A Handheld Active Millimeter Wave Camera

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***Abstract*— A microwave imaging technology is described where large area diffraction limited images are created by a small, low cost, low power, handheld device. The camera actively illuminates targets with a circularly polarized scanning confocal spot beam. Backscattered radiation is collected to form an image on an LCD screen. The camera is configured to image behind walls and other flat surfaces. A set of encoded omni-wheels track camera position so that a 2500mm x 1700mm image may be stitched together. Operating in the 24GHz ISM band, the camera is approximately 6" diameter and 8.5" tall. At this size we believe it enables a broad range of new inspection tasks.**

I. Introduction

Walleye Technologies has constructed a high frequency microwave imager to provide a portable inspection capability. To accomplish our goal the design requires a low cost, handheld, battery powered configuration operating within a license free ISM band that is capable of resolving mm scale objects[1]. The 24.125 GHz ISM band is compatible with low cost since many RF components in this band may be procured for a few dollars.

Figure 1. The Walleye Camera

II. Resolution

Good imaging with 24 GHz radiation requires that the antenna have a high angular subtence about the target to produce reasonable mm scale resolution. The Rayleigh criteria states that two objects separated by D = 0.61*Lambda/NA are resolved as two distinct, separate objects. For the Walleye camera, Lambda = 12.4 mm and Numerical Aperture = 0.60. This indicates two point objects separated by 1 wavelength (~12.4mm) will be resolved as two objects. This criteria generally applies to imaging self luminous object (for instance, as in a passive RF imager).

III. Confocal Imaging

Our camera utilizes active target illumination combined with a scanning confocal illumination and collection geometry. In this case a small illumination spot is imaged on the target concurrent with single point collection of the backscattered radiation from the target as shown in figure 3. In this way resolution is improved by about 40% to approximately 8.5mm lateral spacing[2]. Smaller objects may be detected but not easily resolved as separate objects. The photos below illustrate that this criteria is qualitatively met.

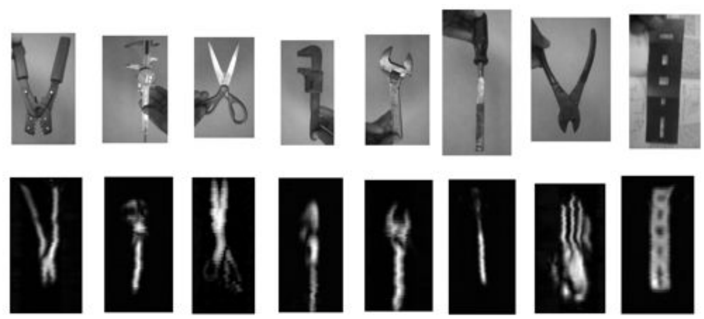

Figure 2. Resolution of some common objects

IV. Architecture Choices

A transceiver array or an electronically steered phased array would have offered good imaging performance but these techniques are not as cost effective as was desired. The use of low cost UWB radar has been demonstrated[3] but FCC bandwidth limitations impose special licensing.

To keep costs low, we chose an antenna architecture using single RF transceiver (see figure 3). Once this decision is made some type of beam scanning means must be utilized to modulate and collect spatial information. It was noticed than an offset Fresnel Zone Plate (FZP) antenna[4] could be used in a rotating configuration to produce a one dimensional circular beam scan. The system architecture is schematically illustrated in figure 3. When the FZP rotates, the beam is scanned in a ~100mm diameter circle. In this mode, the FZP serves a dual function as both the focusing element and the beam scanning element. This rotational motion is about the center of gravity of the FZP. Once the zone plate is spinning, the rotational inertia need only to be maintained and so power consumption is low at less than 0.25W.

