A REPORT ON

AI BASED VITALS PREDICTION SYSTEM FOR ANAESTHESIA MONITORING

Prepared in fulfilment of Practice School 1

Course number - BITS C221/C231/C241 by -

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This opportunity we have had with Yashoda Hospitals has been an excellent chance for conceptual learning as well as professional development. We feel immensely grateful to be given an opportunity to contribute to the healthcare domain and have a positive impact on public welfare. We hope that our humble effort can help the healthcare professionals at Yashoda Hospitals improve the quality of treatment given to their patients.

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ABSTRACT

The present study focuses on the application of artificial intelligence (AI) to predict vital signs following the administration of anaesthesia. With the aim of enhancing patient care and safety during surgical procedures, we sought to develop accurate and efficient models capable of forecasting changes in essential physiological parameters like electrocardiogram (ECG) and blood pressure (BP), in response to variations in anaesthesia dosage. Leveraging a diverse dataset sourced from hospitals and vitalDB, our investigation utilised deep learning architectures such as Recurrent Neural Networks (RNNs), Long Short-Term Memory (LSTM), Gated Recurrent Unit (GRU), and Encoder-Decoder models.

The methodology involved mapping the vital sign data to the corresponding rate and volume of anaesthesia administered, thereby establishing a relationship between anaesthesia dosage and its impact on patient vitals. By employing these cutting-edge AI techniques, our models were trained on extensive datasets, which allowed them to capture complex temporal dependencies and patterns. We utilised a rigorous validation process to ensure the robustness and generalizability of our predictions.

The results obtained through our experiments demonstrated promising performance, showcasing the potential of AI-driven predictions in the anaesthesia domain. The models exhibited high accuracy and precision, providing valuable insights into the dynamic responses of patients' vitals to anaesthesia administration.

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SECTION 1 - ABOUT THE ORGANISATION

1.1 Introduction to the organisation:

Yashoda Hospitals is a chain of multispecialty hospitals based in Hyderabad, Telangana, India with four branches situated in Somajiguda, Secunderabad, Malakpet and Hitech City. Their team of doctors are board certified, experienced in a wide range of subspecialties and passionate about improving patient care. A large team is available round the clock (night and day even on weekends). Their integrated care team ensures that the patient's physical, mental and support systems are working together to produce a holistic outcome.

1.2 Centres of excellence:

The hospital has twelve Centers of Excellence -

1. HEART TRANSPLANT -Team of Heart Specialists and Surgeons available 24X7.

2. CT SURGERY - Center for Minimally Invasive Surgeries and Transplants.

3. NEUROSCIENCE - The Neuro Institute is a regional leader in treating neurological disorders.

4. CANCER - World Leaders in Oncology Care.

5. LIVER TRANSPLANT - A dedicated team with experience in over 2700 Liver Transplants.

6. MULTI-ORGAN TRANSPLANT

7.BONES & JOINTS - World renowned Ortho Specialists performing the latest procedures.

8. NEPHROLOGY - Offers advanced expertise of the best Nephrologists and Surgeons.

9. ROBOTIC SCIENCES - Pioneering team with the highest number of robotic surgeries.

10. SPINE SURGERY -Dedicated spine surgeons to treat emergency trauma and complex deformities.

11. MOTHER & CHILD - comprehensive centre for Maternity and paediatric care.

12 . GASTROENTEROLOGY - A team of world-renowned Gastro specialists and Embryologists.

1.3 Achievements:

The hospital also offers state-of-the-art facilities and holds records for achievements like -

- More than 20,000 cardiac procedures every year.
- Treating the World's largest number (10000*) of cancer patients with RapidArc Technology.
- For the first time in India, Continuous Renal Replacement Therapy (CRRT) was used to treat multi-organ dysfunction, septicemia, refractory CCF, etc. having haemodynamic instability.

SECTION 2 - WORK DONE ON KIOSK PROJECT

The project was aimed at understanding and enhancing the functioning of a medical records dispatch system using a KIOSK. The focus was primarily on eliminating duplication of investigations, which has several disadvantages viz. wastage of valuable resources, inflated medical bills, delay in diagnosis, treatment, and overall patient care, discomfort, anxiety, and inconvenience for the patient and varied accuracies which lead to misinterpretation.

The applications of kiosks in the provision of healthcare, particularly in the dispatch of medical records were studied. Kiosks offer convenience in delivering patient information and can authenticate patients using IDs or biometric verification for data security. Patients can view their test results, discharge summaries, and receive advice for the next steps. The kiosk ensures encryption of data , secure data transmission, reducing paperwork and automatic reminders for scheduled appointments.

We have outlined the process of investigations and assessments in healthcare, involving patients being directed to specialised departments for consultations,based on our visit. The system scans prescription sheets, and patient details are displayed when their YH number is recognized. Unique codes are maintained for various investigations, and additional tests are generated. Patients undergo testing in sample collection wards or radiology departments, and the results are delivered via SMS or email. Online transmission of reports eliminates physical transportation, storage requirements, and secures patient information.

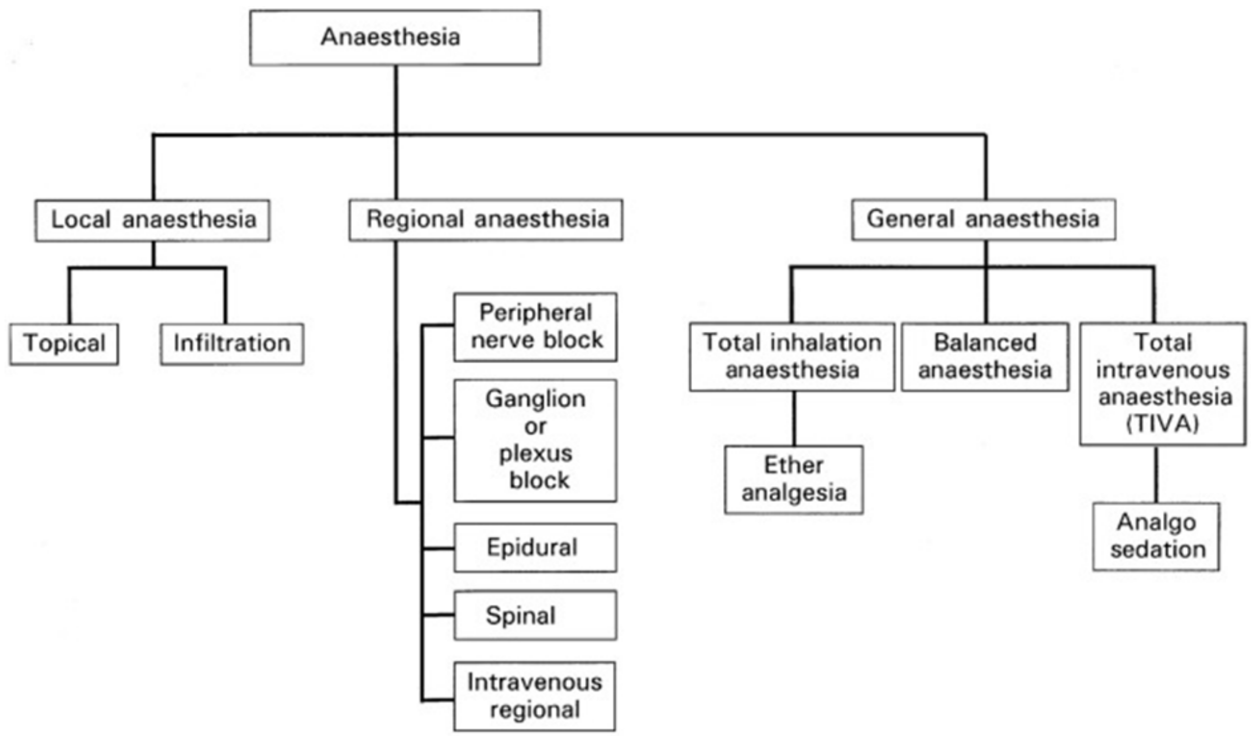
The system integrates with electronic health record systems, improving accuracy and reducing errors. We have learnt that The current system, Clinado, is outdated and based on Visual Basic. The report suggests using a modern JavaScript-based stack, MongoDB or PostGRES for web development, Flutter and the Dart language for user-friendly apps, and combining IP and OP databases for better analysis. The report provides a comprehensive overview of the project, highlighting the disadvantages of test duplication, kiosk applications in healthcare, organisational workflow, and technical suggestions for improvement.

SECTION 3 - INTRODUCTION TO ANAESTHESIA

3.1 What is Anaesthesia?

A controlled state of brief loss of sensation or consciousness induced for medical purposes and surgical procedures. This is the conventional pain relief method employed for the patient during surgeries.

3.2 Classification of Anaesthesia



1. **General anaesthetics:** They are CNS depressants that produce anaesthesia to the entire body, and are characterised by a state of analgesia, amnesia with relaxation of skeletal muscles and loss of reflexes.

   They are employed for surgical operations, hence the patient is unconscious.

   E.g. Enflurane, isoflurane, halothane (liquid inhalation anaesthetics)

   Cyclopropane, N2O (Gaseous inhalation anaesthetics)

   Thiopentone, ketamine, midazolam, propofol (intravenous anaesthetics)

2. **Local anaesthetics:** Medications used for the purpose of temporary and reversible elimination of pain only at specific areas of the body (effect is localised) by blocking the transmission of nerve fibre impulses. These drugs, unlike general anaesthetics, keep the patient conscious.

   E.g. Cocaine, Benzocaine, Butamben, Procaine

3. **Regional anaesthesia:** These are the local aesthetics which are applied close to nerves, but at a distance from the surgical site.

