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UWB Radar: Distance and Positioning Measurements

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Abstract – **The article presents the performance of the bistatic UWB radar applied to measure the distance between transmitter and receiver and to determine the position and velocity of an object. Three different measurement examples will be presented. In the first one, the theoretical limitations of the UWB radar to determine the exact pulse position (distance measurement) will be demonstrated. The second and third example demonstrate UWB radar's ability to measure the object position and its velocity (passive and active positioning approach).**

1 INTRODUCTION

Ultra wideband (UWB) radar is of great interest for a vast number of applications such as surface penetrating radar, surveillance and emergency radar, medical instrumentation, non-destructive testing in civil engineering and the food industry, industrial sensors and microwave imaging and many others.

The fractional bandwidth of the sounding waves for such types of applications should be as close as possible to 200 % resulting in a high spatial resolution and good penetration in materials. An UWB radar is able to detect hidden objects and a high bandwidth not only results in good spatial resolution but also in improved capabilities for object recognition.

Since UWB radars have excellent spatial resolution it is supposed that they can be advantageously applied in the field of positioning and navigation. There are a number of applications that would take advantage of precise indoor positioning and navigation such as automatic storage, tracking of various targets (e.g. at airports), or people in dangerous environments (policemen, firemen) and so on. Global positioning satellites (GPS) based systems are limited in the area of indoor positioning and navigation, because it is only possible to achieve precision to within a few tens of meters [1]. This is obviously insufficient for above mentioned applications. Fortunately, applying UWB based systems in indoor positioning and navigation situations overcomes the drawback of the limited GPS based system accuracy and by achieving centimeter or sub-centimeter positioning precision.

The goal of this article is to illustrate the ability of UWB radar to measure the distance as well as the position and the velocity of an object. Here, three different measurement examples will be presented:

- distance measurement,
- 2D positioning - passive approach,
- 2D positioning - active approach.

The UWB radar available at TU Ilmenau was used for the experiments. It covers the band from near DC to 5 GHz [2] and it transmits instead of ultra short pulses continuous low crest factor signals (spreading sequences).

Firstly, the article describes the UWB radar used for the measurements in more detail. Then, two different positioning approaches are presented. Finally, experimental results of the three measurements mentioned above are illustrated.

2 UWB RADAR

The key to a powerful UWB-radar is the use of an appropriate stimulation signal because the whole device structure and the radar efficiency depends upon it. Therefore, the stimulus should be generated in a stable manner by simple means up to several GHz bandwidth. It should be periodic in order to apply cost effective under-sampling methods for signal gathering and to avoid a spectral bias error [2]. It should also feature low crest factor because such signals do not burden the electronics extremely which results in stable and fast operation. Furthermore, low level signals may be produced in integrated RF-circuits promoting a further improvement in bandwidth.

Signals that meet these requirements are e.g. maximum-length-binary-sequence (MLBS). They can be generated for up to tenths of GHz of bandwidth and they have high energy even at small amplitudes. Thus, they are suitable to be handled by integrated circuits and may be switched extremely fast. Their low crest factor promote a high bandwidth and an excellent jitter performance.

Figure 1 presents the basic concept of the baseband MLBS radar and its implementation as SiGe customer ICs in comparison to a pinhead. This radar covers the band from near DC to 5 GHz [2]. The circuit schematics are completely laid out in a symmetrical manner providing the opportunity to feed all types of antennas. Signal capturing, averaging and impulse compression were managed

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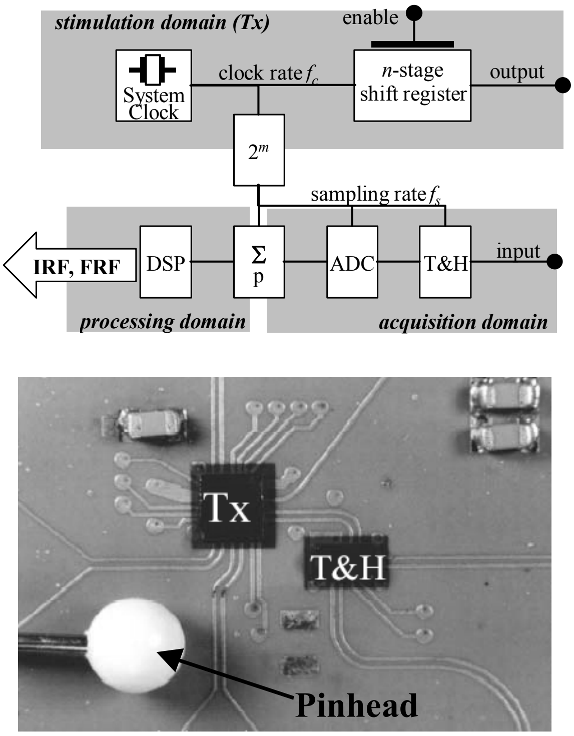
by commercially available components mounted on a 150 x 90 mm PCB [3].



