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IMAGING OF CONCEALED TARGETS ON MANNEQUINS

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ULTRA WIDE BAND MILLIMETER WAVE HOLOGRAPHIC "3-D" IMAGING OF CONCEALED TARGETS ON MANNEQUINS

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INTRODUCTION

Ultra wide band (chirp frequency) millimeter wave "3-D" holography is a unique technique for imaging concealed targets on human subjects with extremely high lateral and depth resolution. Recent "3-D" holographic images of full size mannequins with concealed weapons illustrate the efficacy of this technique for airport security.

A chirp frequency (24 GHz to 40 GHz) holographic system was used to construct extremely high resolution images (optical quality) using polyrod antenna in a bi-static configuration using an x-y scanner.

Millimeter wave chirp frequency holography can be simply described as a multi-frequency detection and imaging technique where the target's reflected signals are decomposed into discrete frequency holograms and reconstructed into a single composite "3-D" image.

The implementation of this technology for security at airports, government installations, etc., will require real-time (video rate) data acquisition and computer image reconstruction of large volumetric data sets. This implies rapid scanning techniques or large, complex "2-D" arrays and high speed computing for successful commercialization of this technology.

HOLOGRAPHIC CHIRP FREQUENCY THEORY

Let us consider a simple near-field scanned (x-y) aperture chirp frequency radar holographic system. The received signal can be expressed as a time-delayed waveform in terms of the target's range (R), frequency bandwidth (B), chirp time (T), and propagation velocity of the medium (c)

$$e_0 = A_0(x, y, f) \cos \left[\omega_0(t - \tau) + \frac{B}{2T}(t - \tau)^2 \right] \quad (1)$$

where $A_0(x, y, f)$ = target amplitude at frequency(f)

$$\tau = \frac{2R}{c} = \text{target delay time}$$

and
$$f = \frac{Bt}{T} + f_0 = \text{chirp frequency.}$$

After receiving the time-delayed waveform, it is mixed with the reference signal

$$e_r = A_r(x, y, f) \cos \left[\omega_0 t + \frac{Bt^2}{2T} \right] \quad (2)$$

and filtered to generate the real part of the holographic signal which can be expressed by the following equation

$$e_h = \frac{A_0 A_r}{2} \cos \left[\frac{4\pi f R}{c} \right] = \frac{A_0 A_r}{2} \cos \left[\frac{4\pi R}{\lambda} \right] \quad (3)$$

where $\phi_0(x, y, f) = \frac{4\pi R}{\lambda} = \text{phase of the target at frequency (f)}$

and $\lambda = \frac{c}{\frac{B}{T}t + f_0} = \text{wavelength at frequency (f).}$

The imaginary part is generated by the Hilbert transform and the two signals can be expressed as

$$e_{hr} = A_0(x, y, f) \cos \left(\frac{4\pi R}{\lambda} \right) \quad (4)$$

and

$$e_{hi} = A_0(x, y, f) \sin \left(\frac{4\pi R}{\lambda} \right) \quad (5)$$

These expressions are very familiar to holographic engineers. They are the holographic signals for each frequency in the chirp and they completely

describe the target's reflectivity and $A_0(x, y, f)$ and the phase $\left(\frac{4\pi R}{\lambda} \right)$.

They can be computed from the following equations.

$$A_0(x, y, f) = \sqrt{(e_{hr})^2 + (e_{hi})^2} \quad (6)$$

$$\phi_h(x, y, f) = \frac{4\pi R}{\lambda} = \tan^{-1} \left[\frac{e_{hi}}{e_{hr}} \right] \quad (7)$$

COMPUTER RECONSTRUCTION OF CHIRP DATA

Let us express the holographic target signals (equations 4 & 5) in the general form and write it for each frequency in the chirp as

$$U(x, y, f) = E(x, y, f) e^{-j\phi(x, y, f)} \quad (8)$$

where $E(x, y, f)$ and $\phi(x, y, f)$ are the amplitude and phase of the target's signal at frequency (f) in the chirp. Now that we have simplified the wide band signal into discrete frequencies, we can use single frequency image reconstruction theory with modifications for multi-frequency image "3-D" integration [1-3].

The multi-frequency image is constructed by simply back propagating the target's plane wave angular spectrum ($A(u, v, f)$) for each digitized frequency in the chirp from the aperture to the target plane. Thus, we now have the angular spectrum of plane waves for each frequency and then vectorially add them to form a multi-frequency spectrum.

We now compute the target's multi-frequency image by taking the inverse Fourier transform of the multi-frequency angular spectrum

$$U_T(x, y, z) = \iint \sum A(u, v, f) \exp \left\{ \frac{j4\pi}{\lambda} \left[1 - \left(\frac{\lambda u}{2} \right)^2 - \left(\frac{\lambda v}{2} \right)^2 \right]^{\frac{1}{2}} z \right\} \exp[j2\pi(ux + vy)] du dv$$

where z is the target plane to aperture distance.

If the target is thick (multiple z planes in depth), each depth plane image is computed and then combined with the other planes to form the in-focus "3-D" image. The length of each depth plane is approximately $\Delta z \approx c/(2B)$.

The brightest pixel points are used in each image plane to form the composite depth "3-D" image.

EXPERIMENTAL RESULTS

A 32 GHz center frequency chirp system with a 100% bandwidth was used to construct ultra-wideband (UWB) holographic images of a male

mannequin with and without a concealed weapon under typical apparel (corduroy suit).

Figure 1 is the UWB (24 GHz to 40 GHz) holographic image of the mannequin without the concealed weapon illustrating the excellent lateral and depth resolution. The buttons, belt, etc., appear transparent against the body and are visible only by the diffraction effects in the dielectrics.

Figure 2 is the UWB (100 GHz to 112 GHz) image of the mannequin with a weapon (Glock 17) located in the waist area and easily seen in the picture.

CONCLUSIONS

We believe Holographic UWB imaging is a viable technique for human surveillance of weapons, etc., that will be used in future security inspection scenarios at airports, government sites and other critical installations.

The successful implementation of this technology is dependent on rapid data acquisition of large volumetric data sets, and real-time display (video rates) similar to a video camera operation.

FIGURE 1

HOLOGRAPHIC IMAGE OF MANNEQUIN WITH CONCEALED GUN (100 TO 112 GHz)

Optical

100 - 112 GHz

FIGURE 2

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