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LABORATÓRIO DE TELECOMUNICAÇÕES

Simulation of FBG temperature sensor array for oil identification via Random Forest Classification

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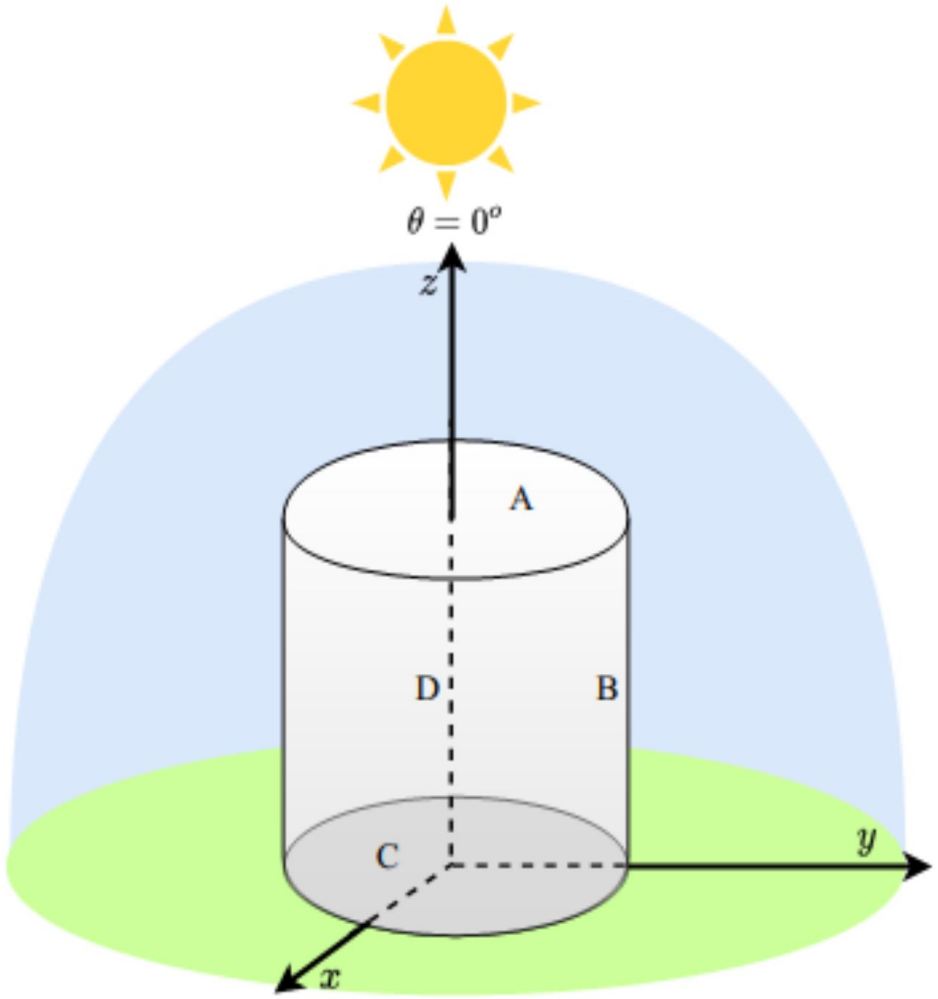
Introduction

- In the oil extraction, the oil arrives in the tanks combined with water, gas, and sludge.
- Several sensors used to identify the water-oil interface as electrical conductors or work with electrical signals.
- A widely used sensor is the Fiber Bragg Grating (FBG) sensor.
- FBG technology is used in the oil industry, due to the temperature variations observed in crude oil tanks.
  - Are naturally sensitive to temperature and strain.
  - Oil classification using only temperature response results in operational and economic benefits, since there are fewer sensors and easy assembly of the sensor array due to FBG inherent sensitivity to temperature variations.

