critical (positive) images and a large set of non-critical (negative) images. There exist 614 images of critical type 1, 243 images of critical type 2, and 1773 images of negative type in this dataset.
- Below figure depicts several samples of positive (critical) and negative (non-critical) sets.

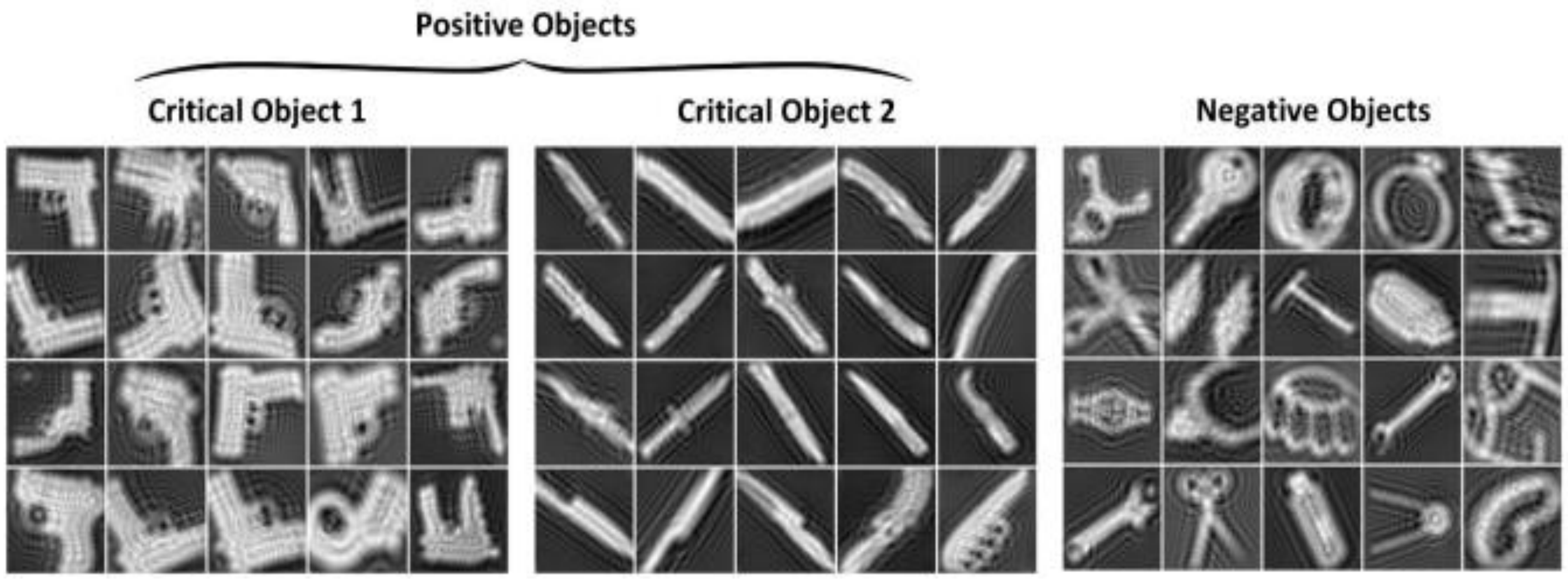


Fig4 : Samples of created dataset

sandhan@iitk.ac.in

Object recognition in millimeter-wave images

- **D. Classification:**

Classification of mmW Structure

  - critical and non-critical objects are respectively referred to as positive and negative class. In this classification framework, the training samples of each class are initially divided into two sets (see the first column in Fig. 5).

