Chittagong University of Engineering and Technology

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Project Report

Artificial Neural Network Based Knee Angle Estimation Using IMU Data

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Abstract:

The accurate measurement of joint angles holds significant importance in the analysis of human gait. Currently, these measurements are predominantly obtained using specialized devices like goniometers or within a gait laboratory equipped with motion capture systems. The recent advancements in Inertial Measurement Unit (IMU) technology, and artificial neural network(ANN) characterized by its affordability and portability, offer a promising avenue for continuous kinematic data monitoring. This study introduces an algorithm that employs artificial neural networks to estimate knee angles based on IMU data. The study involved the deployment of two IMUs, each equipped with tri-axis accelerometers and gyroscopes, strategically positioned above and below the knee of interest. We tested this algorithm in a portion of data that have never been seen by the algorithm before. the waveform of the knee angle with an average RMS error of 1.7.

Introduction:

An inertial measurement unit (IMU) is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the orientation of the body, using a combination of accelerometers, gyroscopes, and sometimes magnetometers. When the magnetometer is included, IMUs are referred to as IMMUs.

IMUs don't directly measure knee angles and other walking details, but they can estimate them. Previous studies used IMUs to figure out how people walk and the angles of their joints. In this study, we have used a computer program called an artificial neural network (ANN) to estimate knee angles using data from two IMUs placed above and below the knee.

A neural network is a brain-inspired model made of interconnected nodes. It learns from data to predict or classify. Great for complex tasks like image recognition. Uses activation functions, and backpropagation for learning. Needs lots of data. Can be hard to interpret due to complexity.

Methodology:

Data:

Two IMUs with tri-axis accelerometers and gyroscopes were used above and below the knee under investigation. Simultaneously, an electro-goniometer was used to measure the angle. There are 5000 rows and 13 columns in the dataset. Among these we have used 4500 data points for training and 500 points for testing the model.

ANN:

We have started our study with a neural network of 1 hidden layer. But we didn’t find acceptable results with the simple neural network.

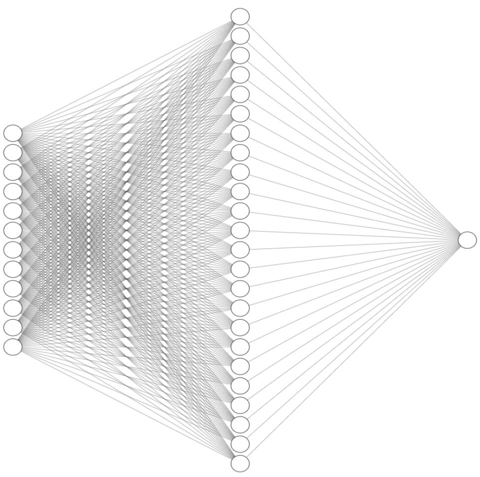
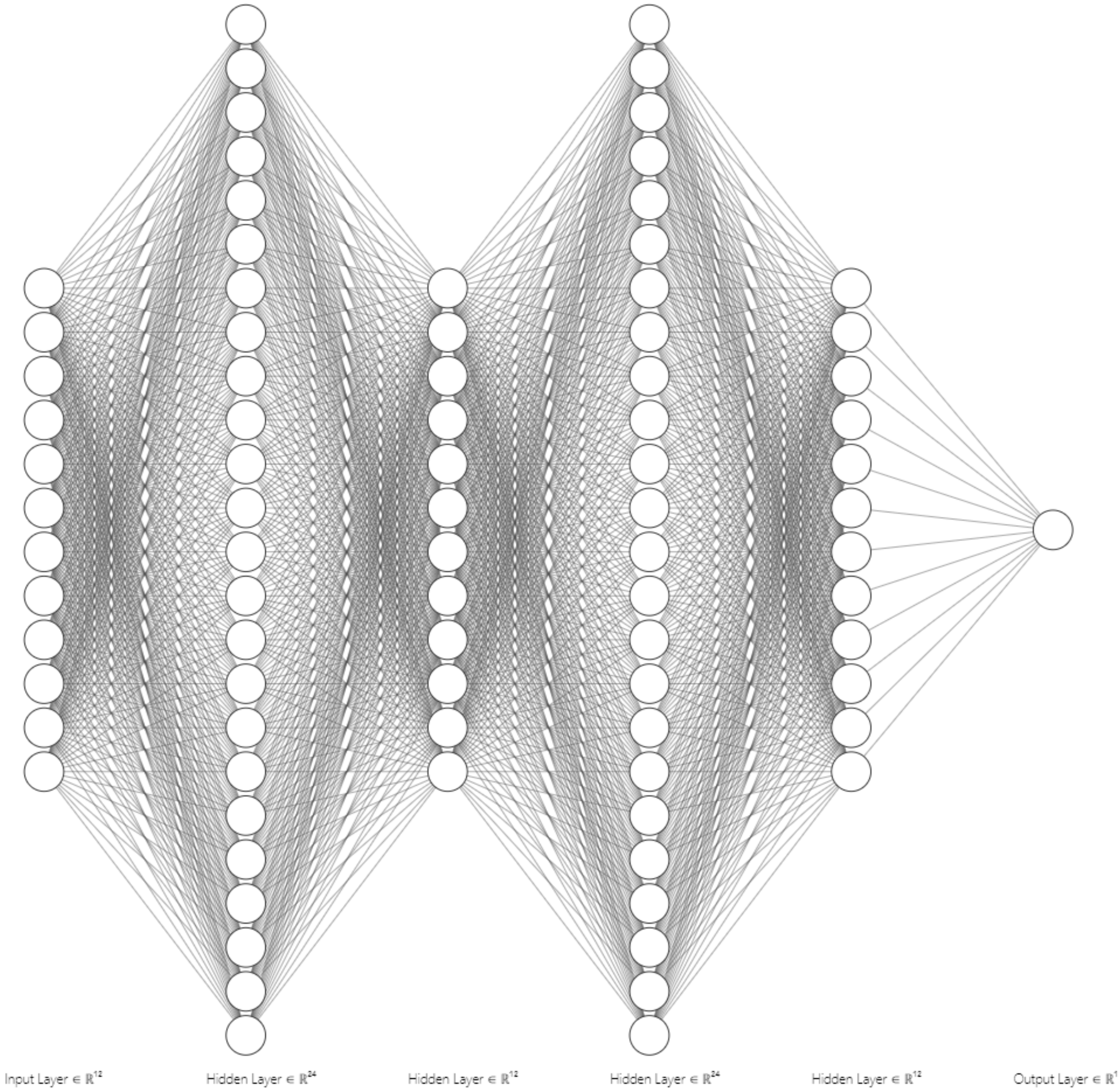


