An SDR-based Experimental Setup for OFDM-based Radar

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***Abstract*—We present a software radio-based testbed for live testing of OFDM radar algorithms. Unlike previous testing setups, the hardware used (Universal Software Radio Peripherals) was low-cost and low-power, thus making the measurement setup both flexible and easy to use. The hardware can be easily battery powered. Both stationary and mobile measurements in realistic scenarios were performed.**

***Index Terms*—OFDM Radar, Software Defined Radio, USRP**

I. Introduction

OFDM radar has recently become a focus of research for use in mobile networks which combine *radar* and *communications* in a single system [1], [2], [3]. Although the proposed concept has been proven both by simulations and measurements, what is lacking is a measurement setup which is simple, small, portable and easily reconfigured. Measurement setups as described in [4] are complex and expensive. To evaluate radar and data communication at the same time several communication partners are required. With a simple and cost efficient setup this would be easily achievable.

In this paper, we will present a software radio-based approach using Universal Software Radio Peripherals (USRPs) which fulfills all these requirements. Although this hardware is not optimized for radar applications, we can still show that the principle works fine. Many measurements were performed, both with a stationary measurement setup and from a moving vehicle. In measurements, we were able to produce radar images with a refresh rate of 10 Hz.

The paper is organized as follows. Section II describes the functionality of the radar system. Section III explains the equipment used in the measurements and gives details on how the setup is configured. In Section IV, the different measurement scenarios are shown and the measurement results are discussed. Section V concludes and discusses further improvements.

II. Radar system description

A. Overview

As explained in [5], acquiring a radar image with OFDM radar works by having transmitter and receiver active at the same time, just like any other radar system. The receiver captures the reflections of the transmitted signal. In addition, the receiver also captures the transmitted signal directly because there is no perfect isolation between transmit and receive antennas. Based on the transmitted signal $\mathbf{F_{TX}}$ and the superposition of the reflected signals $\mathbf{F_{RX}}$ *target estimation* is performed; the details of the estimation process can be found in [5].

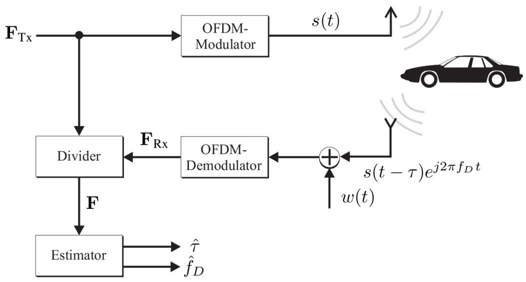


Fig. 1: OFDM Radar System Setup

B. Transmit signal

To provide real-world data, the transmitted signal is modelled similarly to the 802.11p standard [6], which is designed for vehicular environments. IEEE 802.11p uses the 5 GHz frequency range for communication. The measurement setup was not configured to also test the communication system, therefore all transmitted data simply consisted of pseudo-random sequences.

In the current state, the transmit bandwidth can be set to any value up to 25 MHz. The 802.11p standard specifies bandwidths of 5 MHz or 10 MHz. Depending on the scenario, the signal bandwidth was either 10 MHz with a FFT size of 64 and 52 active carries or 25 MHz with a FFT size of 128 and 116 active carriers. By varying these parameters, the measurements were used to both test the usability of the standard-conform signals as well as testing the maximum range accuracy of our setup.

C. Challenges

While synchronisation is easy in simulation, the transmitter and receiver also have to be kept synchronous while performing measurements. Range estimation is performed by estimating the delay between transmit and receive signal; a different starting time for these signals would therefore severely affect the estimated distance of an object. Analogously, Doppler

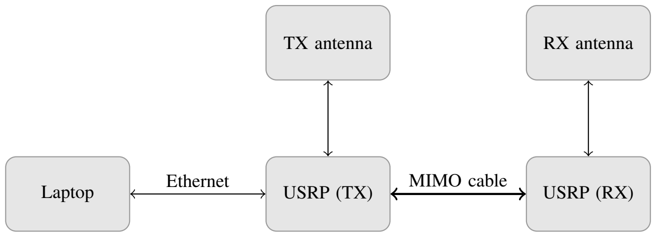


Fig. 2: OFDM Radar Measurement Setup

estimation consists of estimating the frequency offset of the received signal. If the receiving terminal's oscillator were already offset from the transmitter's, the Doppler estimation would also be affected negatively.