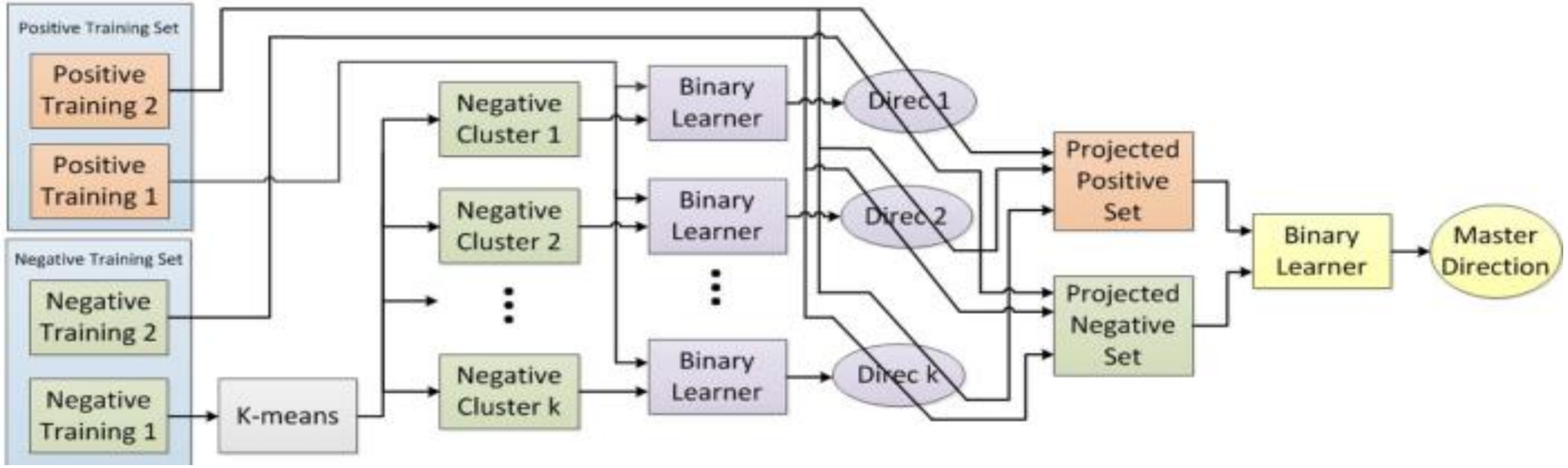


Fig. 5. Learning phase.

- It can be shown that because of the characteristics of this category of images, a holistic-based approach outperforms feature based approaches

Object recognition in millimeter-wave images

- Notice that, if there are multiple different types of critical objects, a separate two-layer classifier is constructed for each critical object. Then, a multiple critical object classifier is created by combining/fusing the results of each classifier

