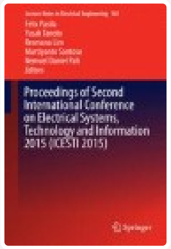

Proceedings of Second International Conference on Electrical Systems, Technology and Information 2015 (ICESTI 2015) pp 47–53

# Coordinates Modelling of the Discrete Hexapod Manipulator via Artificial Intelligence

Felix Pasila & Roche Alimin

Conference paper | First Online: 30 January 2016



Part of the Lecture Notes in Electrical Engineering book series (LNEE,volume 365)

## Abstract

This paper will present how to model the XYZ coordinates of a Discrete Manipulator with two-six discrete pneumatic actuators via artificial intelligence algorithm (AI) efficiently. The XYZ model is said efficient if mathematical calculation of the discrete states of manipulator related to XYZ coordinates, with the inverse static analysis (ISA) problem, can be approximately done via AI. The research method used simulation software and hardware implementation with the case of massive manipulator with two level discrete actuators. Simulations with typical desired displacement inputs are presented and a good performance of the results via AI is obtained. The comparison showed that the parallel manipulator has the Root Mean Squared (RMS) error less than 2 %.

Keywords

**Discrete manipulator** **Artificial intelligence algorithm**

**Inverse static analysis problem**

## References

1. Pasila, F.: Inverse static analysis of massive parallel arrays of three-state actuators via artificial intelligence. PhD Dissertation, University of Bologna (2013)

2. Pasila, F., Alimin, R.: Neuro-fuzzy architecture of the 3D model of massive parallel actuators. ARPN J. Eng. Appl. Sci. **9**(12) (2014)

3. Yang, P., Waldron, K.J.: Massively parallel actuation. In: 2001 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 868–873 (2001)

4. Chirikjian, G.S.: Inverse kinematics of binary manipulators using a continuum model. J. Intell. Rob. Syst. **19**, 5–22 (1997)

5. Lees, D.S., Chirikjian G.S.: A combinatorial approach to trajectory planning for binary manipulators. In: Proceedings of the 1996 IEEE International Conference on Robotics and Automation, pp. 2749–2754 (1996)

6. Sujan, V.A., Lichter D., Dubowsky S.: Lightweight hyper-redundant binary elements for planetary exploration robots. In: 2001 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 1273–1278 (2001)

7. Lichter, D., Sujan V.A., Dubowsky S.: Computational issues in the planning and kinematics of binary robots. In: Proceedings of the 2002 IEEE International Conference on Robotics and Automation, pp. 341–346 (2002)

8. Suthakorn, J., Chirikjian, G.S.: A new inverse kinematic algorithm for binary manipulators with many actuators. Adv. Robot. **15**(2), 225–244 (2001)

9. Ioannis, D., Papadopoulos, E.: Model-based control of a 6-dof

electrohydraulic Stewart-Gough platform. Mech. Mach. Theory **43**, 1385–1400 (2008)

10. Sugeno, T.: Fuzzy identification of systems and its applications to modeling and control. IEEE Trans. Syst. Man Cybern. **SMC-15**, 116–132 (1985)

## Acknowledgments

We would like to thank Ministry of Research, Technology and Higher Education of Indonesia for supporting this research under two years Research Grant 2014-2015, with the Number: 25/SP2H/LPPM-UKP/IV/201.

## Author information

Authors and Affiliations

**Department of Electrical Engineering, Petra Christian University, Surabaya, Indonesia**

Felix Pasila & Roche Alimin

Corresponding author

Correspondence to Felix Pasila .

