Digital Twins and Simulation Testbeds in Biomedical Engineering: From Mathematical Modelling and Classification for Diagnostics to Digital Simulation of Manufacturing Processes

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1 Introduction

The use of digital twins (DTs) and simulation testbeds (STs) have been instrumental in the automotive and aerospace industries. Lately, there are also active research to apply these technologies onto the biomedical engineering field, including mathematical modelling of infectious disease outbreaks within a population, using advanced machine learning (ML) algorithms to detect and classify critical illnesses from biomedical signals, and simulations of biomedical devices and sensors manufacturing processes.

2 Deterministic Mathematical Model

The COVID-19 pandemic had presented much challenges over the past 3 years. Computational simulations of mathematical models have played an important role to enable early indications on the future projections of COVID-19 for populations within regions or countries and are useful to estimate the efficiency of control actions taken. For example, the model shown in Figure 1 can help to inform if and when critical care facilities are compromised, hence protecting public health services [1]. Working with the Department of Health Western Australia, we also developed novel model to predict outbreaks on board cargo vessels, hence protecting international maritime activities and informing the various stakeholders (see Figure 1C) [2].

3 Anomaly Detection and Classification

The rise of ML in recent years has led to the development of advanced algorithms to enhance diagnosis of multiple illnesses using biomedical signal processing. The 10–20 System has proposed the optimal placement of electrodes on the scalp to obtain the best quality readings of electroencephalogram (EEG) (see Figure 1D) [3]. The data gathered could then be used in ML research to detect and classify multiple epileptic seizure types (see Figure 1E) [4, 5].

4 Digital Shadow in Manufacturing

DTs are also crucial to simulate manufacturing processes with multiple operating conditions to enhance fault diagnosis and predictive maintenance, hence improving yield and to achieve better sustainability. Using realistic simulation framework such as Taxim [6], we can generate synthetic data for a robotic gripping process. Figure 1F shows that the synthetic data match the actual components in shape and contour [7].

5 Conclusion

This abstract has presented some of the many areas within biomedical engineering where DTs/STs and simulation testbeds can be most beneficial for government bodies and policymakers to better plan the best course of actions during a pandemic, to enhance diagnosis and prognosis of critical illnesses using machine learning, and to generate synthetic data to complement actual data in simulating biomedical manufacturing processes. Future works include the use of hybrid of conventional model-based techniques and modern data-driven approaches to enhance overall performance.

References

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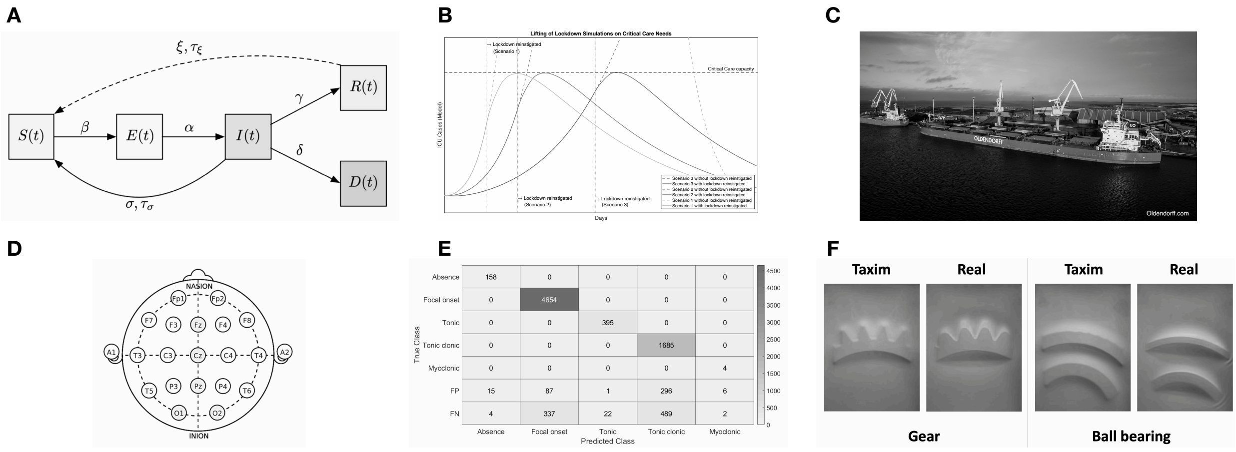

Figure 1: The many applications of DTs/STs in biomedical engineering: A) Mathematical model for COVID-19, B) Simulation to better plan for critical care capacity during a pandemic, C) The MV Patricia Oldendorff cargo vessel, D) The 10–20 System of EEG electrode placement, E) Classification of multiple seizure types using ML, and F) Comparison of generated synthetic data with real objects for manufacturing process simulations.