



D4.1 Data structuring: hologram stop motion frames, databasea, selected body motions

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Executive Summary

The deliverable presents an experimental and a simulated dataset both collected with the purpose of analysing the impact of human body blockage and motions on Electro Magnetic (EM) fields, namely hologram and/or Channel State Information (CSI) frames.

In particular, the hologram CSI frames collected in the dataset account for:

- 1) antenna with uniform vs non uniform radiation patterns, thus supporting beam-steering functions
- 2) dense 2D/3D antenna arrays for hologram data structuring

Measurements and simulations target passive indoor localization applications.

The following contents are covered in this report:

- Short introduction of the HOLDEN project and the collaboration partners
- Measurement dataset and description of the indoor measurement campaign
- FEKO simulated data and assessment of human body blockage in dense 2D and 3D arrays

The datasets considered in this deliverable have been used to validate the signal processing and Hologram frame management tools, namely the generative AI methods, as detailed in D3.6.

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Abbreviations

Abbreviation	Description
3D	three-dimensional
Aalto	Aalto University
BPA	back projection algorithm
CNR	Consiglio Nazionale delle Ricerche
EC	European Commission
EM	electromagnetic
EU	European Union
HE	Horizon Europe
HOLDEN	Ethical design of holography in dense wireless networks
MIMO	multiple input multiple output
MoM	method of moments
PEC	perfect electric conductor
RF	radio frequency
TUM	Technical University of Munich
TWE	University of Twente
UTD	uniform geometrical theory of diffraction
WP	work package
SA	spectrum analyzer
CSI	channel state information
CQI	channel quality information

1. Introduction

1.1. About HOLDEN

The ubiquitous perception by sensing of objects, subjects and gestures is a pivotal challenge for future technology: it enables personalized services such as smart living, automated logistics or interaction through free-space gestures. However, it also challenges ethical and moral boundaries and threatens privacy. HOLDEN proposes a radically new approach to perception by concisely analysing ethical constraints and privacy risks while re-thinking RF-based sensing. We establish necessary conditions for privacy preserving and ethically compliant sensing and develop new paradigms respecting these constraints.

For the first time ever, HOLDEN constitutes a concentrated effort to explore social aspects of RF-sensing to guide the technological advance and to derive technology for ethically and privacy compliant perception.

HOLDEN achieves this goal along three high risk, complementary, and privacy-centric paths:

Path 1: Continuous-space measurement points: Radio-based 3D vision by holographic image processing of RF wavefronts.

Path 2: Discrete-space measurement points: Advanced 3D beamforming for human-scale recognition and tracking through dense massive, connected antenna arrays.

Path 3: Signal processing and learning: High-dimensional tensor processing for the distinction of complex activities and motion from massive-dimensional RF data. The resulting breakthrough approaches and algorithms will be compared against application-level benchmarks via usage scenarios in the fields of logistics, smart living, and free-space

1.2. Partners

The consortium consists of four academic partners and a high-tech SME partner: (a) Aalto University (AALTO), Finland, (b) Technical University of Munich (TUM), Germany, (c) Consiglio Nazionale Ricerche (CNR) and third party Politecnico di Milano (POLIMI), Italy, (d) University of Twente (TWE), Netherlands, and (e) Adant (Adant), Italy. AALTO will be responsible for the project management (WP1), covered by an experienced and dedicated project manager. Ethical aspects (WP2) will be addressed by TWE (Prof. Ciano Aydin) who is a pioneer in the field. Eventual gender differences in the ethical perception will be considered. TUM pioneered RF holography, which makes TUM (Prof. Thomas Eibert) the ideal leader of WP3. In advanced distributed signal and information processing, CNR has through Prof. Stefano Savazzi more than 14 years of experience. CNR will lead WP4. Since more than 10 years, AALTO is active in radio sensing and machine learning based activity recognition. This expertise makes AALTO (Prof. Sigg) the ideal leader of WP5. Adant (Daniele Piazza) will contribute to the market analysis, application possibilities, and validation (WP6). Led by AALTO, dissemination with the website as one the media will be addressed by all

partners. All academic partners are committed to early publication of results, e.g., via arXiv (open science).