## Editor information


Editors and Affiliations

**Electrical Engineering Department, Petra Christian University, Surabaya, Indonesia**

Felix Pasila

**Petra Christian University, Surabaya, Indonesia**

Yusak Tanoto

**Electrical Engineering Department, Petra Christian University, Surabaya, Indonesia**

Resmana Lim

**Electrical Engineering Department, Petra Christian University, Surabaya, Indonesia**

Murtiyanto Santoso

**University of Surabaya, Surabaya, Indonesia**

Nemuel Daniel Pah


## Rights and permissions



## Copyright information

## About this paper

### Cite this paper

Pasila, F., Alimin, R. (2016). Coordinates Modelling of the Discrete Hexapod Manipulator via Artificial Intelligence. In: Pasila, F., Tanoto, Y., Lim, R., Santoso, M., Pah, N. (eds) Proceedings of Second International Conference on Electrical Systems, Technology and Information 2015 (ICESTI 2015). Lecture Notes in Electrical Engineering, vol 365. Springer, Singapore. https://doi.org/10.1007/978-981-287-988-2_4

.RIS .ENW .BIB

DOI

https://doi.org/10.1007/978-981-287-988-2_4

Published

30 January 2016

Publisher Name

Springer, Singapore

Print ISBN

978-981-287-986-8

Online ISBN

978-981-287-988-2

eBook Packages

Engineering

Engineering (R0)

# Lecture Notes in Electrical Engineering

Volume 365

*About this Series*

"Lecture Notes in Electrical Engineering (LNEE)" is a book series which reports the latest research and developments in Electrical Engineering, namely:

- Communication, Networks, and Information Theory
- Computer Engineering
- Signal, Image, Speech and Information Processing
- Circuits and Systems
- Bioengineering

LNEE publishes authored monographs and contributed volumes which present cutting edge research information as well as new perspectives on classical fields, while maintaining Springer's high standards of academic excellence. Also considered for publication are lecture materials, proceedings, and other related materials of exceptionally high quality and interest. The subject matter should be original and timely, reporting the latest research and developments in all areas of electrical engineering.

The audience for the books in LNEE consists of advanced level students, researchers, and industry professionals working at the forefront of their fields. Much like Springer's other Lecture Notes series, LNEE will be distributed through Springer's print and electronic publishing channels.

More information about this series at http://www.springer.com/series/7818

Felix Pasila · Yusak Tanoto
Resmana Lim · Murtiyanto Santoso
Nemuel Daniel Pah
Editors

# Proceedings of Second International Conference on Electrical Systems, Technology and Information 2015 (ICESTI 2015)

Springer

*Editors*
Felix Pasila
Department of Electrical Engineering
Petra Christian University
Surabaya
Indonesia

Murtiyanto Santoso
Department of Electrical Engineering
Petra Christian University
Surabaya
Indonesia

Yusak Tanoto
Department of Electrical Engineering
Petra Christian University
Surabaya
Indonesia

Nemuel Daniel Pah
University of Surabaya
Surabaya
Indonesia

Resmana Lim
Department of Electrical Engineering
Petra Christian University
Surabaya
Indonesia

ISSN 1876-1100 ISSN 1876-1119 (electronic)
Lecture Notes in Electrical Engineering
ISBN 978-981-287-986-8 ISBN 978-981-287-988-2 (eBook)
DOI 10.1007/978-981-287-988-2

Library of Congress Control Number: 2015960766



Printed on acid-free paper

This Springer imprint is published by SpringerNature
The registered company is Springer Science+Business Media Singapore Pte Ltd.

# Contents

## Part III Technology Innovation in Electrical Engineering, Electric Vehicle and Energy Management

# Introduction

This book includes the original, peer-reviewed research papers from the 2nd International Conference on Electrical Systems, Technology and Information (ICESTI 2015), held during 9–12 September 2015, at Patra Jasa Resort & Villas Bali, Indonesia.

The primary objective of this book is to provide references for dissemination and discussion of the topics that have been presented in the conference. This volume is unique in that it includes work related to Electrical Engineering, Technology and Information towards their sustainable development. Engineers, researchers as well as lecturers from universities and professionals in industry and government will gain valuable insights into interdisciplinary solutions in the field of Electrical Systems, Technology and Information, and its applications.

