Radar Sensing of Heartbeat and Respiration at a Distance With Security Applications

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ABSTRACT

Researchers at the Georgia Tech Research Institute (GTRI) have developed a radar that will detect heartbeat and respiration without any physical connection to the subject. The system is capable of making these measurements at ranges exceeding 10 meters. This paper explores the use of the system for the biometric identification of personnel who work in a highly secure environment. The system, used in this application, would use the heartbeat signature of an individual as a biometric identifier. Also, the system could be used to determine the stress level being experienced by an individual on the basis of respiration and heartbeat rates.

1. BACKGROUND

GTRI first developed an early version of a radar vital signs monitor during the mid-1980s. The earlier system was patented and experiments were conducted to determine how well the system would perform in determining which wounded soldiers on the battlefield had vital signs and which did not. This information would be used in live fire situations to determine if a soldier was alive before risking a corpsman's life in a rescue effort. Most recently, a variant of the earlier system was developed for use in the 1996 Olympics held in Atlanta, Georgia.

Prior to the staging of the Olympics in Atlanta, Georgia during the summer of 1996, it was suggested that some Olympic archers and rifle competitors were able to synchronize their shots to fall between heartbeats and thus avoid an approximate 5 milliradian deflection of their arms caused by the ballistiocardiogram or recoil of the body. It was further suggested that this effect would be interesting to show during television coverage of the rifle and archery competition. The concept was to show the heartbeat of the rifle and archery competitors as a superimposed image at the bottom of the television picture. Unfortunately, the television networks chose not to broadcast the archery and rifle competitions that the system was designed to monitor, and as a result the radar was not used for the Olympic application.

2. THE RADAR SYSTEM

The radar system, shown in Figure 1 from front view aspect. Figure 2 shows the electronics package including the transmitter power supply, a microwave transmitter/receiver module, and signal processing circuits mounted on a support arm that is part of the parabolic antenna dish structure. The microwave source couples power direct to the antenna feed. A 1 inch by 1 inch charged coupled device (CCD) television camera (not visible) is mounted on the back of the antenna and the lens is boresighted to the center of the antenna beam. The CCD camera allows the very narrow antenna beam to be aimed with precision on the thorax of the subject being observed with the system. The entire system operates on a 12 volt DC gel-cell battery.

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The operational characteristics of the radar are shown in Table I. The microwave assembly is a frequency and phase stable homodyne radar module purchased off-the-shelf for use as the radar transmitter/receiver.

Table I. Operational Characteristics of Radar Vital Signs Monitor

Frequency of Operation	24.1 GHz
Transmitter Power Output	30 milliwatts
Antenna Type	Parabolic, 24" dish
Antenna Gain	≈40 dB (operation in near-field)