Another problem is the isolation between transmit and receive terminals. Depending on the distance of the targets, the power of the reflected signal is very low. In most cases the power of the direct coupling is higher. This limits the dynamic range.

III. Measurement Setup

A. Hardware

The measurement setup consists of two USRP N210, each equipped with XCVR2450 daughterboards to allow transmission and reception in the $5\,\mathrm{GHz}$ range and a horn antenna. The USRP N210 is a popular software-defined radio which supports different daughterboards to transmit and receive in different frequency ranges. While most of the signal processing is done on the PC and FPGA of the USRP N210, the daughterboard modulates the baseband signal onto the carrier frequency. In addition to modulation several daughterboards also offer low-pass filtering before modulation to reduce aliasing.

The XCVR2450 is the only daughterboard available for the USRP N210 that allows transmitting and receiving in the $5\,\mathrm{GHz}$ range. The modulation and most of the filtering of the XCVR2450 is performed by a MAX2829ETN, which is a 802.11a/b/g transceiver IC. Since full-duplex is not required for *Wireless LAN* this transceiver only offers half-duplex operation, making the XCVR2450 incapable of full-duplex operation.

As explained in Section II OFDM radar requires capturing the reflections while transmitting and therefore requires full-duplex capabilities. To fulfill this requirement two USRP N210 were used. This solves the problem of transmitting and receiving at the same time, but results in an additional problem: *oscillator offset*. To estimate the distance and velocity the propagation delay and Doppler shift of the reflected signals have to be measured with high accuracy. Because each USRP N210 has its own oscillator this results in a frequency offset which is usually higher than the Doppler shift and therefore has to be eliminated. We therefore connected both USRPs with a MIMO extension cable, which offers the possibility to synchronize both oscillators as well as to forward the baseband signal from one device to the other. In this fashion, USRPs could be driven from a single Ethernet connection. The resulting measurement setup is shown in Figure 2.

Compared to the measurement equipment used in [4] the power consumption of this measurement setup is very low. Each USRP N210 has a maximum power consumption of $18\,\mathrm{W}$. Most laptops require less than $50\,\mathrm{W}$. The whole experimental radar system has a power consumption of less than $90\,\mathrm{W}$.

Depending on the scenario different antennas were used. For the stationary setup, we connected horn antennas with a gain of $18.5\,\mathrm{dBi}$. However, the dimensions of the horn antennas are to large for them to be included in the bumper of a car. Therefore patch arrays with a gain of $13\,\mathrm{dBi}$ were used which could be integrated into the test vehicle.

B. Software

The two USRP N210 were controlled using the USRP Hardware Driver (UHD) API. This API makes it possible to synchronize the oscillators and schedule transmit and receive tasks. All samples of the radar burst are transfered to the transmit buffer before the measurement begins. This avoids simultaneous transfers on the ethernet interface and reduces the probability of lost packets. The disadvantage of this solution is the limitation of the burst size. The on-board memory holds a total of 262144 samples, which is therefore the maximum size of an OFDM radar frame. Using the UHD API, it is possible to detect the loss of packets, in which case the measurement is repeated. All signal processing and configuration is performed on the connected host PC using Matlab. Possible configuration parameters include receiver gain, transceiver gain and number of consecutive measurements.

IV. Measurements

A. Scenarios

To evaluate the capabilities of the experimental setup measurements were performed in various scenarios.

