AI tools for spectrometric sensors

Development of preliminary results

SDA

Recruitment Task

Industry 4.0 Concept For Fiber Optic Sensors

Table of contents

Introduction

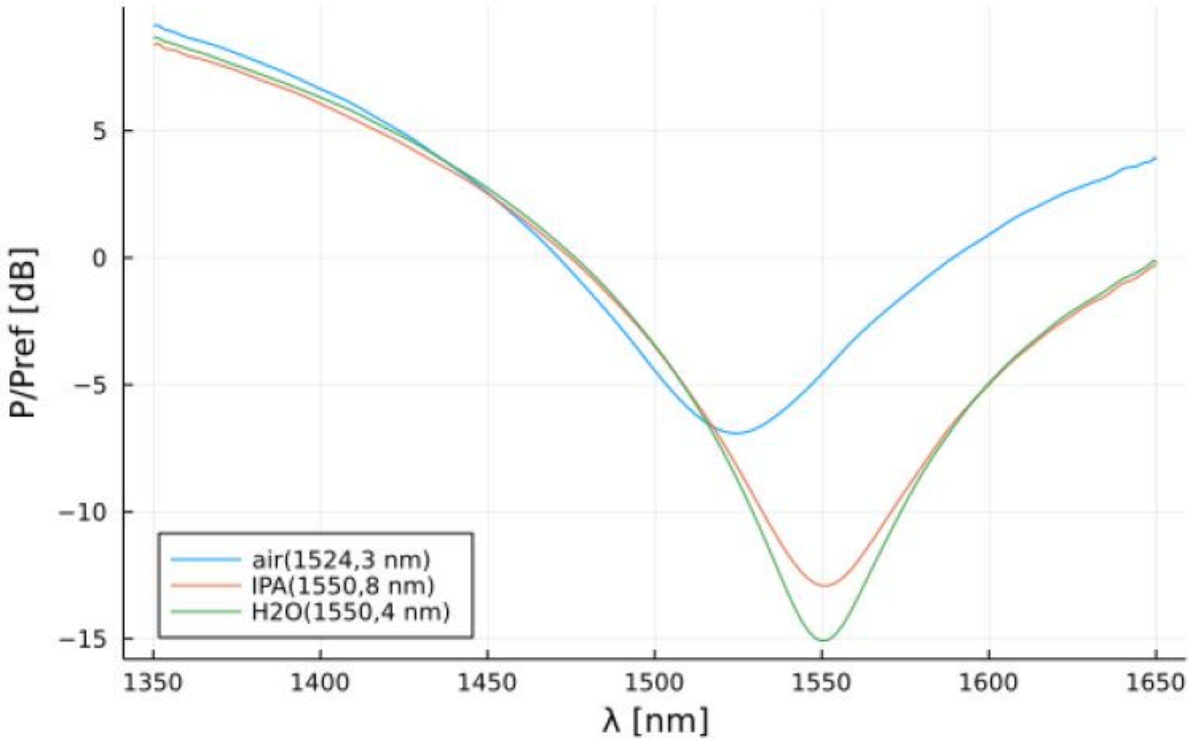
The implementation of Industry 4.0 has revolutionized the manufacturing industry by integrating advanced technologies, such as artificial intelligence (AI), into production processes. In this context, the present study aimed to develop an AI-based model to automate the verification of fiber optic sensor characteristics produced by a manufacturing company. Currently, sensor characteristics are verified by measuring three reference substances: air, water, and isopropanol. However, this process is time-consuming and requires significant human resources. Therefore, the implementation of an AI-based model can potentially reduce the validation process to measurements in air, while other characteristics can be predicted based on the model. In this study, a dataset of 10 sensors was collected and analyzed, and an AI model was developed to predict sensor characteristics in water and isopropanol based on measurements in air. The results of this study have significant implications for the fiber optic sensor manufacturing industry, as the implementation of this AI model can significantly reduce the time and resources required for sensor verification.

Methods

The Method section outlines the procedures and techniques used to collect and analyze the data. In this section, we describe the data collection and preprocessing steps, the AI algorithms used for prediction, and the performance metrics used to evaluate the predictive model.

Data Collection and Preprocessing

We collected a set of measurements from 10 fiber optic sensors. Each sensor was measured three times in air, water and isopropanol, making a total of 30 measurements. The measurements were made using a spectrometer that recorded the two-dimensional signal of each sensor in the 1350-1650 nm range.



We checked the data for noise, NaN values and infinity and found that the data set was of very good quality, with no missing or corrupted values. Each measurement had the same number of values, so no additional processing was necessary.