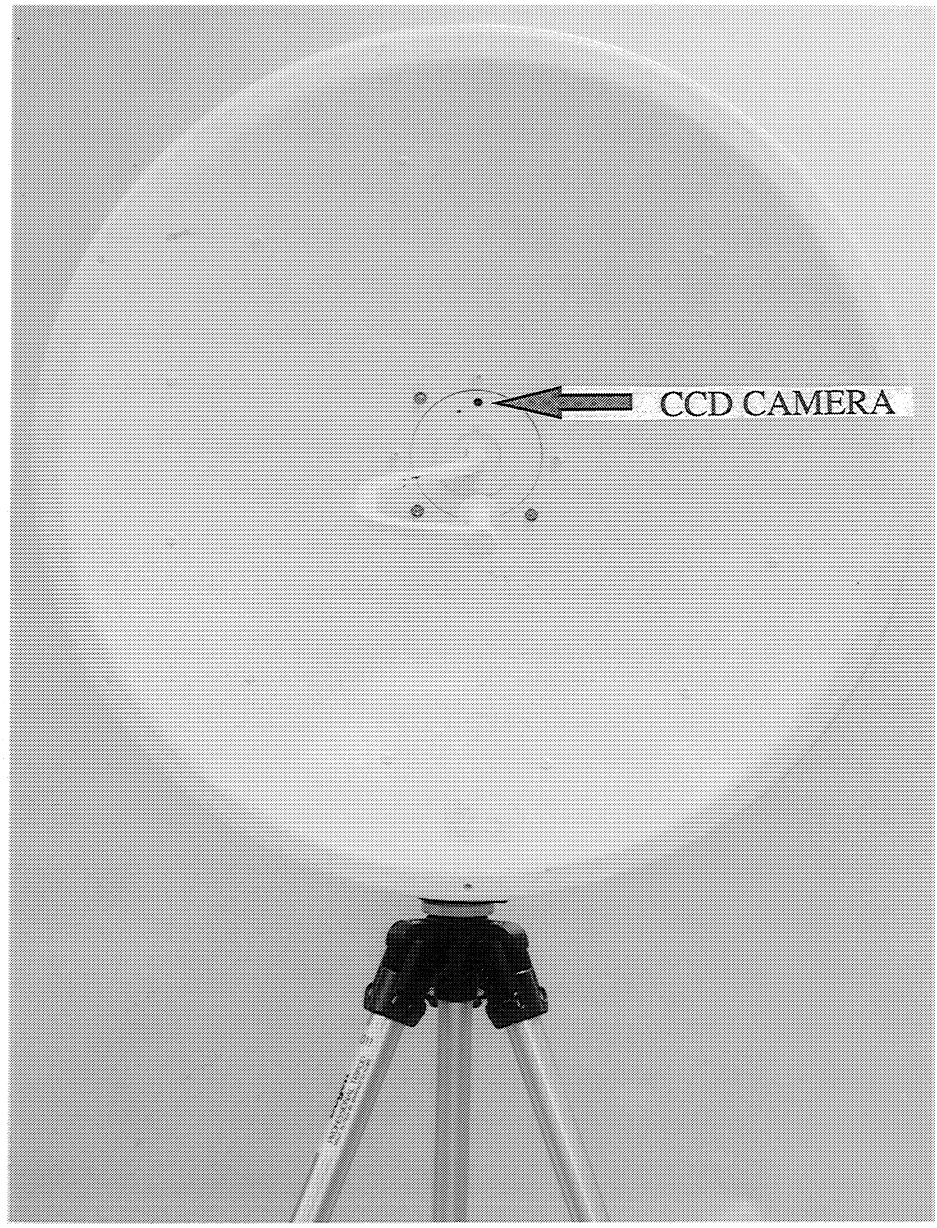

Figure 1. Front view of the radar heartbeat monitoring system developed for use in the 1996 Olympics.

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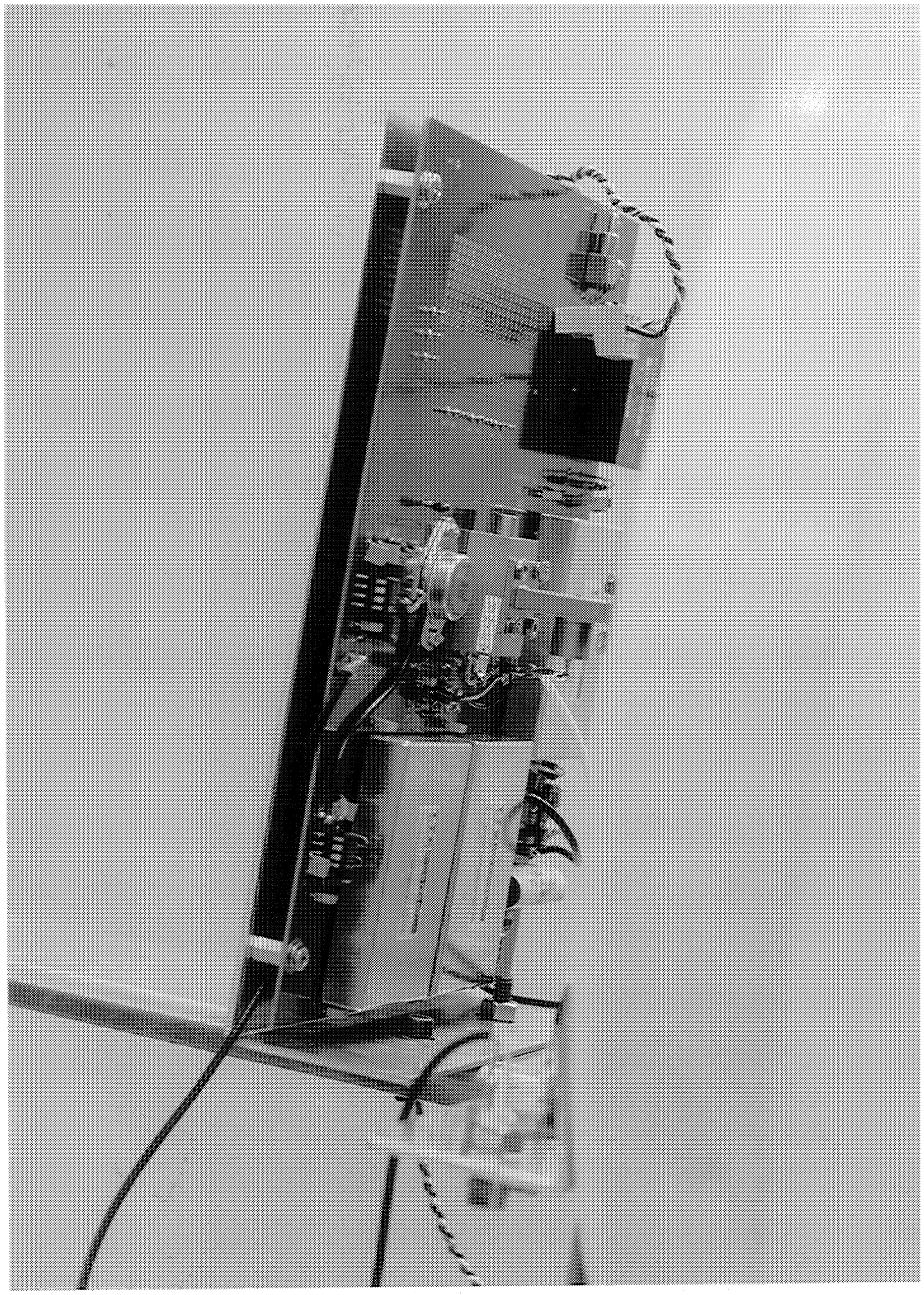

