Development of an Autonomous Wheelchair for The Disabled and Performance Analysis Using ANFIS Model

Modestus O. Okwu (okwu.okechukwu@fupre.edu.ng)
Federal University of Petroleum Resources Effurun https://orcid.org/0000-0002-7761-9659
Lagouge K. Tartibu
University of Johannesburg
Michael Ayomoh
University of Pretoria
Daniel Ighalo
Federal University of Petroleum Resources Effurun

Research Article

Keywords: Wheelchair, automated system, ANFIS, microcontroller, joystick.

Posted Date: August 20th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-59617/v1

Development of an Autonomous Wheelchair for the Disabled and Performance Analysis Using ANFIS Model

Modestus Okwu[1,3], Lagouge Tartibu[1], Michael Ayomoh[2], Daniel Ighalo[2,3]

[1] *Department of Mechanical Engineering Technology, University of Johannesburg, Doornfontein Campus, Johannesburg 2028*

[2]*Department of Industrial and Systems Engineering, University of Pretoria, Hatfield Campus, South Africa.*

[3]*Department of Mechanical Engineering, Federal University of Petroleum Resources Effurun, Delta State, Nigeria*

ABSTRACT

Navigation for persons with physical disability very often poses a major challenge to both the victims and their dedicated navigation assistance-provider. This age-long problem has been a major concern in diverse research fields in the literature ranging from assistive medicine to applied intelligence amongst others. This research work is a build-up to the literature, hence, has presented an automated wheelchair system designed, fabricated and enhanced with joystick capability for obstacle detection and autonomous stoppage. A microcontroller unit known as Arduino uno was built into the system architecture to synchronise the entire set-up by driving the DC motor for directional and linear motion of the wheel chair. The developed system would greatly improve the community of people who have lost some means of independent mobility thereby leading to an improvement in their self-esteem enabling them pursue their vocational and educational goals. Conclusively, the developed system was tested using Adaptive Neuro-Fuzzy Inference System (ANFIS), the sensitivity rule viewer at the first trial gave a total intelligence of 63.8%, further improvement was made and a second trial gave a rating of 75% and the final gave a value of approximately 80%. This shows that the system is efficient, effective and of excellent performance.

Keywords: Wheelchair, automated system, ANFIS, microcontroller, joystick.

1. Introduction

Wheelchairs have evolved from just being chairs with wheels to completely automated personal mobility vehicles to assist the physically challenged. Wheelchairs as mobility systems are useful not only to support the movement of physically challenged persons but vital for ease of movement of sick patients within and out of the hospitals, aged persons at home, sporting activities for the disabled and usage in diverse of emergency situations ranging from road accident rescue operations to fire accident, air accident, maternity emergency and a host of other emergency rescue operations. Self-propelled wheel-chairs with some form of intelligence such as ability to measure and regulate velocity, sense the presence of obstacles amongst others is gradually becoming the focus of the literature on interactive wheel-chairs. According to [1] there are certain categories of people who have not been able to fully benefit and fit into the social groups since they cannot easily access basic skill acquisition centres due to unavailability of self-mobility devices. This has somewhat affected quite a number of paraplegics who very often take to street begging for survival in most developing countries. This in no doubt has totally reduced the gross domestic product (GDP) of such affected nations [2]. Independent mobility is however very important to individuals both children and adults [3]. Unavailability of independent mobility places these categories of people at a disadvantage, with limitation on their vocational and educational goals [4].

A smart wheel chair aims to provide aid to those physically challenged and aged persons by providing them with some sort of mobility which would greatly improve their living [5]. A smart wheelchair extends the navigation capabilities of the traditionally controlled manual and electric wheelchairs. One of the smart attributes of the designed wheel chair in this research is the integration of a systems input control via a joystick device for enhancement of navigational intelligence i.e. obstacle detection and avoidance system. Once the input instruction is completed, the controller unit then synthesizes the command and effects the required action by navigating the wheelchair to the specified position. Smart mobile systems can ease the lives of several disabled persons, particularly those with severe walking impairment by increasing their range of mobility [6]. A self-propelled system will give individual(s) a remarkable physical and psychological sense of well-being and promote feelings of self-sufficiency which can lead to a better self-esteem [7]. This research is focused at the design and development of a smart wheel chair for the physically challenged and aged individuals. The microcontroller and sensor were programmed using Arduino while ANFIS was used to test the functionality of the developed system.

2 Previous Research Works on Wheel Chairs

There are various types of wheel chairs, categorized based on the mode of control or power source for mobility. According to [8] , wheel chairs can be categorized into two types namely: manual driven wheel chairs and electric powered wheel chair.

2.1 Manually Driven Wheel Chair

[9] made intensive investigation while designing a traditional wheel chair. They observed that a good number of disabled persons find it somewhat tough sitting on a wheelchair and manually propelling its wheels. In their proposed design, a lever mechanism was introduced to aid with the transmission of forces for effective propelling of the developed wheel chair. The developed wheel chair is cost effective and requires less effort to navigate. [10] developed a wheelchair to support the physically challenged persons in sporting activities. For safety purposes, they incorporated a self-adjustable cushion to the system. This further served for other purposes such as effectiveness, ergonomical balance, reliability and comfort of the players. [11] considered the need to factor in biomechanical features such as frame and tyre design, propulsion type and a host of other factors in a wheel chair design to support the social participation and physical activities of the disabled persons. [12] looked at the design and construction of a reconfigurable wheelchair to assist disabled children. The chair was developed such that it has the capability to simultaneously position a patient at the standing and sitting positions. The system functioned as a dual purpose device i.e. (rehabilitation and mobility).

2.2 Electric Powered Wheelchair

Quite a number of researchers have conducted research works on wheel chairs powered via electrical means. [13] proposed a paradigm shift from the use of hand propelled wheel chairs to the use of electric powered wheel chairs for the physically challenged persons. The chair has a simple design feature capable of supporting a physically challenged person to move along a staircase with the aid of an inbuilt automatic control system. The designed chair is useful for easy navigation in any environment especially in hospitals and homes. [14] highlighted the importance of utilising non-conventional energy sources such as solar and other related sources. The research presented an electrically controlled wheelchair with user-selectable manual/electric propulsion mode and an auxiliary solar power supply system. [15] ergonomically designed an electric wheelchair for domestic use by aged Indians. This machine was equipped with stair climbing functionalities amongst other features. [16-18] also focused Some on electrical powered wheel chair system design for the disabled.