2. Measured data structures and body motions

The goal of the measurement campaign was to evaluate the effect of body movements (body blockage) on the electromagnetic field (EM) measured by antennas with a variable radiation patterns.

Three different antenna scenarios are analysed featuring:

- i) the omni-omni, where both TX and RX antennas are omnidirectional;
- ii) the omni-dir, where only the TX is equipped with a directional antenna
- iii) the dir-dir scenario where both TX and RX are equipped with directional antennas

Directional antenna parameters are summarized in Table 1. The omnidirectional antennas are vertical monopoles with 2 dBi gain.

Table 1: Spectrum Analyzer (SA) settings and directional antenna specifications.

Spectrum analyser settings		Antenna specs.	
Start/stop frequency	2.149 / 2.649 GHz	HPBW (H)	H: 60 deg
Frequency spacing	1.25 MHz	Polarization	Vertical
Resolution BW	100 kHz	MPBW (V)	V: 76 deg
TX output power	0 dBm	Antenna gain	9 dBi

2.1. Public link

A public link to the dataset is provided as below:

Savazzi, S., Fieramosca, F., D'Amico, M., Rampa, V. (2024). On the impact of the antenna radiation patterns in passive radio sensing: dataset [Data set]. In On the Impact of the Antenna Radiation Patterns in Passive Radio Sensing (Vol. 23, no 2, pp. 503–507). Zenodo. <https://doi.org/10.5281/zenodo.11243149>

2.2. Description

The measurement sessions took place in a hall with size 6.15 m × 14.45 m and floor-ceiling height equal to 3.35 m. Transmit (TX) and receiver (RX) nodes are spaced $d=4.00$ m apart, while the LOS is horizontally placed at $h=0.99$ m from the floor.

The received power is measured using a real-time Spectrum Analyzer (SA) with a built-in tracking generator. The SA tracks 401 frequency points equally spaced with 1.25 MHz. Further settings and related analysis are also detailed in [1]. The body is located at 75 different positions relative to the source and receiver according to the regular 2D grid described in the Figure 1.

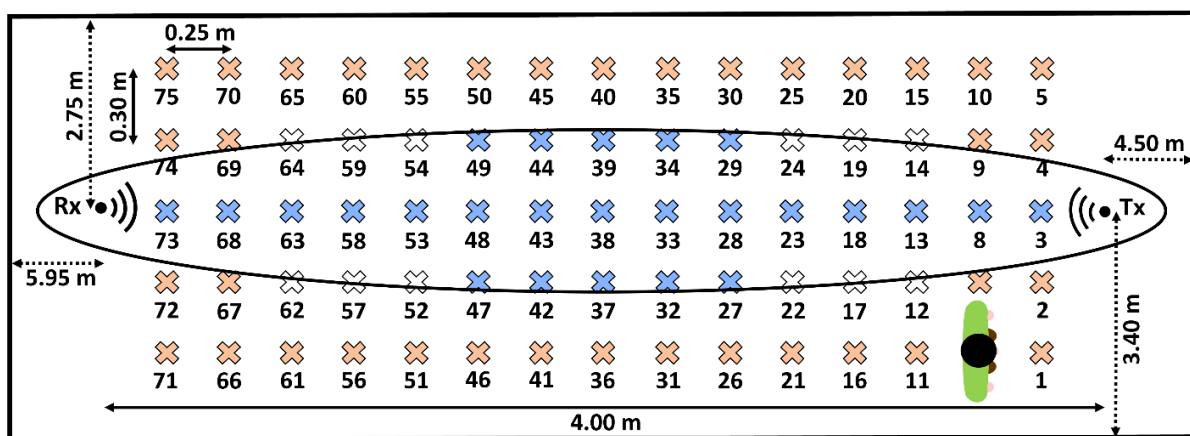


Figure 1: Explored body motions (75 positions on a 2D grid) around the considered link

