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Simultaneous Rotation and Distance Measurement using Multiband Circularly Polarized Radio Link

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Simultaneous Rotation and Distance Measurement using Multiband Circularly Polarized Radio Link

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Abstract **– The paper proposes a method for simultaneous measurement of rotation and distance by using a multi-band circularly polarized radio links. The method is realized using a standard dual-band patch antenna, operating at 1.58 GHz and 2.27 GHz, with respective axial ratios of 1.7 dB and 1.0 dB. Both link distance and antenna rotation were varied from a reference position/orientation from -40 mm to +40 mm and from 0° to 360°, producing a total set of 125 samples. For a noiseless link the distance change and rotation were predicted with respective mean errors of 1.9 mm and 7.3°.**

Index Terms **—Sensors, Antennas, Circular Polarization, Dual-band antennas.**

1. Introduction

It is expected that future implementations of smart society solutions will require data about position and orientation of various daily-use objects. Although positioning and ranging with radio signals has been extensively researched, the orientation sensing is somewhat left behind. Current approaches mostly rely on dedicated sensor [1] and use radio link only to transmit processed data on object rotation.

The proposed paper demonstrated a method to simultaneously measure distance change and rotation from the phase data of a dual-band Circularly Polarized (CP) radio link. The technique is an implementation of the principle reported in [2], which demonstrates the linear dependency between the phase of a CP signal and rotation of its transmit antenna. The aim of this paper is to demonstrate, that the phase changes due to rotation and due to distance change are distinguishable from each other when using dual-band [3-4] or wideband [5] CP. This allows system to be used for simultaneous measurement of both distance and orientation.

2. Principles of operation

As demonstrated in [1], a rotation γ of a source of CP wave changes the phase of transmitted signal proportionally to that rotation and independently of its frequency. On the contrary, a change in link distance Δ_d will also change the phase of the signal, however by a value linearly proportional to the operating frequency. This two effects can be described as:

$$\Delta_{ph}(f_N) = k_N \Delta_d + \gamma \qquad (1)$$

where $\Delta_{ph}(f)$ is the phase change of the transmitted signal, k_N is the wavenumber for frequency f_N; Δ_d and γ are two unknowns, respectively distance change and rotation. If one can measure phase of the transmitted signal at two different frequencies f_1 and f_2, the contributions to the phase shift Δ_{ph} from rotation γ and distance change Δ_d can be separated, thus allowing calculation of both unknowns:

$$\Delta_d = \frac{\Delta_{ph}(f_2) - \Delta_{ph}(f_1)}{k_2 - k_1} \qquad (2)$$

$$\gamma = \Delta_{ph}(f_1) - k_1 \Delta_d \qquad (3)$$

Although measurement at two frequencies is sufficient, the use of more frequencies will reduce the error. It should also be noted that to avoid ambiguities in the measured γ and/or Δ_d the sampling rate should fulfill the Nyquist criteria with respect to the sum of both measured parameters.

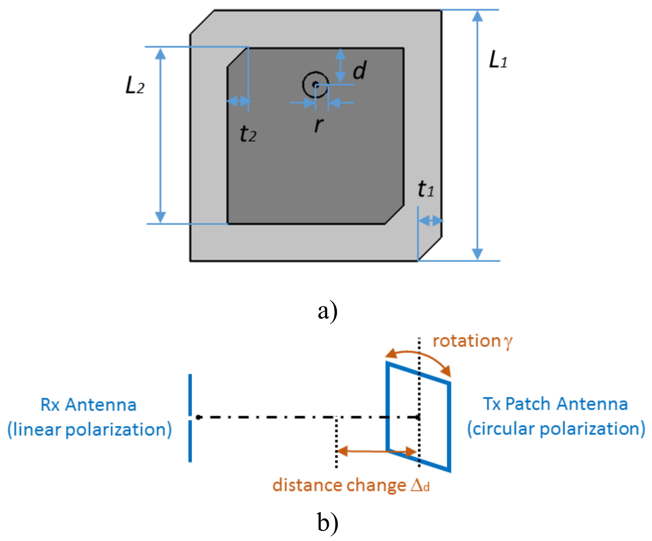

Fig. 1. Details of: a) CP antenna used; b) experimental setup.

3. Proof of concept

The system was simulated in CST Microwave Studio with the dualband CP transmit antenna depicted in Fig. 1a. The antenna comprises of two stacked patches, each with truncated corner. The upper and lower patch operate at 2.27 GHz and 1.58 GHz respectively. It is milled on two layers of Rogers™ RT5880 material (ε_r = 2.2, δ_{loss} = 0.0009), each layer being 1.57 mm thick. Antenna parameters are (all in mm): L_1 = 61.3; L_2 = 42.9; t_1 = 5.8; t_2 = 4.5. A feed is placed at d = 9 mm from the edge of the upper patch. A hole of radius r = 2.3 mm is made in the lower patch to avoid short-circuit with the feed pin. The antenna exhibits an S_{11} of -11.6 dB and -11.2 dB at the lower and upper frequencies respectively. The corresponding axial ratios at boresight are 1.7 dB and 1.0 dB.

The antenna was rotated from 0° to 360° in 15° steps. The distance Δ_d was varied from -40 mm to +40 mm in 20 mm steps, producing a set of 125 simulated scenarios. For each scenario the phase of the linearly-polarized electric field in the farfield (E-field of farfield monitor) was recorded. This is sufficient as the method requires only one CP antenna in the link. The simulation was performed with CST Microwave Studio asymptotic solver with excitation from a farfield source to avoid phase errors caused by changing the mesh when the antenna is rotating. The volume of the simulation domain was kept constant for all configurations in order to ensure the phase is always recorded in the same plane.