2.3 Autonomously Controlled Wheelchair

Smart Wheelchairs are sensory controlled systems designed to have self-governing mobility facilitated by the user's instructional set coming in as input commands. This reduces drudgery associated with navigating the wheelchair. Some wheelchairs are often provided with obstacle detection aids aimed at reducing the chances of collision during navigation. It must be noted that recent generations of wheelchairs are designed and developed with integrated features of artificial intelligence [5]. [19] asserted that holonomic wheelchairs are popular for their ability to move in constrained spaces due to their omnidirectional mobility. They developed a 4 wheel drive Omni-directional wheelchair suited for indoor navigation with reduced wheel slippage and vibration. The result and analysis of their proposed design showed less wheel slippage and vibration in comparison with existing smart controlled wheelchairs. An android platform was integrated to the design to facilitate the necessary motions. In a related research, [20 and 21] developed a wheelchair also premised on an android control platform.

[22] developed an Intelligent Wheelchair (IW) premised on three distinct functionalities viz: user intention recognition, obstacle detection and avoidance and situation awareness. In their work, [23] asserted that users with severe motor impairment may find it difficult to operate a wheelchair when they are in a tight space such as a passing doorway. They proposed a framework which can assist users to overcome such circumstances using a hierarchical semi-autonomous control strategy. [24] developed a wheelchair with sensor networks that detects dangers from an approximate distance of 2meters, distribute awareness and suggest suitable actions to both users and caregivers. [3] carried out several studies and survey which showed that both children and adults benefit substantially from access to a means of independent mobility. They designed and developed a smart wheelchair that uses a voice recognition and head gesture control system with an efficient and user friendly interface. [25] developed an application which made use of smart driving assistance algorithms to support the operator of an automated wheelchair in complex navigation circumstances. They experimented on translational and rotational velocities in situations where an obstacle is positioned along the navigation path. The driving assistance module significantly improved the users performance by preventing all collisions along the way. [26] designed an intelligent wheelchair that helped overcome the challenges faced by physically challenged persons. They employed obstacle detection and avoidance system through a sensor unit. Research on wheel chair with interactive capabilities to overcome the difficulties of manual systems has also been designed [27,28]. Other related research on design and development of smart wheel chair with joystick for easy maneuverability and integrated user voice recognition system, obstacle detecting ultrasonic or infrared sensing systems are contained in [29-37. Research on Omni-directional wheelchairs which possess special manoeuvrability due to the omni-wheels that allows translational and lateral mobility were reported [38, 39,19]. [40] designed a solar-powered motorized wheelchair with a detachable roof incorporated to the design of the wheelchair to support the solar panels. The wheel chair was portably designed and can be folded for easy conveyance by vehicles. [41] proposed the design of a smart solar powered wheel chair with integration of different sensor types to facilitate the navigation of physically challenged persons. So far, good research work on wheel chair has been presented in literature of autonomous systems. The originality in this research is the implementation of ANFIS algorithm in determining the performance of the developed autonomous wheel chair.

3. Materials and Method

The design and fabrication requirements for the proposed intelligent wheelchair comprises three major parts viz: input and control unit accessories, body support framework and a power unit. A handful of the hardware resources were indigenously sourced. These include the mild steel and galvanised pipe for framework, wood and foam for seating unit and tyres amongst others. Specific details of the utilised materials include: Two 12V motors; two 8 inches front wheels, two 5 inches caster wheels, micro-controller unit, a 1 inch galvanised pipe; a $1\frac{1}{2}$ inches galvanised pipe; Angle bars; Capacitors; Four relay modules, Resistors, and, joystick. The seat is a tubular structure made up of angle bars, two galvanised steel pipes of 1-inch and 1½ inches respectively for the conveyance of the seating unit chair and a wheel. The seat consist of four angle bars positioned on the galvanised steel pipe that acts as the support framework. Ergonomical considerations were prioritised in the design process using anthropometric measurements for adult paraplegics as investigated by [2] (See Appendix iii and iv). Parameters considered along with their measurements are as presented in Table 1. The standard architecture of the support frame of the designed wheelchair is as presented in an isometric view in Figure 1.

3.1 The Load Carrying Capacity of the Wheel Chair Frame

This section presents the modelling and analysis procedure utilised in the design of the seat frame. The values obtained for the design of the seat frame are presented in Table 2.

Assumptions: The maximum weight carriage of the framework considering the factor of safety adopted is about 100kg.

Recall that Weight, $w = m \times g = 100 \times 9.81$ (1)

This implies that the frame must be able to carry a load of 981 *N*

$Factor\ of\ safety = \frac{yeild\ strength}{permissible\ stress}$, (Khurmi & Gupta, 2005) (2)

For a good design consideration, the factor of safety (ŋ) must be greater than 1, therefore a factor of safety of 4 was considered for the selected seat frame material made of (mild steel), [42]. The yield strength for mild steel is $247\ Mpa$ [42].

Hence, Maximum allowable stress = Yield strength/Factor of safety $\sigma_b = 61.75\ Mpa$ (3)

Determination of wheelchair induced stress based on seating cross sectional area is given as:

Area of frame = length x breath (4)

Stress induced on sitting frame, $\sigma = \frac{Load}{Area}$ (5)

The stress induced on the seating frame $\sigma = 5.5878\ Kpa$ is lesser than the maximum permissible stress $\sigma_b = 61.75\ Mpa$.

3.2 Speed calculation of wheelchair

This sub-section presents the speed of the wheelchair. The values obtained for speed calculation of the wheel chair are presented in tabular form as presented in Table 3.

Current of the motor (I) = Motor power/Motor voltage (6)

Torque of the motor = Power x 60/2πN (7)

Front wheel periphery = 2πR (8)

Speed of wheelchair = periphery of front wheel x motor speed (9)

3.3 Mode of Operation of the Wheel Chair

The wheelchair operation starts by stimulating the joystick for input command. Movement of the joystick sends a signal to the Arduino board which automatically convert the analog inputs to its digital equivalence via the Analog to digital converter (ADC) mechanism. Once the conversion is done, a signal is sent to the motor driving IC which results in the two DC motors being driven simultaneously in either a forward, reverse, left-turning or right-turning direction. A flow diagram of the operational setup is as presented in Figure 2.

An exploded view of the wheelchair design is presented in Figure 3. Apart from giving a better insight into the design, this integrated view shows connectedness of the system's components. A detailed list of all the materials utilised in the wheelchair design is presented in table 4. The quantity of each material and unit price is also itemised.

The smart wheel chair is controlled via the use of an analogy joystick device which moves in the forward, backward, left and right directions as the input is feed in by the users. An obstacle avoidance ultrasonic sensor was incorporated into the system to stops the wheel chair at a distance of 120cm from any obstacle. This is to prevent accident and promote effective navigation of the system. Due to limitations in the performance of these system such as in their mobility, perception, obstacles avoidance.