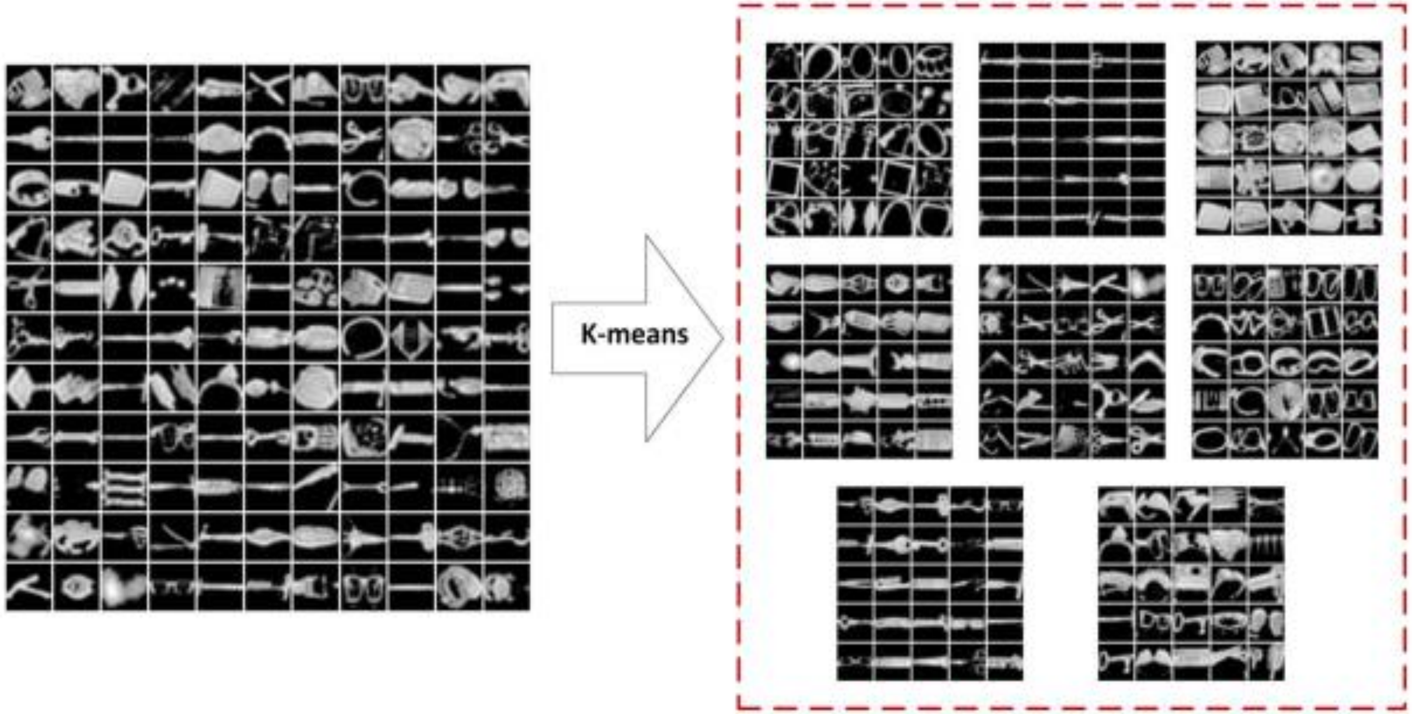


Fig 6: K -means clustering on the negative set (k 8).

Object recognition in millimeter-wave images

- The corresponding mmW images are shown in the first column in below Fig. First, the images were converted to gray scale (second column of figure), and then rotation and scale cancellation were performed on them.

- The threshold for resizing objects was required to be better tuned here compared to the case of simulated images because of the dot noises in the images caused by real conditions and probably the effect of cloth.

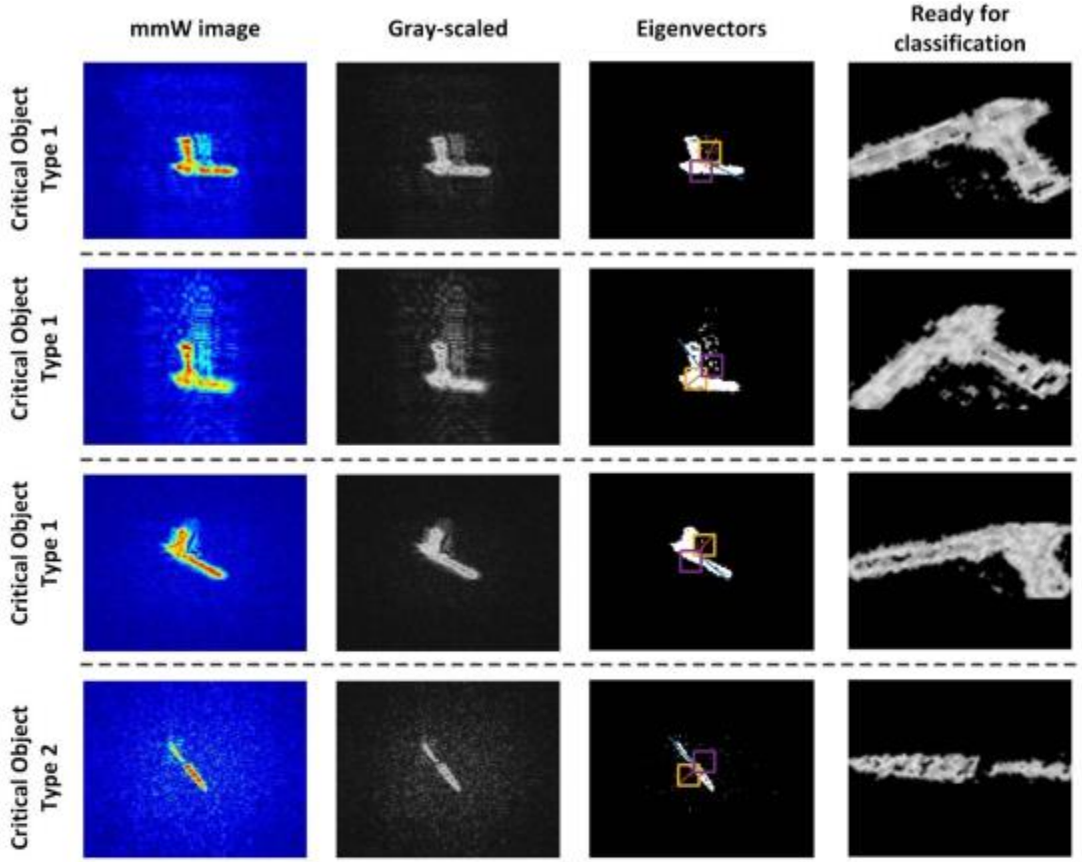
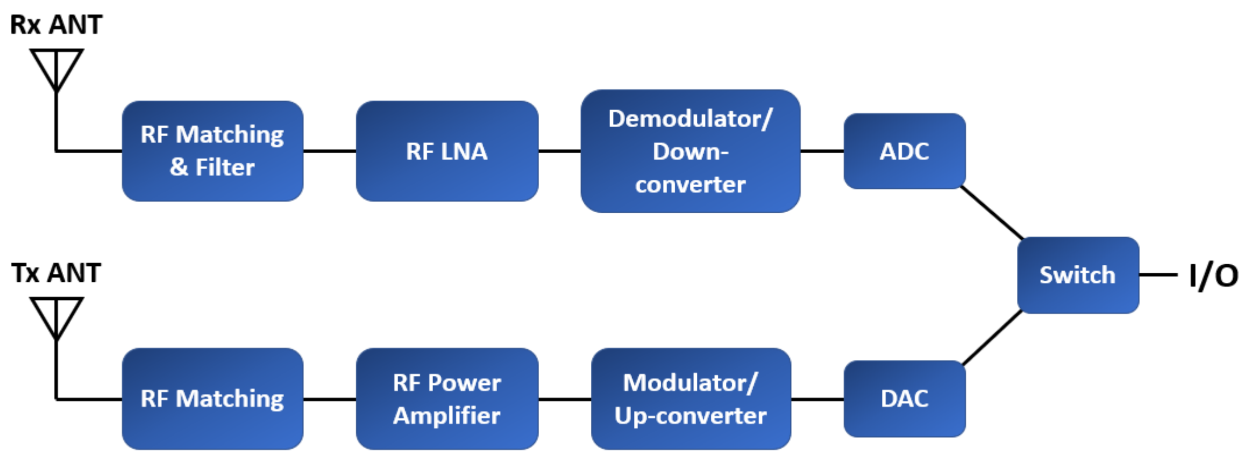