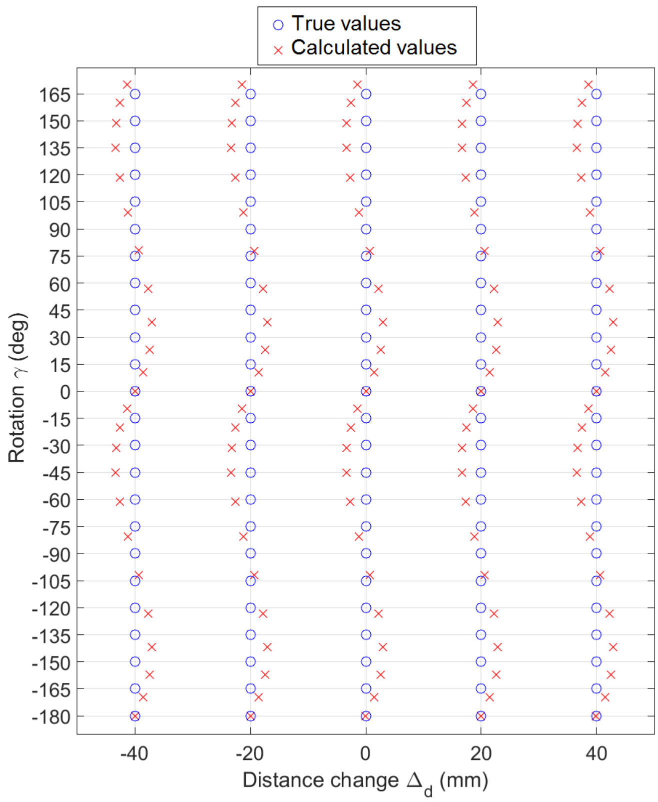

Fig. 2. Distances and rotations calculated with the proposed method versus true values.

4. Results

Fig. 2 depicts γ and Δ_d as calculated with (2) and (3) from the simulated data. The distance change Δ_d was calculated accurately, with errors varying between -3 mm to +3.4 mm. The rotation γ exhibits greater variance, with errors ranging from -15° to +7°. Mean absolute errors are 1.9 mm and 7.3° for distance change and rotation respectively. Both errors oscillate around the correct value as the antenna rotates (see Fig. 3). This is due to the decreased accuracy when using only single CP antenna, as demonstrated in [2]. For applications involving only speed measurements this part of the error will cancel out once the antenna makes a full circle. The errors did not exhibit any tendency in a function of distance change Δ_d.

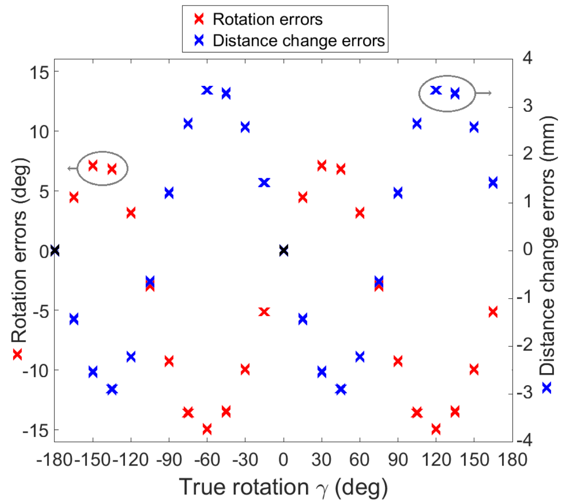

Fig. 3. Distances and rotations calculated with proposed method versus true values.

5. Conclusion

The proposed technique offers a simultaneous measurement of rotation and distance change by recording the phase of a multi-frequency CP radio link. Although the measurement is based on physical properties of CP waves, only one CP antenna is sufficient for its implementation. The technique can be incorporated into existing communications links, thus having potential in widespread usage in future internet of things applications.

Acknowledgment

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References

[1] J. Naqui, J. Coromina, A. Karami-Horestani, C. Fumeaux, and F. Martin, “Angular Displacement and Velocity Sensors Based on Coplanar Waveguides (CPWs) Loaded with S-Shaped Split Ring Resonators (S-SRR)”, *Sensors*, vol. 15, no. 5, pp. 9628-9650, 2015.

[2] V. Sipal, A. Narbudowicz, and M. J. Ammann, “Contactless Measurement of Angular Velocity Using Circularly Polarized Antennas” *IEEE Sensors Journal,* vol. 15, issue 6, pp. 3459-3466, June 2015.

[3] A. Narbudowicz, X. L. Bao, and M. J. Ammann, “Dual-Band Omnidirectional Circularly Polarized Antenna” *IEEE Transactions on Antennas and Propagation,* vol. 61, issue 1, pp. 77-83, Jan. 2013.

[4] Shao-Li Zuo, L. Yang, and Zhi-Ya Zhang, “Dual-Band CP Antenna With a Dual-Ring Cavity for Enhanced Beamwidth” *IEEE Antennas and Wireless Propagation Letters,* vol. 14, pp. 867-870, 2015.

[5] A. Narbudowicz, M. John, V. Sipal, X. Bao, and M. J. Ammann, “Design Method for Wideband Circularly Polarized Slot Antennas” *IEEE Transactions on Antennas and Propagation,* vol. 63, issue 10, pp. 4271-4279, Oct. 2015.