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Single pixel scanning based millimeter wave imaging

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Abstract

A food processing line is comparatively vulnerable to contaminants, whether through inattentive workers and employees or from the processing machines made largely out of steel or from raw materials that are contaminated themselves. Any of these risks can affect quality resulting in poor hygiene or even can put customer health in danger. Millimeter-wave imaging plays a significant role in many fields such as security inspection and medical diagnostics. Moreover, millimeter wave instruments are useful in detecting objects behind and inside visibly opaque barriers such as, concrete walls and plastic boxes. We describe a millimeter wave imaging system that uses a one-dimensional detector in combination with a single pixel mask in order to acquire two-dimensional images out of buried objects inside a bread. Our system can be used to detect metals and salty substances for bread quality control and defect detection. The system uses 60 GHz center frequency to image the target in transmission mode which utilizes a heterodyne sub-harmonic receiver placed in a bi-static configuration.

Keywords: Single pixel, Millimeter wave, Non-intrusive quality control, Foreign object defect detection

Introduction

The invention of cameras has made image retrieval an important research topic. Detector arrays have been used in modern digital cameras to retrieve images. Many digital cameras and cellphones use the technology of complementary metal-oxide-semiconductor (CMOS) and charge-coupled-devices (CCDs) which allow them to take pictures consisting of millions of pixels coerced in a microcircuit no larger than a millimetric spot. Modern digital cameras contain over twenty million pixels, in fact integrating more than this seems out of necessity and a waste of data storage.

Conventional imaging in the spectrum region lower than 30 GHz is impractical due to large apertures needed. Since 1940s, it is known that equipment operating in this part of the spectrum (above 30 GHz) provides excellent penetration of the atmosphere and other inhibitors. In this study, we are mainly interested in systems operating at frequencies higher than 30 GHz and having smaller apertures, therefore a frequency above 30 GHz can readily penetrate a bread which allows to image buried objects inside it.

Single pixel (SP) imaging techniques allow to record an object without a direct line of sight with the object. The earliest technique introduced with SP imaging has been named ‘flying-spot’ that is patented in 1884 by Nipkow who offered the use of a perforated disk to modulate a light source for scanning light spots across a scene (Sen, 2005). Many sophisticated flying-spot cameras were presented later, however this technique is not preferable as it suffers from low signal-to-noise ratio (SNR). It is feasible to reconstruct an image with a SP detector (Pittman, 1995; Shapiro, 2008; Duarte, 2008; Bromberg, 2009). The modern technologies use spatial light modulation range from mechanical masks (Heidari, 2009) to micro-opto-electro-mechanical systems (Coltuc, 2015) and metamaterials using SP algorithm to reconstruct the scene (Bai, 2017). SP camera is a distinct structure for imaging systems, so random masks for imaging based on compressive sensing has been offered by (Chan, 2008).

Millimeter wave and THz imaging add significant contributions to visible, IR and X-ray imaging systems. The advantage of millimeter wave propagation is that it can be used in

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low visibility situations in addition to the fact that it is feasible to work both day and night. Millimeter-wave imaging is an emerging field for rapid imaging systems, since millimeter waves can diffuse through materials such as clothes and polymers for security and detection applications.

In this paper, single pixel scanning based millimeter wave images are obtained for buried objects inside a bread in which screw and salt (inside a nylon transparent plastic bag) are buried respectively for defect detection inside the sample bread. For detecting these objects, a 60 GHz center frequency system in addition with a single pixel mask has been used. Printed circuit board (PCB) covered with copper has been utilized as a mask and a hole with the size of 6.25×6.25 mm2 single pixel exists (without copper) to allow the millimeter wave beam pass through it. The object is mechanically scanned by the single pixel mask in a zig-zag pattern to acquire a two-dimensional image.

Theoretical Background

SP masking technique is applied for the data collected by a SP detector. However, the source and detector positions and the millimeter wave beam are static. The SP mask is formed to obtain the original image. Therefore, the original image is scanned through the mask with a SP hole, in order to acquire corresponding parts of the original image with the size of the specified pixel hole on the PCB mask. For each movement of the mask, a part of the target is recorded through the SP hole and these portions are added to obtain the original image depicted in Figure 1.