4.0 Performance and Evaluation Metrics

Evaluating the performance of any system can be technically challenging due to multiplicity and complexity of component parts interacting both physically and functionally. To effectively evaluate the performance of a smart wheelchair, the following performance objectives were considered: Movement of the wheelchair from one location to another; time to accomplish the task; obstacle avoidance along the path of the system; precision in task accomplishment with limited error; strength in task operation i.e. conveyance of a disabled person from one point to another without a breakdown and energy efficiency of the system. The metrics considered in this research are aimed at giving objective estimations of the smart wheelchair's performance. The metrics include: Goal and objective (GO); time efficiency (TE); path navigation (PN); precision (P), strength (S) and energy efficiency (EE). The metrics were first weighted and the weights were used to show the order of importance of each specific metric in relation to the the design with the aid of ANFIS.

4.1 ANFIS Input Selection and Training

ANFIS input selection was implemented using MATLAB 2016a Toolbox for ANFIS. Figure 4 show the ANFIS architecture for the entire system which denotes a $4(4^6)$ network of rules required to produce a good output. The network training was performed repeatedly using the triangular membership function (MF). The sigmoid function served as the controller for effective performance and selection process. Triangular MF for six input variables were plotted based on measurements assigned to input values (See Appendix V). The goal herein is to test the system performance and functionality of the developed wheelchair via sensitivity rule viewer. Table 5 shows the ANFIS linguistic scale for system intelligence attributes. This ranges from a value of 1 representing very poor to 5 which represents very high. Following this in Table 6 is the performance rating distribution for the smart wheelchair which includes: 0-20 for the poorest rating, 21-40 for low performance rating, 41-60 for good performance rating, 61-80 for satisfactory performance and 81-100 for excellent performance.

4.3 Results and Discussion

As shown in Figures 5-7, the best output response was achieved by taking alpha-cuts represented in yellow colours from variable maps. By adjusting the red lines, the system automatically generated the best output values as displayed at the right hand side of the figures. The three dimensional surface plot for input-output response is as shown in Figure 8a-d. Figures 8a-d represent a graphical illustration of the alphacuts and sensitivity analysis of the output response or rating generated by varying the ruler at the left hand side of the ANFIS toolbox shown in Figure 5-7. To determine the general performance of the wheelchair with regards to system intelligence attributes, the solution response was obtained by refining the weights via alpha cuts and observing the rule viewer platform established in Figures 5-7 and graph 8a-d. The system intelligence attribute used in defining the Gussian MF are categorized into: very high, high, moderate, low and very low. The analysis was done using the ANFIS solution rule viewer developed. Based on the information provided, the ANFIS rule viewer was tuned and adjusted using the red lines from figure 5-7. At the first intelligence test, the rule viewer showed a total system intelligence of 63.6% (satisfactory group). The second test showed a rating of 75% (satisfactory) and the final test showed a rating of 80% (excellent).

Conclusion

The wheel chair was successfully designed, fabricated using the aforementioned component parts and validated. The research was designed to offer assistance to disabled and aged persons while they go about their various activities with ease as the system provides an automated means for its navigation via a joystick using Arduino as the microcontroller unit. The system intelligence test was conducted using ANFIS. The sensitivity rule viewer premised on ANFIS predicted a total system intelligence of 80% which demonstrated excellent performance of the system. Further improvements could be carried out in these areas: Incorporating head gesture sensor for individuals unable to operate a joystick controlled wheelchair, adopting voice controlled feature and a charging system to recharge the battery when depleted.

References

[1] M.K.Shahin, A.Tharwat, T.Gaber, A.E.Hassanien. A Wheel Chair Control System Using Human-Machine Interaction: Single –Modal and Multi-Modal Approaches. Journal of Intelligent System. 2017. doi 10.1515/jisys-2017-0085

[2] Ashiedu, F., & Igboanugo, A. C. Measurement and Evaluation of Anthropometric Data of Nigerian Adult Paraplegics for Wheelchair Design. *Journal of Emerging Trends in Engineering and Applied Sciences*. 2013, 4(1):133-137(ISSN: 2141-7016).

[3] Srishti, Jain, P., Shalu, & Singh, S. Design and Development of Smart Wheelchair using Voice Recognition and Head Gesture Control System. *International Journal of Advanced Research in Electrical Electronics and Instrumentation Engineering. 2015, 4*(5). DOI: 10.15662/ijareeie.2015.0405135

[4] Richard, S., Edmund, L., Steve, H., Illah, N., & David, M. The smart wheelchair component system. *Journal of Rehabilitation Research & Development (JRRD)*.2004, 41 (429-442)

[5] D. P. Singh , L. Garg. "Smart Wheel Chair for Visually Impaired", International Journal of Engineering Trends and Technology (IJETT). 2014, 14(1),13-19. ISSN:2231-5381.

[6] K. Meena, S.Gupta, V.Khare "Voice Controlled Wheelchair. International Journal of Electronics, Electrical and Computational Science. 2017, 6(4)23-27.

[7] Prasad, P., Kumar, P., & Paradesi, E. Smart Wheel Chair. International Journal Of Engineering Science And Computing. 2017, 7(4).

[8] Cooper R.A., Boninger M.L. & Rentschler A., 1999, 'Evaluation of selected ultralight manual wheelchairs using ANSI/RESNA standards', *Archives of Physical Medicine and Rehabilitation* 80(4), 462–467. https://doi.org/10.1016/S0003-9993(99)90287-3

[9] Nikhil, V. B., Mithun, G. K., Dinesh, S. A., Waseem, & Ansari, S. Design and Fabrication of Lever Propelled Wheelchair. *International Research Journal of Engineering and Technology (IRJET),2017 6*(3).

[10] Pezzuti, E., Valentini, P. P., & Vita, L. Design And Optimization Of A Wheelchair For Basketball Using Cad. University of Rome Tor Vergata, Dept of Mechanical Engineering. Rome, Italy: Via del Politecnico. 2006.

[11] Ebrahimi, A., Kazemi, A., & Ebrahimi. Wheelchair Design and Its Influence on Physical Activity and Quality of Life Among Disabled Individuals. *Iranian Rehabilitation Journal*. 2016 14 (2) 85-92

[12] K.M.Goher. A Configurable Wheelchair for Mobility and Rehabilitation: Design and Development. Cogent Engineering, Taylor and Francis. 2016, 3:1261502. http://dx.doi.org/10.1080/23311916.2016.1261502.