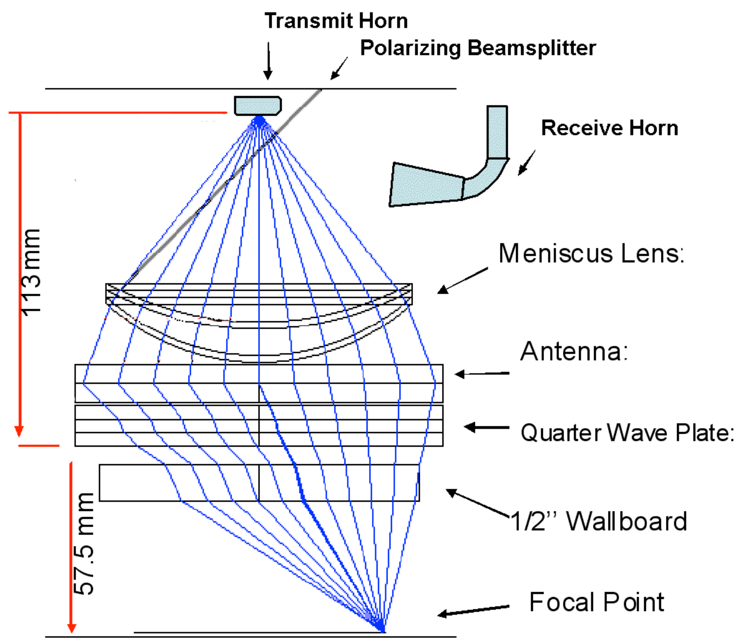

Figure 3. Opto-mechanical architecture

Rotating the FZP element causes the 24GHz RF beam to be scanned in a circle. When the camera is scanned along a wall, the circular pattern is modified by the user motion to form a series of epicycloids. Using position data from the encoded omni-wheels and knowledge of the rotational position of the antenna allows calculation of the position of pixel position for arbitrary camera motion. The simple case for FZP rotation and camera translation is illustrated in figure 4 below. The encoders allow any motion path to be used during scanning as long as the camera speed is kept below 100mm/sec.

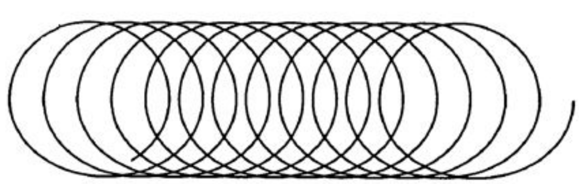

Figure 4. FZP rotation and camera translation

The image is written into large memory buffer that is many times larger than the 480x272 LCD screen. This allows for panning data on the screen for scanning a large wall. When data is scanned with a rotating antenna, the sampled data is in a polar coordinate system and must be mapped into a Cartesian coordinate system corresponding to a physical memory buffer address. The wall tracking encoders allow mapping pixel data into the physical memory buffer address.

The fabrication of the antenna assembly uses molding techniques for low cost. The antenna system is shown in figure 5.

Figure 5. Antenna assembly (left) and FZP element (right

The RF circuit for the scanner is a well known Frequency Modulated Continuous Wave (FMCW) radar circuit[5]. The microcontroller generates all the timing for the ramp generator and sampling the A/D converter. The ramp generator sweeps the VCO from 24Ghz to 24.25Ghz within the ISM band. The directional coupler directs -10dB of the VCO to the TX, the output of the coupler is also connected to the LO of the I/Q mixer. The TX signal passes through the rotating antenna which focuses the beam. The return signal is received by the RX to the RF input of the mixer. The I/Q outputs of the mixer are amplified and then sampled by the A/D converter and stored as pixel data.

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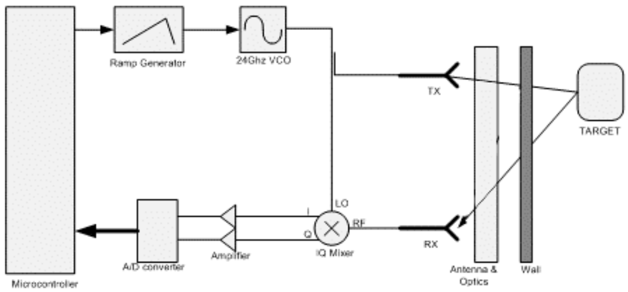

Figure 6. RF Schematic

Microwave imaging allows detection of a wide variety of materials behind walls, fabric, packaging materials and other visibly opaque materials. This low cost architecture can provide RF imaging capability for a number of inspection and security applications. One possible application is the behind wall inspection to detect explosives, listening devices or contraband. The camera provides real time imagery of the scene as the user scans across the target area. The photos below illustrate the camera's imaging capability for various targets behind 5/8" drywall. The RF images are on the left and corresponding visible images on the right.