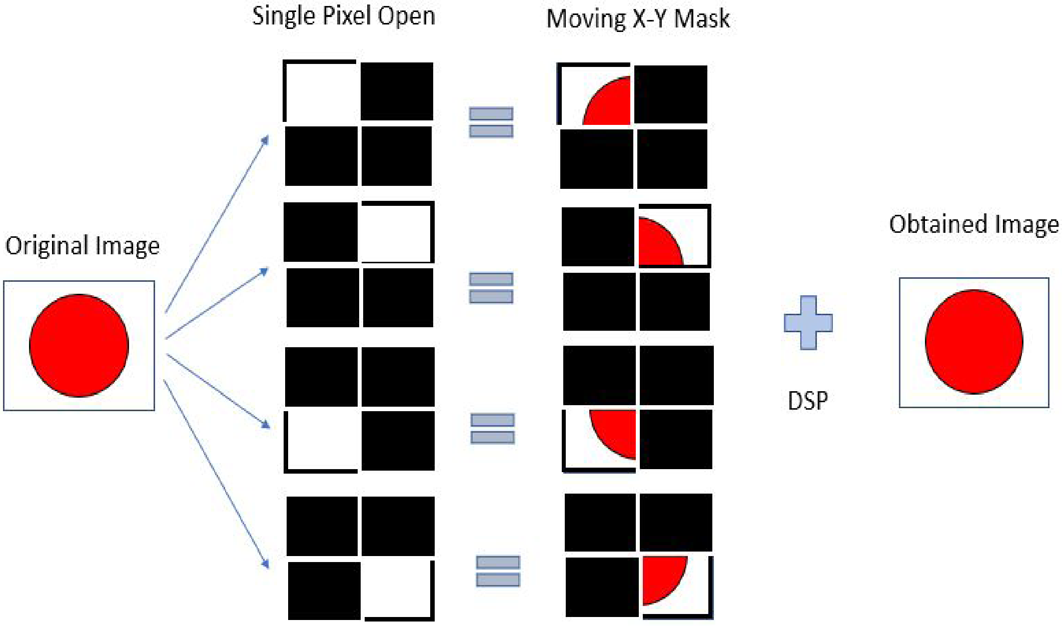

Figure 1. For the original image reconstruction, the single pixel mask is moved in X and Y directions in order to acquire two-dimensional image. The obtained data through single pixel is collected hence, original image is obtained.

Experimental setup

The experimental setup is essentially made of a millimeter wave transmitter, receiver, horn antennas and lenses, where the imaging system operates at a central frequency of 60 GHz. The object is imaged using a frequency-modulated signal. A 10 GHz local oscillator signal is generated using an yttrium iron garnet (YIG) that is amplified with an RF power amplifier. Following that, the amplified signal is multiplied by an RF tripler. The generated 30 GHz signal is modulated through an RF mixer. The modulated signal is then doubled by a sub-hormonic mixer. The 60 GHz signal is transmitted to the collimating lens via the horn antenna. The resulting signal is passed through the single pixel mask filter. Finally, the resulting signal is passed through the single pixel mask which is collected and detected on the receiving antenna by the collecting lens.

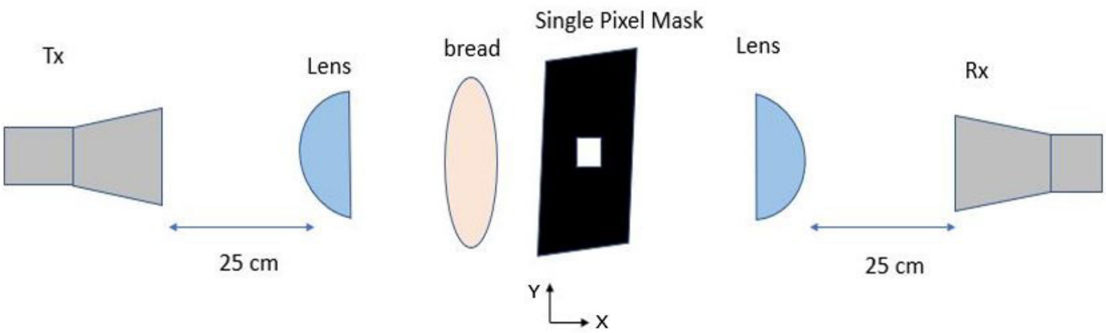

Figure 2. A basic schematic diagram of the millimeter wave system

The signal coming from the transmitting antenna is aligned parallel to the optical axis with the collimating lens located at a distance of 25 cm. The incoming signal illuminates the field of view of the object plane whose image is going to be obtained. The collimated signal is then passed through the single pixel, which is focused to the receiver. However, the collimating lens is made of HDPE material with a diameter of 20.5 cm and a focal length of 25 cm.

