論　文　の　要　旨

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論 文 題 目　Time-domain Impulse Radar Imaging for Breast Cancer Detection Using CMOS Integrated Circuits
（CMOS 集積回路を用いた時間領域インパルスレーダーイメージングによる乳癌検出の研究）

The most commonly used modality for breast cancer detection is X-ray mammography. However, it has some drawbacks such as exposure to ionizing radiation and pain during medical examination. As a complementary method, an ultra-wide band (UWB) microwave imaging system in the frequency domain has been proposed, which is composed of a vector network analyzer (VNA), off the shelf microwave devices and antenna mechanisms with an oil tank, resulting in large occupied area and heavy weight.

In this dissertation, the research on development of the time-domain impulse radar imaging system using CMOS integrate circuits is carried out. In order to make this system portable and mobile and be suitable for clinical use, three generation prototypes are developed. A couple of processing techniques are proposed to solve problems of the lower dynamic range and time resolution of the system. Moreover, a novel artifact removal method is proposed by signal selection and adaptive filter with a prior constraint to handle various complex scenarios. Finally, the clinical tests using the recent hand-held prototype are conducted on excised breast tissues and volunteers.

In chapter 2, the key elements of the breast cancer detection system are reviewed and the configuration of the total system is presented. In order to measure the analog time-domain signals in the system, the measurement method is established by employing the differential outputs of the signal generator. In the measurement, the other GMP output is used as the trigger signal to synchronize the observed signals. Using this method, the signal flow in the system is confirmed. The time domain impulse signals propagation characteristics are investigated by both simulation and experiment. It is found that the reflection from the target with high dielectric constant have the similar shape with the direct wave propagating in horizontal direction. Meanwhile, the calculation of the emission time is illustrated.

In chapter 3, the development of hand-held prototype is presented. In this prototype, a cross-shaped dome antenna array is designed for covering human breast

enabling application in clinical trials. The circuits are redesigned to adapt to the rotation feature. The automatic and precise rotation measurement is achieved by introducing a step motor. The resolution of the sampled signal is dramatically enhanced by utilizing a 12-bit analog to digital converter. A plastic cover is designed and installed on the antenna dome to protect patient and mitigate friction during rotation. The stability of the prototype is investigated. It is found that the detector become stable after warming up for about 2 hours. The specific absorption rate (SAR) distribution is also investigated and confirmed for the safety of the patient.

In chapter 4, the developed systems are used to conduct the detection experiment on phantoms. The target detection cannot be realized by the raw received signals directly. A series of processing techniques are proposed for improving data resolution and image quality. The resolution of the signal amplitude is improved by averaging the multiply-measured signals. The peak search method and least square based method are proposed to compensate the phase deviation caused by system jitter. The finite impulse response (FIR) bandpass filter is adopted to suppress the noise introduced by the quantum error in analog-digital conversion. Further, the displacement measurement and rotation measurement are proposed in order to extract the target response. Owing to the proposed methods and techniques, the successful detection of target in breast phantoms is achieved.

In chapter 5, the artifact removal method using signal selection and adaptive filter with a prior constraint is proposed to extract target reflection in various complex scenarios. In order to evaluate the proposed method, a breast phantom with ham skin is developed. Since the ham is salty and wet, the attenuation of signal is larger. The bubble wrap is also introduced to mimic the imperfect contact scenario. Using the proposed artifact removal method, the target reflections are successfully extracted in complex scenarios and the detectability is improved.

In chapter 6, the detectability of malignant tumors using the developed hand-held detector is evaluated using excised breast tissues after total mastectomy surgery. Totally 18 samples are used for conducting experiment and evaluation. Furthermore, the clinical tests on volunteer patients are conducted by the clinical doctor. Totally 5 patients are recruited at the hospital. The results of the pilot clinical trials are presented. The successful detections of tumors demonstrate the feasibility of developed detector and the proposed signal processing algorithms in breast tumor detection and monitoring.

In Chapter 7, the conclusion is made and future work is discussed.