ICA2025OSLO
14th IWA Specialised Conference on
Instrumentation, Control and Automation

# Classification of waste sludge dry matter ratio by mmWave radar

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**Abstract:** Wastewater treatment facilities produce sludge, which needs to be processed to reduce its water content before disposal or reuse. The dry matter ratio affects the performance of subsequent utilization methods. This study, propose a method utilizing W-band frequency modulated continuous wave radar to classify waste sludge dry matter ratio by analyzing the range profile and the range-azimuth angle heatmap of the reflected signals acquired by multiple input multiple output antennas. This approach relies solely on a single Commercial-Off-The-Shelf (COTS) millimeter-wave radar. Experimental results demonstrate that the proposed approach has achieved promising results to classify waste sludge dry matter ratio.

**Keywords:** Dewatering; sludge dry matter estimation; remote sensing; millimeter wave radar; automotive radar.

## 1. INTRODUCTION

The process of sludge dewatering involves the use of mainly mechanical and chemical processes to separate the water from the solids in the sludge. The process reduces the sludge volume and weight, making it easier to handle, more stable and reduce the environmental impact. The dewatered sludge, typically has a solid content ratio of 15-40% by weight, depending on the dewatering process used (Cao et al, 2021). The ratio restricts disposal method and also affects the transportation costs (Xinwen et al., 2025, Cao et al, 2021). Sludge dewatering is one of the most complex treatment processes and presents challenges to process optimisation (Hewei et.al., 2023). The conventional gravimetric method for estimating dry matter content involves drying the sludge in the laboratory. However, it is time consuming and makes it difficult to control the process in real time.

Modern technologies now offer a variety of sensors and methodologies for moisture estimation of materials. Active microwave systems such as Ground-penetrating radar (GPR) and Synthetic Aperture Radar (SAR) use radar to detect moisture based on backscattering (Yu et al., 2021) **.** For radar sensors, surface geometry and sensor parameters, such as frequency and polarization, significantly affect accuracy (Benellegue et al., 1995)**.**

Recently, millimeter-wave (mmWave) frequencies have gained attention due to their potential for designing compact radar systems. Their ability to penetrate various materials remains limited, restricting their use. However, the affordability of mmWave automotive sensors, combined with their wide frequency range of 76-81 GHz, presents promising opportunities for further radar advancements (Abushakra *et al*., 2022)**.** In this study we evaluate the use of this low-cost sensor to classify waste sludge dry matter content.

## 2. METHODOLOGY

Within the scope of this study, it is aimed to estimate the dry matter content of sludge obtained from wastewater treatment facility with automotive radar sensors, which are much cheaper and

smaller in size compared to the active remote sensing sensors known in the literature, and which have been widely used in autonomous systems and industry in recent years. Automotive radar sensors use V-band (60-64 GHz) and W-band (76-81 GHz) frequencies according to their usage areas. In these bands, the wavelength is as low as 4 mm. Therefore, antenna sizes and radar sensor sizes are very small. With semiconductor manufacturers designing radar transceiver chips for millimeter-wave band radars and the widespread use of these chips, the cost of these radars is decreasing.
We implement our design using the TI AWR1642BOOST EVM radar sensor operating in the 76–81 GHz frequency range. The parameters of the radar system are given in Table 1. The system includes two transmitting antennas (Tx) and four receiving antennas (Rx). All two transmitters and four receivers are utilized for angle of arrival calculations to obtain Range-Azimuth Heatmap. A MATLAB-based data analysis framework processes the collected data, computes range profile in dB scale and range-azimuth heatmap and visualizes relationship between reflection coefficient and sludge dry matter content trends.

**Table 1.** Parameters of AWR1642BOOST EVM Radar

| | |
|---|---|
| ***Type of Sensor*** | FMWC Radar Sensor |
| ***Frequency Band*** | 76-81 GHz |
| ***Number of Antennas*** | 2 Tx & 4 Rx |
| ***Azimuth Field of View*** | +/- 60° |
| ***Elevation Field of View*** | +/- 15° |

Experimental test setup for estimating dry matter content of sludge by using millimeter-wave radar sensor. In this setup, absorber foams were placed in a manner like an anechoic chamber. The sample is placed above the microwave absorbers to minimize the reflection from the surroundings. The distance between radar sensor and the sample is approximately 50 cm. It is sufficient for the far-field scattering theory of electromagnetic signal. Moreover, the side walls of the absorber material are placed at an angle to best absorb the signal.

## 3. PRELIMINARY RESULTS

The signal-to-noise ratio of the electromagnetic signals reflected to the radar from the target in the radar's radiation field depends on the target's radar cross-section and electrical properties. As the water content of the material increases, moisture of the material increases, while dry matter content decreases. As a result of this, the reflection coefficient of the signal returned to the radar increases. However, the small wavelength in millimeter-wave radar systems prevents the wave from propagating through the target and causes the electromagnetic scattering to vary depending on the surface roughness of the target.

