

Analysis of Single-Station and Dual-Station ISAC Channel Characteristics at Different Antenna Heights in Indoor Factory Environments

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Abstract—In order to deeply study how different heights affect the channel propagation characteristics in the Integrated Sensing and Communication (ISAC), this research divides the sensing modes into single-station and dual-station types according to the position difference between the transmitter and receiver at 28 GHz and 38 GHz frequency bands. In the indoor small-scale factory environment, the channels with the simulated machine antenna height of 1.2 meters and the simulated base station antenna height of 2 meters are measured, and the power-delay-angle profile (PDAP) of key scatterers at different heights in the factory environment are analyzed in detail. Furthermore, the influence of antenna height variation on time delay spread (DS) and angle spread (AS) characteristics is deeply studied.

I. INTRODUCTION

The rapid progress of 6G technology, featuring high bandwidth and low latency, when integrated with ISAC technology, significantly enhances the intelligent transformation of the manufacturing industry by enabling real-time monitoring and control in industrial environments, thereby improving production efficiency and management standards [1]. Consequently, there is an urgent need to establish an accurate, comprehensive, and detailed channel characteristic model based on complex factory scenarios. Ensuring the stable and efficient operation of communication and sensing systems in smart factories within complex and dynamic environments.

At present, tests in the integrated sensing and communication factory environment are mainly focused on channel measurement using different frequency bands and constructing channel models by analyzing various parameters, and analyzing the results [2]. A few studies focus on ISAC measurements, investigating the impact of scatterers in the environment on communication performance [3].

II. CHANNEL MEASUREMENT CAMPAIGN

A. Measurement Set-ups

The millimeter-wave measurement system consists of a vector network analyzer, omnidirectional antennas, a turntable, and two standard gain horn antennas. It uses the 28 GHz and 38 GHz frequency bands for channel measurement, with specific parameter settings as shown in Table I.

B. Scenario Deployment

The measurement activities take place inside a small indoor factory, with the scene spanning approximately 17 m in length,

TABLE I
MEASUREMENT PARAMETERS

Parameter	Values	
Center Frequency	28 GHz	38 GHz
Start frequency	26.5 GHz	36 GHz
End frequency	29.5 GHz	40 GHz
Bandwidth	3 GHz	4 GHz
Sweeping points	801	
Sensing TX/RX antenna type	Horn/Horn	
Communication TX/RX antenna type	Omni/Horn	
Horn antenna gain	25 dBi	
Omni-directional antenna gain	3 dBi	
HPBW of Horn antenna	E plane: 9° H plane: 10°	
Tx antenna height	1.2 m, 2 m	
Rx antenna height	1.2 m	
Azimuth rotation range	0°:10°:350°	
Elevation rotation range	-20°:10°:20°	

8 m in width, and about 3 m in height (the infield working area is 5 m × 12 m.), as shown in Fig. 1. Within the space, there are robotic arms and their control consoles, among other instruments and equipment. Specifically, the height of the robotic arm is around 1.2 m, the height of the robotic arm control console is approximately 1.8 m, and the height of the table used for placing instruments is about 1 m. Two measurement modes, single-station and dual-station, were set.

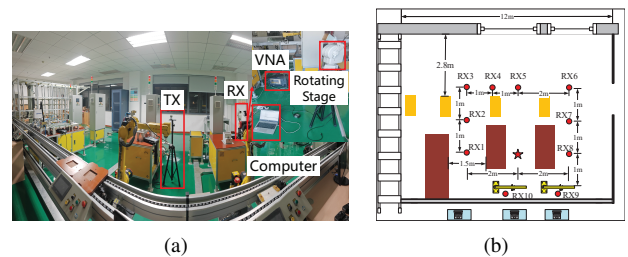


Fig. 1. Small robotic arm factory scene and the measurement setups of scenario deployment.

III. CHANNEL MEASUREMENT AND ANALYSIS

A. PADP Analysis

Fig. 2 and Fig. 3 depict the PDAP of single-station and dual-station in the small-scale factory environment.

In single-station sensing channels, most multipath components (MPCs) are concentrated on single-hop reflections.