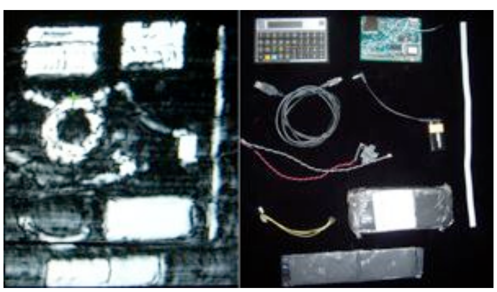

Figure 7. Electronics and Explosives
(Calculator, PCB, USB cable, 26GA wire +Battery, 14-3 wire, 26GA wire and PCB, 26GA wire, C4 simulant, C4 simulant)

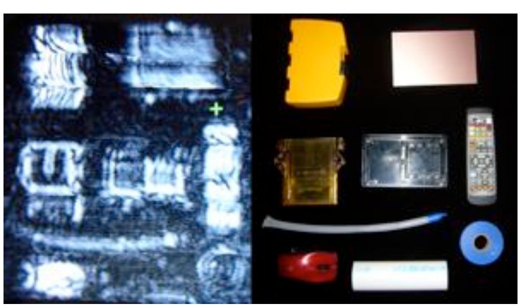

Figure 8. Plastics and Metal
(Drill bit case, copper sheet, plastic cases, TV remote, HDPE pipe, mouse, PVC pipe, PVC tape)

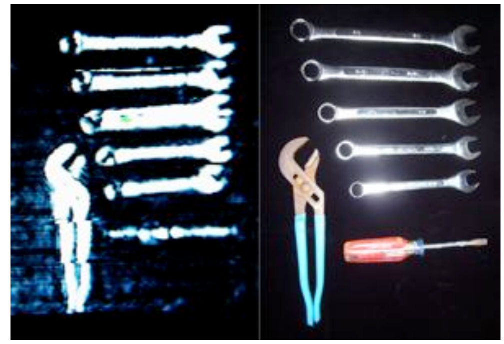

Figure 9. Metal Tools
(Wrenches, pliers, screwdriver)

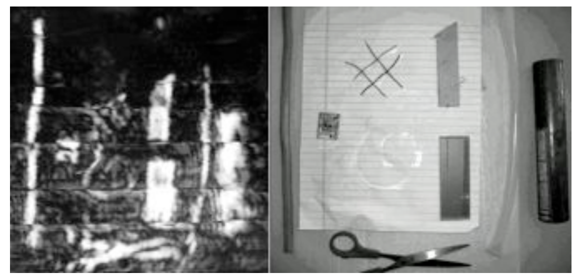

Figure 10. Wire, metal, wood and plastic
(14-3 wire, 30GA #, pine board, HDPE pipe, copper pipe, small PCB, 30GA wire loop, PCB, scissors)

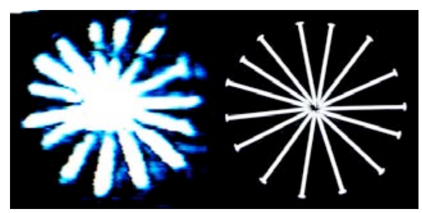

Figure 11. Star Test
(3 1/2" nails arranged as a star)

To achieve the low-cost requirements for the consumer market, the system block diagram is implemented with few components. The major functional requirements of this system are:

Microcontroller & LCD Display

The system design required a microcontroller with a rich set of I/O peripherals including multiple timer/counters, a/d converters, SDRAM controller and general purpose I/O; with a large internal RAM, program FLASH memory, and display control. The LCD display is driven by a DMA controller which access a display buffer in the external SDRAM. This display buffer is much larger than the actual LCD to allow smooth scrolling of a large wall area.