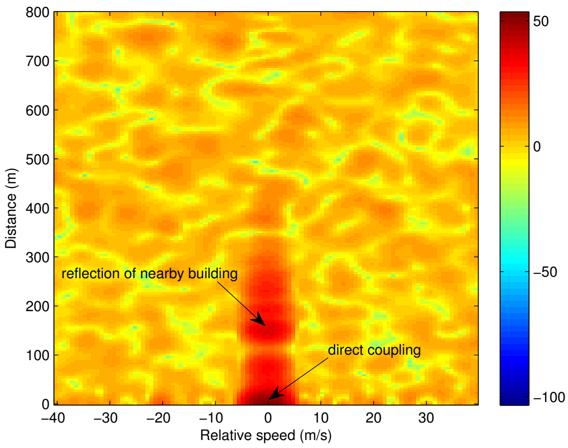
a) Scenario 1: Stationary target: For calibration and testing purposes, a very simple scenario was constructed which consists of a stationary radar measurement system and stationary targets. To reduce clutter, measurements were performed on a rooftop with antennas facing towards a nearby building. The scenario is depicted in Figure 3a.

b) Scenario 2: Moving target: A more realistic scenario with reduced distances. The measurement setup was still stationary but no longer on a rooftop. This causes clutter and reduces the quality of the radar image. A moving target was added to be able to estimate its velocity.

c) Scenario 3: Moving measurement setup: The most realistic scenario is a moving measurement setup with stationary and moving targets. The measurement equipment was installed in the back of a car and antennas integrated in the rear bumper. Measurements were performed on the motorway, at various speeds and in different traffic conditions.

Figure 3b shows the measurement result for a stationary measurement system with one stationary target. The signal bandwidth is $10\,\mathrm{MHz}$ with a FFT size of 64. Out of 64

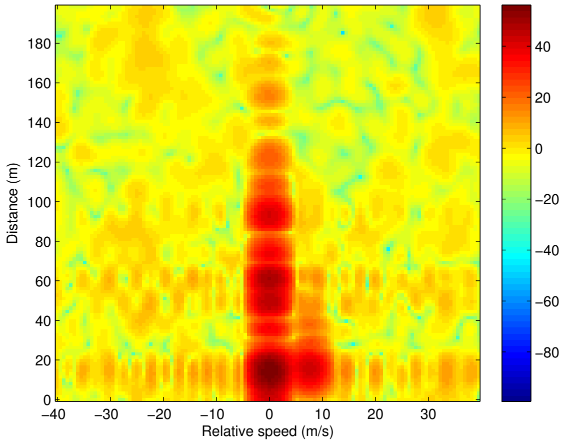
(a) Measurement setup



(b) Measurement result

Fig. 3: Stationary setup and stationary targets

(a) Measurement setup



(b) Measurement result

Fig. 4: Stationary setup with vehicle approaching at a speed of approx. $8\ \mathrm{m/s}$

possible carriers 52 were used. One problem which can be clearly seen in the Figure 3b is direct coupling of the signal. The power of the direct coupling is more than $14\ \mathrm{dB}$ higher than that of the strongest target.

The result including clutter and a moving car is shown in Figure 4b. The moving target can easily be identified despite having the same distance as another car. The result of the clutter is shown with a velocity of $0\ \mathrm{m/s}$.

In the same scenario the car was replaced by a bicycle which has a significant smaller radar cross section. Compared to the radar image of the stationary car the bicycle reflects far less power, but because of the Doppler shift it can still be recognized as a target (see Figure 5).

As shown in Figure 7 the measurement equipment was integrated into a car to perform measurements on the motorway. The result is shown in Figure 6. The direct coupling has a stronger effect because the antennas have weaker isolation compared to the horn antennas. Since all stationary items are moving relative to the car a lot of other objects are shown. The measurement setup can produce radar images with a refresh rate of $10\ \mathrm{Hz}$.