Figure: Initial Proposal

Then move toward a more complex structure. Finally, we stopped with 4 hidden layers. We have designed a neural network with 4 hidden layers. Here is a detailed specification of our neural network.



Neural network specifications:

Input Layer	– 12 Nodes
Hidden Layer 1	– 24 Nodes
Hidden Layer 2	– 12 Nodes
Hidden Layer 3	– 24 Nodes
Hidden Layer 4	– 12 Nodes
Output Layer	– 1 Node

Hidden Layers (4 in total): These are like secret rooms where the network processes the information. In the first hidden room, there are 24 little workers. Each worker takes a look at some of the information and tries to figure out patterns. In the second hidden room, there are 12 workers who continue to analyze the patterns. The third room has 24 workers again, and the fourth room has 12.

Training The model:

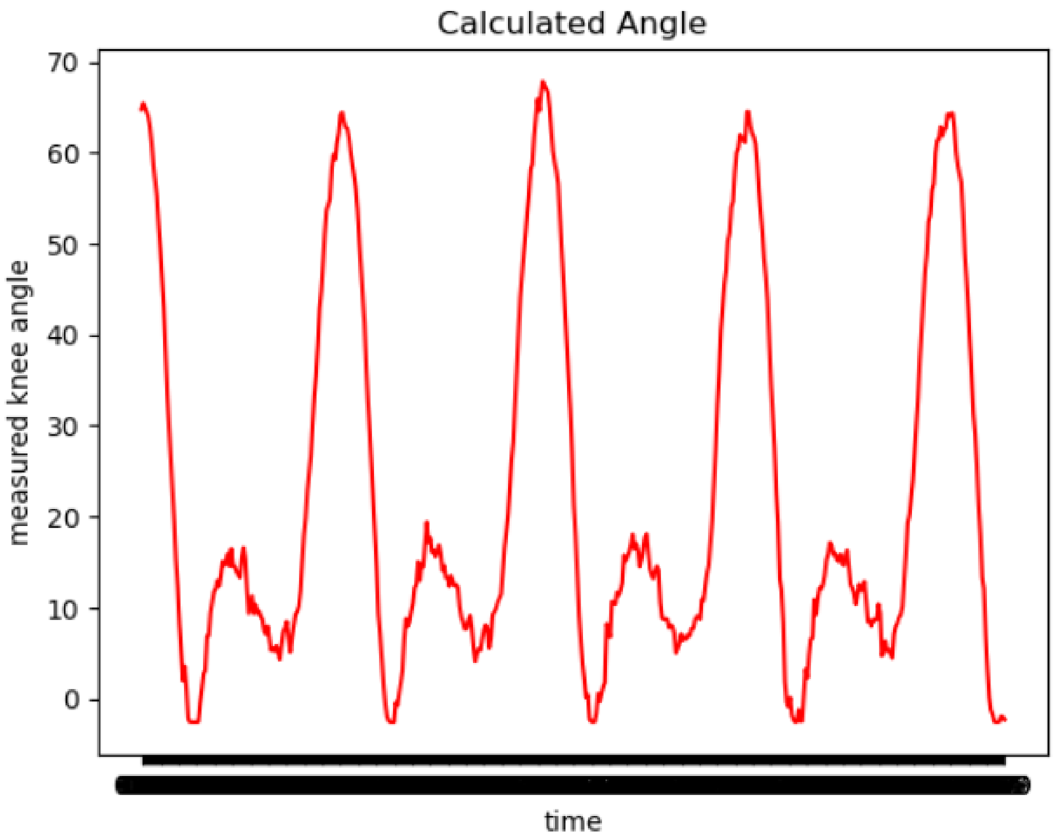
Activation Function – Relu
Optimizer – Adam
Loss Function – MSE
Validation_split – 0.3,
Epochs –200

