Calibration of Low-Cost IoT Turbidity Sensor using Neural Network Regression Model

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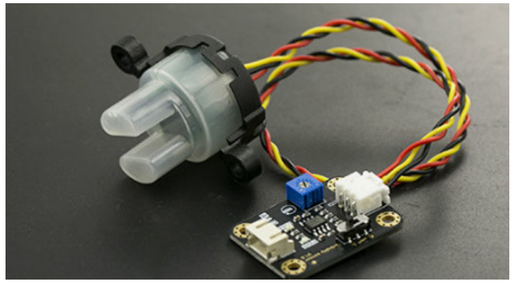
Water Quality Sensor

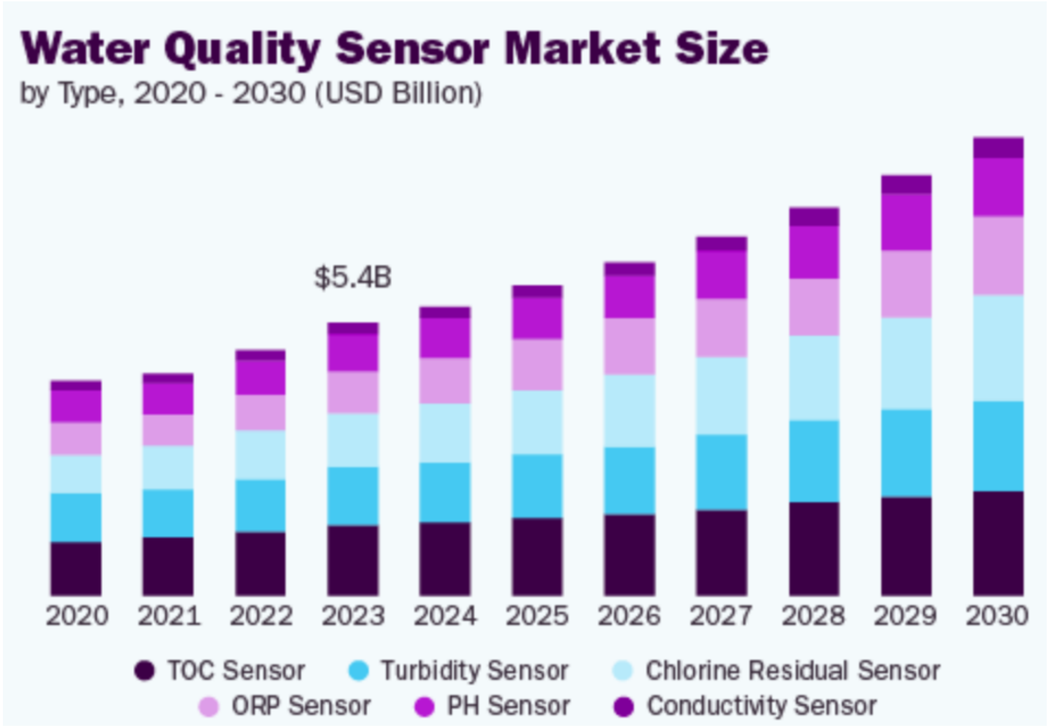
Water is an essential resource that sustains all forms of life and plays a pivotal role in agriculture, industry, and ecosystem balance. Water quality measurement extracts water quality parameter from the water to determine its water quality. Some example for these water quality parameters are turbidity, pH, total dissolved solid (TDS), dissolved oxygen (DO), electrical conductivity (EC), etc.