[13] RazakShehab, A. Design And Implementation Electrical Wheel Chair For Disable Able To Stairs Climbing By Using Hydraulic Jack. *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE),*2013 7(3).

[14] Chi-Sheng Chien, Tung-Yung Huang, Tze-Yuan Liao, Tsung-Yuan Kuo, Tzer-Min Lee, Design and development of solar power-assisted manual/electric wheelchair. Journal of Rehabilitation Research & Development (JRRD). 2014, 51(9)1411-1426

[15] Anirudh, T. S., & Satpathy, J. P. Design of Motorised Wheelchair. *Department of Industrial Design National Institute of Technology, Rourkela*. 2014

[16] Swapna, P., Sharmila, B., & Dharshan, Y. Electric Wheelchair for Physically Challenged. *International Research Journal of Engineering and Technology (IRJET), 2016 3*(5).

[17] Rakshith, R., Ritesh, N. J., Suraj, G. D., & Thrishool, R. *Design And Fabrication Of Multi-Purpose Wheelchair For Differently-Abled Person.* Visvesvaraya Technological University, Belagavi, Mechanical Engineering, Karnataka, India. 2017

[18] Alexander, T. J., Martin, B., Rao, J. T., & Ali, A. Development Of A Transformable Electrically Powered Wheel Chair Into A Medical Emergency Stretcher. *International Journal Of Pharmacy & Technology*. 2016

[19] Kundu, A., Mazumder, O., Chattaraj, R., & Bhaumik, S. Door negotiation of a omnirobot platform using depth map based navigation in dynamic environment. *Seventh International Conference on Contemporary Computing*. 2014.

[20] Aziz, k., Mustafa, M., Hashim, N., Nuri, N., Kadmin, A., & Salleh, A. Smart Android Wheelchair Controller Design. *International Journal For Advance Research In Engineering And Technology. 2015, 3*(5).

[21] Bhardwaj, R., Gupta, P., Jadhav, P., & Kadam, B. Android Based Automated Smart Wheel Chair. *International Journal of Innovative Research in Computer and Communication Engineering. 2016 4*(3).

[22] Yeounggwang, J., Jihye, H., & Eun, Y. K. An intelligent wheelchair using situation awareness and obstacle. *Procedia - Social and Behavioral Sciences 2013, 97.*

[23] Ananda, S. K., Oishee, M., Prasanna, K. L., & Subhasis, B. Design and Performance Evaluation of 4 Wheeled Omni Wheelchair with Reduced Slip and Vibration. *Procedia Computer Science 2017, 105.*

[22] Bell, D., Levine, S., Koren, Y., Jaros, L., & Borenstein, J. Design Criteria For Obstacle Avoidance in a Shared-Control System. *RESNA*. 1994

[23] R.Tomari, Y.Kobayashi, Y.Kuno. Enhancing Wheelchair Manouvrability for Severe Impairment Users.International Journal of Advanced Robotic Systems. 2012 (1-13) DOI: 10.5772/55477.

[24] Miyachia, T., Buribayevaa, G., Igab, S., & Furuhatac, T. A study of “Aware Wheelchair” with sensor networks for avoiding “Two Meters Danger”. 2016. *Procedia Computer Science 96*, 1004-1010.

[25] R¨ofer, T., Mandel, C., & Laue, T. (2009, June). Controlling an Automated Wheelchair via Joystick/Head-Joystick Supported by Smart Driving Assistance. *IEEE 11th International Conference on Rehabilitation Robotics Kyoto International Conference Center,.*

[26] Kalasamy, G., Mohammed, I. A., Manikandan, A., & S, S. Micro-Controller Based Intelligent Wheelchair Design. *International Journal of Research in Engineering & Advanced Technology, 2014, 2*(2).

[27] Kaur, S., & Vashist, H. Automation of Wheel Chair Using Mems Accelerometer (Adxl330). *Advance in Electronic and Electric Engineering, 2013, 3*(2).

[28] Kalantri, R. A., & Chitre, D. K. Automatic Wheelchair using Gesture Recognition. *International Journal of Engineering and Innovative Technology (IJEIT), 2013,2*(9).

[29] Maziddi. Retrieved from AVR micro controller and Embedded Systems: 2008 http://electronics.howstuffworks.com/gadgets /hightech-gadgets/speechrecognition. htm

[30] Tan, C. T., Brian, C., & Moore, J. Perception of nonlinear distortion by hearing-impaired people. *International Journal of Ideology*, 2008, 246-256.

[31] M.Nishimori, T.Saitoh, R.Konishi. Voice Controlled Intelligent Wheel Chair. SICE Annual Conference 2007. Kagawa University, Japan.

[32] Deepak, K. L., Prakshi, V., Addala, V., Prashant, S., Ritakshi, G., Manoj, K. P., & Rajat, B. (2016, May). Smart electronic wheelchair using arduino and bluetooth module. *International Journal of Computer Science and Mobile Computing.2016 5*(5), 433-438.

[33] Freiha, G., Achkar, R., Jan, M., & Mokhadder, M. Smart Assistive Accident Free. *nternational Conference on Robotics, Biomimetics, Intelligent Computational Systems*. 2013.

[33] Freiha, G., Achkar, R., Owayjan, M., & Mokhadder, M. Smart Assistive Accident Free Wheelchair System (SAAFWS). *International Conference on Robotics, Biomimetics, Intelligent Computational Systems.2013.*

[34] Bhardwaj, R., Gupta, P., Jadhav, P., Kadam, B., Kedari, & A. Automation of Wheel Chair Using Mems Accelerometer (Adxl330). *Advance in Electronic and Electric Engineering, 2013,3*(2).

[35] Dharanika, T. (2016, June). Intelligent Wheel Chair for Disabled Person. *International Journal for Innovative Research in Science & Technology, 2016,3*(1).

[36] Saharia, T., Bauri, J., & Bhagabati, C. Joystick Controlled Wheelchair. *International Research Journal of Engineering and Technology,* 2017*, 4*(7).

[37] Lodhi, D., Vats, P., Varun, A., Solanki, P., Gupta, R., Pandey, M., & Butola, R. Smart Electronic Wheelchair Using Arduino and Bluetooth Module. *International Journal of Computer Science and Mobile Computing, 2016, 5*(5).

[38] Krishnan, R., & Pugazhenthi, S. Mobility assistive devices and self-transfer robotic systems for elderly. *Intelligent service Robotics, 2014, 7.*

[39] Mazumder, O., Kundu, A., Chattaraj, R., & Bhaumik, S. Holonomic wheelchair control using emg signal and joystick interface. *Recent Advances In Engineering and Computational Sciences*. 2014.