3.3 Stages of Anaesthesia

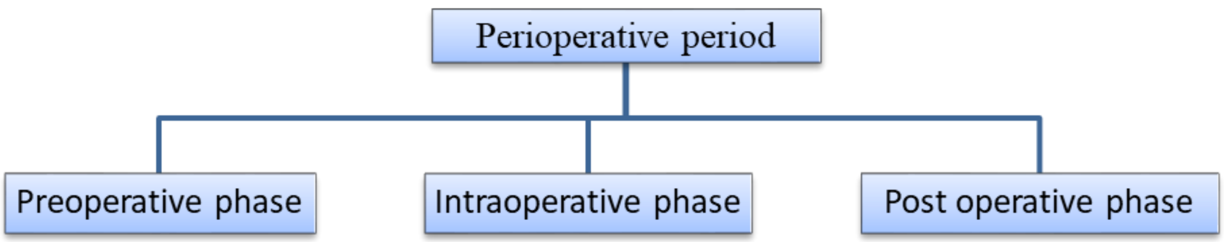
The 4 stages of anaesthesia may be recognised as follows:

STAGE I	**Analgesia**	· Patient is conscious and experiences giddiness and the feeling of drowsiness. · Reduced pain reception is observed. · This stage is exploited in minor surgeries.
STAGE II	**Delirium**	· Begins with loss of consciousness. · Effects like excitement, involuntary activity and increased respiration.
STAGE III	**Surgical anaesthesia**	· Stage of unconsciousness and paralysis of reflexes. · Respiration is normal and BP is maintained. · Surgical procedures are carried out in this stage.
STAGE IV	**Medullary paralysis**	· Depression of vital centres of medulla and brainstem is observed. · Caused mainly due to overdose of anaesthesia. · Respiratory and circulatory anomalies occur.

Therefore, the anaesthesiologist's role is to transition the patient to stage 3 and keep the patient unconscious for the entire duration of surgery by preventing complications.

3.4 Significance of anaesthesia monitoring

Monitoring and controlling the anaesthesia is very important at various phases of a surgical act.



3.4.1 Preoperative phase:

- **Baseline assessment**: The anaesthesia team conducts an examination to establish the patient's blood pressure, heart rate, respiration rate, etc. to generate a reference point for monitoring anaesthesia in the latter phases of operation.

- **Pre-op testing**: Ordering tests like CBP, ECG or other imaging studies helps the doctor in identifying any pre-existing health conditions and administer anaesthesia accordingly.

- **Allergy assessment**: The information about the patient's past medical history that include allergies to any particular medication is also reviewed in order to avoid allergy to any anaesthetic agent administered.

The focus of anaesthesia monitoring is primarily on the intraoperative and postoperative periods as the preoperative phase is only involved in the assimilation of information needed to ensure patient safety for anaesthesia administration and surgery.

3.4.2 Intraoperative phase:

The role of anaesthesia monitoring during an intraoperative period is critical when it comes to patient safety, maintenance of optimum depth of anaesthesia, detecting and acting on any changes in patient's condition.

Some key aspects of the role of the monitoring during surgery are outlined below:

· **ETCO2 monitoring**: It makes sure that the patient's ventilation is secured and proper C2O elimination from the airway is carried out.

· **Oxygenation monitoring**: Pulse oximetry is usually employed in measuring the patient's oxygen levels to ensure adequate oxygenation.

· **Anaesthetic monitoring**: Techniques like bispectral index (BIS) monitoring uses electroencephalography (EEG) to help assess consciousness that the patient has attained. EEG analyses brain activity and guides administration of anaesthesia accordingly.

· **Blood pressure monitoring**: Hemodynamic stability is ensured by continuous blood pressure monitoring. Invasive monitoring lets us measure arterial blood pressure directly and non-invasive techniques that employ oscillometry are also commonly used.

· **Temperature monitoring**: Hypothermia or Hyperthermia are prevented by maintaining Normothermia.

· **Neuromuscular monitoring**: This helps in assessing the degree of muscle relaxation gained during surgery.

Peripheral nerve stimulation techniques like train- of -four monitoring is used to avoid paralysis.

· **Fluid and blood loss monitoring**: Used to maintain adequate hydration and perfusion. Estimation of blood loss and urine output measurement is used for the same.

· **Patient positioning monitoring**: Proper position of patient prevents nerve injuries and other possible surgical errors.

3.4.3 Postoperative phase:

The role of anaesthesia in this phase deals with the management of complications that might arise after a surgery. A few significances are given below:

· **Parameter monitoring**: Monitoring vital signs help in identifying signs of instability like hypotension or tachycardia. Any signs of bleeding, infections or nausea and vomiting are also seen and assessed.

· **Pain assessment and management**: Various pain assessment tools are used in monitoring patient's pain and suggest medication accordingly. This helps in optimization of pain management and provides relief.

· **Respiratory monitoring**: Complications like hypoxemia or respiratory depression can be prevented by using a respiratory support.

· **Recovery and consciousness monitoring**: A smooth transition from effects of anaesthesia to a fully alert state is confirmed when the patient is able to follow commands.

SECTION 4 - MOTIVE FOR THE PROJECT

The anaesthesia monitor used by Yashoda Hospitals tracks and displays the patient's vitals during administration with a time lag of five minutes. Thus, it is not capable of giving a real time analysis of the patient's vitals. In healthcare, accuracy and speed are of paramount importance. Hence the aim of this project is to create an AI model to speed up this process by predicting the patient response to anaesthesia based on the patterns created by past data collected by the machine for numerous patients.

4.1 Advantages of having sync between the machine and monitor

The synchronisation of an anaesthesia machine and a monitor facilitates the efficient delivery of care to patients and the accuracy of data, thereby ensuring patient safety. Following are some advantages of the same:

1. **Accurate Monitoring**: The synchronisation guarantees that the monitor receives data from the machine in real time. This allows for precise monitoring of vital signs such as heart rate, blood pressure, oxygen saturation, mean arterial pressure, tidal volume, carbon dioxide level, and so on. This is essential to assessing the patient's condition during surgery and aids the physician in administering anaesthesia and medications appropriately.

2. **Alarms and Alerts**: While a surgery is in progress, a number of anomalies and critical events are detected. When the machine and monitor are synchronised, the doctor and anaesthesia team are notified in the event of an emergency, i.e., when a

parameter deviates from its normal range, thereby preventing complications and adverse effects.

3. **Seamless integration of data and data recording**: Integration of data between the anaesthesia machine and the monitor enables automatic transmission of patient information such as vital signs, medications administered and dosages, ventilation parameters, gas concentrations, etc.
   The simultaneous recording of data facilitates the identification of patterns that can be used to estimate patient outcomes.

4. **Optimising workflow**: Integration between the two also facilitates workflow efficiency. This feature reduces the time required for manual data entry and consequently eliminates the associated errors. In addition, this allows the medical professional and his or her team to concentrate more on patient care and other crucial areas.

4.2 Role of AI in the sync

Artificial Intelligence (AI) plays a crucial role in enhancing the integration between the anaesthesia machines and the monitors in order to ensure the best provision of healthcare to the patients. . The benefits of employing AI in the same context are outlined below:

1. **Data Fusion and Integration**: AI algorithms are utilised for the integration and synthesis of data from multiple sources, including EHRs, lab results, anaesthesia devices, and other monitors. By combining multiple data sets, a comprehensive view of the patient's physical condition is obtained, which facilitates improved decision-making.

2. **Real-time monitoring and alerting**: AI is capable of analysing the data stream and detecting anomalies in real time. Algorithms powered by AI can generate periodic alerts and alarms to notify the anaesthesia team.

3. **Predictive Analytics**: Artificial intelligence uses predictive analytics to predict adverse surgical events. In this instance, AI algorithms predict the likelihood of complications by analysing the past medical records and real-time data of patients.

4. **Anomaly Detection**: AI algorithms identify any parameter's deviations from its normal value. By establishing certain baseline patterns for individual patients, artificial intelligence identifies various causes for the anomaly, such as apparatus malfunction or deterioration of the patient's physiological state.

5. **Personalised Medicine**: Artificial intelligence analyses complex data and provides recommendations such as optimal drug combinations or concentrations, thereby easing the tedious tasks of anesthesiologists and facilitating the development of anaesthesia protocols.

6. **Controlling the administration of anaesthesia**: Artificial intelligence can optimise the administration of anaesthesia by analysing vital signs and other parameters that are likely to be affected by the quantity of anaesthesia. They assist in recommending new drug concentrations or combinations to combat the adverse effects caused by anaesthesia overdose. This prevents complications and eliminates the patient's likelihood of experiencing respiratory depression, which is the commonly seen effect at Stage 4 of anaesthesia.

7. **Protocol refinement**: Artificial intelligence aids in research by identifying the best practices, optimal medication administrations, and response patterns, thereby contributing to the development of evidence-based protocols that enhance patient care and outcomes.

8. **Real-time feedback**: This feature is essential when conducting clinical trials and other scientific experiments. This facilitates data-driven analysis throughout the study by remotely transmitting patient responses.

SECTION 5 - APPLICATION OF AI IN MEDICINE

1.Simulating and Reconstructing Diseases:
The combination of machine learning with multi-modal datasets allows researchers to reconstruct the underlying mechanisms of disease. Pharmaceutical companies can harness the power of machine learning and in-depth clinical and molecular patient data to simulate drug response at the individual patient level.

2. Developing diagnostics
From military applications to medicine, computation can be used to analyse images. Subtypes of machine learning, such as convolutional neural networks, can identify subtle changes in chest X-ray films, and in some instances, the accuracy levels for diagnosing conditions, such as pneumonia, are equivalent or superior to that of clinicians. Unlike traditional statistical methods, where inferences are made based on the population studied, machine-learning algorithms mimic human cognitive processes when making decisions.

3. Patient Monitoring

Traditionally, doctors begin to treat their patients only after symptoms start to manifest, sometimes not even until the ailment creates a medical emergency. This is slowly changing with the development and increasing use of predictive analytics capable of artificial intelligence models. In the future, machine learning and wearable technology could continuously monitor a person's health by wearable health trackers like those made by FitBit, Apple, Garmin, and other companies. They can share this information with doctors (and AI systems) for extra data points on patient requirements and behaviours, as well as alert the user to undertake more exercise.They can also detect arrhythmias and send alerts to patients through their smartphone apps. AI will likely have a big impact in cardiology, cancer, and neurosciences through remotely monitoring, enabling doctors to nip illnesses in the bud.

4. Robot-Assisted Surgeries

Robotic surgery speeds up and improves the accuracy of surgical procedures. Robotic technology aids surgeons with more delicate and exact surgical motions while the operation is still under the supervision of a person for the decisions taken during the surgery.

5.Detecting Fraud

Medical claims can be made fraudulently, resulting in hundreds of dollars in yearly losses. However with artificial intelligence's automatic claim evaluation, medical insurance fraud can be combated. AI can quickly evaluate, approve, and pay valid claims and also identify invalid ones.

6.Managing Data and Medical Records

Data management is the most extensively used application of artificial intelligence, since the first step in providing healthcare is gathering and evaluating information (such as medical records and other historical data). Robots can gather, organise, track and protect data better than humans and can provide faster and safer access to important medical information.