During the model training we have used Validatin_split 0.3 and 200 Epochs for cross-validation. As this is a regression problem the output was 1 node. The relu activation function is used as It is computationally efficient and widely favored for its ability to introduce non-linearity while avoiding some of the drawbacks of other activation functions. Adam optimizer is used as adam (Adaptive Moment Estimation) optimizer is a popular optimization algorithm for training neural networks. Mean Squared Error (MSE) loss is a common loss function used in regression tasks to measure the average squared difference between predicted and actual values. It quantifies the overall model performance by penalizing larger errors more heavily, making it suitable for assessing continuous numerical predictions.

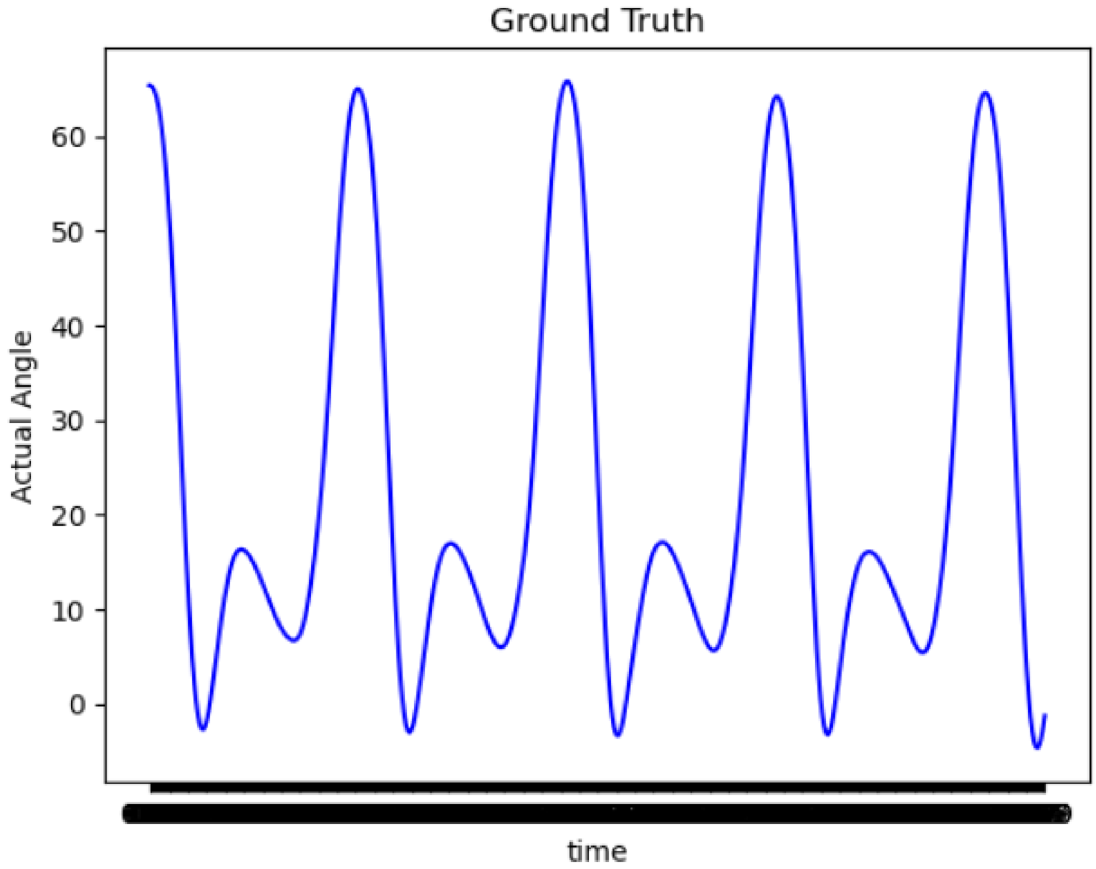
Result:

We have tested our model against a subset of the main data which was unseen during training. On an average, our model gives a 1.7 RMSE loss. It means if the model measures a knee angle of 60, the possibility that the actual knee angle is $60 \pm 1.7\ (58.3\ -\ 61.7)$.

