

Investigation and suppression of multipath influence on indoor radio location in the millimeter wave range

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Abstract — A very high precision 3D radio based positioning system is introduced which can work in a high reflective scenario and reaches an accuracy of a few millimeters. This radio location system is based on a direct sequence spread spectrum (DSSS) transmission at a carrier frequency of 24GHz. This concept demonstrates high robustness against interferers as well as high suppression of reflections. With an adequate object tracking using Kalman filters and a sophisticated combination of the different input information it offers very high precision with an uncertainty of 0.1 mm, even in highly reflective indoor environment.

Index Terms —local positioning, radio location, DSSS, high precision, indoor.

I. INTRODUCTION

In an increasing range of indoor applications a precise localization of objects is required. The growing number of applications - for example object tracking or automatic gauging in industrial environment as well as safety facilities needs robust and highly accurate positioning systems. During the past years, several research efforts have been reported, achieving accuracies in the range of inches [1, 2]. These were FMCW-based systems that detected the transponder mounted at the object by solving the FFT and calculating the hyperbolisation of at least three receivers and one reference station. These state of the art systems were optimized for tracking objects over long distances with a high measurement repetition rate. For industrial applications in a highly reflective scenario demanding an accuracy of a few millimeters however a new concept is required. Thus a radio based positioning concept was introduced in [3] which can offer the required precision. In [4] a first 3D-demonstrator of this DSSS-positioning system has been described. The achieved uncertainty of only around 0.1mm in a resting position within a coverage volume of more than $2m \times 2m \times 2m$ fulfilled the required accuracy. This was reached by a wideband spread spectrum concept in combination with a sophisticated high speed digital signal and data processing. The parameters of the radio system are listed in table I.

The following contribution describes the extension of the system towards a higher robustness in order to handle near range multipath (NLOS) signals. The promising approach for this was to improve the digital signal processing.

The transponders are mounted onto the object to be tracked. As in industrial use these transponders often get close to metal parts the signals are highly affected by multipath propagation effects. Therefore, a high accuracy positioning is hard to get and a new improved signal processing method is necessary in order to suppress such multipath propagation effects.

Several methods are investigated and verified by a simulation with the special designed system simulator [4]. Furthermore the recent algorithm [4] is combined with the new optimal method to suppress multipath propagation effects. So the 3D-transponder can be detected with recent reproducibility, accuracy and improved robustness against multipath effects.

This paper is organized as follows: Initially, we present the scenario in which the 3D-positioning system should work with an emphasis on the industrial environment. Then, we anticipate the distance resolution of the positioning system and two methods for the suppression of NLOS-signals. We verify both methods and combine the optimal method with the recent algorithm. Finally, we show that the accuracy of the new algorithm can be successfully applied in a distance measurement scenario.

TABLE I

RF system parameters of the local positioning system

Parameter	Value
Carrier frequency	24GHz
Bandwidth	3.2GHz
Modulation technique	BPSK
Chip rate $1/T_c$	1.6 Gchip/s
Output power	0dBm
Coverage	10m
Transmission technique	DSSS

II. INDUSTRIAL PROPAGATION SCENARIO

The objective is to evaluate the exact position of the transponders mounted on a marker in a highly reflective area. This combination of transponder and marker is further called radio pen. The realization of this device is described in [5]. The reflective area might be for example a factory floor as shown in fig. 1 which also represents the conditions for the radio positioning system.