Materials and Methods
Simulation Process

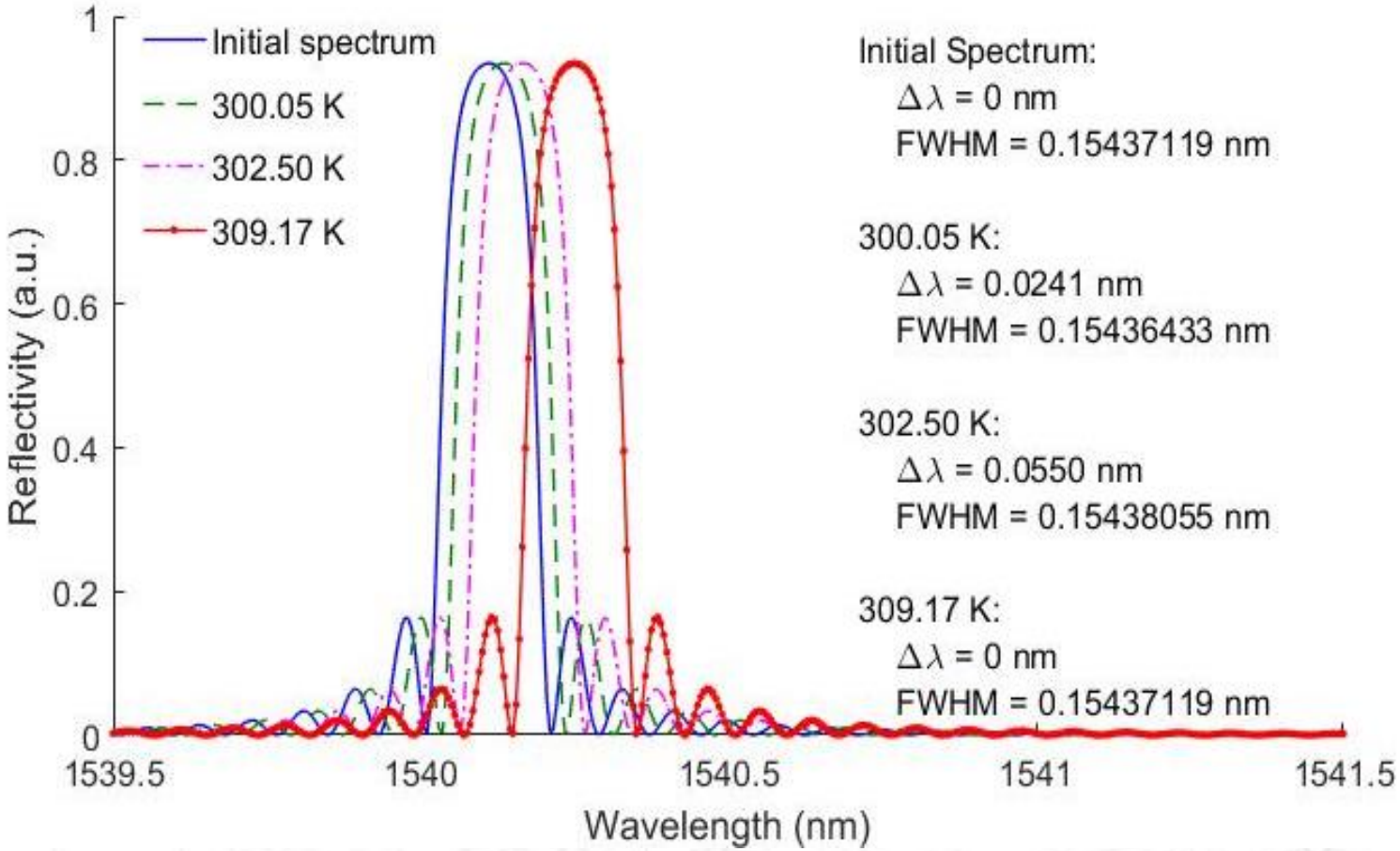
- Tank dimensions:
  - 2m height and 0.8m diameter.
- The oil, emulsion and water layers were simulated.
  - Ambient temperature the thermal conductivity:
    - Water 6.13×10−3W/mK;
    - Oil 1.2×10−3W/mK;
    - Emulsion 3.665×10−3W/mK.



Oil storage tank layout. A = Tank top (constant heat flow), B = Outside wall (convection with the external environment), C = Bottom (adiabatic wall), D = Axisymmetric (adiabatic).

Materials and Methods
Simulation Process

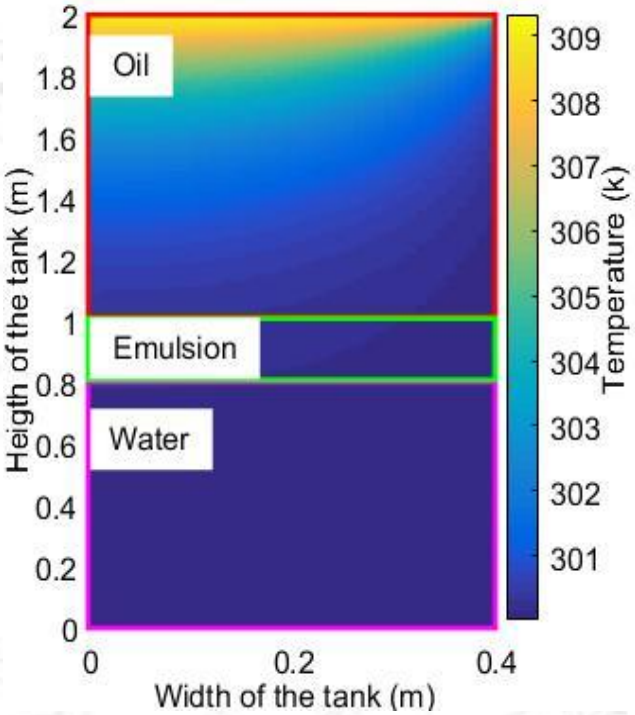
- To identify the fluid with FBG temperature sensors, we simulate different layers heights inside the storage tank, where the total level is always 2 m.



