Prediction of Seat-Off towards assistance for Sit-to-Stand movement by RBFN

Pranav Baraskar, Anjani Kumar Tiwari, Mukul Mohan Yadav, Mayukh Ghosh

Abstract- For proper functioning of the Exoskeleton, we need accurate and reliable event prediction data. The seat-off event needs to be predicted to get the moment when the start-of assistance should be started such that Exoskeleton supports the Sit-to-Stand (STS) movement instead of inhibiting it. We have used a Radial Basis Function Neural Network (RBFN) to learn a relation between inputs and the event. In this piece of work, we have predicted the seat-off event of multiple healthy human subjects through the RBFN network. Due to salient features of the RBFN network such as easy designing, good generalization and strong tolerance to noise we have employed RBFN in our work in predicting seat-off. The method used allows reliable event prediction with joint angles as inputs. This model will be flexible to people as it will recognize the pattern for different people and work accordingly.

I. Introduction

In proper Human-Robot interaction, proper analysis of different events is essential for proper working. This paper focuses on estimating seat-off events during STS movement. Assistance only needs to be provided when the normal reaction due to the chair is not present. Thus the controller needs to know the seat-off event. As the normal reaction decreases gradually in STS movement to zero, at the moment of seat off the gravity compensation provided should be provided with a gradual increase such as at the seat off moment exoskeleton is providing complete assistance. Hence Seat off event need to be predicted earlier so we can time the assisting compensation to reach a maximum value at the moment of seat-off.

Assisted STS with HAL by A. Tsukahara et al.[1] uses force sensors and angles as threshold

to start assistance. There is no need for prediction. The controller uses reference values with a mean trajectory. The disadvantage of the method is that it's not adaptive to the user's intention. It controls the motion of the user to match that of a healthy person.

II. Method

a) Events of Interest

Seat-off: Here, seat-off time is considered the moment when the normal reaction between chair and person reaches 10N for the first time. STS movement is initiated by moving the upper half of the body forward. So the start of STS movement is considered here as the moment when the angular velocity of hip joint reaches 0.25rad/s. This will allow the user to move up to a certain extent without triggering the STS movement.

Start of assistance:

Prediction of seat off model by Kevin Tanghe et al.[9] experimentally calculated that the reaction force from the chair gradually decreases starting on average of 0.3s earlier before reaching zero at the seat off time. Hence prediction is required in order to provide gradually increasing assistance. Start of assistance time is the moment 0.3 earlier to seat off time.

The RBFN network consists of a single hidden layer of neurons with 20 centers. Gaussian function is used as their activation function. Input for the network is the angles of the hip, knee and ankle joint. This are calculated using a video of sit to stand movement and converting it to frames with sampling frequency of 20Hz. The output neuron has the linear function as the activating function, and provides the weighted sum of the individual outputs of the hidden layer as the final output.

b) **Experimental setup**

A few healthy young subjects are chosen for the experiment, 20-23 years old with their weights in the range of 72-82 kg. Subjects are asked to sit on a chair and perform sit-to-stand movement. The chair consists of a wooden platform placed on the top of the chair. This platform has two load cells attached below it in order to record the normal reaction applied by the chair. The load cells are placed in a symmetric fashion. This is to ensure that the weight of the subject is borne by both the load cells equally. The load has a maximum capacity of 100 kg with the rated output as 1.944 mv/V. Output of the load cells are connected in series for output measurement. The load cell is provided with a DC excitation of 12 V. The output of the load cell is measured by a multimeter. To get the joint angles coloured markers are put on points of interest such as the ankle, knee, hip and the shoulder. The entire motion is captured in a fixed video camera.