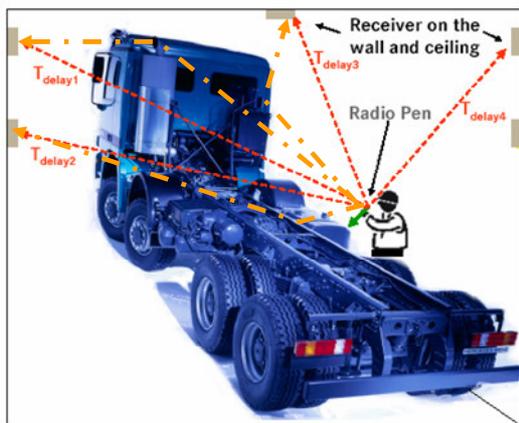


Fig. 1: Multi propagation scenario

In this indoor positioning scenario and considering [3,4] the radio pen transmits the PN-coded signal. The receivers on the wall and ceiling get this signal with a time delay depending on the distance from the radio pen. So, with the time of arrival (TOA) measurement the distance between the receiver and the transmitter can be calculated. With at least four undisturbed receiver signals the 3D position can be calculated via Trilateration. In fig. 1 there are also sketched some NLOS-signals (dotted orange lines) which disturb the received LOS-signal.

Our goal now is to find ways within the limitations given by the system architecture to avoid the deterioration of the localization measurement caused by this disturbed reception.

III. DISTANCE RESOLUTION

One solution to the target above is to make use of the distance resolution of the positioning system. The distance resolution indicates the capability of a system to separate measured objects. Generally the first received signal from the transmitter has to be the LOS-signal and the following signals consequently have to be NLOS-signals, as shown exemplarily in fig. 2. According to theory the resolution of a system is the unambiguous isolation of two stages. For our PN-coded system an unambiguous separation is defined by a single chip, with a duration of T_C . For the PN-coded system we get therefore a distance resolution of

$$\Delta d = c_0 T_C, \quad (1)$$

where c_0 the velocity of light. With the chip duration from table I, the system shows a distance resolution of $\Delta d = 187.5\text{mm}$.

The correlation function (CF) of the received PN-code $c_r(t)$ and the receiver PN-code $c_t(t)$ for a M-sequence-code with the code length N_C is

$$CF(\tau) = \int_{-\frac{N_C T_C}{2}}^{\frac{N_C T_C}{2}} c_t(t) c_r(t+\tau) dt = \begin{cases} N_C & \text{for } \tau = 0 \\ -1 & \text{else} \end{cases} \quad [6]. \quad (2)$$

The delay $\Delta\tau$ of the correlation peak (CP) maximum against the code phase contains the distance information. The red trace in fig. 2 shows the superposition of the LOS-signal of the first incoming CP with the following CP of the NLOS-signal. As sketched in fig. 2 the superposition result can be clearly separated in the LOS- and NLOS-component if the condition

$$\Delta d < d_{NLOS} - d_{LOS} \quad (3)$$

is applied.

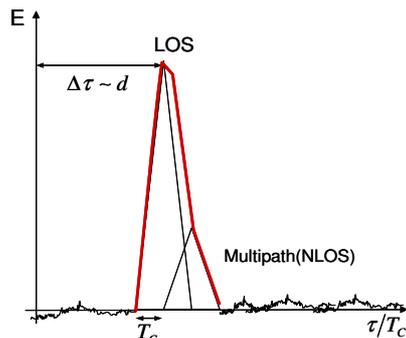


Fig. 2: Distance resolution

Allowing for the condition of (2) an algorithm for the detection of the LOS-CP is investigated.

IV. ALGORITHM

Two methods can be used to calculate the distance: the detection of the first maximum of the CF or the detection of the first rising edge of the CF. In the following both methods are compared.

At first a closer look to the maximum detection, is shown in fig. 3. This method detects the highest peak of the CF inside a search window. With this window the search region over the time shift τ is enclosed. The width of the search window is crucial to suppress MP-effects behind the first CP, because a positive superposition of many NLOS-signals could lead to a bigger CP as the LOS-CP itself.