7. Online Consultation

Utilising artificial intelligence, apps can provide medical consultations based on user medical histories and accepted medical practices. Users enter their symptoms through the app, which compares them against a database of ailments using speech recognition. After that, the app provides a suggested course of action while considering the user's medical history.

8. Nursing Assistants Online

Virtual nursing assistants might help the healthcare sector save $20 billion annually by communicating with patients and sending them to the most suitable care setting. They can monitor patients, respond to their inquiries, assist in identifying ailments based on symptoms, and respond in real-time. Most virtual nursing assistant applications available today make it possible for patients and healthcare professionals to communicate frequently and consistently.

There are fewer risks of unnecessary hospital trips or readmission to the hospital as this occurs in between patient visits to their doctors' offices.

9. Predicting hospital readmissions

With big data analytics, it is possible to predict extreme epidemic conditions using machine learning and high computational power. Contagious diseases can even be predicted with various data sources such as weather reports, reported cases, population density, economic profile, etc.

10. Medication Administration

AI and a smartphone's webcam can be used to automatically and remotely verify that patients are taking their medications and assist them in managing their illnesses.vPeople with significant medical conditions, patients who frequently disregard medical advice, and participants in clinical studies may be the most frequent users of such technology.

11. Help with the administrative workflow

The healthcare sector might save around $18 billion due to AI applications. By automating administrative procedures and paperwork, AI can ensure that healthcare personnel can focus on their primary work, allowing doctors, assistants, and nurses to spend less time on routine duties like requesting tests, recommending drugs, and creating chart notes. The administrative side of healthcare can benefit from technology like voice-to-text transcriptions and natural language processing to analyse thousands of medical papers.

12. Offer individualised care

Personalised care can be delivered via machine learning. It can assist in identifying the traits that suggest a patient will react a sure way to a particular course of treatment. It can forecast how likely a patient's response to a specific treatment will be. The system gains this knowledge by comparing the treatments and results of similar patients' data. This helps doctors create the best treatment plan possible for the patient.

13. Improving gene editing

Additionally, genomic research makes use of AI. Machine learning methods are increasingly incorporated into other fields, including genomic annotation and sequencing. Additionally, genome-based diagnostics employ it. Significant progress has been made in our ability to precisely and cheaply modify DNA .

By integrating more robotic technology and virtual support that improves the effectiveness of care delivery, AI-powered technology is revolutionising healthcare. It enables clinicians to quickly create effective treatment programs for patients and early detection of contagious diseases. These are merely a few options AI is supplying to the healthcare sector. There will be additional opportunities for time savings, cost reduction, and accuracy improvement as innovation pushes the capabilities of automation and digital workforce.

SECTION 6 - PROCEDURE FOR THE CREATION AND IMPLEMENTATION OF AI MODELS FOR HEALTHCARE

6.1 Preparation, collection, and checking of the data

- Medical problem and context:

The first step is to comprehensively understand the medical procedures involved and the parameters measured and analysed for it, accurately identify the problems in the existing framework of collection and analysis of data and their effect on the treatment of the patient. One must also understand the existing software and hardware in place used to execute the system

- Sample size:

It must be ensured the amount of collected data is sufficiently large for the intended purpose. The required sample size for AI model development depends on the specific context, including the used prediction modelling method, the number of features, the proportion of the predicted health outcome, and the desired predictive performance.

- Data quality:

For both feature variables as well as outcomes, this involves the inspection and description of missing data, consideration of potential errors in measurement, and their underlying mechanisms.

- Data preprocessing:

To prepare data for the consecutive phases, or handle identified data quality issues, data preprocessing steps may be applied. Such preprocessing steps can include organising the data, splitting it into different subsets (e.g., training and testing sets), augmenting data, removing outliers, re-coding or transforming variables, standardisation, and imputation of missing data.

6.2 Development of the AI model

- Model selection and interpretability

The following aspects can affect the choice for a certain modelling technique (e.g., regression, decision tree or neural network): prediction performance, interpretability, the familiarity of the modelling technique to the end user, computational requirements, development and validation costs, maintenance, privacy, sample size, and the structure of the data. Neural networks are recommended for high volume, dense, and complex data types.

- Training the AI model

The AI model is trained by feeding datasets into it. The model then trains itself to make predictions based on these datasets and evaluates its accuracy against each new cycle, or passes through all of the available data points. Through the use of machine learning techniques such as including deep learning, the algorithm can analyse the data and make better predictions.

- Testing the AI model

A portion of the training data is set aside to use as testing data to check if the values of the parameters predicted by the model are comparable to the real values. The accuracy of the model is measured in this way and necessary adjustments are made to the model to achieve higher levels of accuracy.

6.3 Validation of the AI model

- External performance evaluation

In practice, an AI model is likely to be applied in a setting that differs from the setting in which the AI model was developed, which may have an impact on AI model performance. In contrast to internal validation, external validation is the application of an existing model to a different population or setting compared to what was used to develop the model.

- Generalizability

Generalizability refers to the AI model's ability to generalise its performance to a new setting. Poor generalizability may be caused by overfitting or training data that were unrepresentative for the new setting. Generalizability can be assessed by using external data from a different time period, place, or healthcare setting.

To ensure the generalizability of the AI model to the intended healthcare setting, developers are advised to extensively validate the model for representative data from that setting. The intended healthcare setting may be different from the population or setting on which the AI model was originally developed (for example an AI model developed for a clinic is applied to a multispecialty hospital). Thus, AI model updating, site-specific training or recalibration is necessary to adapt an existing AI model to a different healthcare setting.

6.4 Development of the software application

- Interoperability

The ability for AI models to interoperate with various existing digital infrastructure of hospitals and clinical care centres is essential for their successful integration into healthcare practice. Various industry standards such as those from the ISO and the IEEE have been made to provide guidance on what data formats to use, how they should be exchanged between system components, and reduce the risk that data are accidentally misinterpreted due to slight differences in meaning of variables.

- Human–AI interaction

A proper design of how end users can interact with the AI model is crucial for its adoption, and effective and safe use in daily healthcare practice. What constitutes a good design depends on the domain, healthcare setting and intended end users. Designing a good user interface and interaction requires careful consideration of the cognitive load of the end by showing only relevant information in the right context, and by allowing adjustment of its behaviour by end users. To arrive at a good design, repeated extensive user experience testing is recommended. The AI model should be evaluated according to how it interfaces with the end user, and how well the AI model and the user perform together in a typical environment.

- Facilitating software updating and monitoring

Updates of or adaptations to the AI model should happen cautiously. End users should be notified clearly about any changes in the AI model, and AI model software should have the ability to roll back to previous versions, in case an update results in significant problems.

- Logging and traceability of predictions by the model

AI model interface should provide sharing of performance data with end users to enable ongoing monitoring of both individual and aggregated cases, quickly highlighting any significant deviations in performance. Such monitoring options should preferably be customizable by the user.

6.5 Implementation and use in daily healthcare practice

- Clinical implementation

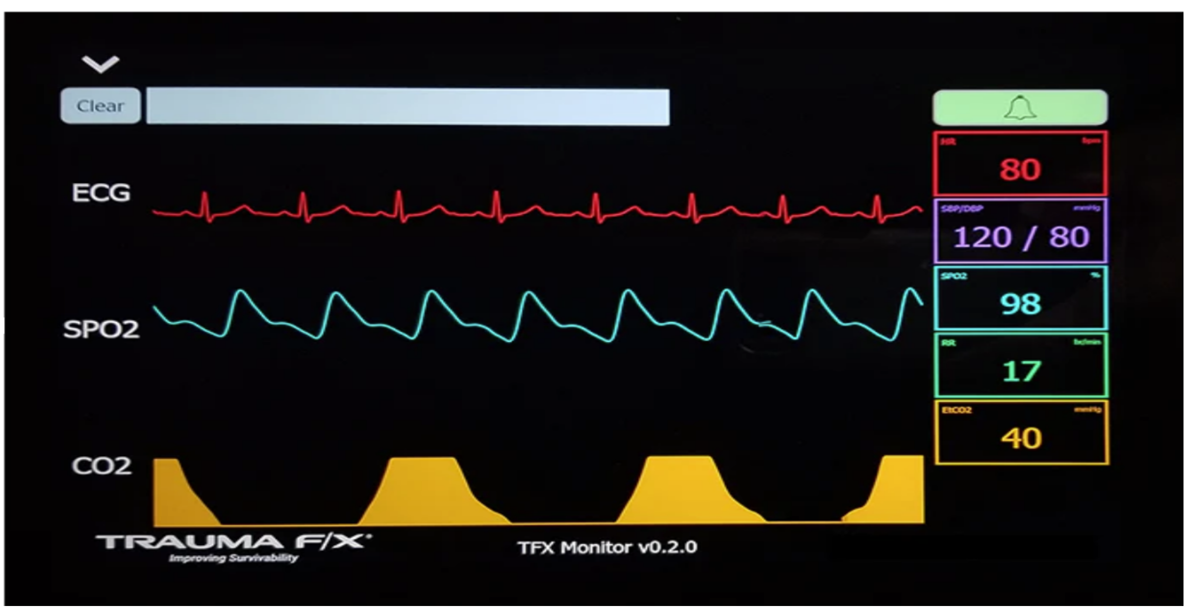
Clinical implementation consists of all the steps that are necessary to deploy the AI model in the healthcare environment outside of the clinical trial setting. One must ensure that the available logistics in place are adequate for the use of the model. For example, the AI model system might require dedicated and locally available hardware.

- Monitoring and auditing

Monitoring refers to the post-deployment evaluation of the behaviour of an AI model throughout its lifecycle. It is performed by the developer and implementers at the implementation site. Auditing refers to periodic quality control checks of the AI model (and all of its monitoring aspects). Among other things, It will aid the detection of failures and near misses and through this strengthen the risk management and security of an AI model. Several aspects of AI model functioning can be monitored, such as distribution of predicted versus observed labels, reliability and reproducibility, types and severity of errors, user satisfaction and user feedback, and clinical outcomes.
Lastly, dataset shifting must also be taken into account. Dataset shift is a change in the composition of the input data caused by changes in clinical or operational practices over time that can lead to the deterioration of AI model performance. IIt can be mitigated by retraining or updating the AI model.

