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Rapid Bacteriological Water Quality Analysis Using a Portable UV-LED/RGB System and Machine Learning

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INTRODUCTION & AIM

Water quality is a crucial determinant of public health, as microbial contamination can lead to severe diseases such as cholera, dysentery, hepatitis, and typhoid fever. Traditional bacterial monitoring methods, including membrane filtration, multiple tube fermentation, and enzyme-based assays, are highly reliable but are limited by long processing times, high costs, and the need for trained personnel. To address these challenges, this research introduces a portable bacterial detection system that integrates a self-loading microfluidic device, UV-LED/RGB sensors, and machine learning algorithms for rapid and automated quantification of *Enterococcus faecalis* in water samples using Most Probable Number (MPN) analysis. By combining microfluidics, fluorescence analysis, and intelligent classification techniques, this system offers a cost-effective and accessible solution for near-real-time microbiological water quality monitoring, enhancing efficiency and enabling faster responses to potential contamination.

METHOD

The proposed portable UV-LED/RGB sensor system is designed for rapid and automated bacterial quantification without requiring extensive sample preparation. The system consists of a multi-well self-loading microfluidic device, a defined substrate assay specific to *Enterococcus faecalis*, a thermoelectric heater for incubation, UV-LEDs for sample excitation, RGB sensors for fluorescence emission acquisition, and a microcontroller for data processing.

Well	0	1	2	3	4	5	6	7
MPN	0	6.1	12.6	19.5	27.1	35.3	44.2	54.2
CI	0	0.8, 44.9	3.1, 51.7	6.1, 62.1	9.9, 73.9	14.3, 86.7	19.4, 100.8	25.2, 116.5
Well	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
MPN	77.8	92.3	109.5	130.5	157.6	195.7	260.9	>260.9
CI	39.2, 154.5	47.8, 178.3	57.9, 207.1	69.9, 243.7	84.6, 293.4	103.6, 369.7	129.8, 524.7	129.8, 524.7