2.3. Database: body motions and motion frames

The database consists of the following files:

- 1) *dir_dir_measurements.csv*: [401x75]: received power measurements [dBm] using antenna with a directional pattern (Table 1) and target on each of the 75 positions of Figure 1. These are ordered following the enumeration of the scenario scheme detailed in the same figure.
- 2) *dir_dir_measurements.csv*: [401x2]: free space received power measurements, namely measurements of the RF field with no target(s) in the area. Dataset is useful to test background subtraction tools. Two measurements have been collected before and after the experiment [dBm]
- 3) *frequency_points.csv* [401x1]: observed 401 frequencies from 2.149 GHz to 2.649 GHz (resolution BW 400kHz, 1.2MHz freq. spacing)

4) *omni_omni_measurements.csv*: [401x75]: received power measurements [dBm] with omnidirectional antennas and target on each of the 75 positions. These are ordered following the enumeration of the scenario scheme (see Figure 1).

5) *omni_omni_measurements.csv*: [401x2]: free space received power measurements (before and after the experiment) [dBm]

6) *average_radio_map_generation_example.m*: a script written in MATLAB software which serves as an example used to analyze the effect of body motions for varying positions of the subject in the monitored area.

3. Dense 2D array simulations and data structures

The following dataset has been created using FEKO software and serves to investigate the impact of human body blockage on electromagnetic (EM) fields as observed by receiver antennas arranged in dense 2D/3D arrays.

3.1. Public links

A public link to the dataset is provided as below:

- 1) Fieramosca, F., Savazzi, S., Rampa, V., & D'Amico, M. (2024). FULL-WAVE EM SIMULATION OF HUMAN BODY BLOCKAGE BY DENSE 2D ANTENNA ARRAYS [Data set]. IEEE. <https://doi.org/10.21227/v4wa-mt22>
- 2) Link for dataset download: <https://zenodo.org/records/11243471>

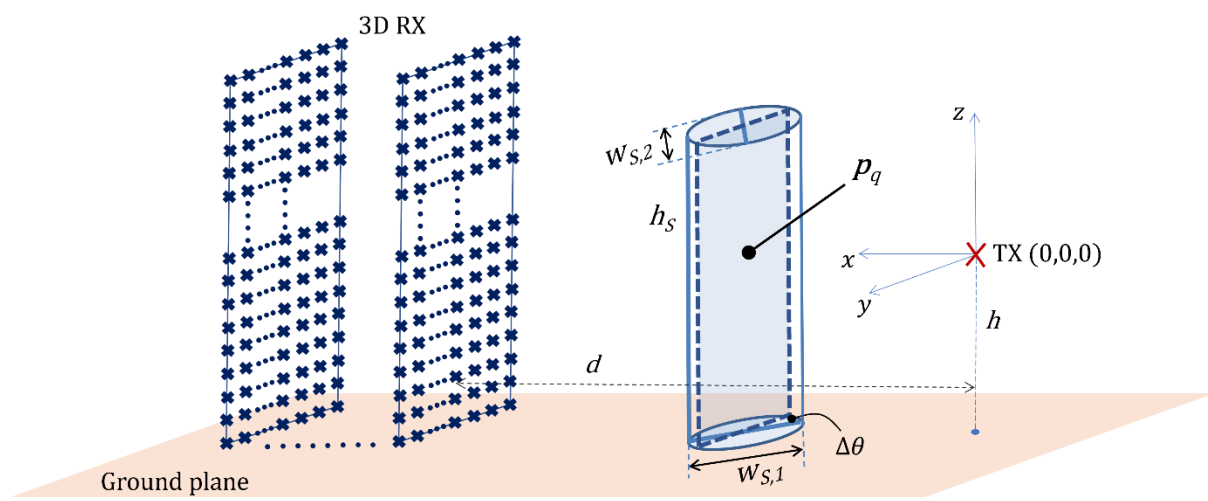


Figure 2: 3D deployment of the radio link using a 3D array of 50 x90 x180 measurement points. The center of the first surface of the array is placed at distance $d=4$ m from the source (TX) and it is orthogonal to the Line-Of-Sight (LOS) path connecting the TX with the measurement points (3D RX).