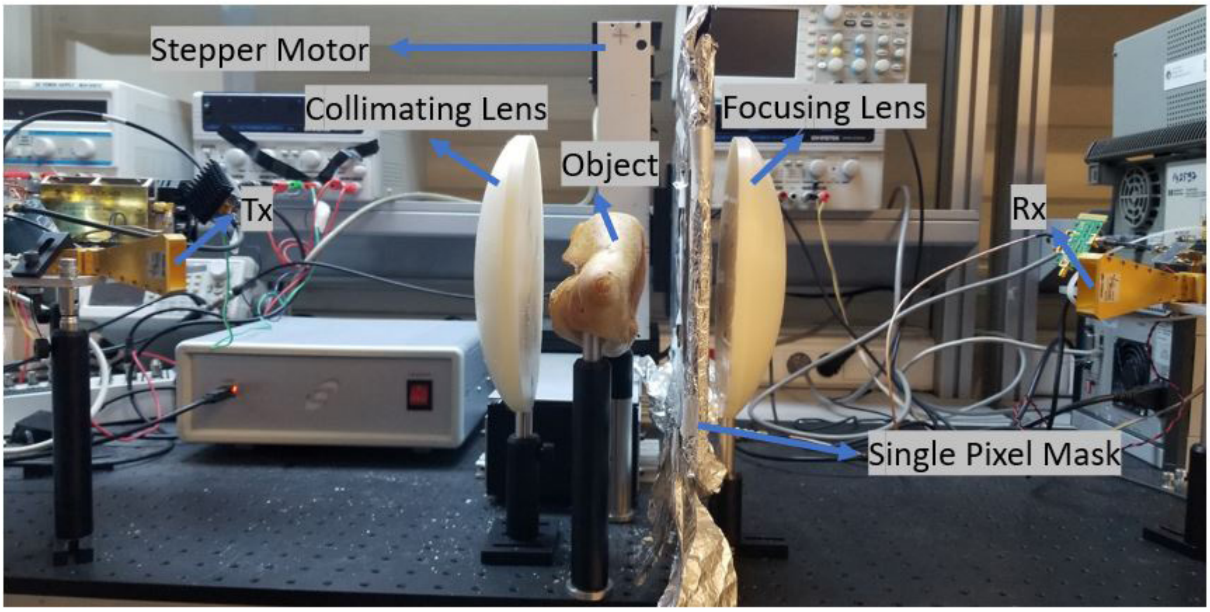

Figure 3. Experimental setup of the system

The SP mask is in the imaging plane and scanned in the x-y direction. However, a two-dimensional movement (x-y) is required in order to form the image in the SP detector. The image passed through the SP is focused by the lens which is located 25 cm away from the receiving antenna. The receiver side lens is made of POM material which directs and focuses the incoming wave to the receiver. The refractive index of the lenses is approximately n = 1.54 and the radius is r = 40 cm. A medium frequency signal power is obtained at the receiver and converted to DC voltage via a logarithmic RF power detector. The pixel size of each mask is selected as 6.25 x 6.25 mm^2 in order to reduce the diffraction effect in the system with 60 GHz center frequency and 5.0 mm wavelength. Due to the 5 x 10 cm^2 viewing area of the sample, the resulting images were formed with a resolution of 8 x 16 pixels.

Results and Discussion

Imagery can be generally categorized in two ways. The first is known as passive imaging that uses the reception of natural radiation where, objects emit electromagnetic radiation at a certain degree of temperature, which is reflected from the scene (Yujiri, 2003). The second is by sending radiation from a source towards the scene and gathering the reflection, which is known as active imaging. In this experiment an active millimeter wave imaging system is adopted.

In the image reconstruction procedure, the single pixel is mechanically scanned by the help of a stepper motor that moves the single pixel PCB 16 pixels in x-direction and moves 8 pixels in y-direction to scan the field of view, with a size of 5 x 10 cm^2 of the sample bread. Therefore, the object is placed in the illuminated area of the bread.