The topics of ICESTI 2015 provide a forum for accessing the most up-to-date and authoritative knowledge and the best practices in the field of Electrical Engineering, Technology and Information towards their sustainable development. The editors selected high quality papers from the conference that passed through a minimum of three reviewers, with an acceptance rate of 50.6 %.

In the conference there were three invited papers from keynote speakers, whose papers are also included in this book, entitled: “Computational Intelligence based Regulation of the DC bus in the On-Grid Photovoltaic System”, “Virtual Prototyping of a Compliant Spindle for Robotic Deburring” and “A Concept of Multi Rough Sets Defined on Multi-Contextual Information Systems”.

The conference also classified the technology innovation topics into five parts: “Technology Innovation in Robotics, Image Recognition and Computational Intelligence Applications”, “Technology Innovation in Electrical Engineering, Electric Vehicle and Energy Management”, “Technology Innovation in Electronic, Manufacturing, Instrumentation and Material Engineering”, “Technology Innovation in Internet of Things and Its Applications” and “Technology Innovation in Information, Modeling and Mobile Applications”.

In addition, we are really thankful for the contributions and for the valuable time spent in the review process by our Advisory Boards, Committee Members and Reviewers. Also, we appreciate our collaboration partners (Petra Christian

University, Surabaya; Gunadarma University, Jakarta; UBAYA, Surabaya, University of Ciputra, Surabaya, Institute of National Technology, Malang and LNEE Springer, Germany), our supporting institution (Oulu University, Finland, Widya Mandala Catholic University, Surabaya and Dongseo University, Korea) and our sponsors (Continuing Education Centre, Petra Christian University, Surabaya and Patrajasa Resort Hotel, Bali).

On behalf of the editors Felix Pasila

# Chapter 4
# Coordinates Modelling of the Discrete Hexapod Manipulator via Artificial Intelligence

**Felix Pasila and Roche Alimin**

**Abstract** This paper will present how to model the XYZ coordinates of a Discrete Manipulator with two-six discrete pneumatic actuators via artificial intelligence algorithm (AI) efficiently. The XYZ model is said efficient if mathematical calculation of the discrete states of manipulator related to XYZ coordinates, with the inverse static analysis (ISA) problem, can be approximately done via AI. The research method used simulation software and hardware implementation with the case of massive manipulator with two level discrete actuators. Simulations with typical desired displacement inputs are presented and a good performance of the results via AI is obtained. The comparison showed that the parallel manipulator has the Root Mean Squared (RMS) error less than 2 %.

**Keywords** Discrete manipulator · Artificial intelligence algorithm · Inverse static analysis problem

## 4.1 Introduction

Discrete manipulator (DM) is a manipulator that consists of a number of actuators which are arranged in serial and/or parallel. In general, DM mechanism consists of a combination of joints, where the actuators can move and serve the manipulator like a prismatic joint. DM has been developed for a wide range of applications such as motion simulators and bio-mechanic applications.

To achieve variation range and accuracy, the architecture of DM practically requires a large number of discrete actuators that can be arranged in a hybrid series-parallel configuration. In designing a DM, the Jacobian matrix method is proposed in determining actuator states of the DM. However, this method has its

F. Pasila (✉) · R. Alimin
Department of Electrical Engineering, Petra Christian University,
Surabaya, Indonesia
e-mail: felix@petra.ac.id



F. Pasila et al. (eds.), *Proceedings of Second International Conference on Electrical Systems, Technology and Information 2015 (ICESTI 2015)*,
Lecture Notes in Electrical Engineering 365, DOI 10.1007/978-981-287-988-2_4

disadvantages because Jacobian matrix can only control a few number of actuators. One method to overcome the complexity of the solutions that have been proposed to overcome the limitations of the Jacobian matrix in designing DM is using Inverse Static Analysis (ISA) [1], where one of the ISA solution is using AI [2].