With courtesy of MEODAT GmbH Ilmenau

Figure 1: Basic concept of baseband MLBS radar and its implementation as SiGe customer ICs

3 POSITIONING

There are two different positioning approaches: active and passive. The main difference between these two approaches is that the active approach presumes that objects to be positioned "cooperate" with the positioning device and carry one part of its hardware usually receiver whereas the passive approach is a standalone positioning device. This fact results in following features:

- Active approach:
  - Object cooperation is necessary
  - Synchronization between transmitter and receiver is necessary
  - Easy signal (LOS signal) detection
- Passive approach:
  - No object cooperation – can be used as a standalone positioning device
  - The object radar cross section (RCS) is assumed to be known
  - Problematic signal (non-LOS) detection – constrained coverage
  - Perfect synchronization between transmitter and receiver

4 EXPERIMENTAL RESULTS

The theoretical limitations of the developed UWB radar to determine the exact pulse position (distance measurement) are demonstrated by the first experiment. The measurement was performed by the UWB radar, which transmitter and receiver were connected through the mechanical delay line allowing 0.1mm precise delay measurements. Performed were 38 measurements with different delays adjusted by the delay line (20 measurements with 200 µm delay step, 9 measurements with 2mm delay step and 9 measurements with 2cm delay step). Calibrated measured data are displayed in Figure 2.

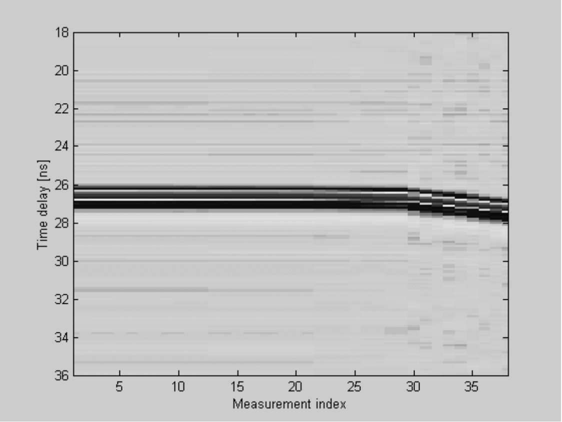


Figure 2: Measured data

Each measured scan contains 511 samples that are spaced 111ps apart from each other. It means that the delay estimation using only a simple maximum value detection would only provide resolution of about 3cm. The resolution can be iteratively increased by using a maximum likelihood (ML) estimator. The result of the delay estimation using ML estimator minimizing the cost function by Gauss-Newton method is presented in Figure 3. The solid line represents ideal delay and black dots represent the estimation result.

The estimation error is depicted in Figure 4. Here, it is possible to see that the error for small delay variations (first 20 scans) is under 200um. The estimation error increases as the delay variations are larger. This can be explained by the fact that the estimation results depend on the measured pulse shape. Since the shape is influenced by interfering signals (e.g. electronics cross-talk) the larger the pulse position variation the higher is the influence of the interfering signals on its shape. This effect can be diminished or completely removed by proper calibration.