[40] Gupta, M. C. Solar Powered Wheelchair with Retractable Panels. *United Cerebral Palsy & Global Partners Competition*, 2010.

[41] K.K.Sharma, D.K.Bansal, A.Jangir, A.Kumar, B.K.Pathak, V.Singhal. Hi-Tech. Solar Wheel Chair. Int. Arch. Applied Science and Tech. 2017, 8(1) 1-7.

[42] Khurmi, R. S., & Gupta, J. K.. *A Textbook of Machine Design.* New Delhi: Eurasia Publishing House (PVT.) Ltd. 2005.

Figures

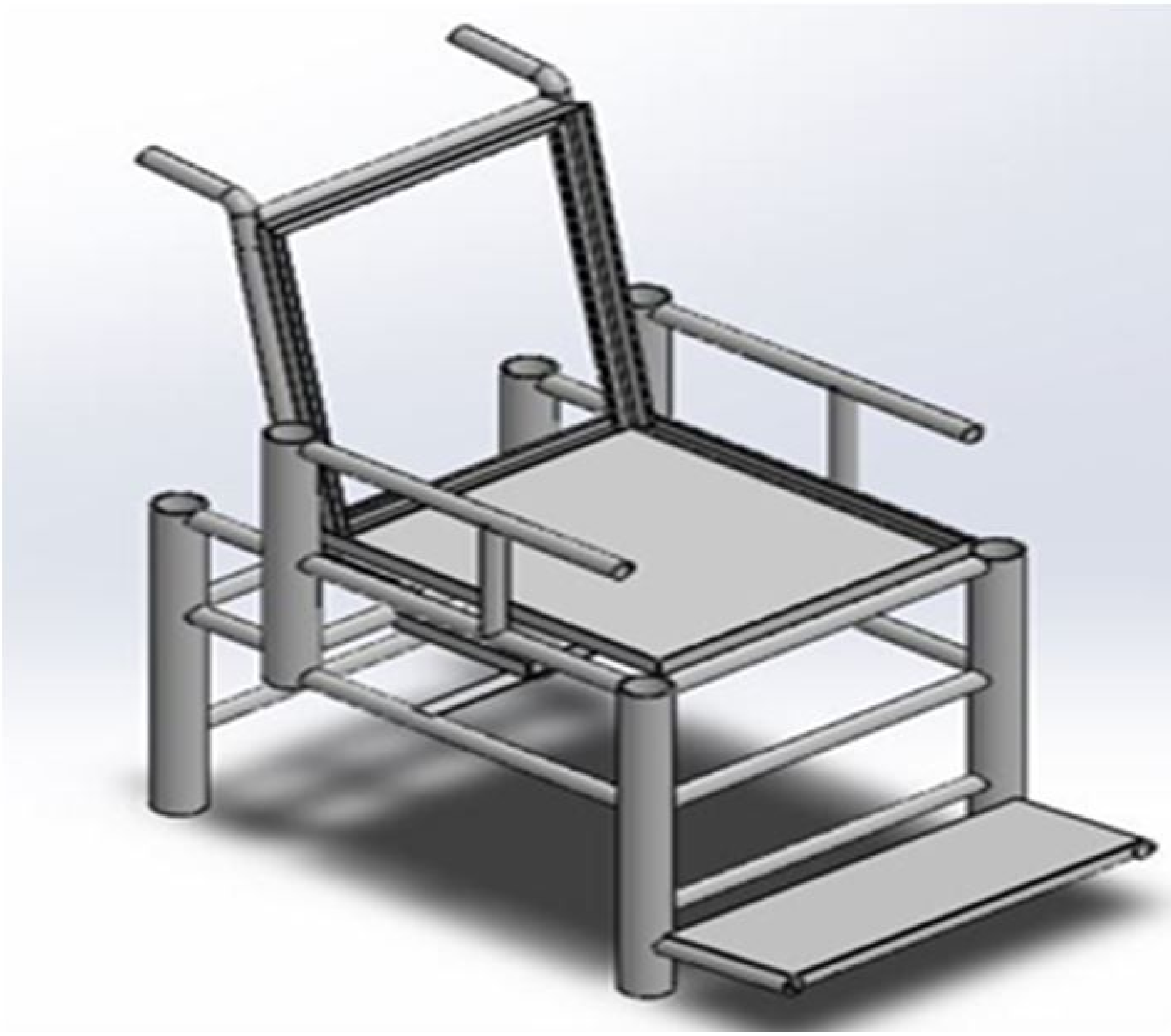

Figure 1

Chair Frame Design

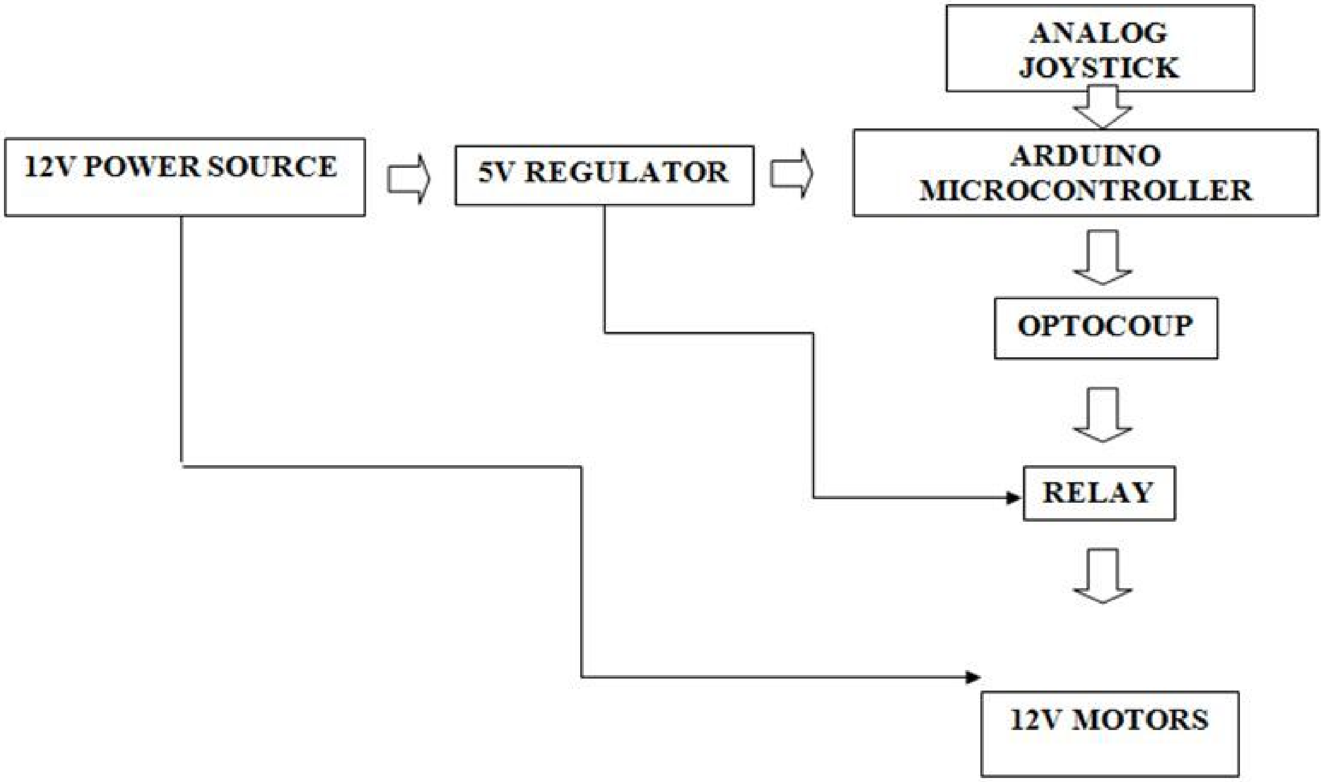

Figure 2

Block diagram of operational set-up

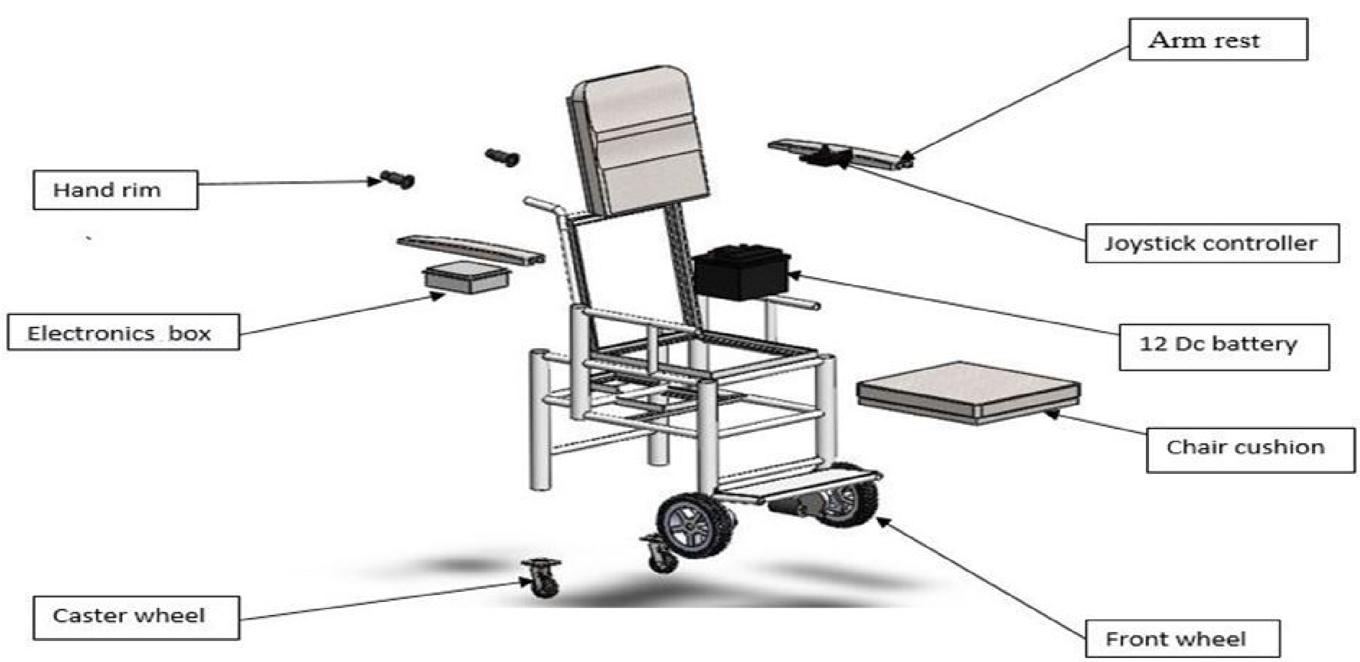