Water turbidity sensor



IoT Sensor: ~USD 20

Commercial Sensor: ~USD 6k



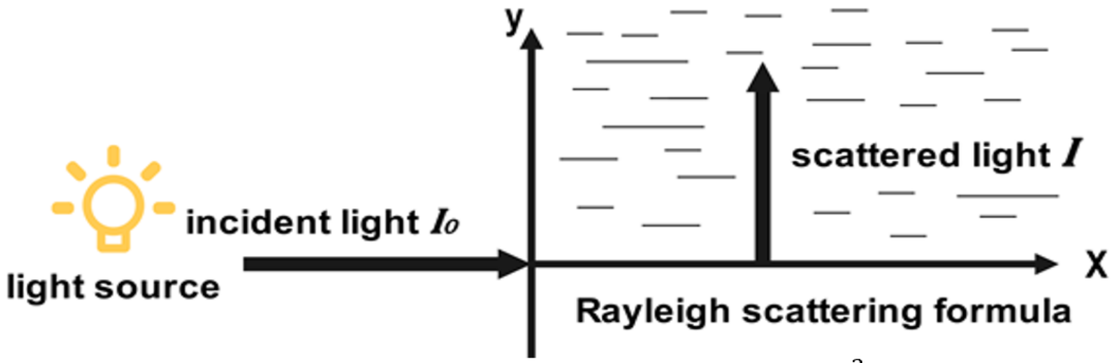
(Source: Water Quality Sensor Market Size, Share & Trends Analysis Report By Type https://www.grandviewresearch.com/industry-analysis/water-quality-sensor-market-report)

Problem statement

Challenge of water turbidity IoT sensor: Data precision and consistency issue

IoT sensors measurement commonly produce measurement errors, with problems pertaining to measurement linearity, offset, and noise related issues.