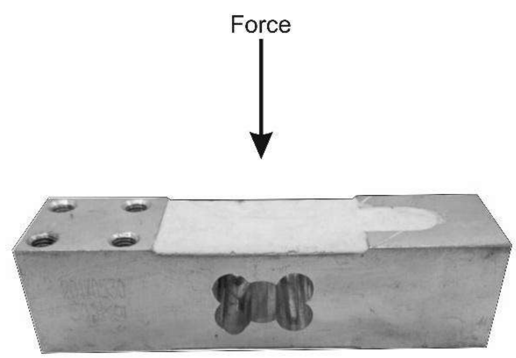

Fig: Load cells

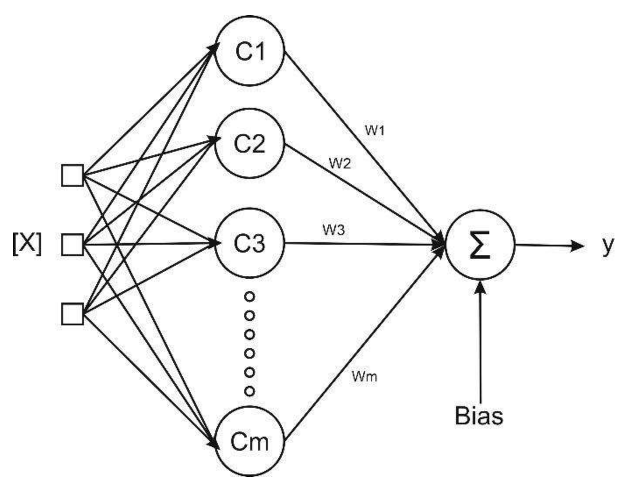

Fig: RBFN Network

The entire 2-3 s clip of the STS movement is divided into different frames at a rate of 0.05s. The coordinates of the coloured markers are determined for each of the frame. These coordinates are used to determine the angles of ankle, knee, and the hip at different time instants.

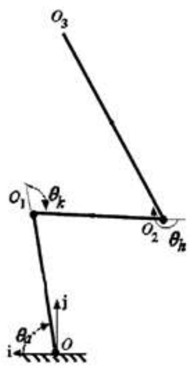

Fig: Positions of angles

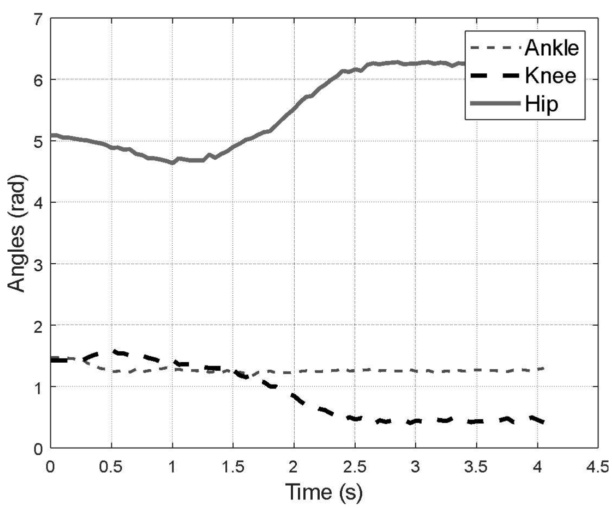

Fig Angle variation with time

The instant at which the hip angular velocity reaches the value of 0.25 rad/s is used as the reference time [9]. The angles of the ankle, knee and hip at this instant are used as the three inputs for the neural network. The instant at which the normal reaction applied by the chair, measured with the help of the load cell, falls below 10 N is the seat-off moment [9]. This normal reaction is measured using load cells placed on the chair. The output of the network is the time at which this event takes place itself, referred to as the seat-off time (SoT).

The angular velocity of joints was calculated by finite difference approximation from angle data of the hip joint.