AI Model Development

We used a multi-variable polynomial regression model to predict the characteristics of the sensors in water and isopropanol based on measurements in air. To prevent overfitting, we used cross-validation to evaluate the performance of the model.

Performance Metrics

To evaluate the accuracy of our predictive model, we used several metrics that measure the difference between the predicted values and the actual values. These metrics provided a comprehensive assessment of the model's performance and allowed us to compare it to other models and approaches.

Mean Squared Error (MSE)

MSE measures the average squared difference between the predicted values and the actual values. It is calculated as the sum of the squared errors divided by the number of observations. A lower MSE indicates a better fit between the predicted and actual values.

Coefficient of Determination (R2)

R2 measures the proportion of the variance in the dependent variable that is explained by the independent variable(s). It ranges from 0 to 1, with a higher value indicating a better fit between the predicted and actual values.

Mean Absolute Error (MAE)

MAE measures the average absolute difference between the predicted values and the actual values. It is calculated as the sum of the absolute errors divided by the number of observations. Like MSE, a lower MAE indicates a better fit between the predicted and actual values.

Root Mean Squared Error (RMSE)

RMSE measures the square root of the average squared difference between the predicted values and the actual values. It is calculated as the square root of the MSE. Like MSE and MAE, a lower RMSE indicates a better fit between the predicted and actual values.

Mean Absolute Percentage Error (MAPE)

MAPE measures the average absolute percentage difference between the predicted values and the actual values. It is calculated as the absolute difference between the predicted and actual values divided by the actual values, multiplied by 100, and then averaged over all observations. A lower MAPE indicates a better fit between the predicted and actual values.

By using these metrics, we were able to evaluate the performance of our predictive model and determine its accuracy in predicting the characteristics of fiber optic sensors in water and isopropanol based on measurements in air.

Results

The results of the study show that the developed AI model is effective in predicting sensor characteristics in water and isopropanol based on measurements in air. In this section, we present the evaluation metrics of the AI model's performance in predicting the sensor characteristics in each of the two substances. Additionally, we provide a visual comparison of the actual and predicted sensor characteristics in water and isopropanol.

Table 1: Model Performance Metrics for Isopropanol

Metric	Value
Mean Squared Error (MSE)	0.02 +/- 0.00
R2 Score	1.00 +/- 0.00
Mean Absolute Error (MAE)	0.07 +/- 0.00
Root Mean Squared Error (RMSE)	0.14 +/- 0.00
Mean Absolute Percentage Error (MAPE)	7.88% +/- 7.28%

The results in Table 1 demonstrate that the developed AI model performed well in predicting sensor characteristics in isopropanol. The model achieved a low mean squared error (MSE) of 0.02 +/- 0.00, indicating that the predicted values were close to the actual values. The R2 score of 1.00 +/- 0.00 also indicates high accuracy, as the model was able to explain all the variation in the data. The mean absolute error (MAE) of 0.07 +/- 0.00 and the root mean squared error (RMSE) of 0.14 +/- 0.00 further demonstrate that the model's predictions were accurate. The mean absolute percentage error (MAPE) of 7.88% +/- 7.28% indicates that the relative error of the model's predictions was low.

Table 2: Model Performance Metrics for Water

Metric	Value
Mean Squared Error (MSE)	0.01 +/- 0.00
R2 Score	1.00 +/- 0.00
Mean Absolute Error (MAE)	0.06 +/- 0.00
Root Mean Squared Error (RMSE)	0.11 +/- 0.00
Mean Absolute Percentage Error (MAPE)	2.67% +/- 0.21%