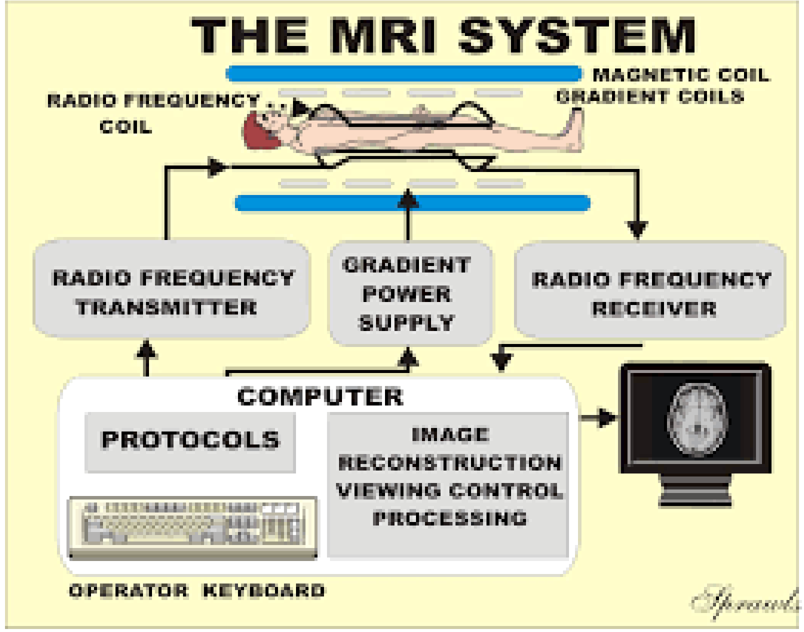
Fig : Pre-processing on real mmW images. Columns from left to right respectively represent mmW images, gray-scaled images, eigenvectors for canceling rotation, and the prepared image for classification.

sandhan@iitk.ac.in

Millimeter-wave in Biomedical:

- The application of millimeter-wave and microwaves in biomedical imaging and diagnostics, however, remains a field with many uncharted territories. The microwave community has so far had limited contributions to medical imaging, except for the radio-frequency (RF) component design for magnetic resonance imaging (MRI) systems.