The single pixel mask is made from a 10 x 10 PCB covered with copper and exactly a SP hole left open in the middle of the PCB. The size of the pixel is 6.25 x 6.25 mm2 that is scanned on the surface of the object 128 times in a two-dimensional pattern. The millimeter wave penetrates the bread with little signal attenuation and penetrates metal and dense masses with large signal attenuation. The transmitted beam is scattered through the solid and dense materials hence, results in a low power transfer to the receiver that helps to recover the hidden object inside the sample bread. A target with an approximate length of 4 cm is placed in the middle of the bread horizontally and the SP mask is scanned through the sample bread. Hence, the foreign object is imaged as depicted in Figure 4.

Before placing the object, the signal-to-noise power ratio (SNR) is 23 dB. After placing the bread, the incoming signal experiences 3 dBm attenuation. Locating foreign objects inside the bread further attenuates the transmitted signal by 12 and 19 dBm for salt and screw, respectively. Since the metal atoms are bounded together by a strong chemical bond called metallic bonding, the screw causes higher attenuation than salt. The signal is more attenuated where the foreign object is placed and as a result of this, less power is transferred to the receiver. After analyzing the signals, the foreign objects can readily be seen as depicted in Figure 4 and Figure 5. The dynamic range is 23 dB without placing an object between the transmitter and receiver.

After placing the screw inside the bread, it is imaged inside it and then the screw is removed. Following that, the nylon plastic bag filled with salt is placed inside the bread. The same procedure has been repeated, scanning the field of view with the SP mask and the data is sent to the receiver for each movement of the stepper motor where, each step length is 6.25 mm. The foreign object is detected inside the sample bread as depicted in Figure 5.

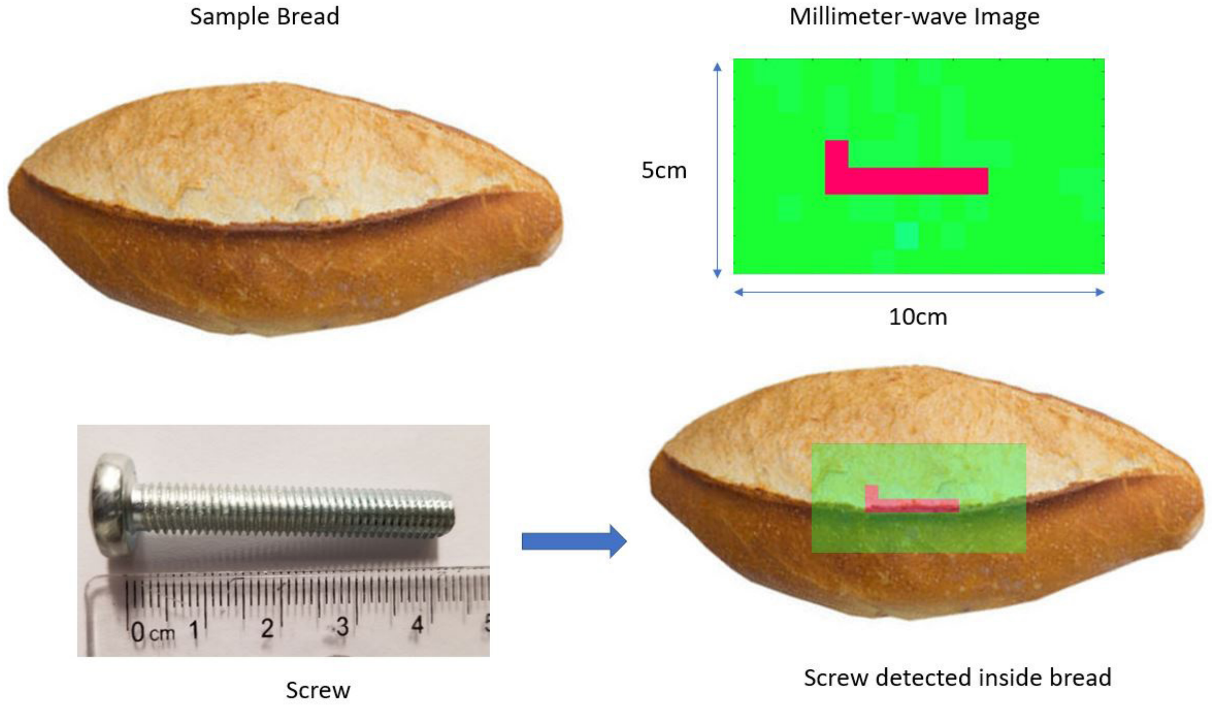

Figure 4. The screw is placed inside the bread considering an image area of 5 x 10 cm^2. However, the image of the foreign object seems sharp due to the pixels not being rounded the pixels.