Figure 2. Electronics package mounted on the back of the antenna showing the various system components.

The system is presently operated in the continuous wave (CW) mode. The Gunn device transmitter radiates a signal to the target. The energy reflected from the target is detected by a mixer diode. A portion of the 24.1 GHz signal from the transmitter is used as the local oscillator signal. If there is no Doppler shift between the transmitted and received signal, there is no detectable output at the mixer other than a DC level. However, any movement of a subject causes a change in the phase between the transmitted and received signal. The output signal is amplified and filtered using a pass-band filter. The filter bandpass is specified to split the respiration signature and heartbeat signature into two channels of information. Also, the filter is designed to eliminate the plasma modulation caused by fluorescent lights.

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3. DATA PRODUCED BY THE SYSTEM

Figure 3 shows a typical time domain radar cardiogram signature produced by the system (time increases from left to right of the plot). The maximum amplitude on the plot is plus or minus 5 volts. Each major time division is 0.1 seconds. There is a slight positive DC off-set which causes the radar cardiogram to be slightly asymmetrical above and below the zero volt centerline. The subject was at a range of approximately 4 meters from the radar when the data were taken. The source of the signature shown in Figure 3 is thought to be a pressure wave that is induced at the surface of the chest by the heart's pumping motion. Experiments have been conducted to determine if any of the phase induced variations in the time domain signal shown in Figure 3 are artifacts of the system signal processing, such as filter ringing or other processor induced effects. The circled areas were marked to show that the heartbeat amplitudes are very repetitive from beat to beat. The author is satisfied that the heartbeat signature that is being sensed and shown in Figure 3 is real and that each part of the heartbeat signature complex correlates with some part of the activity of the heart. This conclusion is also supported by observations of others, as reported in the literature.