SECTION 7 - ANAESTHESIA MONITOR PARAMETERS

After being assigned the project, we received guidance from our mentor, Dr. Pratap, who emphasised the importance of visiting the hospital to gain a comprehensive understanding of the project's requirements. During the hospital visit, Dr. Pratap provided a detailed explanation of the project, its prerequisites, and the key features that needed to be considered. We were first explained about the vitals monitoring machine.



<u>Parameter Definitions</u>:

HR: Heart Rate, expressed in beats per minute

PVC: Premature ventricular contractions (PVCs) are extra heartbeats that begin in one of the heart's two lower pumping chambers (ventricles). These extra beats disrupt the regular heart rhythm, sometimes causing a sensation of a fluttering or a skipped beat in the chest.

SpO2: Stands for saturation of peripheral oxygen. It is the measure of oxygen that haemoglobin cells in the circulatory system have attached to them.

etCO2: End-tidal carbon dioxide ($EtCO_2$) is the level of carbon dioxide that is released at the end of an exhaled breath. It reflects the adequacy with which carbon dioxide (CO_2) is carried by the blood back to the lungs and exhaled.

imCO2: inspired minimum carbon dioxide, or the smallest value sensed during inspiration.

NBPm - non-invasive arterial blood pressure, mean
NBPd - non-invasive arterial blood pressure (diastolic)
NBPs - non-invasive arterial blood pressure (systolic);

awRR: stands for airway respiratory rate

CVP: stands for central venous pressure. It is the pressure in the thoracic vena cava near the right atrium. It can be used to estimate a patient's fluid volume status, assess cardiac function, and gauge how well the right ventricle of the heart is functioning.

SECTION 8 - ALL-IN-ONE VITALS MACHINE

8.1 Importance of All-in-One Vitals Monitoring Machine:

The implementation of an All-in-One Vitals Monitoring Machine offers several benefits in surgical care, including:

1. **Greater patient safety**: Real-time monitoring of vital signs using all-in-one vital signs monitors and Holter ECG monitors enables healthcare professionals to promptly respond to any changes, minimising the risk of complications and ensuring optimal patient outcomes.

2. **Enhanced patient comfort**: Continuous monitoring of vital signs reduces the need for frequent manual checks, providing patients with improved comfort and convenience.

3. **Advanced monitoring capabilities**: All-in-one digital vital signs machines and Holter ECG monitors offer enhanced monitoring capabilities, allowing simultaneous tracking of multiple vital signs. This facilitates early identification of potential problems, leading to improved patient care and reduced complications.

4. **Improved data accuracy**: The utilisation of all-in-one vital signs monitors and Holter ECG monitors enhances data accuracy, resulting in more reliable results and higher-quality care.

5. **Cost-effectiveness**: By replacing manual monitoring methods, all-in-one vital signs monitors offer a more cost-effective solution, reducing expenses associated with labour-intensive monitoring practices.

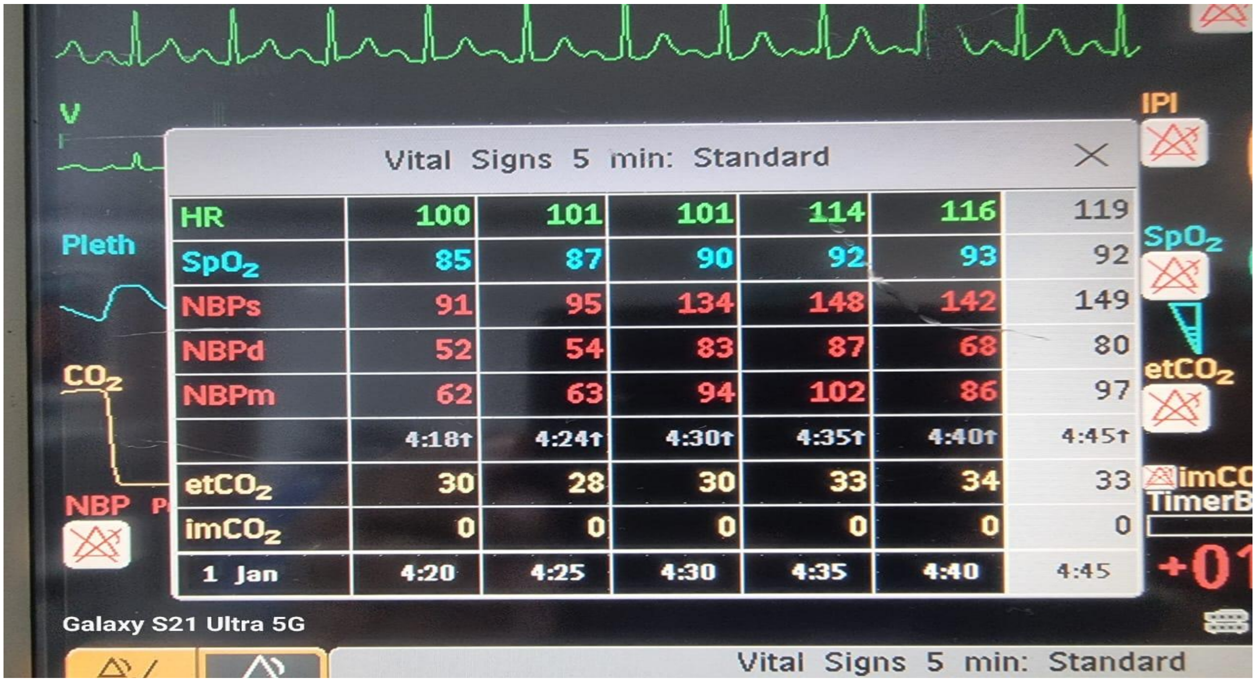
8.2 Applications of All-in-One Vitals Monitoring System:

The all-in-one vitals monitoring system finds applications in various stages of surgical care, including:

1. Preoperative monitoring: All-in-one vital signs monitors facilitate the assessment of a patient's health before surgery, measuring vital signs such as heart rate, blood pressure, oxygen saturation, and temperature. Holter ECG monitors are useful in evaluating the heart's electrical activity, particularly in cardiac surgery cases.

2. Intraoperative monitoring: All-in-one vital signs monitors ensure patient safety during surgery by maintaining a constant monitoring of vital signs. Holter ECG monitors aid in monitoring the heart's electrical activity during specific surgical procedures.

3. Postoperative monitoring: All-in-one vital signs monitors are valuable in the recovery room for continuous monitoring of vital signs, ensuring a safe and smooth recovery process. Holter ECG monitors can detect any abnormalities in the heart's electrical activity that may have occurred during surgery.



SECTION 9 - VITALDB

9.1 AI Implementation:

To further enhance patient care, we have embarked on developing an AI model to assist anesthesiologists in predicting changes in patients' vitals during surgery. Our goal is to aid in maintaining patient stability and identifying the need for any adjustments in anaesthesia.

9.2 Data Collection and Training:

To train and test our AI models, we require a substantial amount of data. We have received assurance of receiving the necessary data from the hospital in the coming days. In the interim, we have explored publicly available datasets related to vital signs on the internet. We utilised data from VitalDB for training our AI models and aim to utilise real-time data from the hospital for testing purposes. We have obtained approximately 100 cases, which we anticipate will cover a diverse range of scenarios.

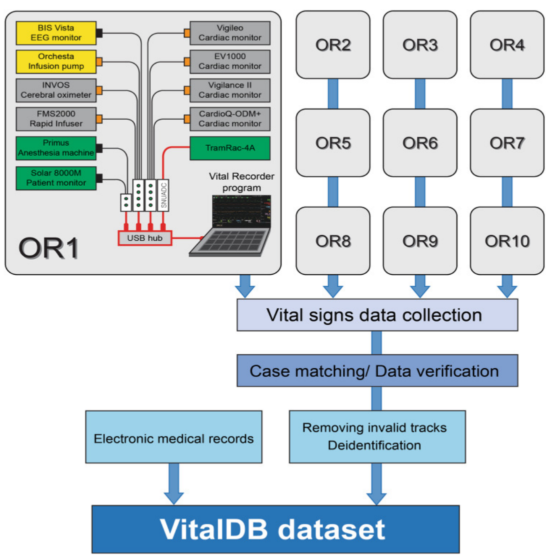
The implementation of an All-in-One Vitals Monitoring Machine and the integration of AI have significant implications for surgical care. Through real-time monitoring and advanced predictive capabilities, these technologies offer the potential to enhance patient safety, improve outcomes, and streamline the surgical process. Our ongoing efforts involve the collection of relevant data and the development of AI models to support anesthesiologists in maintaining patient stability during surgery.

Taking these into consideration, we started working on the model of the Artificial Intelligence which would aid the Anesthesiologist by predicting any changes in the vitals of the patient undergoing the surgery or if there are any necessary changes of anaesthesia to be made so that the patient is maintained in a stable condition.

9.3 About the Dataset

While there were quite a few datasets available on the internet, we decided to work with the VitalDB Dataset since it met all our requirements in terms of the parameters used. The VitalDB (Vital Signs DataBase) is an open dataset created to facilitate machine-learning studies related to monitoring vital signs in surgical patients.

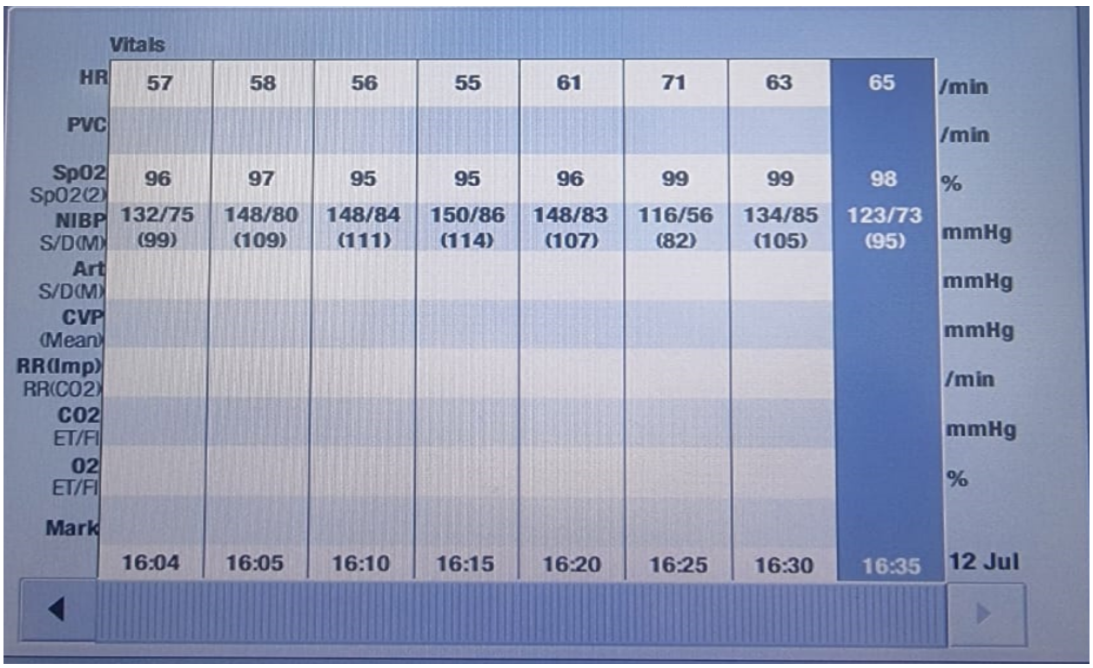
This dataset contains high-resolution multi-parameter data from 6,388 cases, including 486,451 waveform and numeric data tracks of 196 intraoperative monitoring parameters, 73 perioperative clinical parameters, and 34 time-series laboratory result parameters.