The accuracy of this method is based on the sampled analog CF with the sampling frequency $1/T_S$. With respect to the concept [3] the CF after the analog demodulation is AD-converted. Accordingly the uniformly distributed error from the time discretion is

$$t_e = \frac{T_S}{2} \quad [7]. \quad (4)$$

Corresponding to (4) the theoretical reachable distance accuracy ϵ_M is

$$\epsilon_M = \frac{c_0}{N_C T_S}. \quad (5)$$

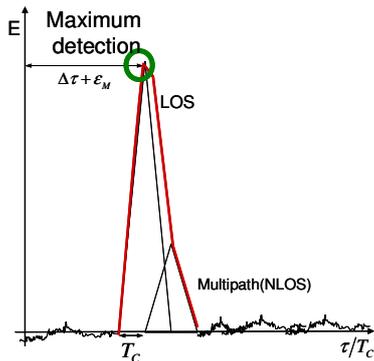


Fig. 3: Measurement accuracy, Maximum detection

The edge detection of the first correlation peak is the second method to get the code phase shift delay $\Delta\tau$. In this case several measurement points of the time discrete CF of the first rising edge are used. At the next step a line is laid optimally over these measured points. The code shift is proportional to the intersection of the calculated line with the x-axis. So the code shift $\Delta\tau$ results to the distance as

$$d = c_0 \left(\frac{1}{N_C T_S} \Delta\tau + T_C \right). \quad (6)$$

Subsequently the rising edge of the CF is measured with three measurement points. This constellation is shown in fig. 4.

With this method the distance accuracy ϵ_E , which is influenced from the AD conversion resolution n_b in bits, can be calculated as

$$\epsilon_E = \frac{c_0}{2^{n_b} N_C T_S}. \quad (7)$$

This means, that the theoretical accuracy of the edge detection better than the maximum detection by a factor of 2^{n_b} .

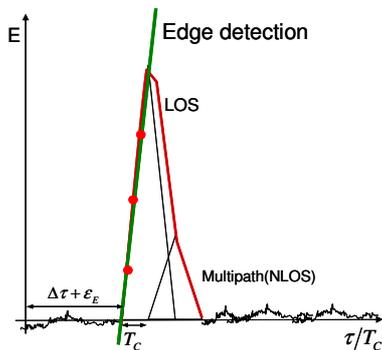


Fig. 4: Measurement accuracy, Edge detection

In the next step both methods are investigated according to their robustness against multipath effects. For this purpose a special system simulator [4], designed to get technical expertise of the system before a demonstrator was developed

is used. This simulator was further continually used to verify the implemented system during the development phase of the demonstrator.

IV. SIMULATION

The simulator of the PN-coded positioning system was designed with the functional blocks transmitter, propagation channel and receiver. The transmitter contains the code generator, the oscillator, the amplifiers and the filters. Each of these components has its special subset of parameters such as noise value, jitter and their frequency response. The channel is modeled by a single LOS-signal, several NLOS-signals and additional white Gaussian noise (AWGN). By setting all parameters of the channel module the system is able to handle as well a highly reflective scenario and a scenario without reflections. The receiver was modeled using different architectures, like the direct conversion and the superheterodyn principle.

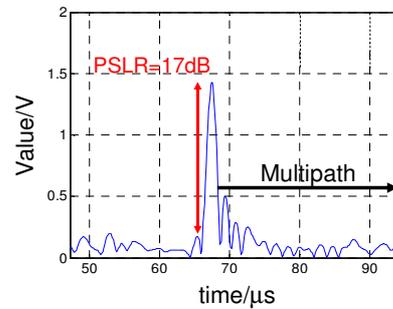


Fig. 5: Simulation

The simulator output is the magnitude and the phase delay of the correlation function over the time. An example of the CF magnitude output is shown in fig. 5. Here, the first peak represents the LOS while the subsequent peaks are from multipath effects. This example results in a peak to side lobe ratio (PSLR) of 17dB.

V. VERIFICATION AND RESULTS

As our special system simulator offers the ability to model the propagation channel with or without reflections now the accuracy of distance measurements with the peak detector and the edge detector can be simulated and compared in different environments. An essentially capability of the simulator is further on its feature to shift the length of NLOS-paths in very small steps corresponding with parts of a chip. Additionally very short LOS- and NLOS-paths differences are simulated.