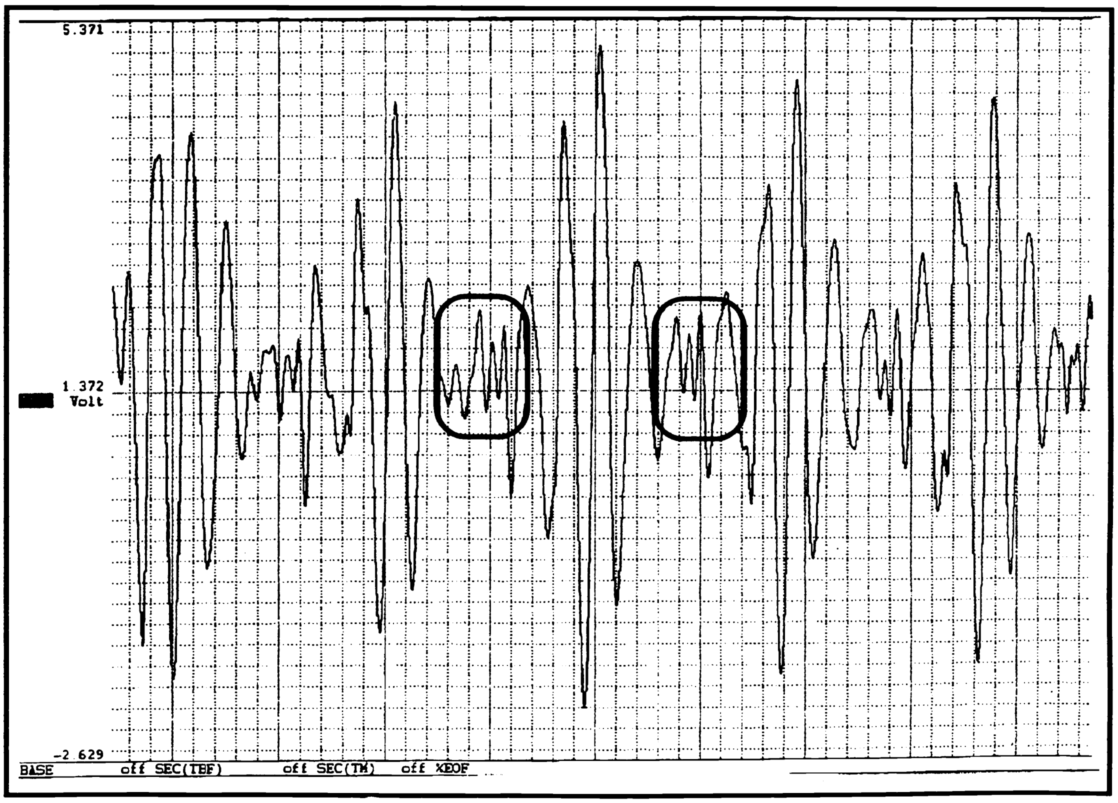

Figure 3. The radar cardiogram of subject 1 showing the fine resolution of the data.

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4. RADAR CARDIOGRAM VARIABILITY

A file of over 20 radar cardiogram records were recorded using the author's colleagues as test subjects. Figure 4 shows the radar cardiogram of a subject different from the subject shown in Figure 3. A comparison between the radar cardiogram in Figure 3 and the radar cardiogram in Figure 4 shows the smaller amplitude features found in Figure 4. These features are different than the small amplitude features shown in Figure 3 and appear to be correlated between heartbeat events. The major impulses between samples are also different. In Figure 3, the amplitude of the first and leading primary impulse is always higher than the second or trailing impulse. In Figure 4, the amplitude of the first primary impulse is less than the second impulse. The features in both figures have proven to be repeatable and relatively stable.

