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Preliminary Study on Design and Application for UWB Radar Signal Characterization

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Abstract

In this paper, we present the feasibility of applying UWB radar signal to material characterization and distance measurement. Distance detection by using dynamic energy visualization method was presented and showed good agreement. This technique might be useful for searching and rescuing humans in disaster sites.

Keywords: UWB, Signal detection, Distance measurement, Directional antenna, Clutter and noise, Disaster application.

INTRODUCTION

Since the approval by the Federal Communications Commission (FCC) of the United States in 2002 for unlicensed radio applications, ultra wide band (UWB) technology has gained significant attention in both academia and industry for wireless communication applications [1]. The FCC has assigned the 3.1 to 10.6 GHz band with an effective isotropic radiated power of below –40 dBm/kHz for UWB communications [2]. UWB communications use very narrow pulses with the duration in nanosecond range for the transmission of data, and this enables the transmission of high data rates over 100 Mbps. In addition, UWB systems can coexist with other communication systems in the same frequency band by using low power levels. Therefore, the advantages of UWB communications are low transmit power, high data rate, and low interference [2].

Due to its unique characteristics, UWB technology has many applications such as short-range communications with high data rates for wireless USB-like communications, wireless sensor networks with low data rates for precise ranging and geolocation, and radar systems with high spatial resolution and obstacle penetration capabilities [3].

For the purpose of communications, industrial standards based on UWB technology such as IEEE 802.15.3a (high data rate) and IEEE 802.15.4a (low data rate) have been developed [4]. IEEE 802.15.3a provides a UWB wireless link as a cable replacement with transfer data rate over 100 Mbps between consumer electronics appliances. On the other hand, IEEE 802.15.4a supports wireless sensor networks with low- to medium-rate communications (50 kbps to 1 Mbps) with ranges of 100 m with centimeter accuracy positioning capabilities. The applications for IEEE 802.15.4a would be real-time locating system in logistics, precision ranging, healthcare, and process automation via RFID or wireless sensor network technologies.

For UWB radar sensing and imaging applications, UWB radar has a variety of applications in distance measurement, through-wall target detection, human vital sign monitoring, search-and-rescue mission at disaster sites, collision avoidance, building inspection, medical imaging, and surveillance [5].

In this paper, material and distance characterizations via raw signals using UWB radar system was implemented and distance measurement based on dynamic energy visualization was shown as one of possible applications. Section 2 contains the summary of our research and interest into the background of our experimental approach related UWB radar features. Section 3 will discuss design of application system for experiment. Section 4 will show our results and Section 5 will conclude our experiment and discuss future works.

RELATED WORK

A. UWB radar features

UWB radar transmits extremely short electromagnetic pulses with nanosecond duration into an object and examines the received signal in order to acquire the information of the object. The high spatial resolution of the UWB radar resulting from using ultrashort time pulses allows for the detection of closely positioned objects and provides the object information about shape, position, and material content. The shorter the pulse width of a UWB radar, the more accurate the distance measurement can be. The measurable detection distance depends on the average effective radiated power, the target response, the propagation medium and the clutter [6].

UWB radar can penetrate a variety of materials such as plastic, wood, rubber, dry soil, glass, and concrete because the short pulses spread their energy over a broad frequency range. UWB radar also has a low impact on natural environments such as snow, rain and fog. Biological materials including skin, muscle, fat, blood, and bone also can be penetrated. It has excellent tolerance to narrow band electromagnetic waves and noise from external devices.

B. Distance measurement application

UWB radar measures the distance by calculating the time-of-arrival (ToA), which is the difference in time that the pulse signal transmitted from the transmitting antenna is reflected on the target object and received on the receiving antenna, as shown in Figure 1. For instance, if the time (t) between sending a pulse and receiving its returned signal is 20 ns, we can infer that the signal was reflected at the target after 10 ns. If the target is in air, we can assume that the pulse velocity is c = 3.0×10^8 m/s, the speed of light. Using the simple relationship, d = ct/2, we find the reflecting target was positioned 3 meters away from the radar [7].

However, distance measurements become challenging when the material properties of an object are unknown. Since propagation velocity is dependent on materials, assumptions are made about the electromagnetic properties and thickness of object materials.

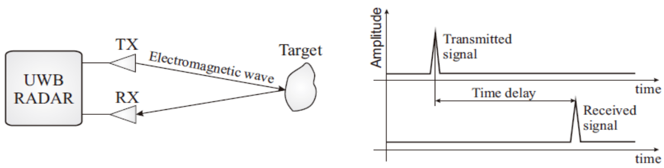


Figure 1: Basic principle of UWB radar [8].

The received signal of UWB radar will always contain more information than only the reflections from the objects of interest. The term ‘clutter’ is used to describe the general unwanted reflections from the environment. The term ‘noise’ describes the rest of the deviations from the actual signal, such as thermal, atmospheric and electrical noise [9].