A DM, which the actuators are assigned with a limited number of state, is intended to reduce the complexity of the mechanism and to develop a manipulator without sensors [1]. Several solution of using DM in the sense of ISA Problem, such as: exhaustive search mechanism via brute-force [3]; differential geometry and variation of calculus [4]; combinatorial of heuristics computation [5, 6]; genetic algorithm methods [7]; probability theory and computation [8]; Hopfield networks and Boltzmann machines algorithms [3]. Even though most of the proposed solution methods are relatively effective in reducing problem complexity (from exponential to polynomial time), the resulting of proposed solutions still have slow calculations in terms of real-time computation.

Previous studies which are closely linked to the control of DM using artificial intelligence was conducted by Pasila [2]. This study focused on controlling the 6 DOF parallel manipulator using neuro-fuzzy method. The parallel manipulators used in this research have more than six prismatic actuator with Spherical-Prismatic-Spherical -3D mechanism. Results obtained from this study is that the parallel manipulator twisted due to the way the actuators are arranged and still have big error in terms of RMS.

The goal of this research is to design a two-level discrete manipulator for bio-mechanical purposes with 12 discrete actuator. Here, the ISA solution uses Neuro-Fuzzy network. The second objective is to obtain a state approximation for each actuator to obtain efficient results with Root Mean Square (RMS) error of less than 5 %.

## 4.2 Research Methodology

### *4.2.1 Design of the Discrete Manipulator*

The discrete manipulator model used in this paper consists of three parts of body, the upper and the medium platform that serve as moving body, and the lower platform that serves as a fixed body. All bodies are connected to the two-six pneumatic actuators. The bodies are circular and have similar diameters. Moreover, the simulation software used Solidworks Motion Study (SW) in order to determine the dimensions of the fixed and the moving platforms for the DM, as well as the location of each actuator. This trial and error method was done to obtain dimensions of the fixed and the moving platforms that accommodate the actuator arrangement. By doing this, the manipulator will not go to an unexpected twist. In this paper, the minimum number of actuators required in order to prevent a twist in the manipulator is 6 actuators for each level. This gives the number of actuator used was determined to be double-six or 12 actuators. In order to determine the position of each actuator, a novel parallel manipulator was implemented which based on hexapod Stewart-Gough platform [9].

### 4.2.2 Generating Data via SW Software

Data gathering was done via software simulation SW software, by measuring the position of a selected point on the upper platform. The motion simulation generates 1596 data, where each the data consists of coordinates along X, Y, and Z axis along with the combined states on the moving platform. Some of the extracted data can be seen in Table 4.1.

### 4.2.3 Neuro-Fuzzy network as AI Method

This sub-section presents the diagram of the considered model, like shown in Fig. 4.1. The architecture, has three inputs (desired axises) and 12 outputs (actuator states), is called as feedforward Neuro-Fuzzy type Takagi-Sugeno [10].

In particular, the control method presents the Gaussian membership functions $G_j^n$ ($j = 1, 2, 3$; $n = 1, \ldots, 12$), as a fuzzyfication variable for input pairs $\mathbf{Z} = [R_x, R_y, R_z]$,

**Table 4.1** Selected data of two-six hexapod mechanism (1 = extend, 0 = floating, -1 = retract)

| Lower Manipulator States | | | | | | Upper Manipulator States | | | | | | Axis Coordinates | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | S11 | S12 | X | Y | Z |
| 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | -1 | -1 | 0 | 1 | 6 | 24 | 627 |
| 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | -1 | -1 | 0 | 6 | 27 | 623 |
| 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | -1 | -1 | 0 | 1 | -85 | -83 | 574 |
| 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | -1 | -1 | -18 | -4 | 628 |
| 0 | 1 | 1 | 0 | -1 | -1 | 0 | 1 | 0 | 1 | 0 | 0 | 50 | 15 | 707 |
| -1 | -1 | 0 | 1 | 1 | 0 | 1 | 0 | -1 | -1 | 0 | 1 | -9 | 19 | 623 |
| -1 | -1 | 0 | 1 | 1 | 0 | -1 | 0 | 1 | 1 | 0 | -1 | 9 | 51 | 574 |
| 1 | 1 | 0 | -1 | -1 | 0 | 1 | 0 | -1 | -1 | 0 | 1 | 10 | -22 | 627 |
| -1 | 0 | 1 | 1 | 0 | -1 | 1 | 1 | 0 | -1 | -1 | 0 | -11 | -12 | 619 |
| 0 | -1 | -1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 15 | -2 | 728 |