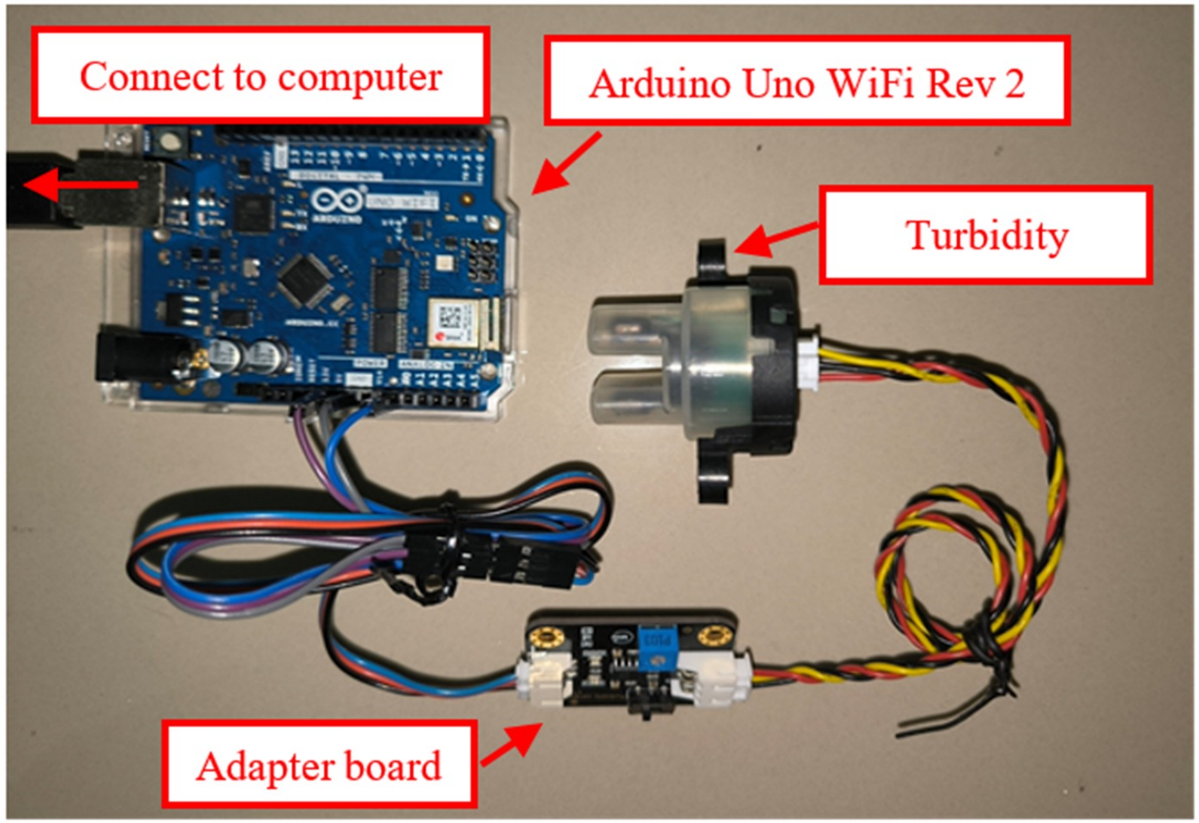
Water turbidity measurement principle

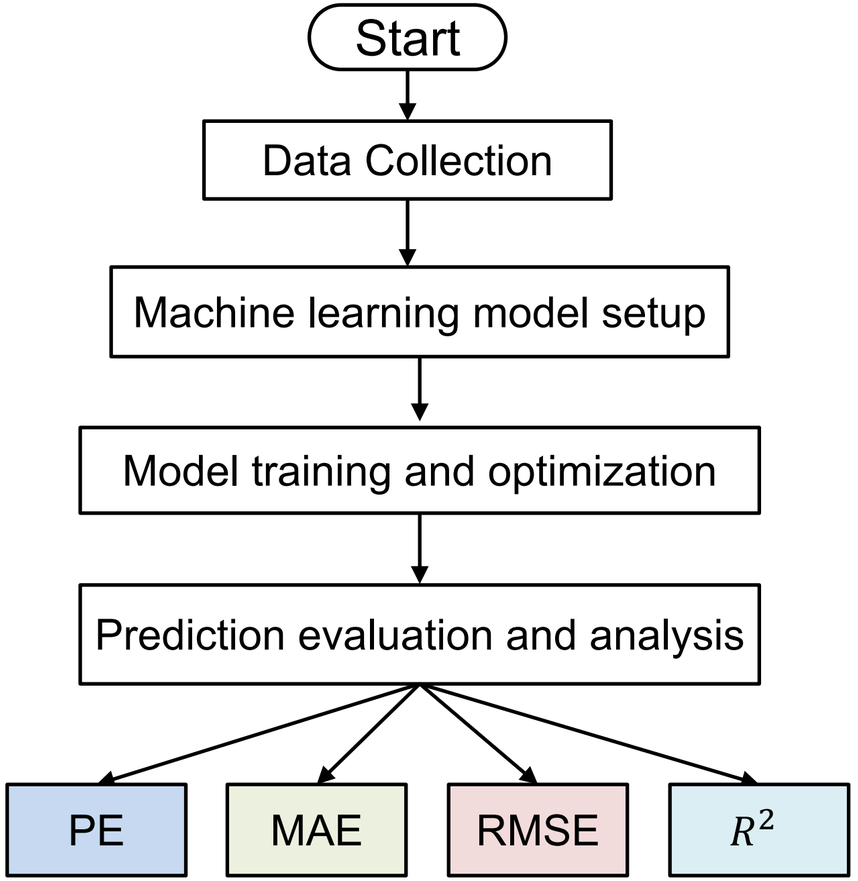


$$I = \frac{9\pi^2}{\lambda^4 \mathrm{r}^2}\left(\frac{\mathrm{n}_2^2 - n_1^2}{n_2^2 + 2n_1^2}\right)^2 v^2 N I_0 \left(\frac{1+\cos^2\theta}{2}\right)$$

Methodology and experimental setup

Experimental setup





Neural Network Regression Model

Neural network regression model is a machine learning approach that predicts a continuous output variable based on inputs data. The neural network structure comprises of input layer, hidden layer, and output layer. Each neuron computes a weighted sum of its inputs plus a bias term, given by

$$a_j = \sigma\left(\sum_i w_{ji}x_i + b_j\right)$$

where σ, w_{ji} and b_j are the activation function, weight, and bias.

Performance evaluation metrics

i) Prediction error, $PE = T_{NTU,i} - \hat{T}_{NTU,i}$

ii) Mean absolute error, $MAE = \frac{1}{n}\sum_{i=1}^{n}\left|T_{NTU,i} - \hat{T}_{NTU,i}\right|$.

ii) Root mean square error, $RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(T_{NTU,i} - \hat{T}_{NTU,i}\right)^2}$.