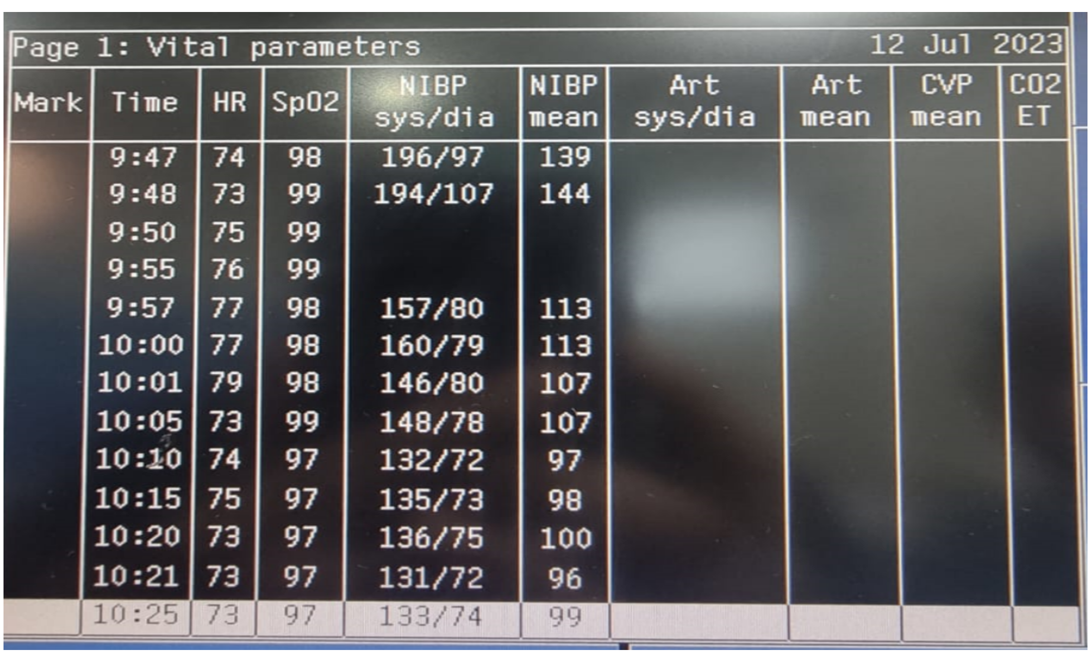
Data were obtained from non-cardiac (general, thoracic, urological, and gynaecological) surgery patients who underwent routine or emergency operations at Seoul National University Hospital, Seoul, Korea from Aug 2016 to Jun 2017. Of the 7,051 eligible cases, cases with local anaesthesia (239), incomplete recording (279), and loss of essential data tracks (145) were excluded. Finally, 6,388 cases (91%) who received general anaesthesia, spinal anaesthesia, and sedation/analgesia were included in the dataset .

The dataset was available in the form of a python library and a Web API which we used, in order to use the data in our project .

We used the data from VitalDB to train our AI models and wanted to use the real time data that we would get from the hospital as Testing data. We got about 100 cases as such which we hope will help cover various cases. The pictorial representation of the data that we got was of the following format



Vitals	16:04	16:05	16:10	16:15	16:20	16:25	16:30	16:35	12 Jul
HR	57	58	56	55	61	71	63	65	/min
PVC									/min
Sp02 Sp02(2)	96	97	95	95	96	99	99	98	%
NIBP S/D(M)	132/75 (99)	148/80 (109)	148/84 (111)	150/86 (114)	148/83 (107)	116/56 (82)	134/85 (105)	123/73 (95)	mmHg
Art S/D(M)									mmHg
CVP (Mean)									mmHg
RR(Imp) RR(CO2)									/min
CO2 ET/FI									mmHg
O2 ET/FI									%
Mark									



Page 1: Vital parameters 12 Jul 2023

Mark	Time	HR	Sp02	NIBP sys/dia	NIBP mean	Art sys/dia	Art mean	CVP mean	CO2 ET
	9:47	74	98	196/97	139				
	9:48	73	99	194/107	144				
	9:50	75	99						
	9:55	76	99						
	9:57	77	98	157/80	113				
	10:00	77	98	160/79	113				
	10:01	79	98	146/80	107				
	10:05	73	99	148/78	107				
	10:10	74	97	132/72	97				
	10:15	75	97	135/73	98				
	10:20	73	97	136/75	100				
	10:21	73	97	131/72	96				
	10:25	73	97	133/74	99				

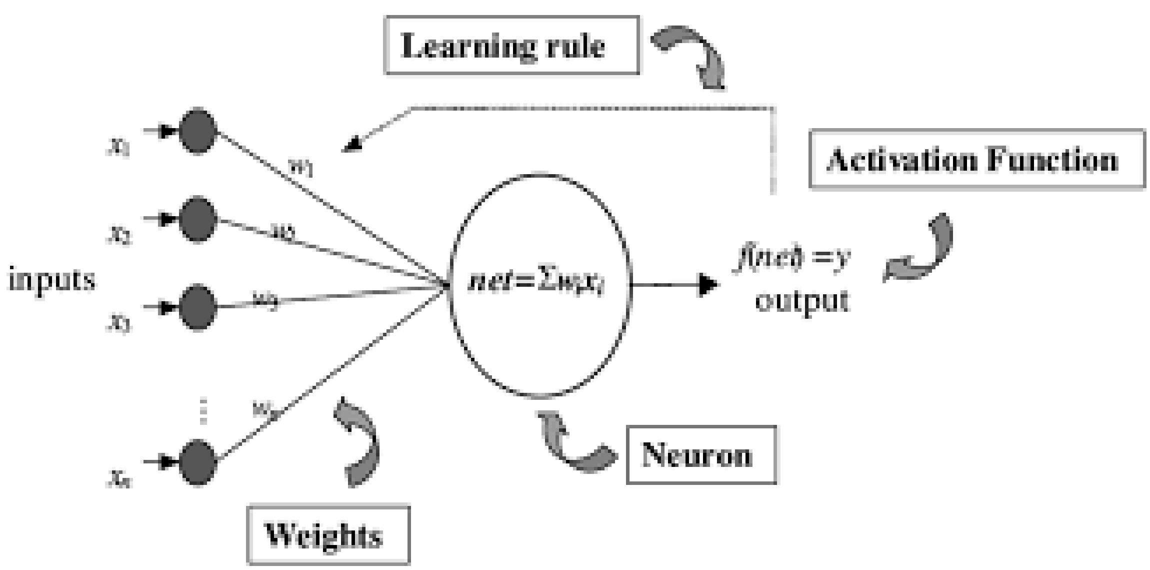
SECTION 10 - NEURAL NETWORKS

Neural networks, also known as artificial neural networks or simply ANNs, are a powerful subset of machine learning models inspired by the human brain's structure and functioning. They have gained significant popularity in recent years due to their ability to learn and make predictions from complex data patterns.

At the core of a neural network lies the neuron, the fundamental building block. Each neuron receives input signals, performs computations on them, and produces an output signal. The computations can vary from neuron to neuron and it's called its activation function . These signals, analogous to the electrical impulses in the brain, are numerical values that represent the information being processed.

A neural network consists of interconnected layers of neurons, forming a network structure. The input layer receives the initial data, such as images, text, or numerical values. The output layer produces the desired results, such as classification labels or predictions. In between, there can be one or more hidden layers, which play a crucial role in capturing intricate patterns and relationships within the data.

Neural networks excel in tasks that involve pattern recognition, such as image classification, natural language processing, and speech recognition. They can automatically extract relevant features from raw data, adapt to new information, and generalise well to unseen examples.



Here are the steps followed in building a deep learning-based neural network -

1 - Data Preparation: The data that would be used to train and test the ANN was gathered and preprocessed. This involved tasks such as data cleaning, normalisation, feature engineering, and splitting the dataset into training and testing sets.

2- Network Architecture Design: The appropriate architecture for your ANN was chosen based on the problem statement. This included determining the number of layers, the number of neurons in each layer, the activation functions, and any specific modifications like dropout or batch normalisation.

3 - Initialization: The weights and biases of the ANN were decided. Proper initialization can play a crucial role in the convergence and performance of the network during training.

4 - Training: The training dataset was used to optimise the network's parameters (weights and biases). This process was done through backpropagation, where the errors are propagated backwards through the network to adjust the weights and reduce the loss function.

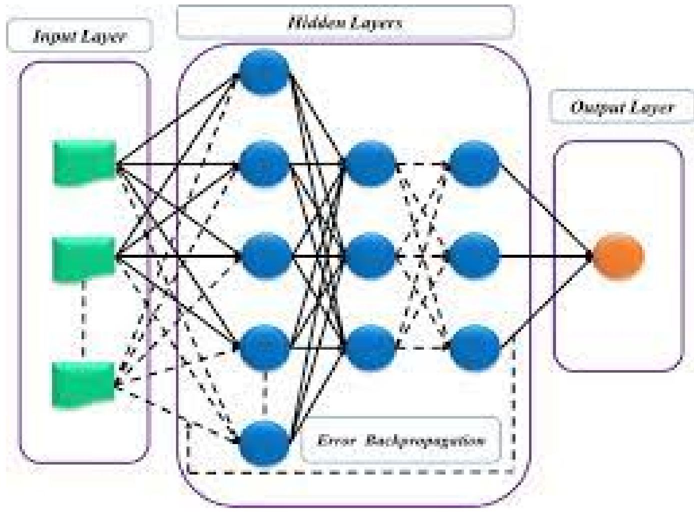
5 - Validation and testing: The ANN's performance was validated and tested on a validation dataset during training to monitor for overfitting or underfitting.