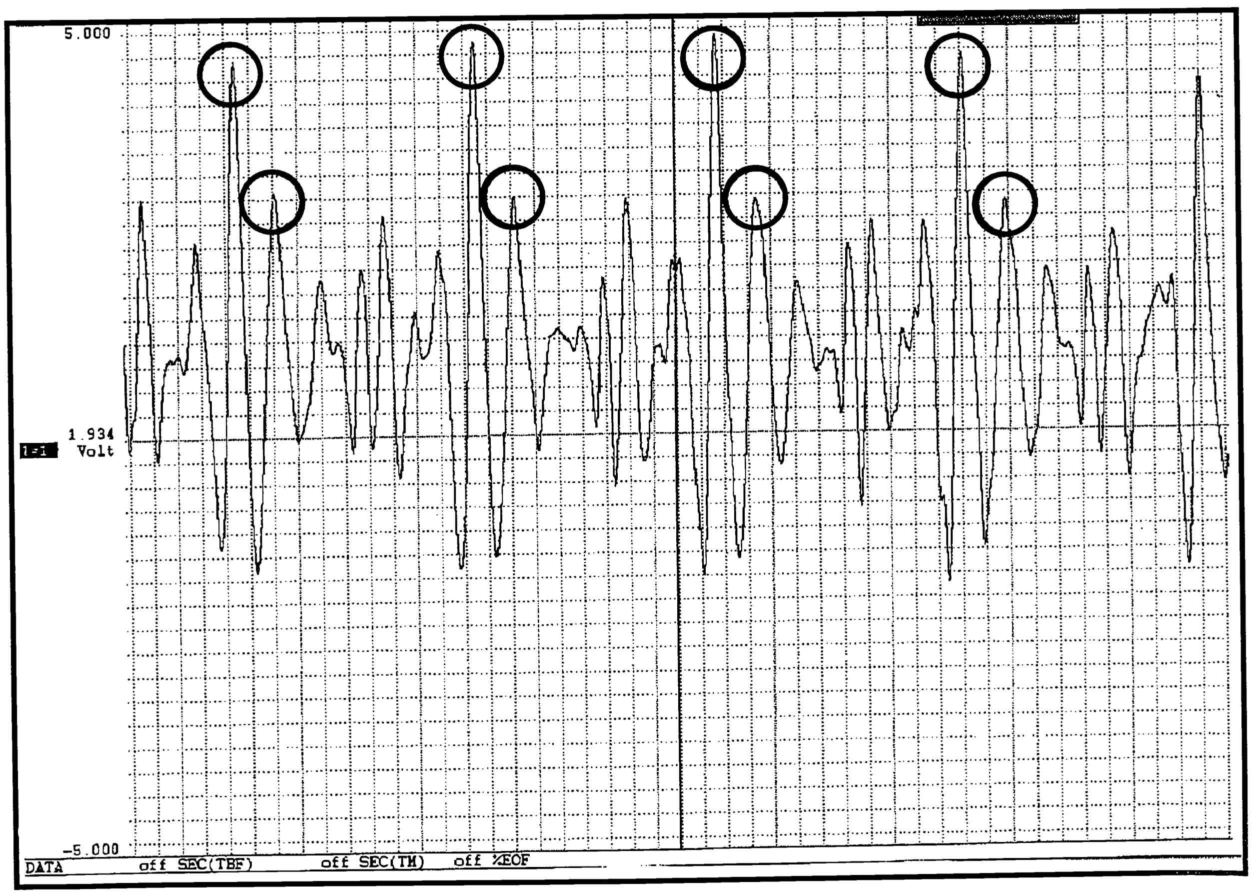

Figure 4. Radar cardiogram of subject 2 showing a different signature than that shown in figure 3

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5. SECURITY APPLICATIONS

The biometric identification sensor would be ideal in applications where someone would access the system on a very regular basis, usually daily. At the time of the first registration, the individual would stand in front of the system for 20 seconds while approximately 20 heartbeat sequences were recorded. Those sequences would be put into a master database for future reference. Each day, when the individual is required to access their high security area, a short scan using the radar heartbeat monitor would be taken during the identification and verification process. The database master heartbeat record would be compared to the access sample. Radar heartbeat features taken during the access scan would be compared to those features in the database. A match of heartbeat signatures would allow access to the security area.

As permanent changes occur in a subject's radar heartbeat signature, the changes would be recorded and verified, and the master record would be modified to reflect the changes. This procedure of updating the master signature file should allow compensation for a heartbeat radar signature that is slowly changing over time. In fact, one inducement for personnel to use the system might be their notification of heartbeat signature change so that they could seek a medical opinion as to the cause.

The practicality of using the system to identify personnel who would access the security area infrequently must still be analyzed. The stability of the radar heartbeat signature over long periods of time has not yet been determined. However, in a high security installation, persons who require access on an infrequent basis are usually required to re-register with those access systems that are in place at the facility upon the occasion of each visit.

6. MICROWAVE EXPOSURE LEVELS

There is a heightened awareness of electromagnetic radiation exposure in the United States. There has been a highly publicized controversy over a policeman who operated speed radar and subsequently developed cancer after a long exposure to the radar. Additionally, there have been unsubstantiated reports of cellular telephones causing brain tumors in the user. The estimated radiated power from the radar, at the ranges over which the system is used, is well below the 10 milliwatt per square centimeter radiation standard for microwave ovens and is also well below the suggested 1 milliwatt per square centimeter standard for other radiating systems. Therefore, the radar is arguably safer than other systems widely used in the United States today.

7. SUMMARY

Measurement of the radar cardiogram at a distance is achievable using inexpensive techniques. The Georgia Tech Research Institute is continuing to develop both security and medical applications for the system. Work continues on developing a capability to allow a moving subject's radar cardiogram to be measured.

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