In UWB radar system, the transmitting and receiving antennas are usually placed very close to each. In the received signal, a constant bias called ‘power leakage’ appears due to the close location between the transmitting and receiving antennas and this bias can be considered as clutter. These Clutter and noise need to be removed as much as possible from the received signal for accurate measurement.

DESIGN OF APPLICATION SYSTEM

This section discusses the applied implementation technique. The applied applications are consisting of two parts: first, hardware system configuration and second, signal characterization. The implemented application in this preliminary work is more focus on distance measurement application and UWB signal characterization.

The system used in this paper is a micro-scale racer with signal identification function that measures and analyzes the displacement signal generated by the object by implementing centimeter-class high-resolution radar on a single chip and connecting it to the Raspberry Pi 2 open hardware board [10]. The basic system hardware connections are outlined in Figure 2.

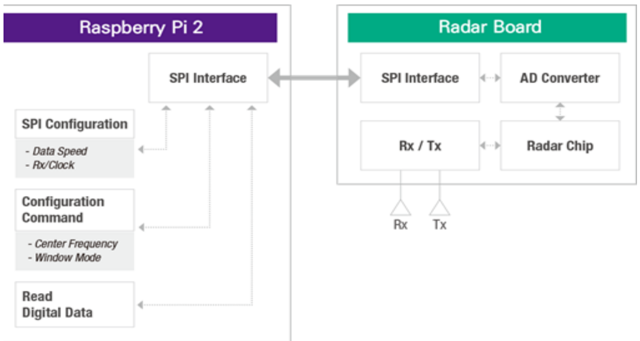


Figure 2: The Conceptual system description for overall application [11].

The antenna used in this experiment is a UWB directional antenna. Table 1 describes the characteristics of the directional antenna [12]. The characteristics of the radar sensor module on radar board used in Figure 2 are described in Table 2. The radar module uses sockets which then use a library provided by Raspberry Pi to communicate data.

Table 1: Description of UWB directional antenna

Parameter	Value
Type	Sinuous type
Gain	Avg. 5 dBi
Antenna Angle (3GHz-4.2GHz)@-3dB	70degree
Physical Size	50x50x15 [mm]

Table 2: Characteristics of radar sensor module

Parameter	Value
Detection distance	Max. 15m
Frequency Range	2.5-5GHz
Bandwidth	1GHz
Output Power	0.2-10 [mW]

EXPERIMENTAL RESULTS

The radar module uses sockets which then use a library provided by Raspberry Pi to communicate data.

A. Experimental setup and data set

The signals used in the experiments detected echoed signals from air, concrete wall, and steel doors. The system configuration described in the previous chapter has been shown in Figure 2, and Figure 3 shows experimental setup. In order to see the basic signal of each material, the UWB radar signals at the same distance of 200 centimeters for concrete wall, wood and steel plate are measured. The number of receive signal is 600 samples on 10 meters.

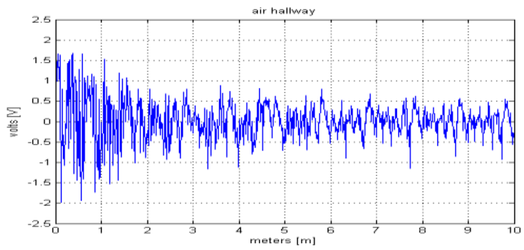
(a)

(b)

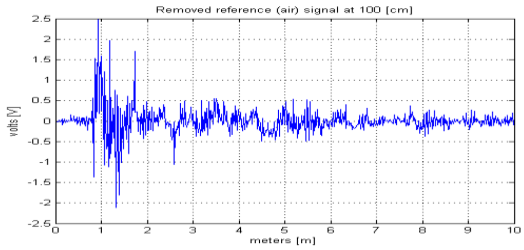
Figure 3: UWB radar system. (a) Experimental setup (b) capturing UWB radar signal against concrete wall (Width 46 x Height 44 x Thickness 10 [cm]) in hallway environment.

B. Distance measurement effect

For distance measurement application, the received signal cannot be clearly differentiated along different distance 100 [cm] and 200 [cm] against reference (air) signal in hallway environment. In order to avoid clutter and noise components, first we processed that received UWB signal should be rectified by subtracting reference signal from received signal. Figure 4-(a) described reference signal and Figure 4-(b) and (c) described removed reference signal at 100 and 200 [cm] of distance, respectively. For more effective information, we have used dynamic energy visualization by computing energy of limited duration (about 31 samples on received signal [13]. Figure 4-(d) and (e) showed the energy visualization. Even though the experimental results did not show complete distance measurement, the overall results have been shown convincible information around measured distance as shown in Figure 4



(a)