RF module timing control and input

The timing is critical for keeping the ramp generator synchronized to the A/D sampling input sampling. Multiple timers in the microcontroller keep drive the ramp generator and the A/D input sampling. The RF module uses the ramp generator to modulate a 24Ghz VCO. The RX signal is used by the detector to generate a low intermediate frequency which is amplified and sampled by the A/D converters in the microcontroller.

Rotating Antenna

The antenna is driven from a DC motor from a DC regulator circuit. The speed is open loop, but the rotational time of the antenna is measured by an index sensor which provides the positional timing and rotational timing of the antenna. The pixels on the wall are sampled every 1 degree of rotation based on the rotational time divided by 360.

Wall Position

Wall position is provided by 3 encoders which measure X, Y and calculated rotation. Using the wall position calculation provides the XY position in memory for the data to be stored.

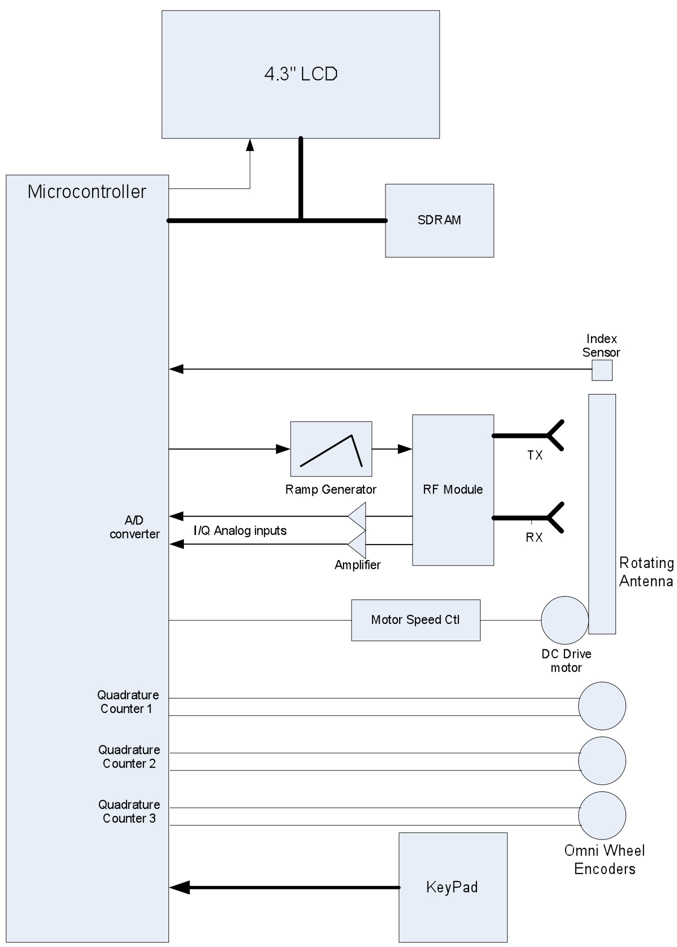

Figure 12. Low-Cost Scanner System Block diagram

IV CONCLUSION

We have described a compact imager that utilizes a FZP focusing and scanning antenna to image mm scale objects behind walls. We expect this technology will evolve and enable a wide array of new inspection tasks.

REFERENCES

[1] United States Patent 7,626,400

[2] Webb, Robert. "Confocal Optical Microscopy". Rep. Prog. Physics 1996: 427-471.

[3] United States Patent 5,896,102

[4] Hristov, Hristo. *Fresnel Zones in Wireless Links, Zone Plate Lenses and Antennas*. January 2000. Artech House Publishers , 2000. 290. Print.

[5] Komarov, Igor, and Sergey Smolskiy. *Fundamentals of short-range FM radar*. Artech House Publishers, 2003. Print.