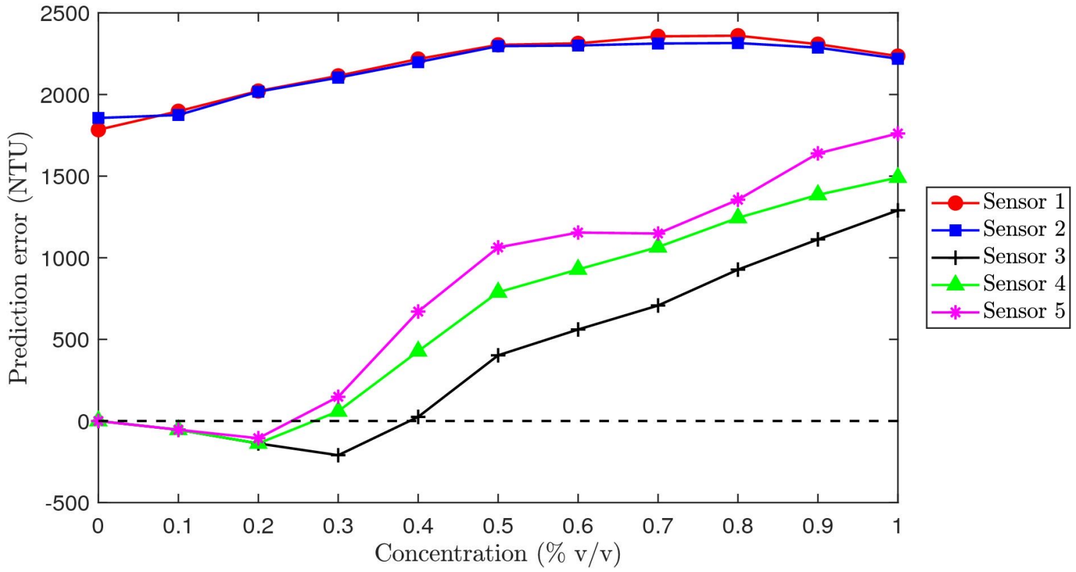
iii) Coefficient of determination, $R^2 = 1 - \frac{\sum_{i=1}^{n}\left(T_{NTU,i} - \hat{T}_{NTU,i}\right)^2}{\sum_{i=1}^{n}\left(T_{NTU,i} - \bar{T}_{NTU}\right)^2}$.

Water turbidity measurement (before ML Calibration)

Water quality measurement using IoT sensor using conventional formulation $T_{\text{NTU}} = -1120.4V_{\text{out}}^2 + 5742.3V_{\text{out}} - 4352.9.$

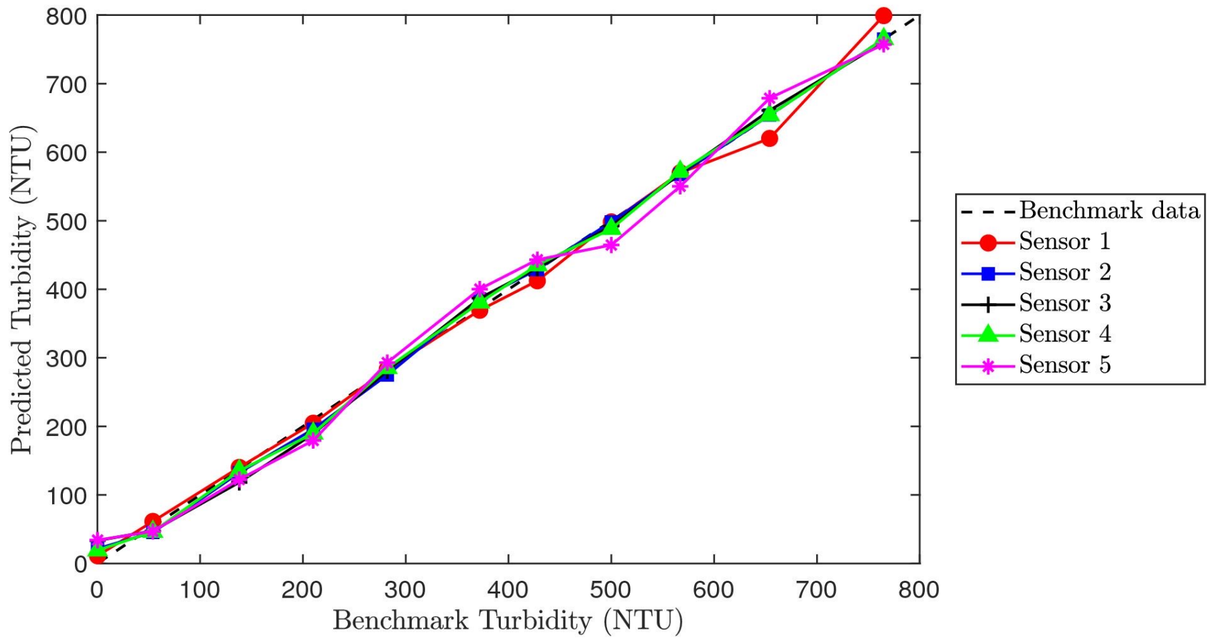
No.	Water amount (ml)	Dairy product amount (ml)	Turbidity meter (NTU)					
			S1	S2	S3	S4	S5	TM
1	100	0	1784	1856	0	0	0	0
2	100	0.1	1951	1928	0	0	0	54
3	100	0.2	2159	2155	0	0	32	138
4	100	0.3	2324	2313	0	269	358	210
5	100	0.4	2499	2480	307	709	952	282
6	100	0.5	2676	2668	774	1160	1435	372
7	100	0.6	2741	2728	988	1356	1582	428
8	100	0.7	2856	2812	1207	1565	1648	500
9	100	0.8	2927	2882	1494	1811	1922	567
10	100	0.9	2962	2941	1766	2039	2293	654
11	100	1.0	3000	2984	2055	2256	2526	765