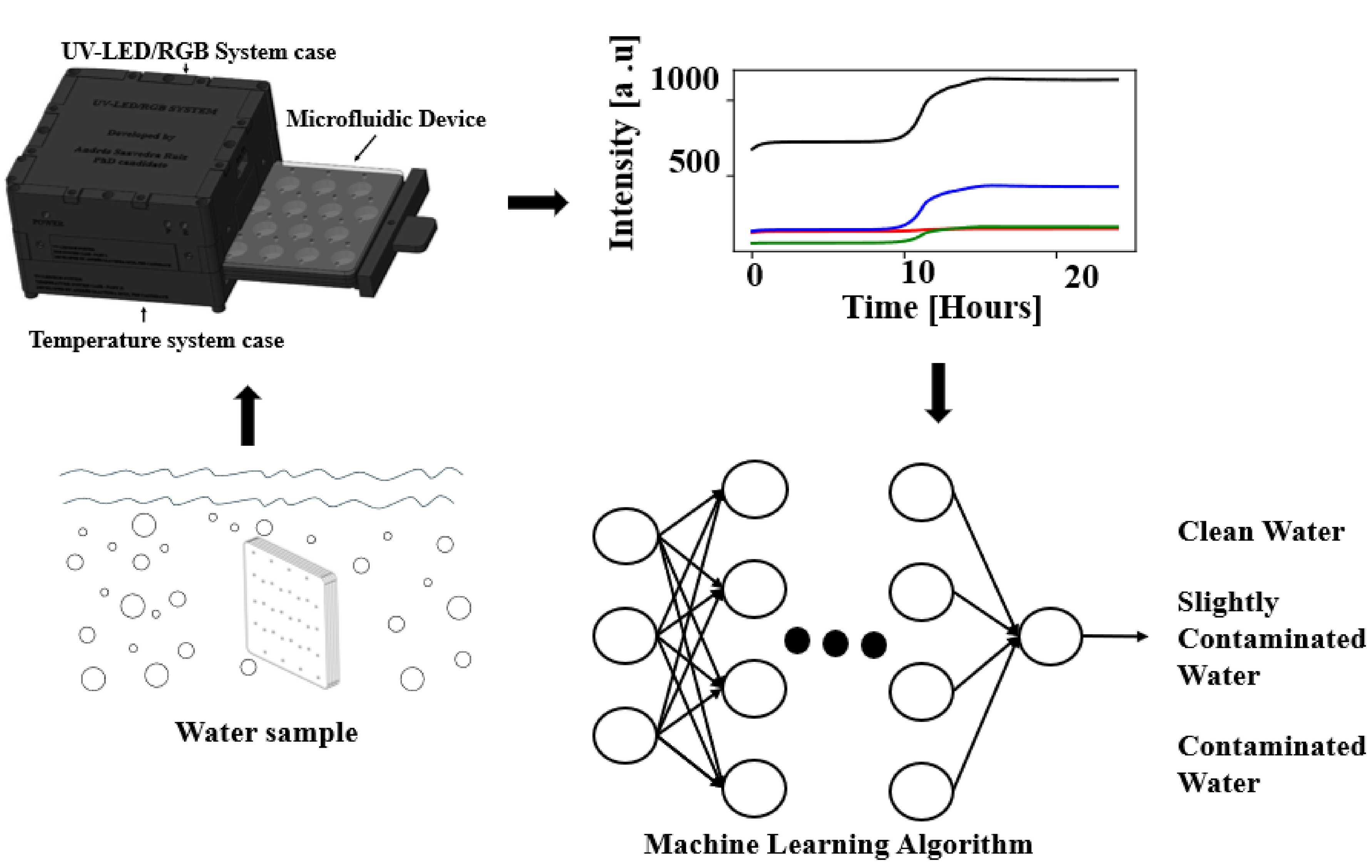

Fig 1. System Architecture: MPN table, UV-LED/RGB System, Microfluidic Device, and Neural Network Interaction.

Figure 1 shows the microfluidic device features independent wells that autonomously load with sample water upon submersion. The number of wells and volume per well are optimized for bacterial quantification using Most Probable Number (MPN) analysis. The MPN value table shown in Figure 1 was designed by our team to identify bacteria in freshwater and seawater samples in accordance with EPA standards. Pre-loaded fluorogenic assay reagents dissolve upon sample introduction, facilitating bacterial detection. Fluorescence signals are captured by RGB sensors and analyzed using machine learning (ML) algorithms. Four ML algorithms will be evaluated: Multilayer Perceptron Neural Networks (MLPNN), Support Vector Machines (SVM), Random Forest (RF), and Logistic Regression (LR).