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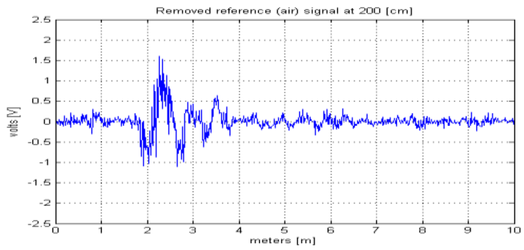
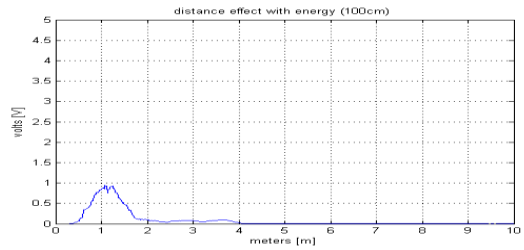
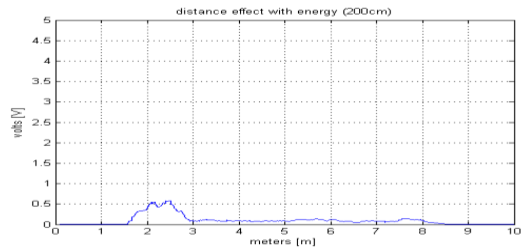


(c)



(d)

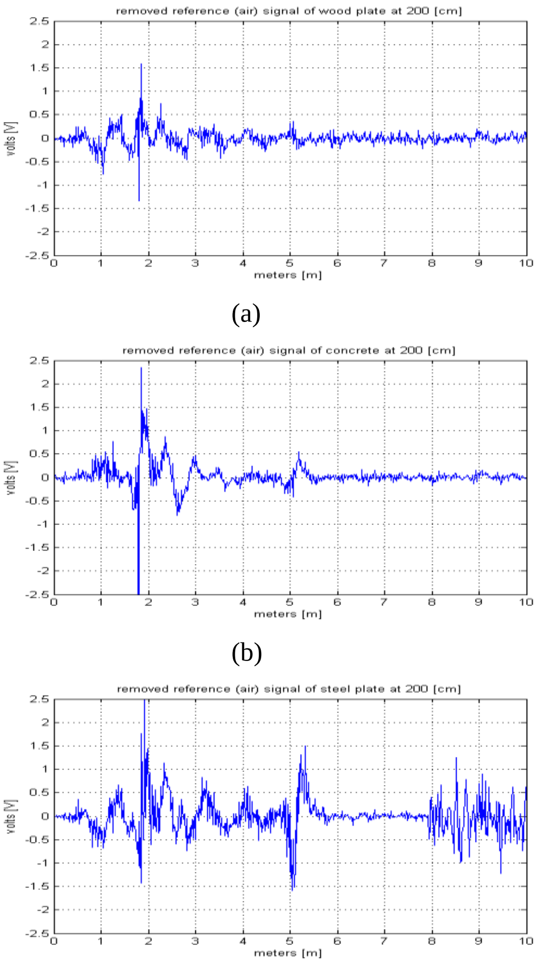


(e)

Figure 4: Results of distance measurement with raw signal and energy visualization at (a) reference (air) signal on hallway environment, (b) removed reference signal at 100 [cm], (c) removed reference signal at 200 [cm], (d) distance measurement at 100 [cm] with respect to (b) and (e) distance measurement at 200 [cm] with respect to (c).

C. *Characterization of UWB radar signal*

In order to compare the UWB radar signal, the received aw data for air, concrete wall, wood and steel plate first rectified by subtracting reference signal out of raw data as explained previous section. Figure 5 showed wood, concrete wall and steel plate at 200 [cm] of distance. As can be seen in Figure 5, we could figure out each material's characteristics on raw data itself. However, in order to effectively utilize the UWB radar signal used in various applications, the received signal must be reprocessed by filtering process and need to be smooth. In particular, the distance detection application performed in this experiment calculates the energy of the raw signal that changes instantaneously and displays the converted value at the near distance.



(a)

(b)

(c)

Figure 5: The raw signals with removed reference (air) signal: (a) wood, (b) concrete wall, and (c) steel plate at 200 [cm] of distance.

CONCLUSION

In this paper, we have explored UWB radar system for various material characterizations and distance measurement for human's movement application. For material characterization, the received radar signals have clutter and noise and could not classify them effectively even though we have seen differentiations among them. Distance measurement application using UWB radar system has been shown excellent distance detection with energy visualization results and shows possibility to be useful for search-and-rescue in disaster sites. Even though our experiment has been shown in primitive results, it could be seen possibility for various applications. However, since the UWB radar signal has its own features against various materials, it is necessary to examine a method for adopting at a higher accuracy though signal filtering process. Also, as a future application field of this study, it is necessary to study applying to various antenna types and simulations.

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