SECTION 11 -TYPES OF NEURAL NETWORKS

Here are the different types of neural networks that are used for this -

11.1 Feedforward Neural Networks:

Feedforward neural networks, also known as multilayer perceptrons (MLPs), are the most basic and widely used type of neural networks. They consist of multiple layers of neurons, each layer connected to the next in a sequential manner without any loops or feedback connections.



Input Layer:

- The input layer receives the initial data or features to be processed by the network.
- Each neuron in the input layer represents a feature or attribute of the input data.

Hidden Layers:

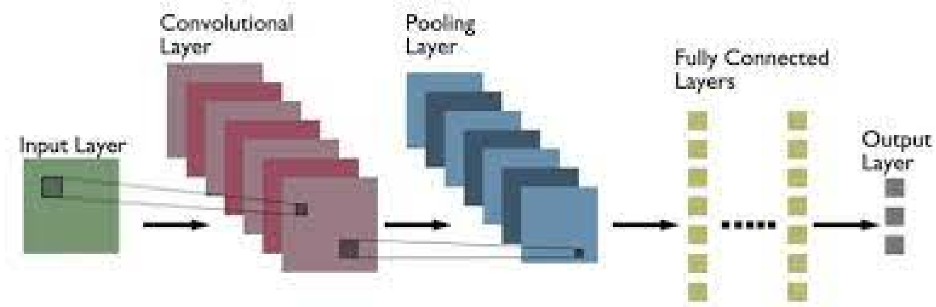
- The hidden layers, sandwiched between the input and output layers, perform computations and extract relevant features from the input data.
- Each neuron in a hidden layer takes inputs from the previous layer and produces an output based on its weights and activation function.
- The number of hidden layers and neurons per layer can vary depending on the complexity of the problem.

Output Layer:

- The output layer produces the final results or predictions based on the processed information from the hidden layers.
- The number of neurons in the output layer is determined by the nature of the problem, such as binary classification, multi-class classification, or regression.

<u>11.2 Convolutional Neural Networks (CNNs)</u>:

Convolutional neural networks are particularly effective for image and video analysis tasks due to their ability to capture spatial relationships and patterns in data.



Convolutional Layers:

- Convolutional layers apply a set of learnable filters or kernels to the input data.
- Each filter detects specific local patterns or features by performing convolution operations.
- Convolution involves sliding the filter over the input data, computing dot products at each position, and producing feature maps.

Pooling Layers:

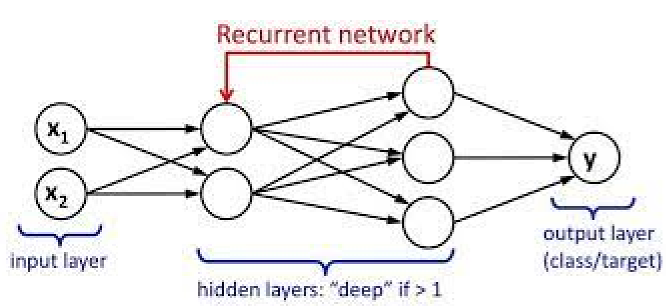
- Pooling layers downsample the spatial dimensions of the feature maps generated by the convolutional layers.
- Common pooling operations include max pooling and average pooling, which reduce the dimensionality while retaining the essential features.

Fully Connected Layers:

- Fully connected layers are similar to those in feedforward neural networks.
- They receive the flattened output from the previous layers and perform classification or regression based on the learned features.

<u>11.3 Recurrent Neural Networks (RNNs)</u>:

Recurrent neural networks are designed to process sequential or time-dependent data, making them suitable for natural language processing and speech recognition tasks.



Recurrent Connections:

- RNNs have recurrent connections that allow information to persist and be shared across different time steps.
- Each neuron receives input not only from the previous layer but also from its own previous state, creating a feedback loop.

Long Short-Term Memory (LSTM) Cells:

- LSTM cells are a specialised type of RNN unit that can selectively remember or forget information over long sequences.
- They incorporate gating mechanisms, such as input, forget, and output gates, to control the flow of information through time.

Gated Recurrent Units (GRUs)

- GRUs are a type of recurrent neural network (RNN) architecture designed to overcome the vanishing gradient problem.
- They use specialised gating mechanisms, which allow them to capture and propagate relevant information across time steps more effectively than traditional RNNs.

Bidirectional RNNs

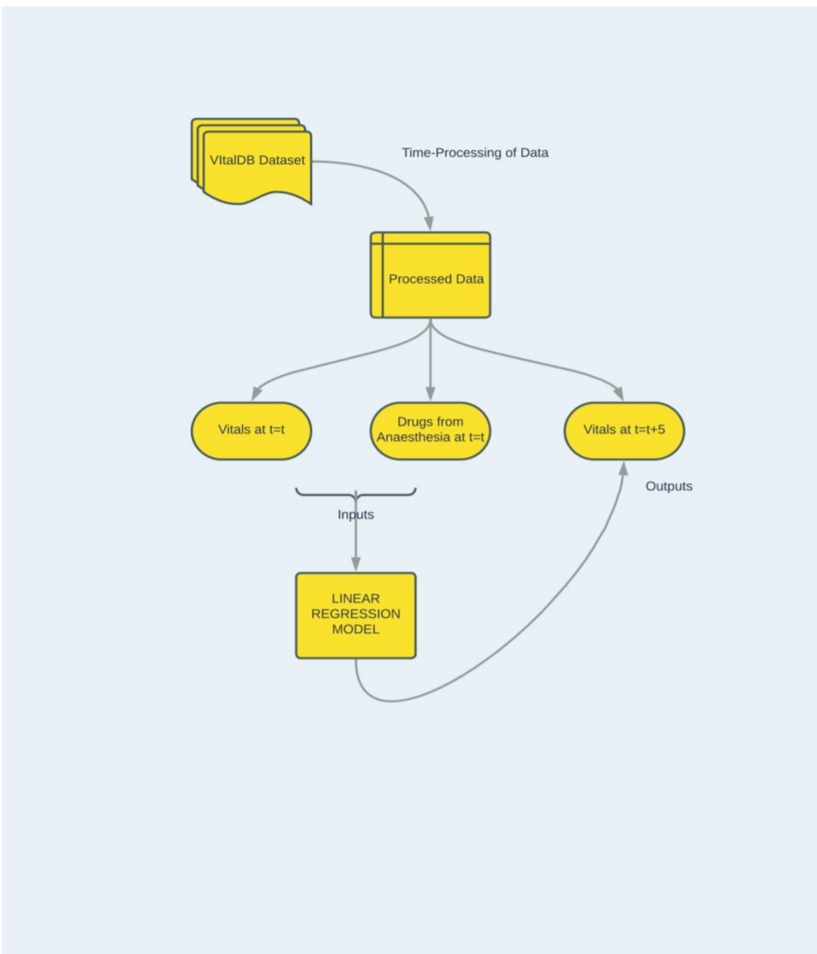
- Bidirectional RNNs process the input data in both forward and backward directions simultaneously.
- This allows the network to capture dependencies from both past and future contexts, enhancing its understanding of the sequential data.

SECTION 12 - OUR ARCHITECTURES

12.1 Regression Model:

We started off working on the Vital_DB Dataset with the most basic model of Regression. The expected outputs(vitals at t = t + 5) being a set of values dependent on the vital values, and the anaesthetic inputs at present time t, we tried the most basic ML model for prediction of a set of non-finite values, which is the Linear Regression Model.

This therefore is where we decided to start off with, in our model experimentation.



Code: https://github.com/avadoe/Anaesthesia_/blob/main/regression.ipynb

Post this designing and coding, we thought of the obstacles caused due to this.

The first one is the general lack of non-linearity in time-based data. If the underlying relationship is non-linear, the Linear Regression model will fail to give satisfactory results.

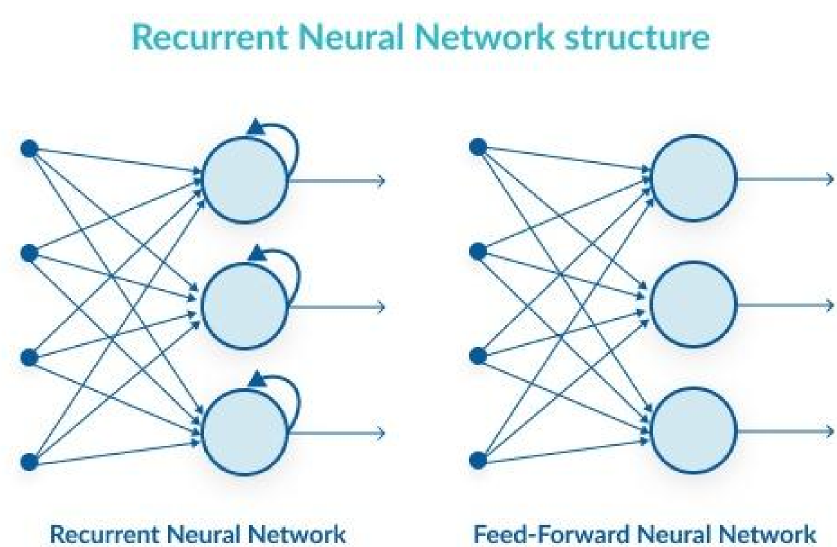
Linear Regression assumes the stationarity of the statistical properties of the data, like mean and variance. However with the data we're dealing with here, which is medical data, there is a high possibility of a violation of this property due to trends or lags.

12.2 RNN Models:

As we progressed from the simple Linear Regression model, we decided to approach this problem using the pre-existing norms of analysing and learning time-series data, which is with the use of RNNs (Recurrent Neural Networks).

These networks are powerful temporal models used to capture information regarding dependencies, which makes them extremely efficient at not only time-series models, but also speech recognition, machine translation etc.

Unlike feedforward neural networks, which process inputs independently, RNNs have Recurrent connections that allow information to be passed from one step to the next, creating a form of AI Memory within the network.