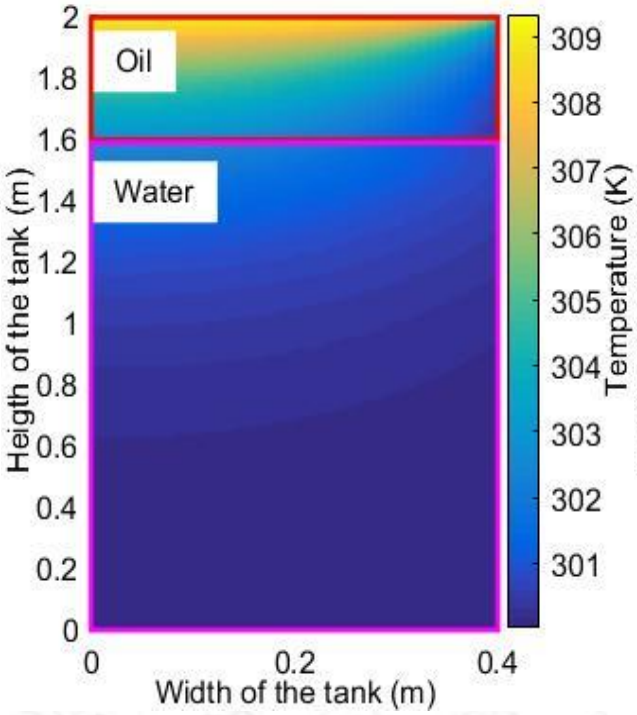
FBG spectra for three simulated temperature conditions. The initial spectrum is also presented for comparison purposes.

Materials and Methods
Simulation Process

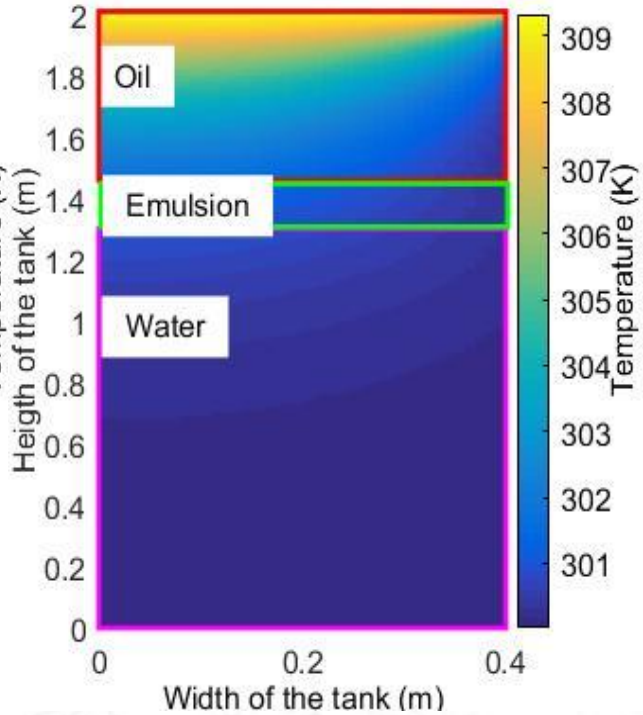
Examples of temperature distribution in the oil tank



Temperature distribution of the fluid in the tank, on **zy plane**. Oil= 1.00 m, Emulsion= 0.20 m and Water = 0.80 m.



Temperature distribution of the fluid in the tank, on **zy plane**. Oil= 0.40 m and Water = 1.60 m.



Temperature distribution of the fluid in the tank, on **zy plane**. Oil= 0.55 m, Emulsion= 0.15 m and Water = 1.30 m.

Materials and Methods
Random Forest

- Random Forest (RF) is an ensemble-learning algorithm.
- RF robust and precise than those in which unique learning is considered.
- In RF, different random bootstrap samples are considered for each selected classification tree
  - The samples are, then, distributed identically, resulting in low error and bias in the classification.
- Reducing the total variance of the classification.

