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An improved aided sit-to-stand kinematic model evaluation

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ABSTRACT – This paper presented an enhancement on the kinematic model of the Functional Electrical Stimulation supported sit-to-stand motion. It is essential for enhanced control system design to secure clinical acceptance. Considered is the work of Nuzik *et al.* as the basis to ascertain the level of achievement, it yielded an average improvement of 24% in accuracy. Hence, the expectation is a better controller for the system and model flexibility.

1. INTRODUCTION

Functional Electrical Stimulation (FES) is a method that utilises electrical pulses of usually low energy to restore human body movements artificially in subjects with paralysis due to trauma associated with the nervous system [1, 2].

Control systems have been employed to enhance the process, but still require improvements [2, 3]. As literature have it, improving plant model can make the control system better [4, 5].

The study is limited to obtaining an improved version of the kinematic model for FES supported sit-to-stand (STS) movement reinstatement. Also, is limited to simulation studies and for people with paraplegia.

2. THE FES STS KINEMATIC MODEL

Formulation of the FES aided STS movement was credited to the works of Nuzik *et al.* [6], Tsukahara *et al.* [7], Stevermer and Gillette [8], Fattah *et al.* [9], Kamnik *et al.* [10], Yu *et al.* [11], Jovic [12], and Davoodi and Andrews [13]. Figure 1 illustrates the idea and shows the middle of the movement. The initial is the sited position, and final is standing position.

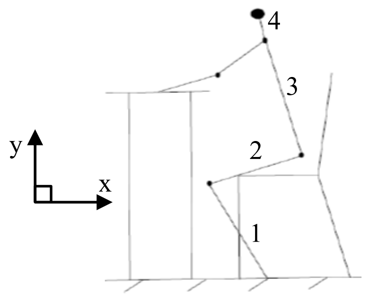

Figure 1 Conceptualised FES aided STS transition.

The movement was on the basis that it occurs in the two-dimensional frame. The kinematic model obtained was by utilising the Denavit-Hartenberg (DH) approach. The transformation is given in Equation (1) [14, 15].

$$T(\theta)_n^o = A_j^o A_n^j \tag{1}$$

Where A_j^o are the segments transformation in sequence and is given in Equation (2). Adjacent segment are connected and rotate about z-axis according to the convention. Where: d_j is the offset along the common z-axis, θj is angle about the common z-axis, r_j is the length of segment under consideration, αj is the angle around the x-axis, s means $sine$, and c $cosine$.

$$A_j = \begin{bmatrix} c_{\theta j} & -s_{\theta j}c_{\alpha j} & s_{\theta j}s_{\alpha j} & r_j c_{\theta j} \\ s_{\theta j} & c_{\theta j}c_{\alpha j} & -c_{\theta j}s_{\alpha j} & r_j s_{\theta j} \\ 0 & s_{\alpha j} & c_{\alpha j} & d_j \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

Literature showed that scholars considered three significant segments when modelling the FES aided STS manoeuvre, such as the works of Tsukahara *et al.* [7], Fattah *et al.* [9], Kamnik *et al.* [10], Yu *et al.* [11], Jovic [12], and Davoodi and Andrews [13], n becomes three (3). In this study, the proposed model has an additional segment added to enhance accuracy and flexibility; breaking the third segment into two. It makes the number of segments four and thus, n equals four (4) in the transformations. Equation (3) and equation (4) give the earlier and proposed models. Where; 1, 2, 3, and 4 refer to the various angles of segments.

$$T(\theta)_3^o = \begin{bmatrix} c_{123} & -s_{123} & 0 & A_{123} \\ s_{123} & c_{123} & 0 & B_{123} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

$$A_{123} = r_1 c_1 + r_2 c_{12} + r_3 c_{123}$$

$$B_{123} = r_1 s_1 + r_2 s_{12} + r_3 s_{123}$$

$$T(\theta)_4^o = \begin{bmatrix} c_{1234} & -s_{1234} & 0 & A_{1234} \\ s_{1234} & c_{1234} & 0 & B_{1234} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$A_{1234} = r_1 c_1 + r_2 c_{12} + r_3 c_{123} + r_4 c_{1234}$$

$$B_{1234} = r_1 s_1 + r_2 s_{12} + r_3 s_{123} + r_4 s_{1234}$$

3. RESULTS

Figure 2 is the comparison of the paths obtained from the earlier, proposed, and reference models. Figure 3 is the comparisons of individual paths. The reference model was the standard model used for evaluating the level of improvement obtained, proposed by Nuzik *et al*. [6], as a standard STS model that could aid physiotherapists. The result shows RMS errors 98.98 cm and 85.27 cm for the earlier models, and 80.84 cm and 60.93 cm for the proposed model. It, therefore, means reduced errors of 18.14 cm and 24.34 cm in paths along the y-axis and x-axis respectively. Also, corresponding to improvements of 18% and 29% respectively. Hence, resulted was an average accuracy growth of 24%.