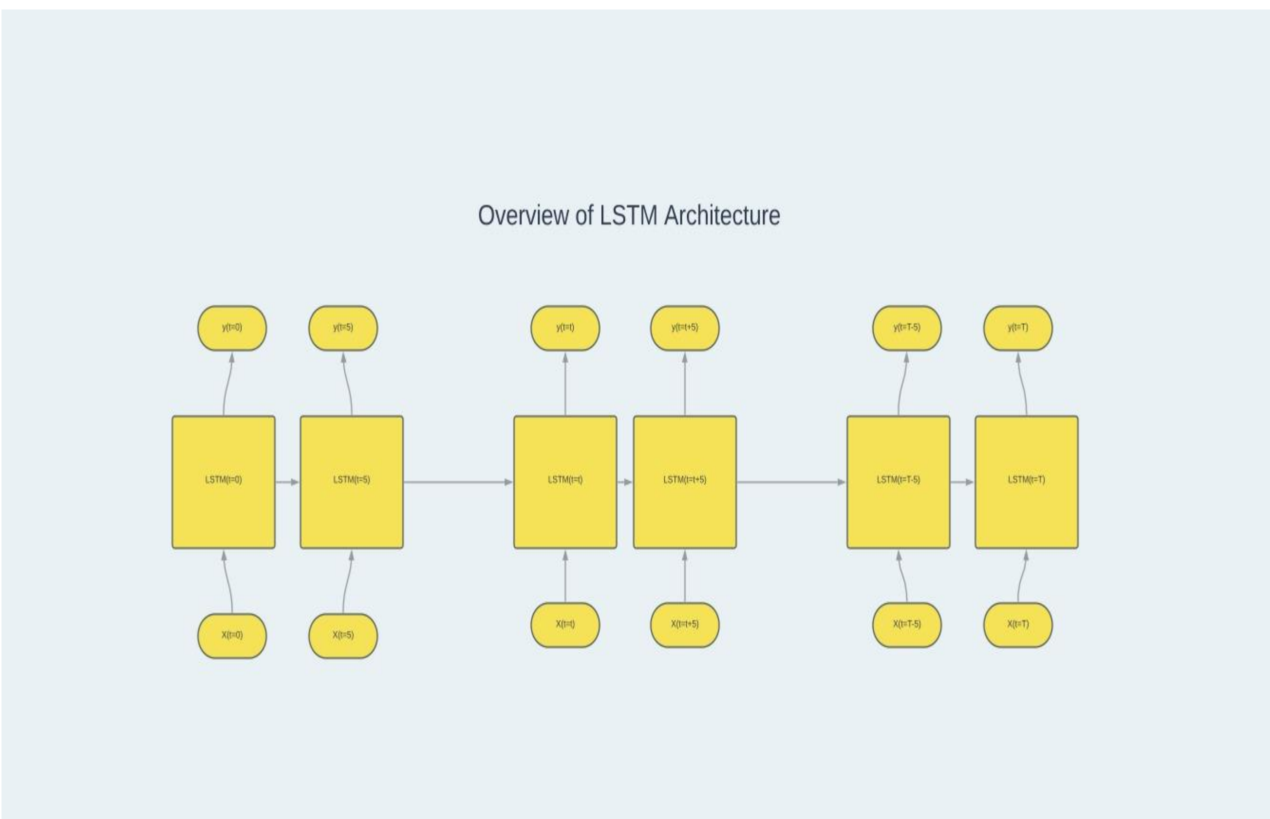
The important thing to observe here is the fact that the input, x and the previous hidden state, h(t-1) are taken together through the activation function to compute a new hidden state h(t).

However, traditional RNNs suffer from the vanishing gradient problem, which is to a high extent rectified by Advanced RNNs with more complex architectures, like LSTMs (Long Short Term Memory), GRUs (Gated Recurrent Units), which have become the de-facto for modelling Sequential data.

The following is an example of an LSTM-governed model to handle time-data.

The schematic diagram presents an overview of the architecture of LSTMs, which themselves can be unidirectional or bidirectional, based on the choice of the model architect.

The figure presents a basic unidirectional LSTM.



12.2.1 LSTM Model:

The first RNN Model we coded, was an LSTM Model. This model, from our study, is something we expected would overcome the limitations of traditional RNNs. Unlike simple RNNs, LSTMs are structured with gates, namely the Input Gate, Forget Gate, and Output Gate.

The memory cell is the primary component of an LSTM, and that is where the present state of the cell is maintained.

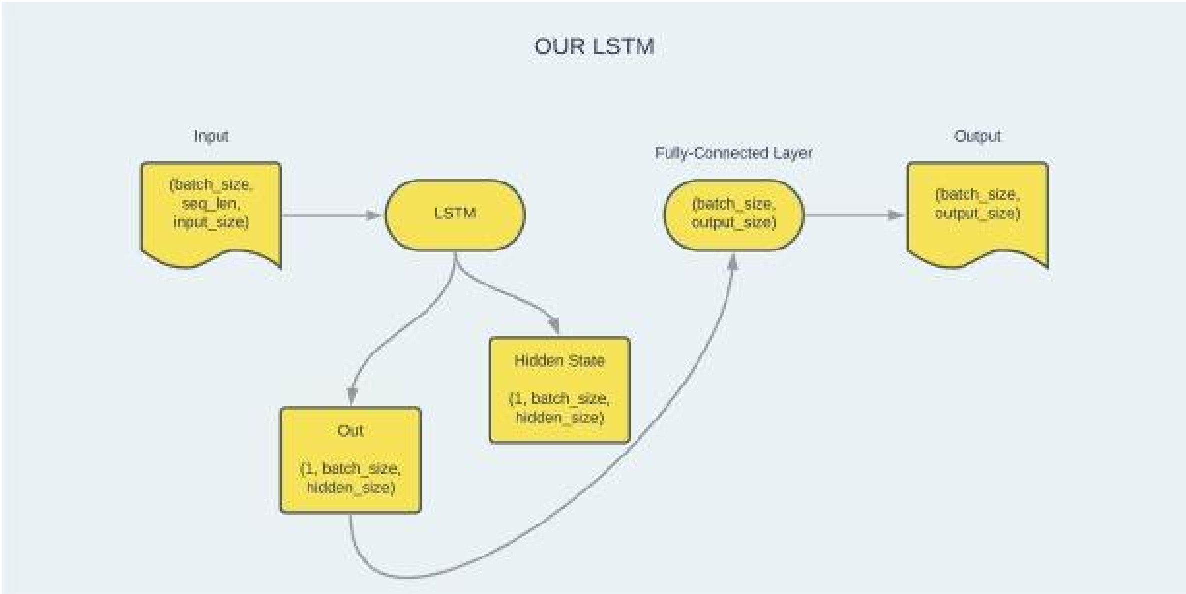
The input gate is the selective filter, which determines how much new information is supposed to be stored in the memory cell. The forget gate is a selective discarder, which erases information which the model decides to be no longer useful. The output gate controls the flow of information, either to the Fully Connected Layer, or the next hidden state.

The decision regarding the shapes of data as they pass through the different layers as tensors has been taken after experimenting with multiple standard conventions.

The fully connected layer, also called Dense layer in a Deep Learning vocabulary, are generally used post a complex architecture leading to the output tensor. They are widely used to learn non-linear relationships, and making predictions, not only in Regression and Classification, but also in Generative Modelling.

In our code, we have used the ReLU activation function on the outputs of the Linear Layer to add a degree of nonlinearity to the predictions, thus allowing the model to learn more complex relationships between the input and output data.

The following schematic diagram presents our code for the designed LSTM Model in a pictorial fashion.



Code: https://github.com/avadoe/Anaesthesia_/blob/main/lstm_model.py

<u>**12.2.2 GRU Model**</u>:

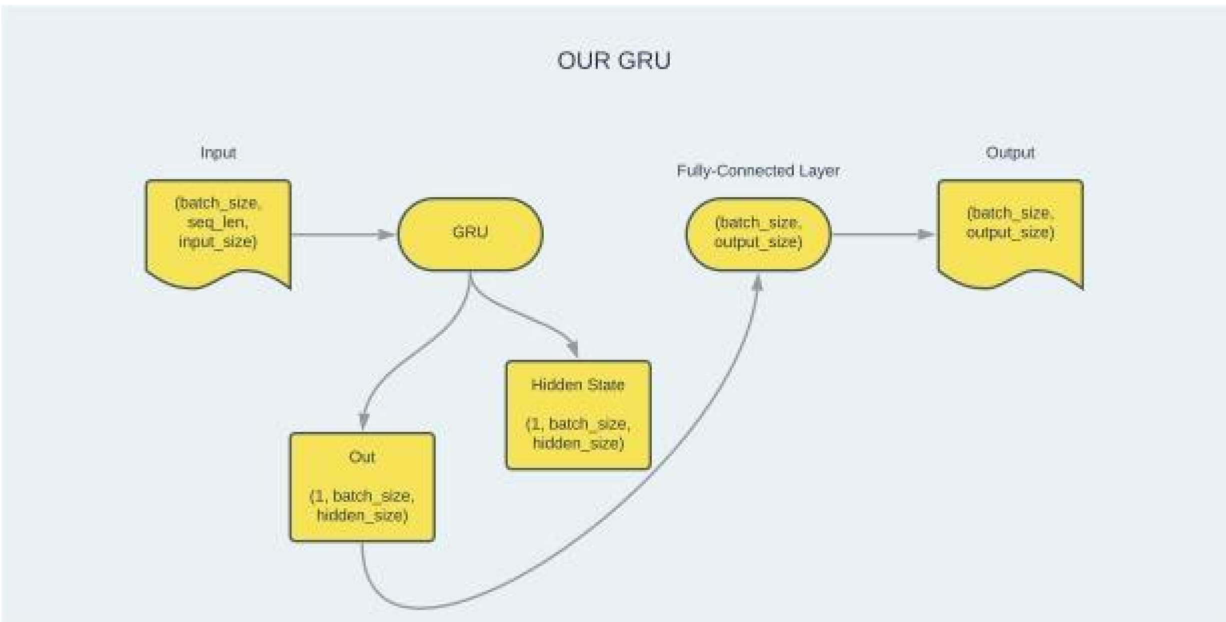
After coding out the LSTM Model, we studied about a simpler architecture where the forget and input gates are merged together and Memory cell state and the hidden state as well. This architecture is formally referred to as the GRU, or the Gated Recurrent Unit, and has wide applications in the field of capturing Long-Term Dependencies in Sequential Data. Although theoretically the LSTM Model is supposed to perform better than the GRU Model due to the more complex architecture, we decided to include a GRU Implementation of this RNN as well, keeping in mind the computational power of the CPUs/GPUs used in the computers in Yashoda Hospital during the live-prediction, during the surgical procedure.