3.2. Description

The simulation scenario involves an Hertzian dipole emitting radiation at 2.4868 GHz and positioned at a height of 0.99 meters. Field measurements are taken over a 3D array with multiple 2D arrays at varying distances from the source. An anthropomorphic obstacle

representing a human body is included, featuring dimensions and material properties based on muscle composition (for more details, please refer to D3.6).

Simulations are conducted with the body at different positions and orientations relative to source and receivers considering real and imaginary part of EM field samples. The scenario highlighted in the Figure 2 includes no additional obstacles.

For a 2D RX array at distance $d=4\text{m}$ from the TX, the simulations considered three body positions:

(1) $x=2\text{m}$, $y=0\text{m}$,

(2) $x=2\text{m}$, $y=0.25\text{m}$

(3) $x=2\text{m}$, $y=0.50\text{m}$.

Further simulations mimic micro-movements like translations along x and y axes by $\pm\lambda/4$ (λ is the wavelength) increments and rotations at each position by angles 0° , 45° , 90° , and 135° , aiming to replicate real-life motions. In total, we simulate 3 positions, and for each of them, we consider 9 micro-positions (0 or $\pm\lambda/4$ increments along x and/or y around the main position - the one with both increments equal to zero -) with 4 rotations for each. Therefore, there are a total of $3 \times 9 \times 4$ simulations.

The entire scenario involves 3D layouts of receiver arrays, with 50 surfaces composed of 90×180 elements spaced by $\lambda/10$.

3.3. Database: body motions and array setup

The dataset comprises both .EFE files and MATLAB data, each representing a simulation position and containing real and imaginary components of the electric field received at each receiving point. Each file consists of a matrix sized 810000×6 , where 6 denotes the real and imaginary components in the x , y , and z directions, and 810000 is derived from $90 \times 180 \times 50$, representing the grid of receiving points.

Each file within the dataset is labelled to convey its parameters. For example, "x2_y0.25_dxpl4_dyml4" denotes the position ($x=2\text{ m}$, $y=0.25\text{ m}$). Moreover, "dxpl4" represents the increment along the x -axis by plus $\lambda/4$. "dpl4" and "dp0" are alternative options that can replace "dxpl4" if the increment is negative or there is no increment along the x -axis.

Similarly, "dyml4" denotes the decrement along the y -axis by minus $\lambda/4$. "dyl4" and "dp0" can substitute "dyml4" to signify a different positive increment along the y -axis or no increment at all.

As an example, in Figure 3 (discussed also in D3.6) we report the average and standard deviation map of the EM field amplitudes collected by receivers on the 2D surface array of 90×180 elements. When the target moves, only a subset of receivers is affected by such movements. Using the relative position of these receivers in the 2D array manifold, it is possible to trace back the offset of the body blockage from the LOS path as well as to distinguish

specific human body parts most susceptible to movements and variability (arm movements and shape).