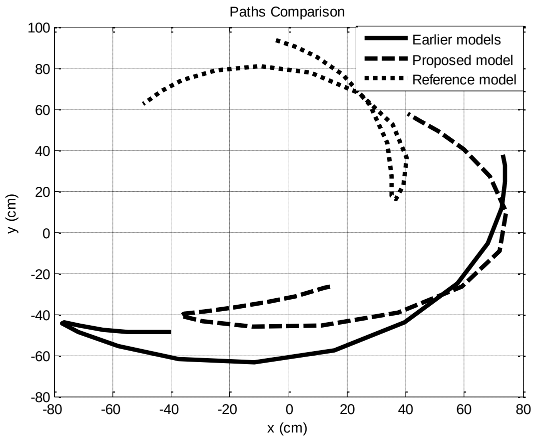

Figure 2 Paths comparison illustration.

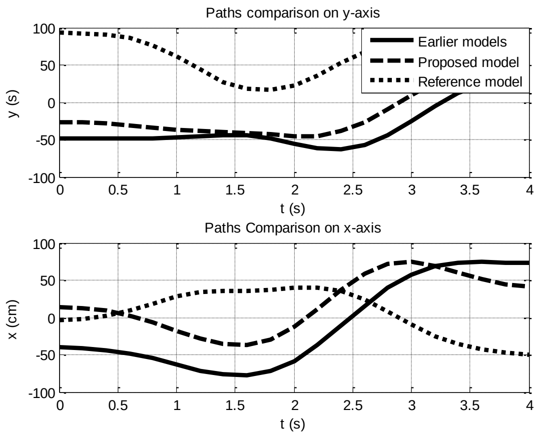

Figure 3 Separate paths comparison illustration.

4. SUMMARY

Development of the proposed model using an additional segment compared to earlier models was successful for the FES-induced STS reinstated movement. The upgrade is vital towards attaining clinical acceptance, as it would aid in an improved control system design for the system. It amounts to an improvement of 24% accuracy over to previous models. Additionally with higher flexibility, in the sense that it eases the task of inserting additional information into the separated joints as research is still ongoing. Thus, the expectation is achieving higher control systems performance for the FES-assisted STS movements.

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REFERENCES

[1] S. Gallas, J. P. Marie, A. M. Leroi, and E. Verin (2010). Sensory transcutaneous electrical stimulation improves post-stroke dysphagic patients. *Dysphagia 25*, 291-297.

[2] E. M. Schearer, Y.-W. Liao, E. J. Perreault, M. C. Tresch, W. D. Memberg, R. F. Kirsch, *et al.* (2014). Multi-muscle FES force control of the human arm for arbitrary goals. *IEEE Transactions on Neural Systems and Rehabilitation Engineering 22*, 654-663.

[3] C. L. Lynch and M. R. Popovic (2008). Closed-loop control of induced muscle contractions," *IEEE Control Systems Megazine,* 40-50.

[4] K. K. Ibrahim and B. Salam (2011). Modelling and control of paraplegic's knee joint (FES-swinging). PhD Thesis, University of Sheffield.

[5] N. B. M. Nasir (2017). Intelligent Modelling and Control with Fatigue Reduction for FES Induced Knee Joint of Hemiplegic for Rehabilitation. Doctor of Philosophy, Faculty of Electrical and Electronic Engineering, UTHM.

[6] S. Nuzik, R. Lamb, A. VanSant, and S. Hirt (1986). Sit-to-stand movement pattern: a kinematic study. *Physical Therapy* 66, 1708-1713.

[7] A. Tsukahara, R. Kawanishi, Y. Hasegawa, & Y. Sankai (2010). Sit-to-stand & stand-to-sit transfer support for complete paraplegic patients with robot suit HAL. *Advanced robotics 24*, 1615-1638.

[8] C. A. Stevermer and J. C. Gillette (2016) Kinematic and Kinetic Indicators of Sit-to-Stand. *Journal of applied biomechanics 32*, 7-15.

[9] A. Fattah, M. Hajiaghamemar, and A. Mokhtarian (2008). Design of a Semi-Active Semi-Passive Assistive Device for Sitto-Stand Tasks. *16th. International Conference on Mechanical Engineering-ISME2008.*

[10] R. Kamnik, J. Q. Shi, R. Murray-Smith, & T. Bajd (2005). Nonlinear modeling of FES-supported standing-up in paraplegia for selection of feedback sensors. *IEEE Transactions on Neural Systems & Rehabilitation Engineering 13*, 40-52.

[11] N.-Y. Yu, J.-J. J. Chen, and M. S. Ju (2001). Closed-loop control of quadriceps/hamstring activation for FES-induced standing-up movement of paraplegics. *Journal of Musculoskeletal Research 5*, 173-184.

[12] J. Jovic (2012). Towards a functional assistance in transfer & posture of paraplegics using FES: From simulations to experiments. Université Montpellier II-Sciences et Techniques du Languedoc.

[13] R. Davoodi and B. J. Andrews (1998). Computer simulation of FES standing up in paraplegia: A self-adaptive fuzzy controller with reinforcement learning. *IEEE Transactions on Rehabilitation Engineering 6*, 151-161.

[14] M. W. Spong, S. Hutchinson, and M. Vidyasagar (2006). *Robot modeling & control* 3: Wiley NY.

[15] B. Siciliano, L. Sciavicco, L. Villani, and G. Oriolo (2010). *Robotics: modelling, planning and control*: Springer Science & Business Media.