The simulator's propagation channel module is based on the AWGN-channel model where the LOS-path is disturbed by one additional NLOS-path. To verify both detection methods the LOS-path has to maintain the same distance of 2000mm and the AWGN channel the same noise level for the whole verification. The variable for this verification is the relative

distance between the LOS and the NLOS-path expressed in chip numbers, starting with 0 chips and ending with 3 chips. The subset of these constellations of the different NLOS-paths is shown in fig. 6.

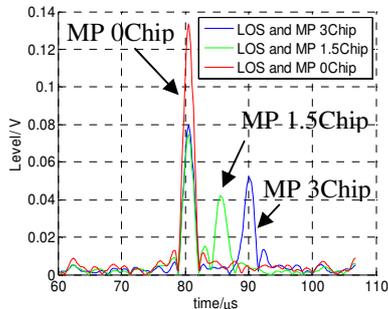


Fig. 6: Test set CF of a LOS- and a MP-signal

The simulation results are shown in fig. 7 where the calculated distance of the maximum detection (red dotted curve) and the edge detection (blue star marked curve) are plotted over the relative distance between the LOS- and the NLOS-signal on the x-axis.

From 3 chips (at the right end of the x-axis) down to a relative delay of 1.5 chips only a small distance errors occur with both methods. With short delays however the peak detection shows errors of about 15mm at 1.5 chips up to 45 mm at 0.6 chips. With the edge detection the error in the distance measurement stays below 5mm as long as the NLOS-path is not shorter than 0.4chips.

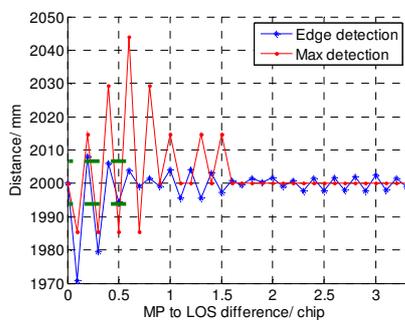


Fig. 7: Distance estimation without additional filtering

So, a positioning system with the edge detection method can suppress NLOS-paths errors if the path difference is above

$$\Delta d = 0.4c_0 T_c = 75\text{mm} \quad (8)$$

if a threshold in the distance error of $\lambda/2 = 6.25\text{mm}$ is given, with the wave length $\lambda = 12.5\text{mm}$ of the carrier frequency.

The object of the edge detection algorithm to get this 0.4chip is to set the parameter of the calculated line for the measured edge in a way, that the noise floor of the CF does not affect the lower measured points and also get the upper measured points as deep as possible by considering a stable edge approximation.

The plot at fig. 8 shows the result of a distance measurement in a resting position with the new implemented edge detection in the proved algorithm. An uncertainty of only about 0.1mm by means of standard deviation can be measured for a static distance.

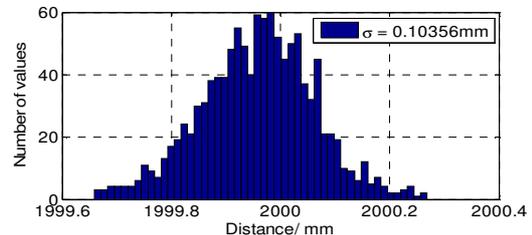


Fig. 8: Distance estimation

VI. CONCLUSION

The PN-coded 3D radio location system at a carrier frequency of 24GHz and a bandwidth of 3.2GHz has been introduced with a new algorithm to suppress multipath effects for the precise tracking of a transmitting antenna via three parallel distance measurements in a multi reflective area. The resolution of the system is increased from 187.5mm to 75mm. Further more the new algorithm together with the Kalman filter algorithm can be reproduced with an uncertainty of about 0.1mm at static positions of the transponder.

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