The differences between this and the LSTM Model are the absence of a unique and separate hidden state in the GRUs. This, on the plus side, makes GRUs very much more efficient computationally, since there are fewer gates to process, and fewer parameters to compute.

The important thing to note from our GRU Implementation is the fact that the overlying design and the structure of the code is very much similar. The pre-processing is exactly the same and the core idea is very similar, except for the internal architecture of the units in a network of GRUs.

The following is a diagrammatic representation of our GRU architecture:

Code: https://github.com/avadoe/Anaesthesia_/blob/main/gru.py



Summarising the LSTM and GRU Models using the code for reference, specifically the following lines:

out, _ = self.lstm(x)

out = self.fc(out[:, -1, :])

or

out, _ = self.gru (x)

out = self.fc(out[:, -1, :])

The _ stores/ discards the hidden state of the network, and the second line indexing represents the latest time-step for the output sequence for each sample in the batch.

In this way, we're just keeping track of the output's with respect to time.

12.2.3 Encoder-Decoder Model:

The final model we decided to try was the Encoder-Decoder Model. This is a commonly used architecture for sequence-to-sequence tasks where an input sequence is transformed into an output sequence, with 2 distinct blocks of networks operating on the data.

The Encoder and Decoder by themselves are unique and individual mini-model architectures, with not a well-defined output and not a well-defined input respectively.

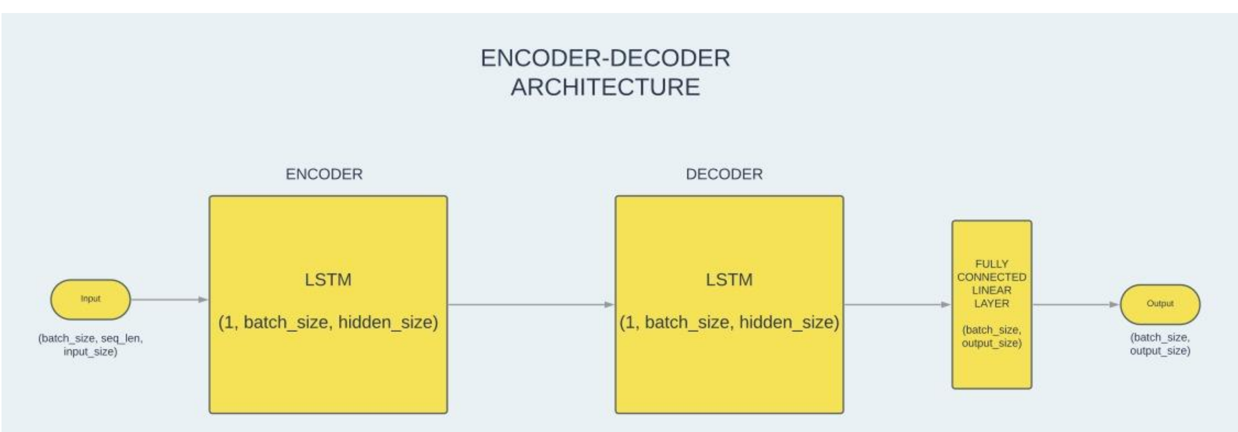
Our Design Choice:

We went with an LSTM-based Encoder as we pass the input data batch-wise. We decided to stick with an LSTM because of the relative modernity of the LSTM model in general, but it could very well be replaced by a GRU Model, with minimal difference in code.

We passed the outputs of the encoder layer through the Decoder layer, in which we decided to use the LSTM architecture again, just to keep a coherence.

The outputs of the Decoder Layer then pass through a Fully Connected Layer, and with some feature processing into the shape (batch_size, output_size), we predict the outputs of this batch of data 'X'.

The following figure illustrates our Encoder-Decoder model:



Code: https://github.com/avadoe/Anaesthesia_/blob/main/encoder_decoder.py

Our code defines the Encoder-Decoder model class, and the tensor shape-changes are along the lines picturised in the above figure.

With these RNN-only Models we managed to design working Deep Learning architectures that process the numerical data that is the vitals taken from the live monitoring during a surgical procedure, and to decently low error, predict the values of these vitals 5 minutes later. The ideas concerning the aspect of time-series predictions are, for the most part, covered in the paths we took to make the models we've described above in relative detail.

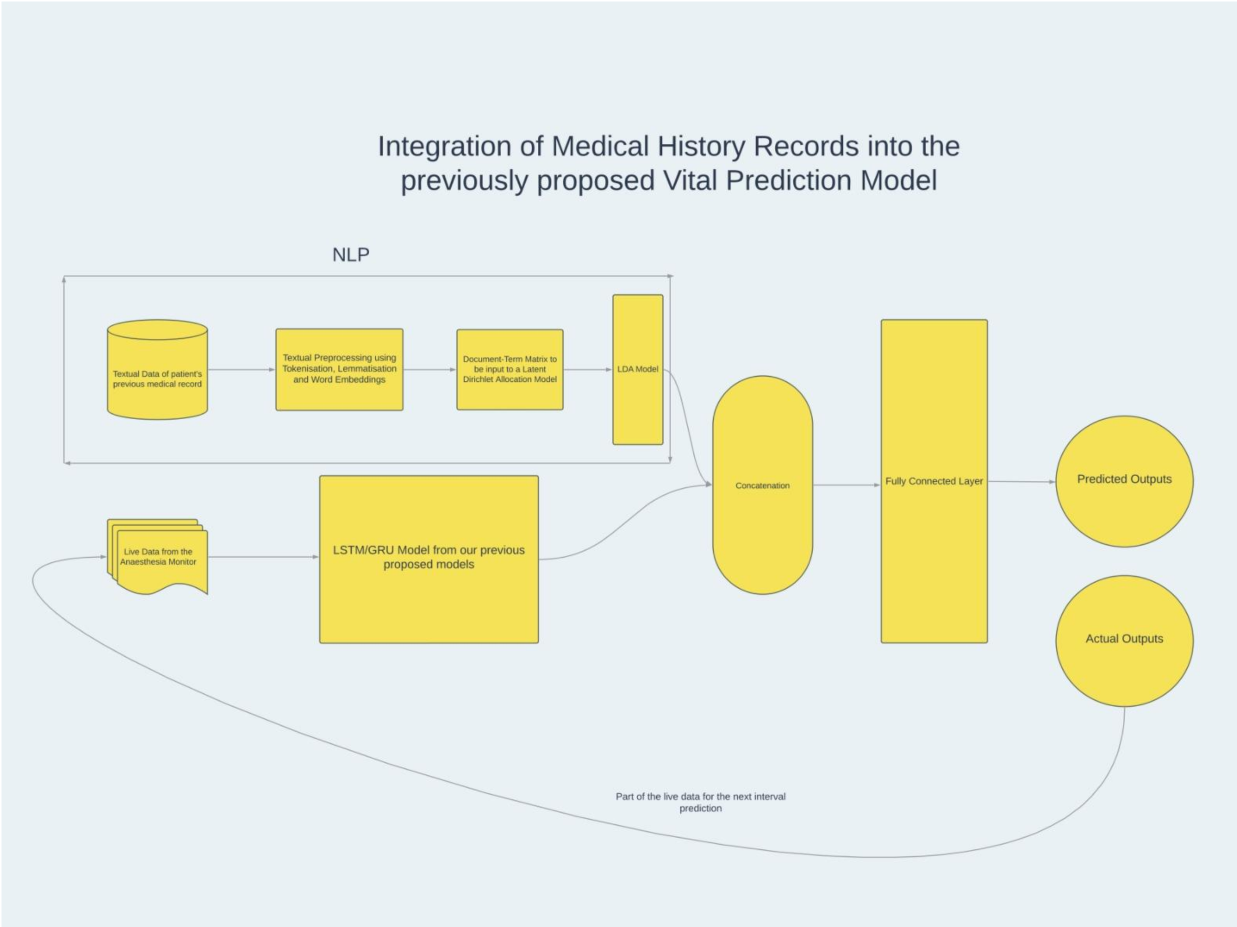
Post working on these models, we've also learnt from Dr. Pratap Reddy about a database consisting of the previous medical records of a patient, which we were informed, would be important inputs to the prediction AI, for previous medical records do have a lot to add to the reasons of the fluctuation of vitals etc. for a patient.

This data is in the textual form. Consequently, we thought of architectures for models which would take this textual data as input as well, going together with the already existing RNN Model from the ones suggested above, for a more subject-specific output.

Therefore, we designed a Natural Language Processing architecture, which can be integrated into, say, the Encoder-Decoder model, having a concatenating layer.

12.3 Integrated NLP Model:

The following figure represents our design for this model:



The governing idea behind this design was the fact that we could use NLP techniques like word embedding to generate an attention model for the words in the textual data. This would later be encoded into numerical representations using one of Word-Embeddings with models like Word2Vec, GloVe etc., or tokens generated using Tokenization or Indexing after a processing of the data. This encoded data would be merged with the data from the LSTM/GRU outputs from our numerical-processing models and generate predictions using a computation through a Fully Connected Layer.

This suggested NLP+LSTM network is fully compatible to handle the data which can be scraped from the website already present and accessible to the doctor, and the data which can be fed into the computer live during the operation.

The NLP Model for a specific patient can be trained beforehand, so that there’s not much wastage in computational power or time, and so that it’s ready to be processed once the inputs from the RNN part of the network are ready.

CONCLUSION

Overall, it’s been an enlightening experience working on this, collaborating with Yashoda Hospitals on this project whose domain is very much the future of this world, Artificial Intelligence. In summary, we learnt extensively about AI, its applications, and even got the opportunity to dive deeper into the theoretical aspects of Machine Learning, and Deep Learning.

While in the process of this project . we were successful in designing a Deep learning model that could predict a patient's vital signals to a reasonably accurate degree and thus hopefully the same can be applied to Yashoda hospital's monitoring architecture so that the time delay in the anaesthesia machine would no longer be an issue to the doctors

This amazing learning experience of working with an organisation as influential in many ways as Yashoda Hospitals, truly was enriching in teaching us team work, organisational structure and functioning, and made us very much aware of the fields we’ve yet to explore. We’d like to thank Dr. Sreedhar sir, for being supportive through all junctures of this PS1 journey, and Dr. Pratap Reddy Sir, for willing to give us an audience whenever needed, and providing any and all help needed.

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