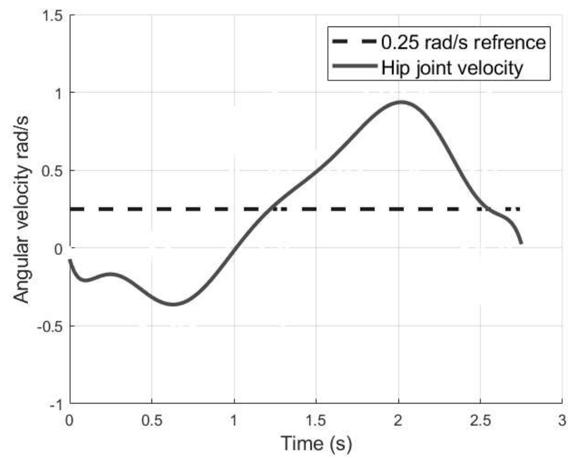

Fig: Angular velocity variation with time

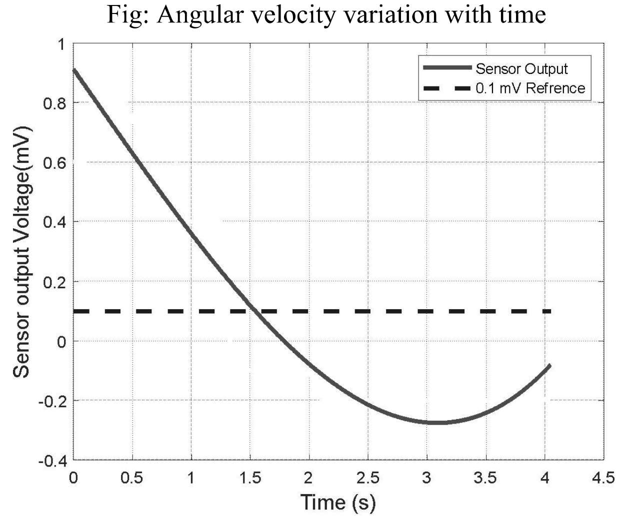

Fig Variation of Normal reaction with time measured in (mV)

Testing

The STS movement is performed by several individuals with different heights, weights, and ages. These are used to accumulate the training data for the network. The training data is essentially the ankle, knee, and hip angles at the seat-off time (SoT).

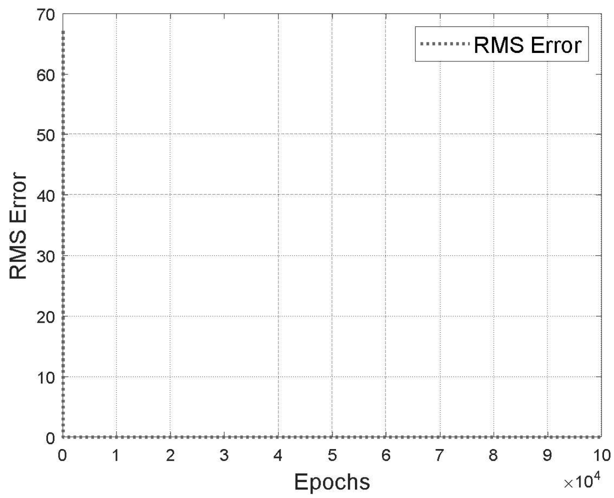

Fig: RMS error vs Epochs

After the network training is done, it is tested against a test case in which we enter the inputs, and the seat-off time as per the clip is expected as the output.

III. Results

Several criteria used for evaluations are:

- Seat off Error: Difference between predicted and actual Seat off time.
- Early Error: Errors when predicted seat off is earlier than expected.
- Late Error: Errors when predicted seat off is later than expected.

With the increase in width of the centres, deviation results in an early error, while the smaller the width is late error increases with it.

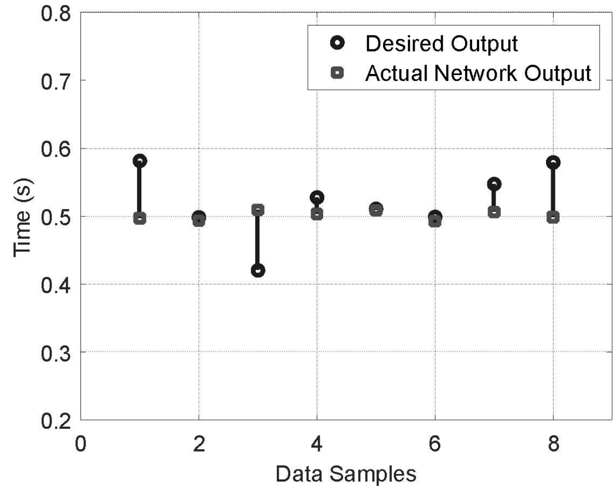

Fig: Results of RBFN testing

In the plot output, the seat-off moment predicted vs already known experimental values are plotted. Seat off error is within reliable range.

In the error plot it can be seen that Early error of 5% and late error of 8% is observed as minimum and maximum. Most of the errors are late errors as it can be observed. Elimination of early error is more important than elimination of error as late seat off is preferable over unprepared seat off. This can be achieved by manipulating the bias. Error present is under acceptable range of 10%.

Using Back Propagation Neural Network the results are quite different. Predicted seat-off time follows the expected value with some error as compared to RBFN with some occasional errors.

