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## **Radar Fundamentals and Applications**

### **Introduction**

Radio Detection and Ranging (Radar) can be used in many different settings to locate, monitor, or track various types of targets. After the formal publishing of Maxwell's equations in 1864, Christian Huelsayer "proposed the use of radio echoes in a detecting device designed to avoid collisions in marine navigation" [1]. By 1935, the first practical radar system was established. Since then radar has become an important tool for the military, but radar also has commercial uses such as vital sign monitoring. This paper reviews the fundamental theory behind radar as well as its applications in both military and civilian settings.

### **Fundamentals of Radar**

The radar emitter sends out a beam of radio waves and listens for their return. The system can either be continuous, where energy is sent and received at all times, or Doppler, where a single pulse is sent, transmission is halted while listening for responses, then repeated as shown by the National Oceanic and Atmospheric Administration [2]. One emitter/receiver node can be used, or many can be linked together to work cohesively as a phased array radar, shown by Garrod [3]. Each channel of the system has its own emitter and receiver that, when working with the other channels, can digitally steer the beam of energy. As opposed to physically rotating the emitter and receiver, the phased array radar can scan a larger area faster.

After the waveform is sent and received, the signal processing algorithm can begin. As shown by Yu [4], once the received waveform is filtered, the phase shift correlates to the distance to the target that caused a reflection. The frequency, or Doppler shift, encodes the speed and direction of the target. A target moving toward the emitter will have a higher received frequency while a target moving away from the emitter will have a lower frequency. This information is used to track and predict a target location.

### **Maritime Radar Systems**

As outlined by the radar apparatus patent [5], the radar system signal processor is comprised of multiple parts that work together to process and interpret the returned signal as useful information. The received signal is immediately sent to the analog to digital converter (ADC) which samples the signal so that it can be worked on. Next, it is sent to the detector, where the reception signal is used to generate an in-phase and out-of-phase signal. The phase calculator then acquires certain parameters, such as ground

speed, heading, and antenna azimuth angle, to factor into the previously calculated in-phase and out-of-phase signals. These signals are sent to the Doppler processor. This stage includes a sweep buffer, Doppler filter band, and log detectors. The sweep buffer is a memory for storing the complex reception signals and stores the reception data for many sweeps. At the end of the Doppler processor, the range and speed of the target has been calculated by looking at the change in frequency from the transmitted signal to the received signal. At this point, the final processed waveform can be sent to some form of display in real-time or stored for further examination.

### **Vital Sign Monitoring**

Radar has been used as a vital sign monitoring system, as demonstrated by Tariq [6]. When a continuous wave reflects off of a “quasi-periodically moving surface with no net velocity such as the human chest,” the measured phase variation is directly proportional to the motion of the chest and frequency of the wave. This radar system captures both heart rate and breathing. The magnitude of the breathing signal is much higher than that of the heart rate because the surface is moving much more relatively. This means that the heart rate signal must be extracted and separated from the returned signal via advanced signal processing techniques and utilizing filters and windows. Tariq suggests Butterworth filters with a sliding Hanning window. Using an autocorrelation function and peak detection in the Fourier transform, the desired heart and respiration rates can be resolved.

### **Conclusion**

Radar has been used extensively for both military and civilian use for over a century. Several steps of signal processing are involved and require advanced concepts and knowledge. Most of the processing is done in software but multiple components of hardware (antennae, sensors, ADC, etc.) are required to generate and receive the waveforms, but the rest is manufactured in code. Considerations must be made to produce real-time results and account for noise and precision errors. Lastly, the range of frequencies that the signal processor must work with must be designed such that the ADC can effectively sample and reconstruct the signal.

### **References**

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