RESULTS & DISCUSSION

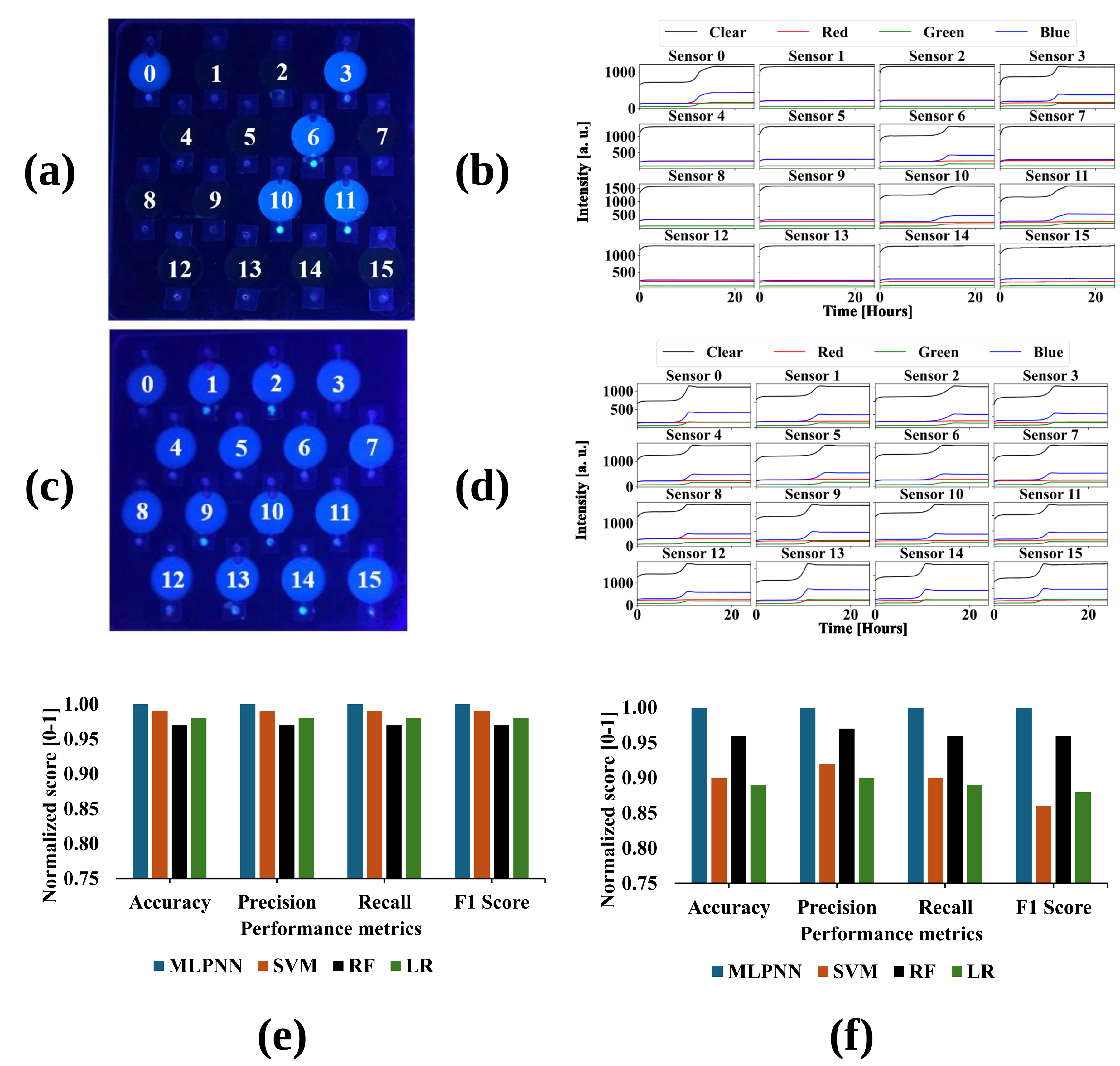

Fig 2. (a) Microfluidic device with 16 wells exposed to UV light, pellet 50-80 CFU. (b) Response of the 16-well microfluidic device to UV light for a pellet of 50-80 CFU. (c) Microfluidic device with 16 wells exposed to UV light, pellet 3k-7k CFU. (d) Response of the 16-well microfluidic device to UV light for a pellet of 3k-7k CFU. (e) Evaluation metrics for ML algorithms using 24 hours of normalized data & 2-hour derived step. (f) Evaluation metrics for ML algorithms using first 30 minutes of normalized data & 1-minute derived step.

Figures 2(a) and 2(c) illustrate the response of the 16-well microfluidic device to UV illumination during experimental tests using bacterial pellets containing approximately 50–80 CFU and 3,000–7,000 CFU, respectively. Fluorescence emission was observed in 5 wells and 16 wells, which, based on MPN estimation, correspond to approximate concentrations of 35.3 CFU and over 260.9 CFU. Figures 2(b) and 2(d) show the RGB signal acquisition from the UV-LED/RGB system during these experiments, exhibiting a characteristic sigmoidal pattern typically associated with bacterial growth. Figure 2(e) presents the output of machine learning algorithms trained on datasets representing 24 hours of incubation for each experiment. In contrast, Figure 2(f) shows predictions generated using only the first 30 minutes of data. Notably, both the MLPNN and RF models demonstrated the ability to identify bacterial growth within the initial 30 minutes of incubation.

CONCLUSION

These results highlight the effectiveness of the UV-LED/RGB microfluidic system, combined with machine learning models, in enabling rapid and reliable detection of bacterial growth, achieving accurate predictions within the **first 30 minutes** of incubation with near-perfect performance metrics.

FUTURE WORK / REFERENCES

A multispectral sensing system will be developed to enhance the current fluorescence-based approach, enabling the detection of additional components such as sediment particles and other materials typically found in freshwater and marine samples.