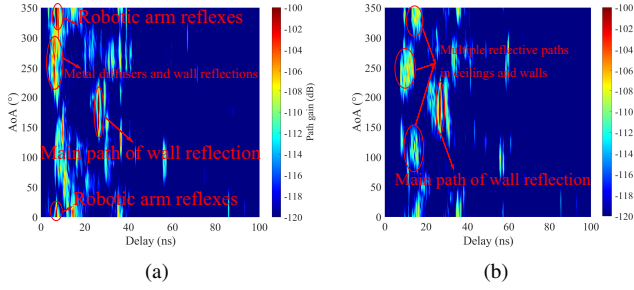


Fig. 2. PDAPs at different heights in single-station sensing channel, (a) at 1.2 m and (b) at 2 m.

Analyzing the propagation delay and measured angular delay allows locating scatterers in the environment. When the antenna height is low, the receiver will be affected by numerous scatterers, resulting in strong echoes from walls and robotic arms. For example, in Fig. 2(a), the reflected echo from the wall at 180° of the receiver and the reflected echo from the robotic arm in the factory environment from about 340° to 10° have strong signal strengths. However, due to multiple reflections, the echoes from complex scatterers are relatively weak. Conversely, when the transmitting antenna is higher than most scatterers in the environment, the main source of the received signal is the reflection from the nearby wall, as shown in Fig. 2(b), and the echo strengths from other scatterers are also weakened as the antenna height increases.

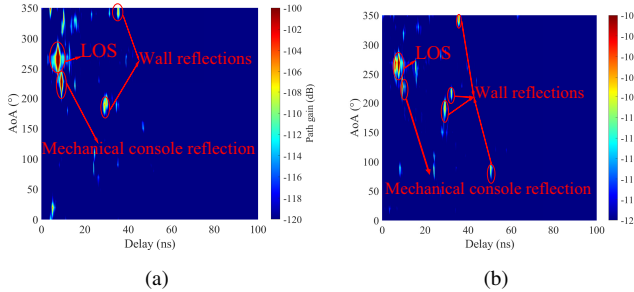


Fig. 3. PDAPs at different heights of RX8 in dual-station sensing (a) machine height (1.2 m) and (b) base station height(2 m) .

And in the dual-station measurement, the same situation as in the single-station measurement also occurs. As shown in Fig. 3, as the antenna height rises, the multipath in the scattering path shows a decreasing trend.

B. RMS Delay and Angular Spreads in Dual-Station Sensing

Fig. 4 shows the distribution of delay spread and angle spread at ten measurement points at different heights across two frequency bands. Due to the presence of a large number of reflection and scattering sources in the factory environment, such as walls, ceilings, and numerous metal scatterers, there are more multipath components generated as signals propagate through these scatterers, resulting in a relatively dispersed delay distribution.

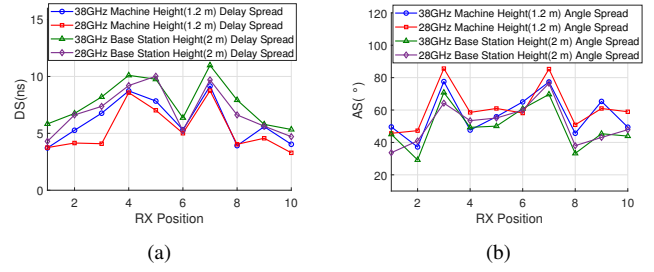


Fig. 4. Delay spread and angular spread at different heights and frequencies(a) delay spread.(b) angular spread.

Since the number of scatterers at low positions in the environment is significantly more than that at high positions, receivers at low positions naturally experience smaller DS but relatively larger AS. Moreover, the DS depends more obviously on the frequency. As the frequency increases, the loss increases and the number of multipaths decreases, which leads to a reduction in delay spread. As for the AS, it shows a trend opposite to that of the DS.

IV. CONCLUSIONS

This paper simulates different heights for machines and base stations in an indoor small-scale factory environment and conducts single and dual-station measurements of communication and sensing channels at both 28 GHz and 38 GHz frequency bands. By examining the PDAP of single-station and dual-station sensing, the distribution of scatterers in the environment can be understood. The research results show that as the antenna height increases, the number of scatterers in the environment decreases, the time-delay spread increases, and the angle spread decreases, demonstrating a transition trend from dense to sparse. This work is expected to promote research on ISAC channel modeling measurements at multiple frequencies and heights in factory environments.

ACKNOWLEDGEMENT

This work was supported in part by the National Natural Science Foundation of China (62271095, 62171071), The Natural Science Foundation of Chongqing (CSTB2022NSCQ-MSX1125), The Science and Technology Research Program of Chongqing Municipal Education Commission (KJZD-K202300607).

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