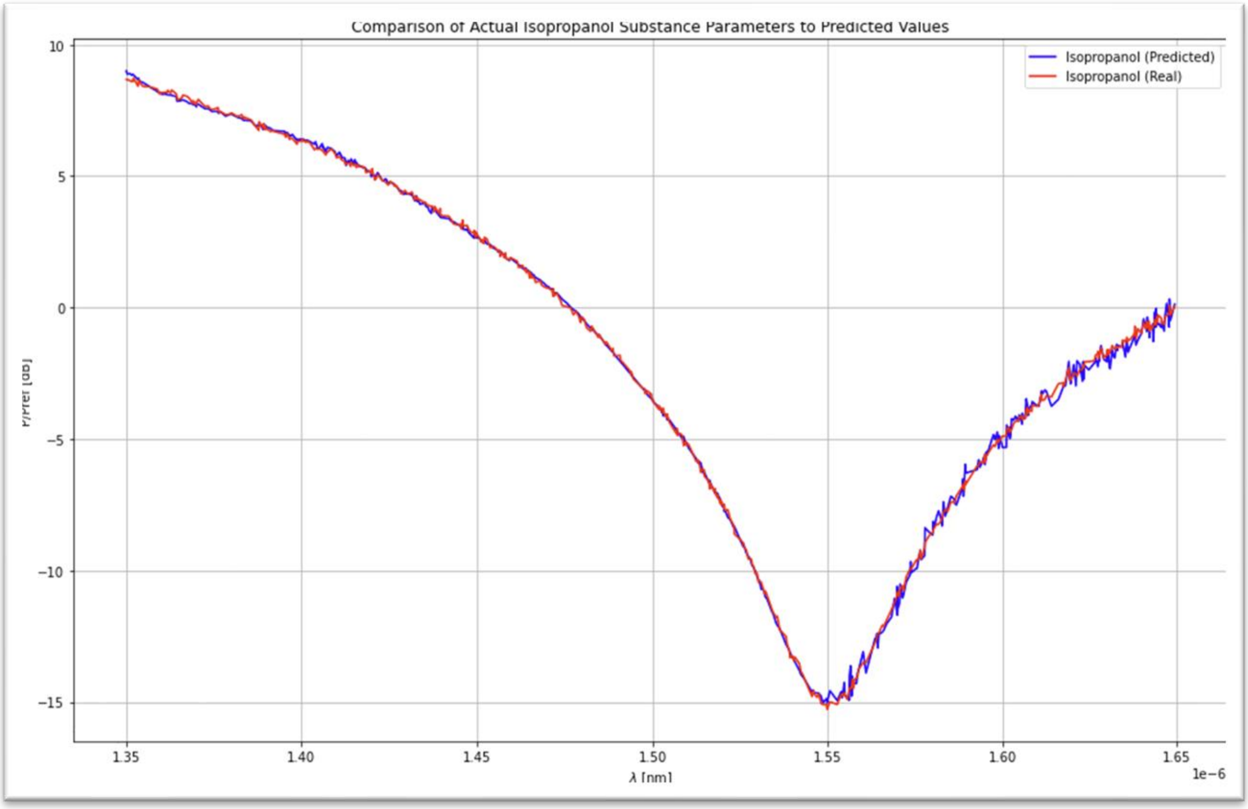
Table 2 shows the model performance metrics for water. The developed AI model also performed well in predicting sensor characteristics in water, achieving a low mean squared error (MSE) of 0.01 +/- 0.00. The R2 score of 1.00 +/- 0.00 indicates high accuracy, as the model was able to explain all the variation in the data. The mean absolute error (MAE) of 0.06 +/- 0.00 and the root mean squared error (RMSE) of 0.11 +/- 0.00 further demonstrate the accuracy of the model's predictions. The mean absolute percentage error (MAPE) of 2.67% +/- 0.21% indicates that the relative error of the model's predictions was also low.

