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INTRODUCTION

1.1 BACKGROUND

Microwave radar has been used for remote sensing applications for many years. Most common applications include displacement and low velocity measurement (Kim and Nguyen, 2003; Kim and Nguyen, 2004; Benlarbi et al., 1990; Rasshofer and Biebl, 1999), distance and position sensing (Stezer et al., 1999), automobile speed sensing (Meinel, 1995), and vital sign detection (Lin, 1992). Traditionally, microwave radar can be divided into two categories: the pulse radar and the Doppler radar. The pulse radar determines the target range by measuring the round-trip time of a pulsed microwave signal. It does not directly measure the velocity of a target but the velocity can be calculated. The Doppler radar, on the other hand, measures the velocity of a target directly. If the target has a velocity component, the returned signal will be shifted in frequency, due to the Doppler effect. On the hardware side, the pulse radar uses powerful magnetrons to generate microwave signals with very short pulses of applied voltage. In order to overcome the pulse radar’s disadvantage of high cost due to the expensive magnetron, the frequency modulated continuous wave
(FMCW) radar was invented in recent years. Compared with the pulse radar, the FMCW radar can be integrated with solid-state technology, and has the advantages of superior target definition, low power, and better clutter rejection. However, the FMCW radar requires accurate control (modulation) of both the frequency and amplitude of the transmitted signal, and is mainly used for range detection. To measure both the displacement and the velocity, a system using millimeter-wave interferometry (Kim and Nguyen, 2003) was reported. It used a quadrature mixer to realize the coherent phase-detection process effectively. It has a very high detection resolution, but has a limit on the minimum measurable speed (Kim and Nguyen, 2004).

1.2 RECENT PROGRESS ON MICROWAVE NONCONTACT MOTION SENSORS

With contributions from many researchers in this field, new detection methods and system architectures have been proposed to improve the detection accuracy and robustness. The advantage of noncontact/covert detection has drawn interest on various applications. While many of the reported systems are bench-top prototypes for concept demonstration, several portable systems and integrated radar chips have been demonstrated.

1.2.1 Microwave/Millimeter-Wave Interferometer and Vibrometer

The development of various instrumentations and techniques for vibration measurement and analysis has become increasingly important. Conventional vibration sensing elements comprise displacement or velocity transducers. One of the most widely used is the accelerometer. A piezoelectric-based accelerometer can produce an electrical output proportional to the vibratory acceleration of the target it is attached to. Another contact measurement instrument is the linear variable differential transformer (LVDT), which works as a displacement transducer that can measure the vibratory displacement directly.

Some of noncontact vibration measurement instruments are laser based, such as laser Doppler vibrometer, laser interferometer, and laser displacement sensor. These devices are usually expensive and have
their limitations as well, such as inevitable calibration and narrow detection range. On the other hand, microwave/millimeter-wave interferometer or vibrometer has been used for applications in instrumentation such as plasma diagnostics and nondestructive characterization of material.

Millimeter-wave interferometric sensor with submillimeter resolution has been reported by Kim and Nguyen (2003). Resolving displacement within a fraction of a carrier wavelength, the sensor has high resolution in submillimeter range. The sensor system operates in Ka-band and is completely fabricated using microwave and millimeter-wave integrated circuits. Radio frequency (RF) vibrometer based on nonlinear Doppler phase modulation effect (Li and Lin, 2007a) has also been reported most recently. It detects vibration movement by analyzing the relative strength of vibration-caused harmonics at the radar baseband output. With a quadrature architecture supporting a complex signal demodulation technique, the RF vibrometer realizes the measurement of not only a purely sinusoidal periodic movement, but also vibrations comprised of multiple sine waves of different frequencies. Compared with laser-based sensors, microwave/millimeter-wave interferometer and vibrometer can have a low cost and a much larger detection range.

### 1.2.2 Noncontact Vital Sign Detection

The principle of detection based on frequency or phase shift in a reflected radar signal can be used to detect tiny body movements induced by breathing and heartbeat, without any sensor attached to the body. There are several advantages to a noncontact vital sign detection solution: physically, it neither confines nor inhibits the subject, making the detector ideal for long-term continuous monitoring applications. Also, the reliability can be increased as a subject is unaware of the measurement and therefore is less likely to alter their vital signs. Additionally, accuracy is enhanced because of the lack of surface loading effects that have been shown to reduce the accuracy of some other measurement methods. This noncontact remote detection of vital signs leads to several potential applications such as searching for survivors after an earthquake and monitoring sleeping infants or adults to detect abnormal breathing conditions.
While the concept of noncontact detection of vital signs has been successfully demonstrated by pioneers in this field before 2000 (Lin, 1975; Chuang et al., 1991; Lin, 1992; Chen 1986), research efforts in this century have been moving the technology development toward lower power, lighter weight, smaller form factor, better accuracy, longer detection range, and more robust operation for portable and handheld applications. Among many possible applications this technology can be used for, healthcare seems to be drawing most of the interest. As an example, a baby monitor using this technology was recently demonstrated (Li et al., 2009a). The baby monitor integrates a low power Doppler radar to detect tiny baby movements induced by breathing. If no movement is detected within 20 s, an alarm will be triggered. With growing interests in health and life sciences by the engineering community, many researchers have been contributing to technology advancement in this field. Although, many results were demonstrated using bench-top prototypes or board-level integration, their architectures still show the potential of being implemented on chip. In fact, there have been several reports of vital sign radar sensor chips based on various architectures (Droitcour et al., 2002; Droitcour et al., 2003; Li et al., 2008b; Li et al., 2009c; Li et al., 2010b).

1.3 ABOUT THIS BOOK

Although, many researchers are working on the microwave motion sensing technology and a large number of articles have been published in recent years on state-of-the-art applications such as vital sign detection and interferometry, it is difficult to find a book that reviews this technology and unveils the trends of future development. This book first reviews the theory and fundamentals of microwave motion sensor in Chapter 2. It then discusses the hardware development of microwave motion sensor in Chapter 3, including radar transceiver architectures, antenna systems, and special building blocks. In Chapter 4, advances in detection and analysis techniques will be discussed, covering system consideration, modeling, and signal processing. Several application case studies will be provided in the first part of Chapter 5, followed by the discussion on development of standards and state of acceptance. Finally, future development trends and microwave industry outlook will be presented in Chapter 5.
This book not only covers the theory and technical details of related technologies, but also plenty of applications. The tight connections of this technology to healthcare, industrial, and military services will be exemplified in this book. Potential research opportunities will also be illustrated to scientists from the microwave, electronic circuit, signal processing, and healthcare points of view. The intended audience of this book includes microwave engineers and researchers, microwave application engineers, researchers in healthcare institutes, developers of military and security equipment, and scientists in biomedical engineering.