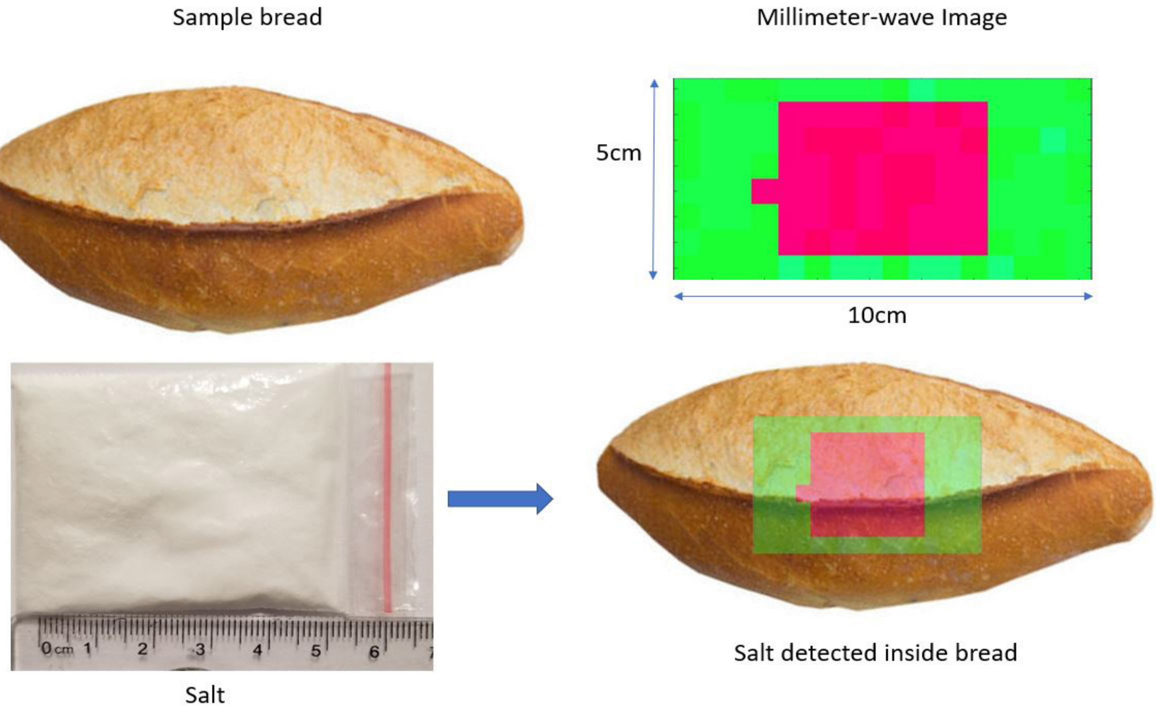

Figure 5. Salt is placed inside the bread and as a dense mass mm-wave can barely pass through it that results in detecting the mass. The minimum detectable object is 2 mm^2

Conclusion

As a result of all, a SP scanning based millimeter wave system has been demonstrated for detecting foreign objects inside a bread. This method can be used for non-intrusive quality control and foreign objects detection. The application of this method with bread and other food supplements is proposed for various real-life scenarios which threaten the human life. Experimental procedure is done on a sample loaf of bread that weights 250 gr with dimensions of 30 cm and 10 cm length and width, respectively. We have imaged the objects in transmission mode, therefore, there would be no effect on the imaging performance if the sample is rotated or placed in a different way. Since there is no rounding, the boundary pixels look sharper. The minimum detectable object inside the bread is 2 mm2. Studies on imaging plastic materials that cannot be detected due to our operating frequency band and require higher frequency for more sensitive detection are planned in the future.

Compliance with Ethical Standards

Conflict of interest

The authors declare that for this article they have no actual, potential or perceived the conflict of interests.

Author contribution

The contribution of the authors is equal. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

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Consent for publication

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