The measurements were performed with seven different sludge samples taken from the wastewater treatment facility. First, the dry matter contents of these samples were determined by Gravimetric method to validate the automotive radar results. Then, a container made from foam materials was placed under the radar sensor, which was placed in a down-looking position as shown in Fig. 1, and the samples to be tested were placed in this container.

**(a)** **(b)**

**Fig 1.** (a) Sludge sample (b) Radar test measurement with foam container to test samples

In order to increase the accuracy of the measurement and to minimize errors due to the position of the container, the foam container was placed in 8 different random positions with small deviations from the center. According to backscatter electromagnetic wave from the samples, Range-azimuth angle heatmaps were calculated for each location. Mean and standard deviation values were calculated for 8 azimuth angles (approx. from -5 to 5 degrees) in the heatmap. The results are given in Table 2. The percentage values were obtained by gravimetric method and are inversely proportional to the dry matter content of the samples. Higher percentage indicates lower dry matter ratio in other words higher moisture level.

**Table 2.** Reflection coefficient level (dB) of samples for 8 different azimuth angle indices

| ***Sample dry matter ratio*** | ***Range-Azimuth Heatmap Indices*** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *0* | | *1* | | *2* | | *3* | | *4* | | *5* | | *6* | | *7* | |
| | Mean | Std | Mean | Std | Mean | Std | Mean | Std | Mean | Std | Mean | Std | Mean | Std | Mean | Std |
| 14.1% | 76.3 | 2.8 | 76.6 | 2.7 | 76.7 | 2.5 | 76.8 | 2.2 | 76.9 | 1.7 | 76.9 | 1.1 | 76.9 | 0.6 | 76.8 | 0.5 |
| 15.8% | 84.0 | 1.2 | 84.7 | 1.6 | 85.1 | 2.2 | 85.0 | 2.9 | 84.5 | 3.6 | 83.6 | 4.5 | 82.1 | 5.6 | 80.5 | 6.3 |
| 19.5% | 71.3 | 7.3 | 73.3 | 7.0 | 76.4 | 4.2 | 78.4 | 2.7 | 79.6 | 1.8 | 80.3 | 1.2 | 80.6 | 0.9 | 80.4 | 1.0 |
| 19.9% | 81.8 | 2.6 | 82.5 | 2.7 | 82.8 | 2.9 | 82.7 | 3.1 | 82.2 | 3.4 | 81.5 | 3.6 | 80.4 | 3.8 | 79.0 | 3.9 |
| 21.2% | 76.9 | 5.6 | 77.0 | 5.6 | 76.8 | 5.4 | 76.3 | 5.2 | 75.5 | 4.9 | 74.4 | 4.3 | 73.2 | 3.1 | 71.4 | 1.5 |
| 21.6% | 68.6 | 2.5 | 70.1 | 2.3 | 71.3 | 2.8 | 72.2 | 3.2 | 72.9 | 3.5 | 73.3 | 3.8 | 73.4 | 4.1 | 73.1 | 4.3 |
| 22.6% | 80.1 | 3.0 | 79.5 | 2.4 | 78.5 | 1.9 | 76.8 | 2.7 | 74.3 | 4.5 | 73.2 | 5.2 | 74.6 | 4.0 | 75.8 | 3.9 |

In Table 2, indices 3 and 4 generally correspond to the center point of the foam container. The mean value and standard deviation of the 8 repeated measurements taken for each sludge with different dry matter content values were analyzed for each point separately. Looking at index number 4, the following discrepancy is easily seen: for 14.1% and 15.8% dry matter, the radar reflection coefficient was 76.8 dB and 84.5 dB, respectively. Ignoring the measurements for the sludge with 14.1%, which might also be caused by non-homogeneity of the sample or measurement errors, the measurements for the other samples are consistent. The measurements for the 21.8%, 21.6% and 22.6% sludge sample, which are close to each other, are close and

consistent, especially at measurement points 5 and 6. This indicates that W-band FMCW radar is a potential sensor for sludge dry matter content measurement.

## 4. CONCLUSION AND FUTURE WORK

In this paper, we offer an automotive radar-based waste sludge moisture sensing technology. Preliminary result indicates that the automotive radar technology is a potential sensor for sludge dry matter content measurement. We investigate the proposed millimeter-wave FMCW radar system with restricted experiments in this paper. For this reason, our future work will investigate the performance of the systems in different conditions such as a greater number of sludge samples, different type of the antenna beamwidth and signal frequency bandwidth of radar, various heights and orientations of the radar sensor. Moreover, the effect of high-resolution spectral estimation algorithms on the performance of raw radar data will be examined.

## ACKNOWLEDGMENTS

The authors gratefully acknowledge financial support through SMART4ENV project. This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101079251 (SMART4ENV-Enhancing the Scientific Capacity of TUBITAK MAM in The Field of Smart Environmental Technologies for Climate Change Challenges). Melek Dasbasi is supported by grant 2211-A of TUBITAK scholarship programme.

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