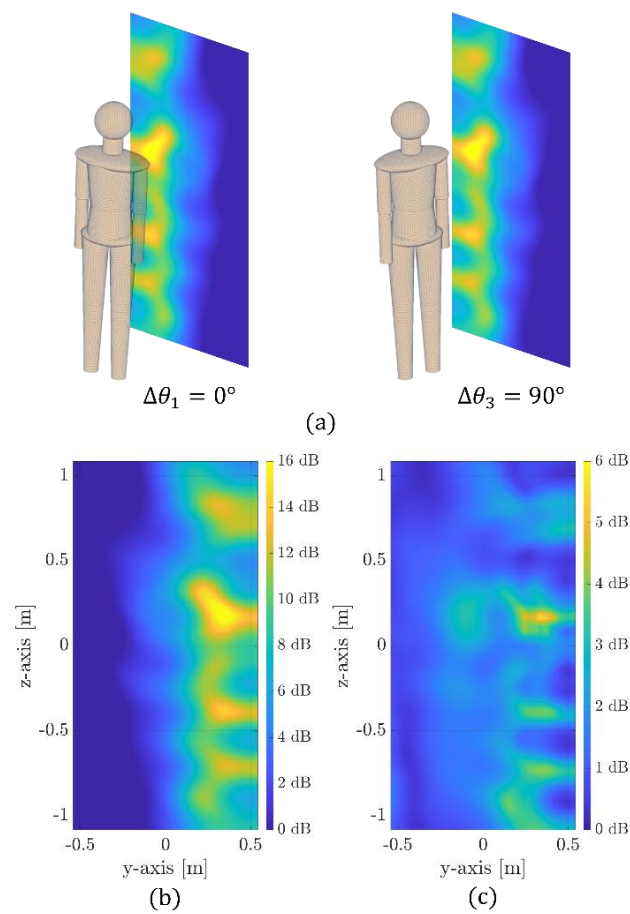


Figure 3: Visual example of an imaging map of attenuations observed on a 2D surface grid of 90x180 elements using the proposed dataset.

4. Conclusion

The deliverable described two simulation datasets which support the analysis of the human body blockage effects on the EM field observed by receiver antennas organized into single antennas with varying radiation patterns and dense 2D/3D array layouts. The datasets can be used to validate imaging tools as verified in D3.6 and to assess the impact of antennas with non-uniform antenna characteristics as well as the impact of involuntary body movements on EM blockage and related effects.

The datasets are intended to support the analysis and the validation of array processing techniques for passive indoor localization such as Direction of Arrival estimation (DOA) on azimuth/elevation, which tracks the perturbations of the DOA field as induced by body movements as well as 2D beamforming. These algorithms will be considered for technology transfer in WP6. Considering passive body localization applications, the dataset allows to study of the impact of body micro-movements on the magnitude/phase of the EM field and the points of the 1D/2D/3D array manifold that are most vulnerable to them. The analysis is of interest for holography (WP3) ray-tracing [5], tomography, and array processing (WP4) scenarios.

Future works targeting WP4 activities will be focused on the design and implementation of array processing algorithms to detect variations in target height/shape and detect movements of body parts. Furthermore, the study can be extended to tomographic and holographic analysis, facilitating a deeper insight into the spatial distribution of signals over 2D and 3D dimensions.

2. References

- [1] F. Fieramosca, et al., "On the impact of the antenna radiation patterns in passive radio sensing," *IEEE Antennas and Wireless Propagation Letters*, vol. 23, no. 2, pp. 503–507, Feb. 2024
- [2] "RSA500 Series Real Time Spectrum Analyzers," [online], accessed: Feb 6, 2024. Available: <https://www.tek.com/en/products/spectrum-analyzers/rsa500>
- [3] Stefano Savazzi, et al. "Electromagnetic-informed generative models for passive RF sensing and perception of body motions," *IEEE Open Journal on Antennas and Propagation*, doi: 10.1109/OJAP.2024.3407199
- [4] F. Fieramosca, et al. "Full-wave EM simulation analysis of human body blockage by dense 2D antenna arrays." *arXiv preprint arXiv:2405.09346* (2024).
- [5] E. Plouhinec, et al., "A UTD Elliptic Cylinder Model for Studying Body Orientation Influence on Human Blockage," *IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC'23)*, Venice, pp. 68–73, 2023.

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