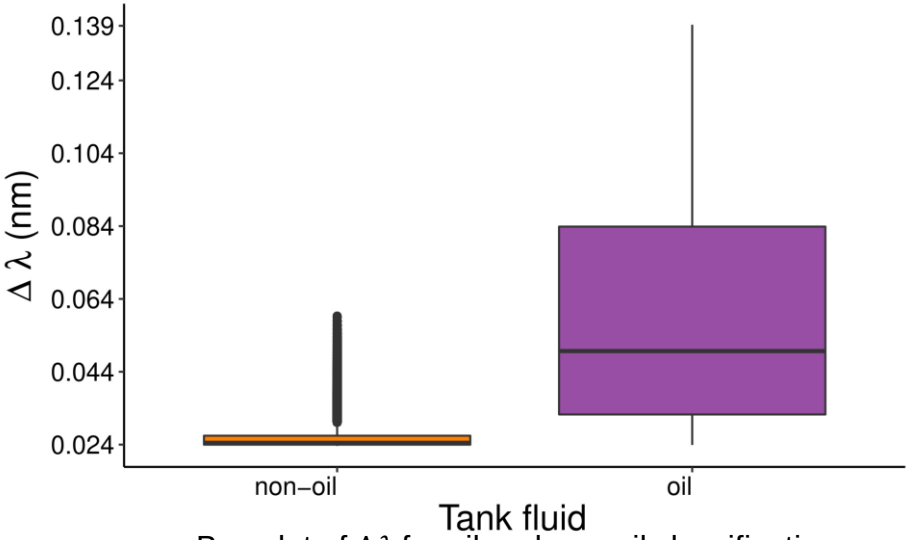
Materials and Methods

- To the temperature distribution found, we **dichotomized the classes in oil and non-oil: water and emulsion**.
- Variables: location of each FBG, $\Delta\lambda$ and the FWHM of the FBGs were extracted.
- The output of the algorithm is the classification of the oil (and non-oil).
- To select the ideal number of FBGs, we started with 200 FBGs with equidistant distribution, assuming a 2 m fiber.
- To validate the results, cross validation was employed (Train= 65%, Test= 35%)

Results and discusion

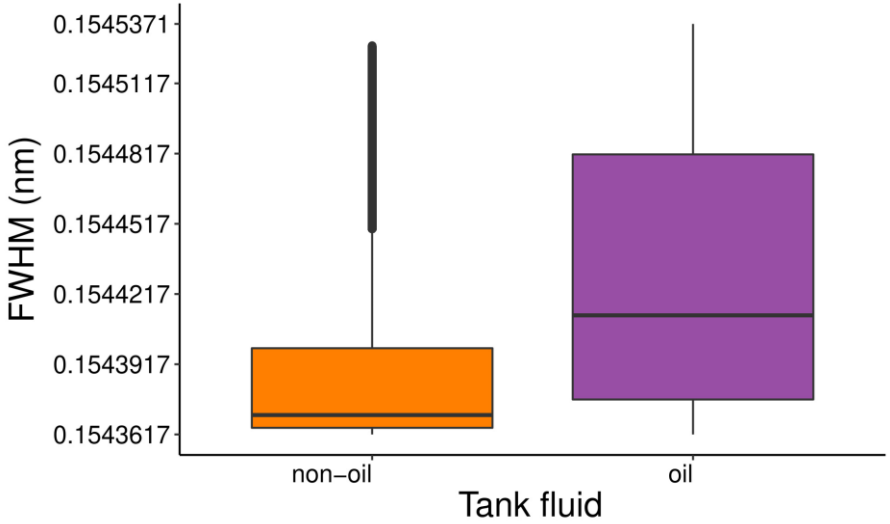
- Started the selection process at 200 equidistant points
  - Then 6, 8, 10, 12, 25, 50 and 100, with different distributions along the fiber
- The oil and non-oil classification were done by RF
- The RF input variables were $\Delta\lambda$, FWHM, and the location of the FBG relative to the tank.
  - The expected output in the algorithm was the fluid classification: oil or non-oil.
- It is also possible to indirectly estimate the oil level based on the classification

Results and discusion



Box plot of $\Delta\lambda$ for oil and non-oil classification.