Figure 3

Exploded View of Wheelchair Design

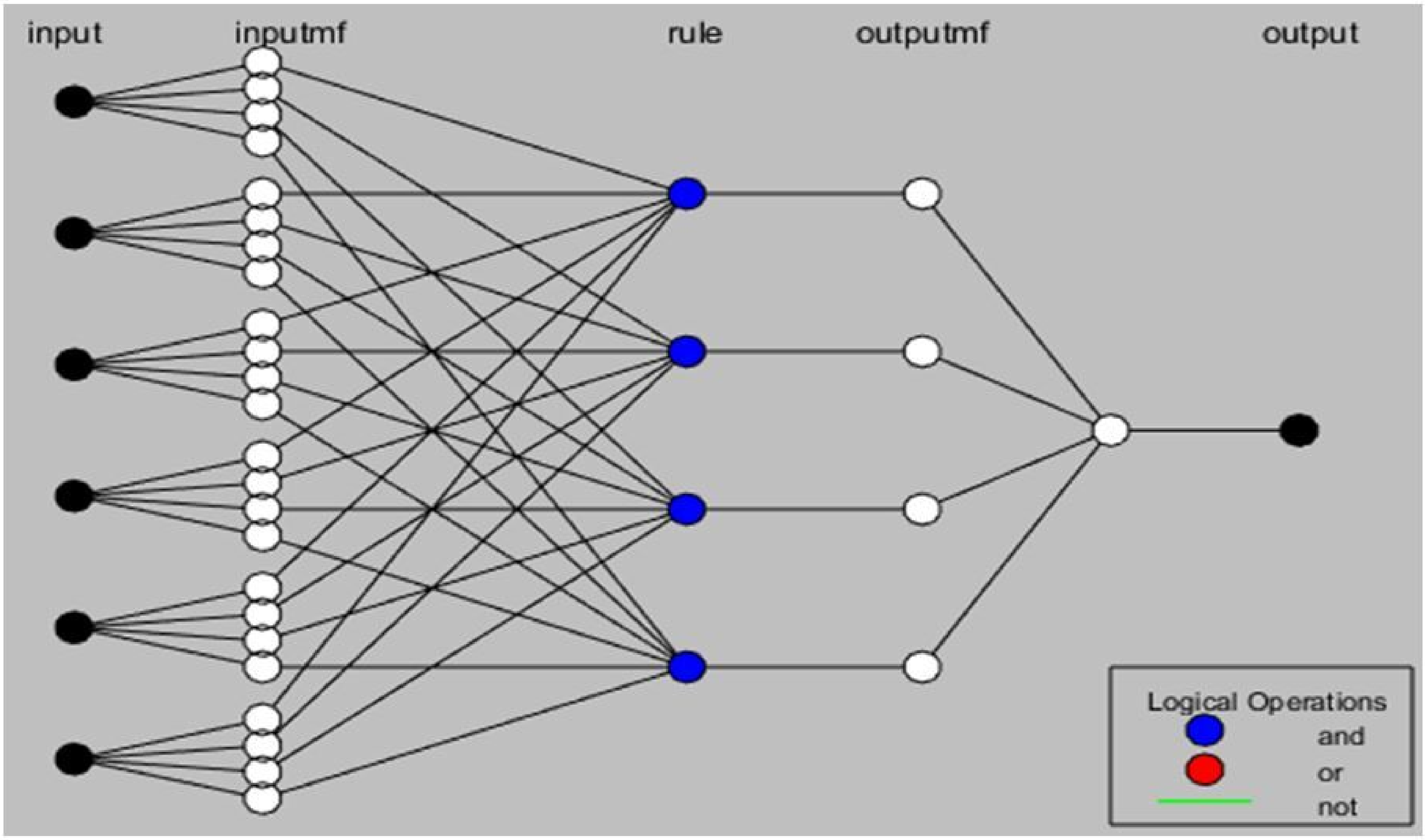

Figure 4

ANFIS Structure Showing Six Input Variables with Sigmoid Function as Controller

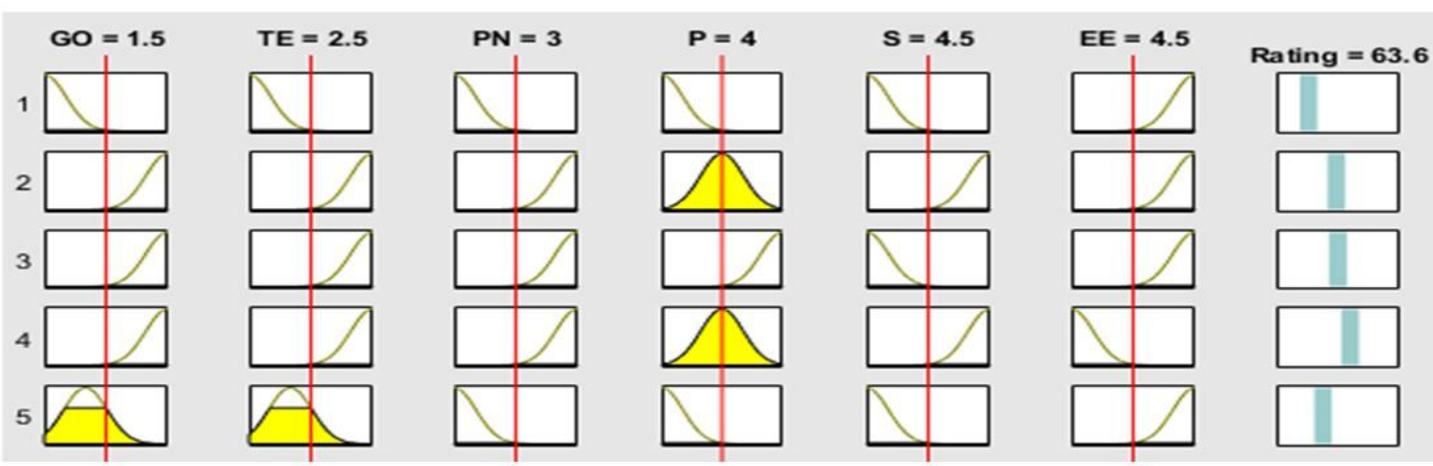

Figure 5

ANFIS Rule Viewer for First Test

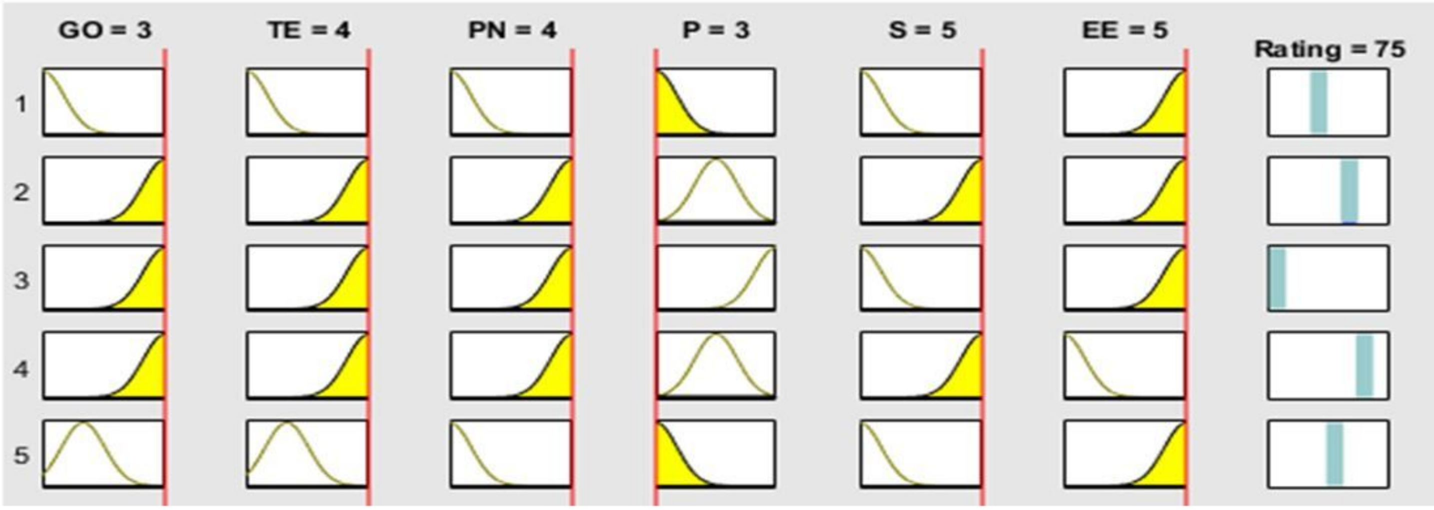