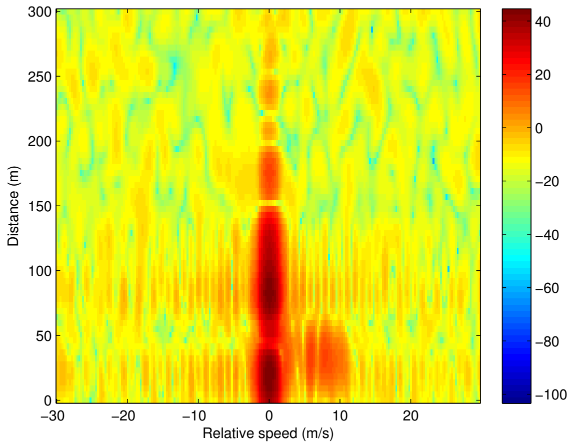


Fig. 5: Measurement with stationary measurement setup and a moving bicycle.

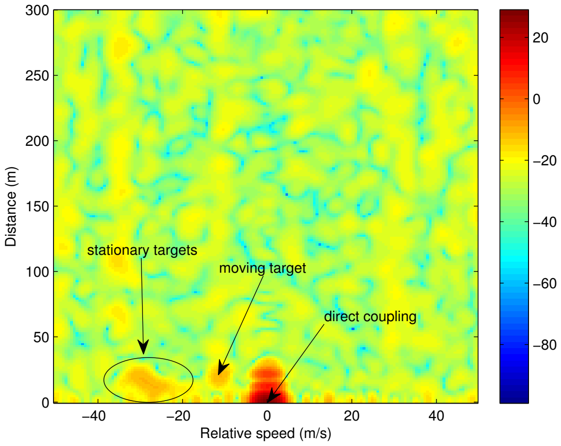


Fig. 6: Measurement on motorway with mobile measurement setup and stationary/moving targets

V. Conclusion and Future Work

The measurement results show that it is possible to construct an OFDM Radar system with USRPs. This offers a low price, flexible measurement setup where measurements can be performed in many scenarios to test the usability of radar algorithms.

While already delivering good results the accuracy could be improved if the signal bandwidth were increased. The DAC/ADC of the USRP N210 offer a complex sample rate of $100\ \mathrm{MS/s}$; however, this is currently not supported by the software. Modification of the firmware to use the buffer also for received signals would allow to use an increased signal bandwidth, potentially allowing the use of the full $100\ \mathrm{MHz}$. This would improve the range resolution to less then $2\ \mathrm{m}$.

Fig. 7: Setup for motorway measurements

References

[1] C. Sturm, E. Pancera, T. Zwick, and W. Wiesbeck, "A Novel Approach to OFDM Radar Processing," *Radar Conference, IEEE*, May 2009.

[2] C. Sturm, T. Zwick, and W. Wiesbeck, "An OFDM System Concept for Joint Radar and Communications Operations," *Vehicular Technology Conference, 2009. 69th IEEE*, April 2009.

[3] C. Sturm, "Gemeinsame Realisierung von Kommunikation und Radar auf Basis von OFDM," Ph.D. dissertation, Karlsruhe Institute of Technology, 2011, available online at www.ubka.uni-karlsruhe.de.

[4] C. Sturm, M. Braun, T. Zwick, and W. Wiesbeck, "Performance Verification of Symbol-Based OFDM Radar Processing," *Radar Conference, IEEE International*, 2010.

[5] M. Braun, C. Sturm, and F. K. Jondral, "Maximum Likelihood Speed and Distance Estimation for OFDM Radar," in *IEEE Radar Conference*, Washington D.C., 2010.

[6] IEEE Computer Society, *IEEE Std 802.11p-2010 (Amendment to IEEE Std 802.11-2007 as amended by IEEE Std 802.11k-2008, IEEE Std 802.11r-2008, IEEE Std 802.11y-2008, IEEE Std 802.11n-2009, and IEEE Std 802.11w-2009)*, 15 2010.