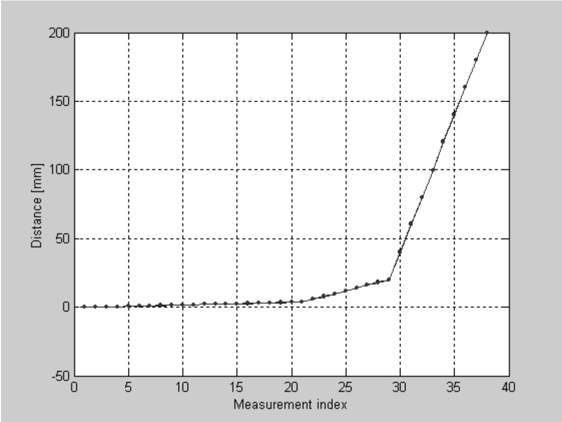


Figure3: The distance estimation

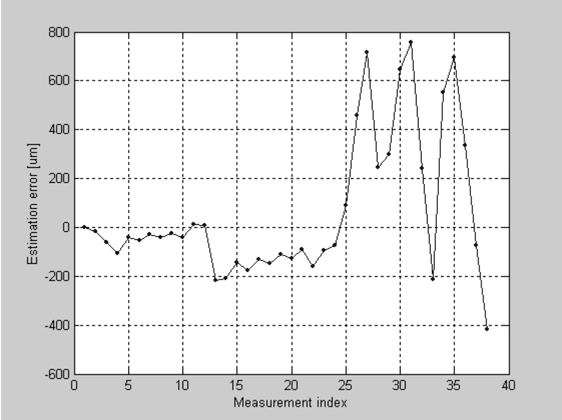


Figure 4: Error of the distance estimation

The second and third example demonstrate UWB radar ability to measure object position and its velocity (for the simplicity only 2D positioning was performed). In these examples both passive and active positioning techniques are presented. In both cases, objects to be tracked were mounted on a positioning unit [4] allowing the precise positioning of objects in an area of 2 meters by 4 meters with 0.75 mm precision in two directions. Continuous sweeps may be realized with a maximum displacement speed of about 130 mm/s in x-direction and 170 mm/s in the y-direction, respectively.

Objects to be positioned were moved along a predefined track with the maximum velocity allowed by the positioning unit. There were 8 positions at which the objects stopped for two seconds. Data was geathered by the UWB radar with measurement rate adjusted to be approximately 11 scans per second and the whole measurement lasted only for about 90 seconds. A linear Vivaldi antenna array containing four antennas was used as the receive antenna and a biconical omni directional antenna was used as the transmit antenna.

The second example demonstrates the passive positioning approach. Here, the object to be positioned was a metal box with the size of 0.5m x 0.5m x 0.1m. The RCS of the box was not taken into account. Thus, the positioning accuracy will be only comparable with the box size since its RCS is strongly angle dependent.

Two different methods for the distance estimation were compared. The first method estimates distance only using match filter (MF) and maximum value detector. The second method uses ML estimation.

The result of the positioning using the MF based method and signals from two receive antennas (from array with the maximum distance between antennas) are illustrated in Figure 5. Here, the solid line represents the object track followed by the positioning unit. Estimated positions are illustrated as dots. Receive antennas are illustrated as circles and transmit antenna is illustrated by an asterisk around the beginning of the coordinates system.

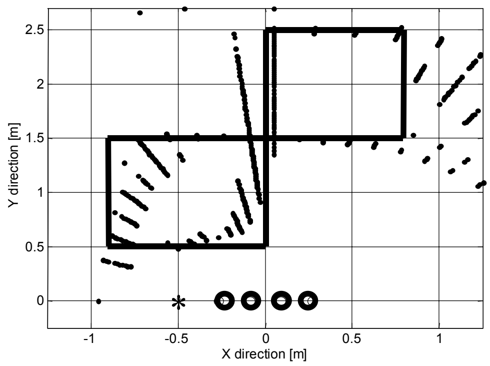


Figure 5: Position estimation – passive approach

In the figure, it is possible to see that the estimated positions do not create a fluent track, however they are scattered into "clusters". This is caused by the limited resolution of the MF based distance estimation method that is only about 3cm. This drawback can be improved by a better estimation technique. Figure 6 contains results of the position estimation using ML

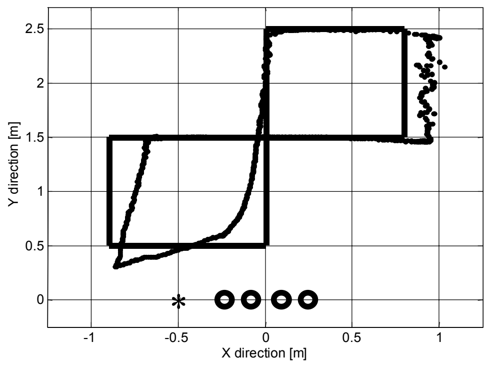


Figure 6 ML position estimation – passive approach

distance estimation method. It is possible to observe that the estimated positions follow a continuous track. However, it is obvious that estimated track is far away from the real one. This is caused by neglecting the RCS of the tracked object. This disadvantage can be removed only by taking into account the object RCS or implementing active approach for the object positioning.