Figure 6

ANFIS Rule Viewer for Second Test

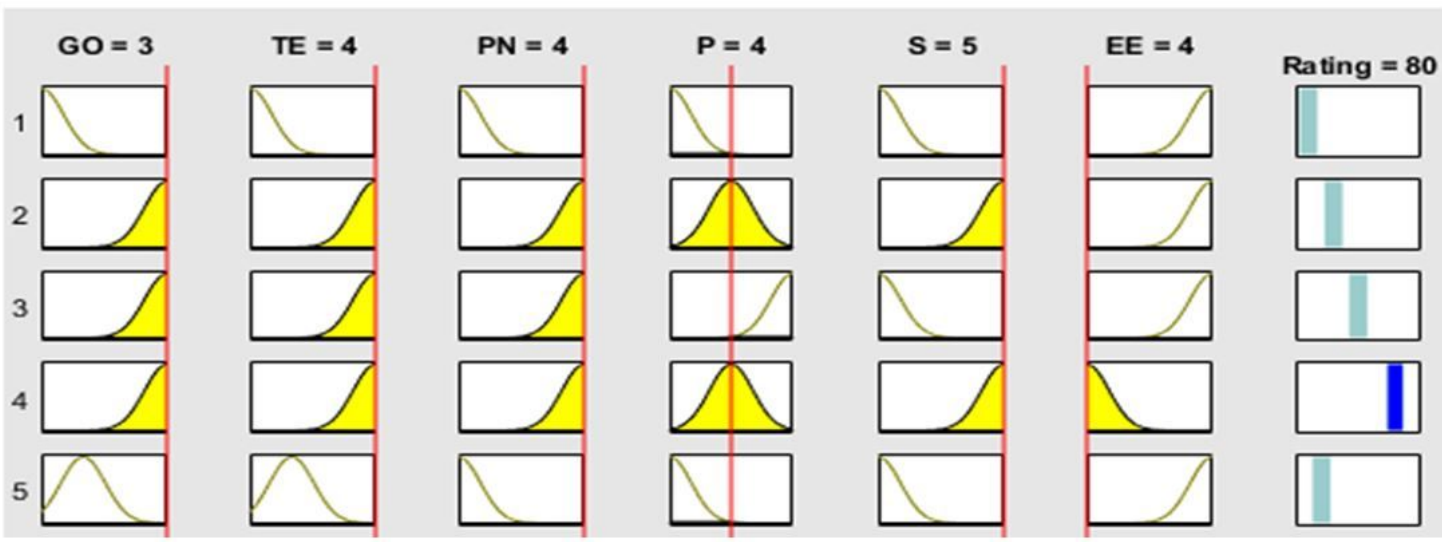

Figure 7

ANFIS Rule Viewer for Final Test

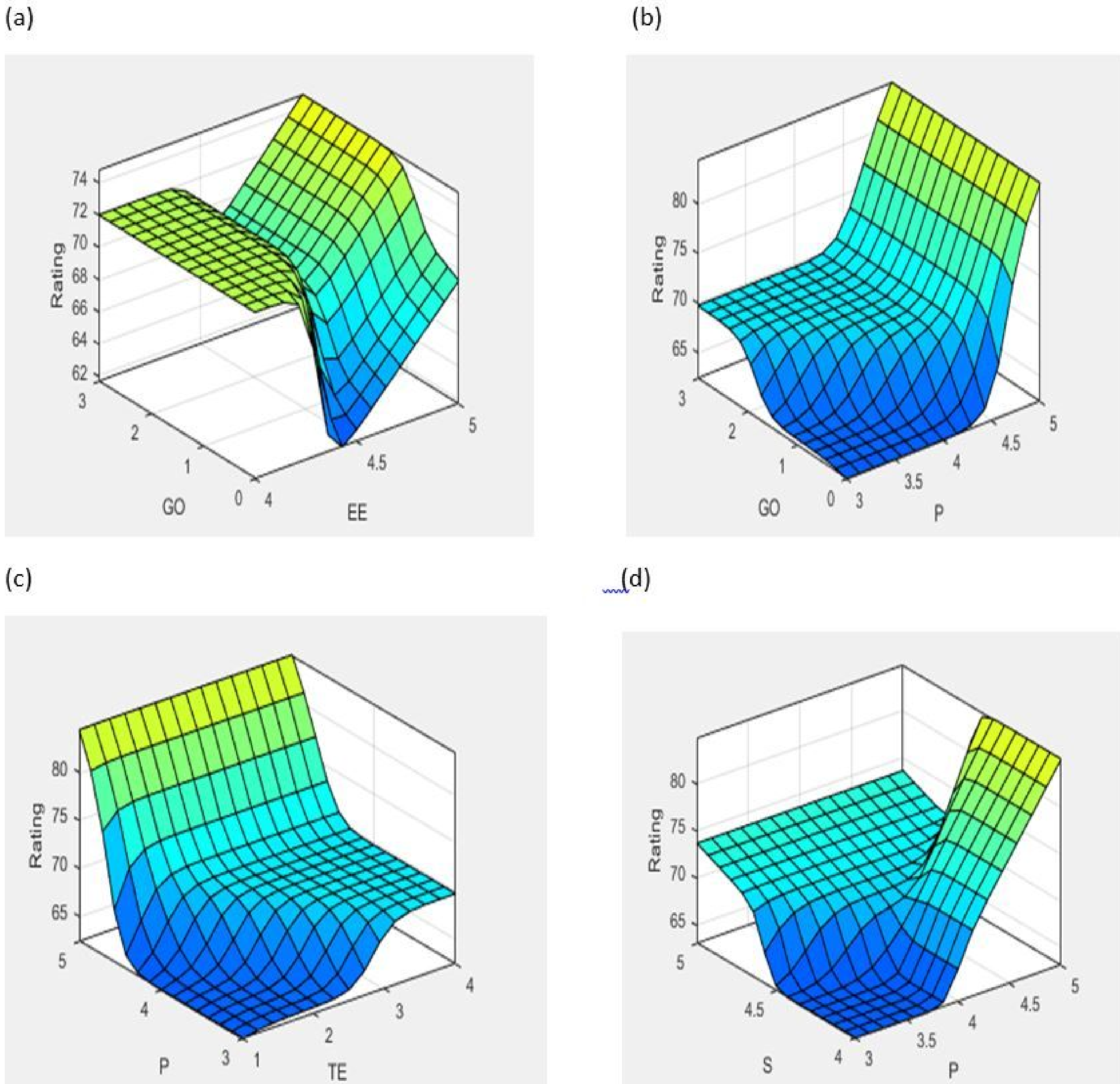

Figure 8

ANFIS Surface Plot Showing Input to Output Responses

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix.doc