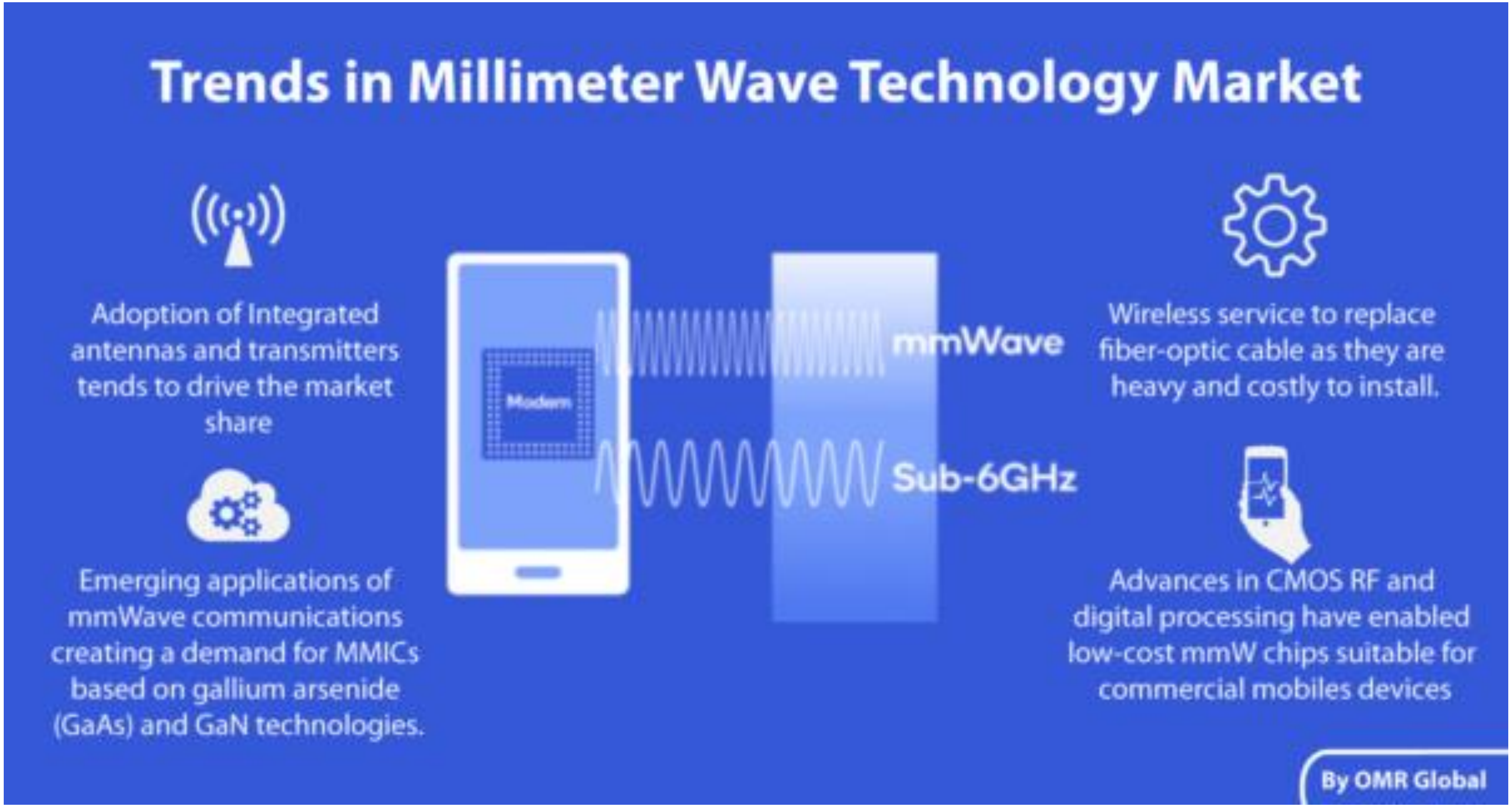


Advantages, Disadvantages and Uses

- **Advantages:** In telecommunications, millimeter wave is used for a variety of services on mobile and wireless networks, as it enables higher data rates than at lower frequencies, such as those used for Wi-Fi and current cellular networks. Antennas for millimeter wave devices are smaller than for other frequencies, making them more suitable for small internet of things (IoT) devices.
- **Disadvantages:** millimeter waves are absorbed by gases and moisture in the atmosphere, which reduces the range and strength of the waves. Rain and humidity reduce their signal strength and propagation distance, a condition known as rain fade.
- **Applications:** Millimeter wave has numerous uses, including telecommunications, short-range radar and airport security scanners. In telecommunications, it is used for high-bandwidth WLANs and short-range personal area networks (PANs). Its high bandwidth capacity is ideal for applications like short-distance wireless transmission of ultra-high definition video and communications from small, low-power IoT devices.

sandhan@iitk.ac.in

Trends in mmW



Thank you

sandhan@iitk.ac.in