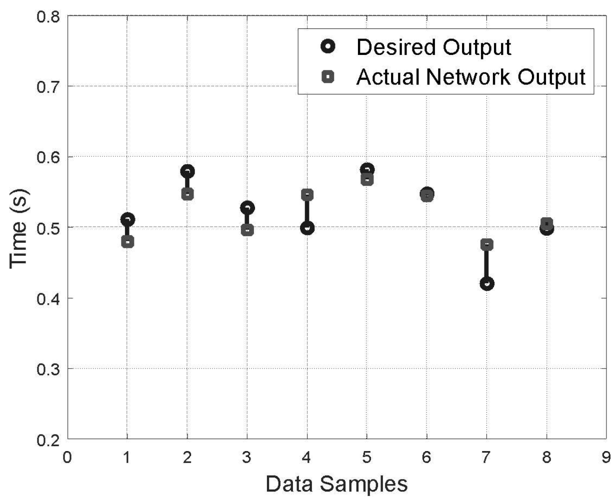

Fig: Results of BPN testing

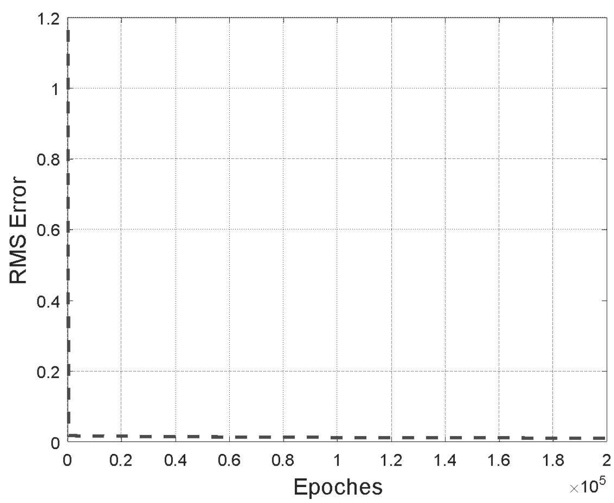

Fig: BPN RMS Error

IV. Discussion

Real-time prediction of seat-off event is achieved here, assisting the sit-to-stand movement. The model works only if the testing data is similar to the training data. If the data is less representative, errors will be more. Comparing RBFN and BPN it is observed that BPN take more epochs to learn as while RBFN takes less number of epochs for approximately same RMS error. The instances of error are greater in BPN while as compared to RBFN. Absolute error is less in RBFN as compared to BPN but both are present in reliable range of error.

V. Reference

[1] K. Junius et al., “Mechatronic design of a sit-to-stand exoskeleton”, in Proc. 5th IEEE RAS/EMBS Int. Conf. Biomed. Robot. Biomechatron., 2014, pp. 945-950.

[2] A. Tsukahara, R. Kawanishi, Y. Hasegawa, and Y. Sankai, “Sit-to-Stand and stand-to-sit transfer support for complete paraplegic patients with robot suit HAL”, Adv. Robot, 2010

[3]M. Afschrift, F. De Groote, J. De Schutter, and I. Jonkers, "The effect of muscle weakness on the capability gap during gross motor function: A simulation study supporting design criteria for exoskeletons of the lower limb," Biomed. Eng. Online, vol. 13, no. 1, p. 111, 2014.

[4] R. Van Lummel, E. Ainsworth, J. Hausdorff, U. Lindemann, P. Beek, and J. Van Dieen, "Validation of seat-off and seat-on in repeated sit-to-stand movements using a single-body-fixed sensor," Physiol. Meas., vol. 33, no. 11, p. 1855, 2012.

[5]J. K. Lee and E. J. Park, "Quasi real-time gait event detection using shankattached gyroscopes," Med. Biol. Eng. Comput., vol. 49, no. 6, pp. 707712, 2011.

[6]L. K. Hansen and P. Salamon, "Neural network ensembles," IEEE Trans. Pattern Anal. Mach. Intell., vol. 12, no. 10, pp. 993-1001, Oct. 1990.

[7]Jinkun Liu , “Radial Basis Function Neural Network Control for Mechanical Systems”, 2013

[8]Abbas Fattah, Sunil K. Agrawal, Professor Glenn Catlin, John Hamnett , “Design of a Passive

Gravity-Balanced Assistive Device for Sit-to-Stand Tasks”, 2021

[9]Kevin Tanghe, Anna Harutyunyan, Erwin Aertbelien, Friedl De Groote, Joris De Schutter , Peter vrancx, Ann Nowe, “Predicting Seat-off and Detecting Start-of-Assistance Events for Assisting Sit-to-Stand With an Exoskeleton”, 2016

[10]Daniela Miranda Linares, “Modelling and Control of Lower Limb Exoskeletons and Walking Aid for Fundamental Mobility Tasks”, November 2016