Prediction error

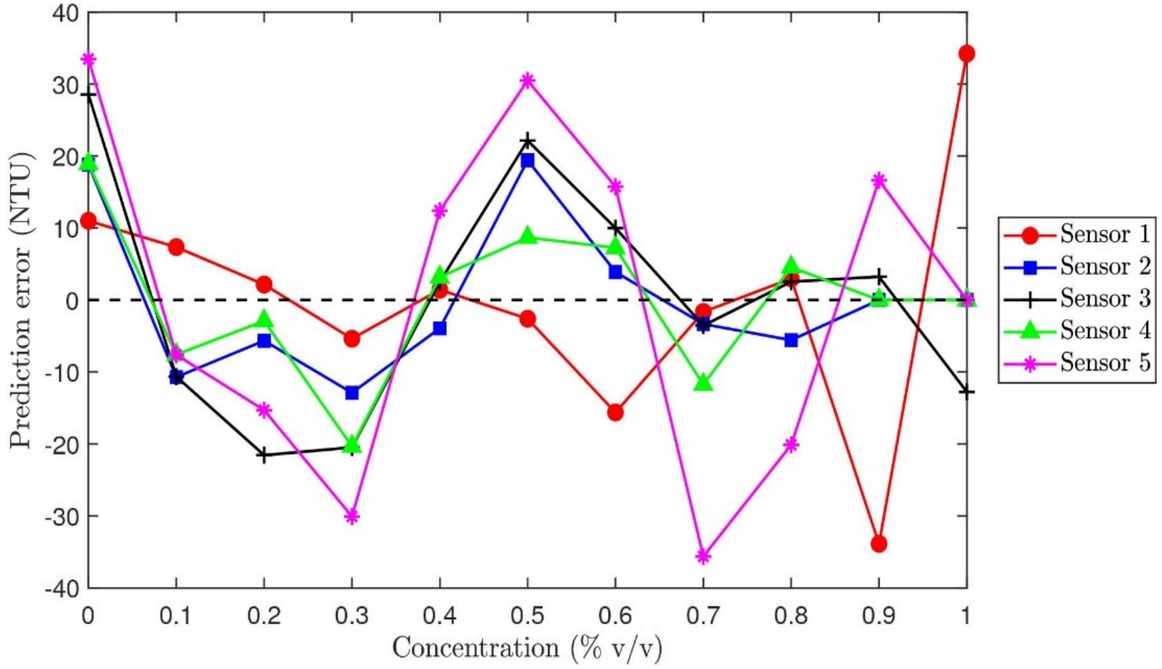


Water turbidity measurement (after ML Calibration)

Turbidity NTU prediction using neural network regression model



Prediction error



Summary

Performance evaluation on the IoT turbidity sensors

Sensor	MAE	RMSE	R^2
S1	10.75	15.93	0.9955
S2	7.66	10.07	0.9982
S3	12.54	15.38	0.9958
S4	7.74	10.15	0.9982
S5	19.77	22.56	0.9909

Summary of findings

- Using neural network regression model, the prediction error of the sensors, tested in the range of 0 to 800 NTU, can be reduced to within ± 40 NTU.
- Using machine-learning calibration, it helps minimize the systematic deviations of the low-cost IoT water turbidity sensors.

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THANK YOU

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