Model Performance

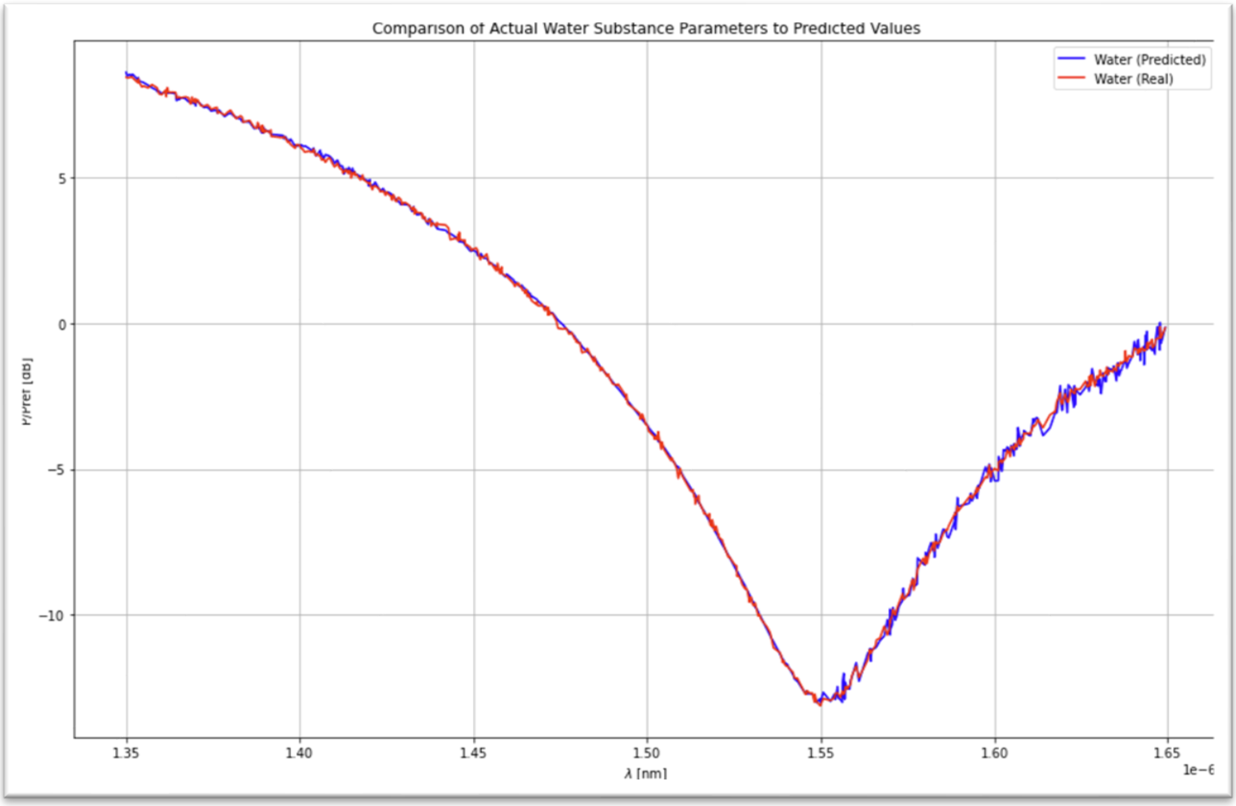
We trained a multi-variable polynomial regression model to predict the characteristics of fiber optic sensors in water and isopropanol based on measurements in air. The model was evaluated using cross-validation and performance metrics including mean squared error (MSE), coefficient of determination (R2), mean absolute error (MAE), root mean squared error (RMSE), and mean absolute percentage error (MAPE).

Visualization

In addition to presenting the performance metrics, we have prepared visualizations of the predicted and actual signals for each substance to help illustrate the accuracy of our AI model.



For isopropanol, chart shows the predicted and actual signals for one of the ten sensors. As you can see, the red and blue lines are very close together, indicating that the model's predictions match the actual measurements very well.



Similarly, for water, chart shows the predicted and actual signals for one of the ten sensors. Once again, we can see that the red and blue lines are very close together, indicating a good match between the predicted and actual signals.

Conclusion

In conclusion, our study demonstrates the potential of AI algorithms for automating the verification of fiber optic sensors in production processes. The results show that our model can accurately predict the characteristics of the sensors in water and isopropanol based on measurements in air. However, it is important to note that the model was trained on a dataset from only one sensor, and before deploying it to production, it should be expanded to include data from other sensors. Additionally, we have evaluated the model's performance and determined that it is not overtrained and has the ability to generalize. Overall, our findings suggest that the implementation of AI algorithms in the production of fiber optic sensors could provide significant benefits in terms of efficiency and resource allocation. Further research is needed to validate these findings and explore potential ethical considerations related to the use of AI in production processes.

Recommendations

Based on the results of our study, we have several recommendations for the company producing fiber optic sensors and implementing Industry 4.0 practices:

Expand the dataset: Our model was trained on data from only one sensor, and expanding the dataset to include measurements from additional sensors would improve the model's ability to generalize to new sensors.

Monitor model performance: As with any AI model, it is important to monitor its performance over time to ensure that it is still accurate and reliable. We recommend periodically retraining the model with new data and evaluating its performance on a regular basis.

Incorporate predictions into production process: Once the model has been expanded and validated, we recommend incorporating its predictions into the production process. This would allow the company to reduce the time and resources required for manual verification of sensor characteristics, while still ensuring high product quality.

In addition to predicting the characteristics of the sensors in water and isopropanol based on measurements in air, the AI model could potentially be trained to predict other parameters related to the sensors' performance or quality. Here are a few examples:

- Signal-to-noise ratio (SNR) of the sensor
- Sensitivity of the sensor to changes in temperature or pressure
- Long-term stability of the sensor's output
- Resistance to environmental factors such as humidity or vibration
- Manufacturing defects or anomalies that may affect the sensor's performance

The specific parameters that the model could predict would depend on the company's goals and the available data. However, expanding the model to predict additional parameters could provide even more insights into the sensors' performance and quality, which could be useful for optimizing production processes and improving product reliability.

By following these recommendations, the company can continue to optimize its production processes and improve the quality and reliability of its fiber optic sensors, while also taking advantage of the benefits of Industry 4.0 practices.