The third example illustrates the active positioning approach. Here, object to be positioned was omni-directional transmit antenna attached at the positioning unit and connected with the UWB radar by a long cable. It means that there were no problems with the transmitter-receiver synchronization. The result of the positioning using the MF based method is depicted in Figure 7. Here, estimated position are scattered into "clusters" what can be removed by the better distance estimation method as can be seen in the Figure 8, where results of the ML estimation method are presented.

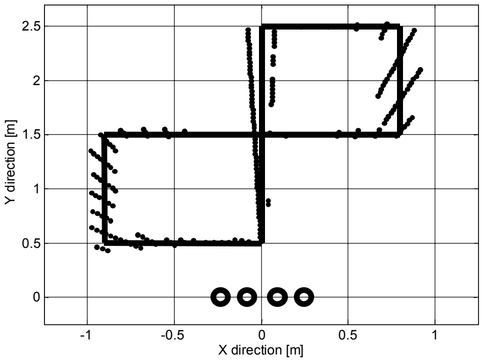


Figure 7: Position estimation – active approach

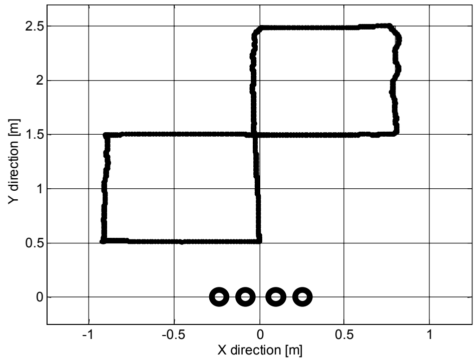


Figure 8: ML position estimation – active approach

Figure 9 contains results (magnitude of the velocity vector) of the object velocity estimation based on the data presented in Figure 8. It is possible to recognize object stops that lasted for 2 seconds (zero velocity), velocities around 130mm/s that corresponds to the track parts where the object was moved in X direction with the maximum X positioning unit velocity and velocities around 170mm/s that corresponds to the track parts where the object was moved in Y direction with the maximum Y positioning unit velocity.

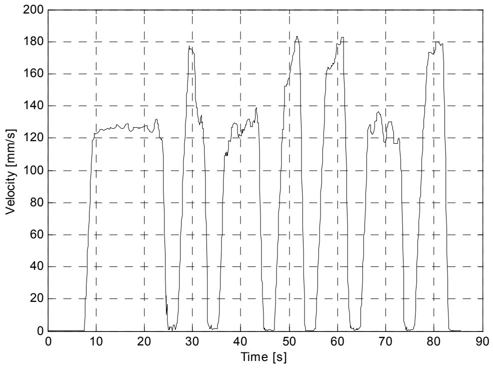


Figure 9: Velocity estimation – active approach

5 CONCLUSIONS

In this article the basic advantages and drawbacks concerning two different positioning approaches were shortly discussed. An example of the system performance applying UWB radar for the distance measurements or object positioning was presented. It was shown that it is possible to achieve distance resolution on the order of fractions of millimeter and position resolution on the order of a centimeter using UWB radar with sophisticated estimation procedures. The positioning and distance measurement can be a useful add-on feature to our UWB radar and can broaden its implementation environment.

REFERENCES

[1] G. Opshaug, P. Enge, "GPS and UWB for Indoor Navigation", GPS Conference, Sep 2001 , Salt Lake City, USA

[2] J. Sachs, M. Roßberg, P. Rauschenbach, P. Peyerl, J. Friedrich, "Integrated UWB Radar Circuit for Base Band Applications from DC to 5 GHz," GRS 2000 , October 2000, Berlin, Germany

[3] M. Roßberg, J. Sachs, P. Rauschenbach, P.Peyerl, K. Pressel, W. Winkler, D. Knoll, "11 GHz SiGe Circuits for Ultra Wideband Radar," IEEE Bipolar/BiCMOS Circuits and Technology Meeting, Minneapolis, USA September 25-26, 2000

[4] R. Zetik, J. Sachs, B. Schneegast: Non-Destructive Testing with Imaging Radar: First Experience with a Laboratory Equipment. Proceedings IWK-98, Ilmenau