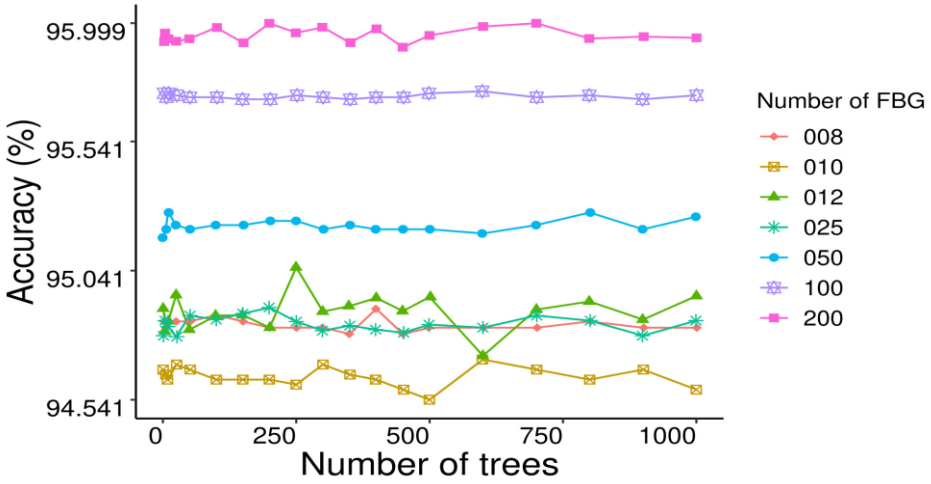
Note that only some values above the third quartile of the non-oil class intersect with the oil class. Thus, $\Delta\lambda$ separates almost correctly the two classes.



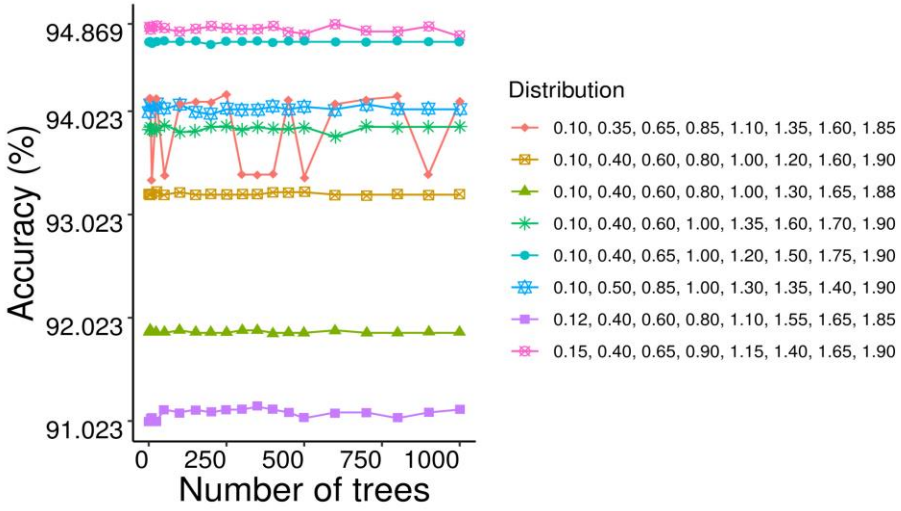
Box plot of FWHM for oil and non-oil classification.

FWHM cannot correctly divide two classes due to the high intersection between classes. Thus, we can assume that the FWHM is less significant than $\Delta\lambda$ for the fluid classification.

Results and discusion



Number of trees per accuracy in the best prediction based on the RF algorithm.



Number of trees per accuracy when using 8 FBGs in different distributions.

- The classification is mutual exclusive, has Bernoulli distribution.
- The accuracy tested with 8 others, using the Tests for Two Proportions (5% significance)
  - 200 FBGs: p-value = 0.0003742,
  - 100 FBGs: p-value = 0.007578,
  - 50 FBGs: p-value = 0.292,
  - 25 FBGs: p-value = 0.9888.
- Temperature sensor with 8 FBGs has the same accuracy as sensors with 25 or 50 FBGs.
- The location of the FBG influences the observed accuracy.

Conclusion

- This paper proposes, via simulation, the use of FBG temperature sensors for the identification inside the oil tank.
- We observed that FWHM has lower influence for the classification than $\Delta\lambda$.
- The parameters were observed based on the temperature variations fluids inside the tank.
- The RF algorithm was applied for the classification, since it is indicated for data that have low distinction between the classes.
- The ideal number of FBGs for the simulation was 8, since it has lower production cost and higher spectral efficiency when compared to 200 or 100 sensor arrays fiber.
- Then, through the Tests for Two Proportions, it was found that when using 8 FBGs at a 5% significance level, its accuracy is equal to using 25 or 50 FBGs n the sensor array.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Thanks!