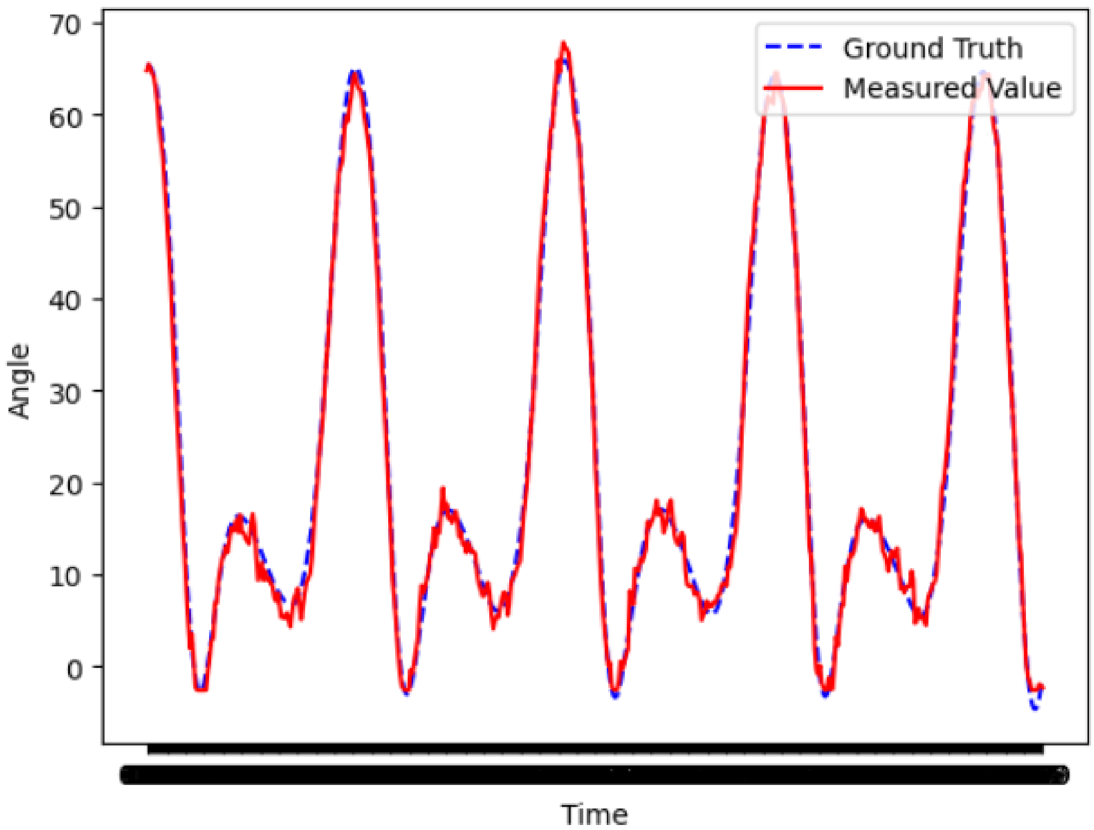
We have plotted our measured angle against time, and here is how it looks like.



If we plot the ground truth it will look something like this.



Here we plotted the ground truth and the measured value simultaneously and see the overlap. For most of the points, two values overlap.



Future Work:

Future studies will investigate the effectiveness of this artificial neural network (ANN) using IMU data collected from a larger group of participants. By including more individuals, our goal is to make the training data more diverse, which can help prevent the ANN from becoming too specialized. We also aim to explore various positions along the limb segments to find the best location for placing IMUs. This will help us determine the optimal axis (x, y, or z) for capturing movement data.

Furthermore, we plan to assess the accuracy of using IMUs on the opposite limbs to estimate knee angles on the limb of interest. This could provide valuable insights into the potential for cross-limb analysis.

In addition, it is important to consider different ANN architectures and levels of complexity. This involves experimenting with the number of hidden layers and the nodes within each layer. Such investigations can help us fine-tune the neural network to achieve even better performance and results in estimating knee angles from IMU data.

Conclusion:

In this study, we focused on analyzing the knee angle during walking on a level surface. To effectively predict the knee angle from the IMU data, we employed a feed-forward Artificial Neural Network (ANN) architecture comprising four hidden layers. During the model training process, we partitioned the data, using 90% for training and 10% for validation. Remarkably, our developed model exhibited a promising performance, yielding a root mean squared error (rmse) loss of 1.7. Our ANN model performed optimally when the IMUs were positioned both above and below the knee. This study underscores the potential of IMU technology and ANN methodologies in non-invasive knee angle estimation during ambulation.