Development of a Method for Detecting Two-Phase Flow Patterns with a Vibration Sensor

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Motivation – Why use a vibration sensor for detecting two-phase flow patterns?

- In CST systems with direct steam generation the detection of two-phase flow patterns is crucial for efficiency and safety
- Low-cost, non-invasive vibration sensor with data-driven model as an alternative to Wire Mesh Sensors (WMS)
- Field-tested at a Fresnel solar collector plant in Amman, Jordan (Figure 1)

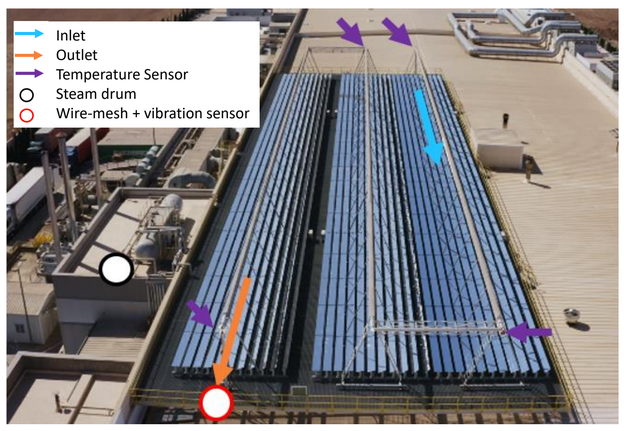

Figure 1: Aerial view CST system in Amman [1]

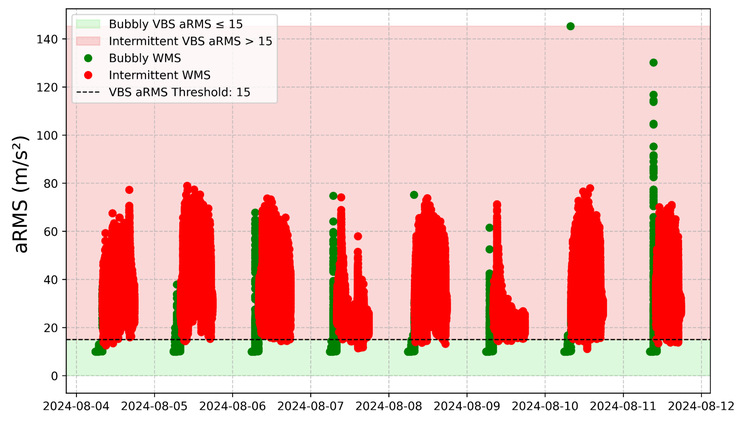

Figure 2: Vibration data with marked flow patterns [2]

Methodology:

- **Vibration sensor** mounted externally at the outlet of the Fresnel collector loop, installed alongside a Wire Mesh Sensor (WMS) for data collection and validation (Figure 3)
- Data driven model uses acceleration Root Mean Square (aRMS) data from vibration sensor to infer the flow pattern
- **WMS data** used for model training and validation

Figure 3: Vibration Sensor mount in Amman, Jordon plant [1]

Flow pattern classification model

- Threshold-based approach classifies between bubbly and intermittent flows (only two patterns available from WMS dataset)

Membership regression model

- Quasi-probabilistic output: model predicts membership values for flow patterns based on vibration data

Results:

Flow pattern classification model

- 99% accuracy in distinguishing bubbly vs intermittent flows

Flow Pattern	Precision	Recall	F1-Score	Number of Data Points
Bubbly	1.00	0.94	0.97	60,427
Intermittent	0.99	1.00	0.99	274,032

Membership regression model

- Random Forest Regression showed best predictive performance $R^2 = 0.92$ for intermittent and bubbly flows

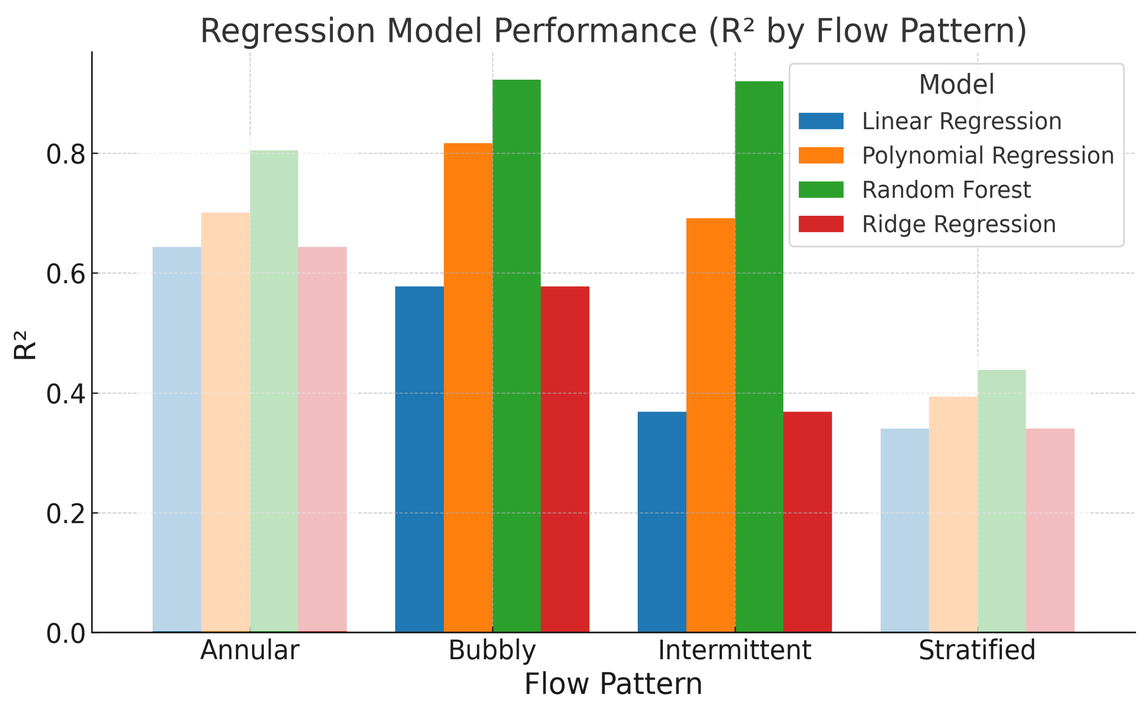

Figure 4: Comparison of R^2 scores for different regression models predicting flow pattern memberships

Conclusion and Outlook:

- A simple vibration sensor combined with a data-driven model can serve as low-cost alternative to complex sensors (WMS) for two-phase flow detection in CST systems
- The developed method demonstrates high accuracy in the test setup while requiring only limited data
- Validation must be extended to a broader range of flow patterns and other CST plants to generalize the approach

References:
[1] Industrial Solar GmbH, 2023
[2] Shehata A., "Development of a Method for Detecting Two-Phase Flow Patterns with a Vibration Sensor," Master's Thesis, DLR–Institute of Solar Research, Cologne, and Carl von Ossietzky Universität Oldenburg, Germany, 2025 (under review).

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