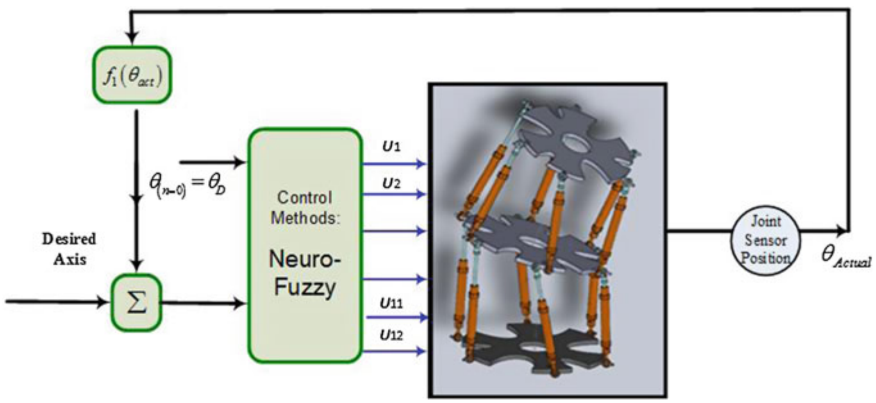


**Fig. 4.1** Control mechanism via Neuro-Fuzzy network, No. of set input = 3, No. output = 12, No. optimal membership function 6, training method: LMA

where $R_x$, $R_y$, $R_z$ are the input set of the orientations with respect to the XYZ Euler coordinates,

$$G_j^n(Z_j = \exp\left[-\left((Z_j - C_j^n/\sigma_j^n)\right)^2\right] \tag{4.1}$$

with $C_j^n$ and variance $\sigma_j^n$ together with the corresponding fuzzy rules $FR^n$ can be written as:

$$\begin{aligned} FR^n &: IFZ_1 is G_1^n ANDZ_{21}\, is\, G_2^n \\ THENy_i^n &= w_{0i}^n + w_{1i}^n Z_1 + w_{2i}^n Z_2 \end{aligned} \tag{4.2}$$

where $w_{0i}^n, w_{1i}^n$ and $w_{2i}^n$(for $i = 1, \ldots, 10$, and $n$ = 1, …, $M$, $M$ is the number of optimized rules for the model, here M = 6) being the Takagi-Sugeno parameters.

$$\bar{u}_i = \sum_{n=1}^{M} y_1^n \left[\prod_{i=1}^{3} G_j^n(Z_j) / \sum_{n=1}^{M} \prod_{i=1}^{3} G_j^n(Z_j)\right] \tag{4.3}$$

$$U_{State\_i} = round(\bar{u}_i) \tag{4.4}$$

Equations (4.3), (4.4) are derived by approximating the actuator activation states $u_i$. through possible states (+1, 0 or −1) via threshold processes. These give the actuator states as approximated solution.

## 4.3 Results and Discussions

In this paper, the data simulation is generated from the 3D SW software. At this point, Figs. 4.2 and 4.3 show the implementation of the discrete manipulator with 12 actuators along with the graphs of data simulation results and their neuro-fuzzy model respectively. The total dataset for model use 1596 data which are already selected and sorted from the smallest to the largest value.

Moreover, Fig. 4.3 describes the comparison between the simulation results obtained with the SW software, which shows the approximate value when the actuator is discretely controlled. In addition, it can be seen that the position along X, Y and Z axis closely have generated similar value compared to the continuous controller form. As a result, the RMS error of coordinates modeling in X, Y and Z are 1.43, 1.34 and 1.75 % respectively. The total performance has, in average, 1.51 % of RMS error.

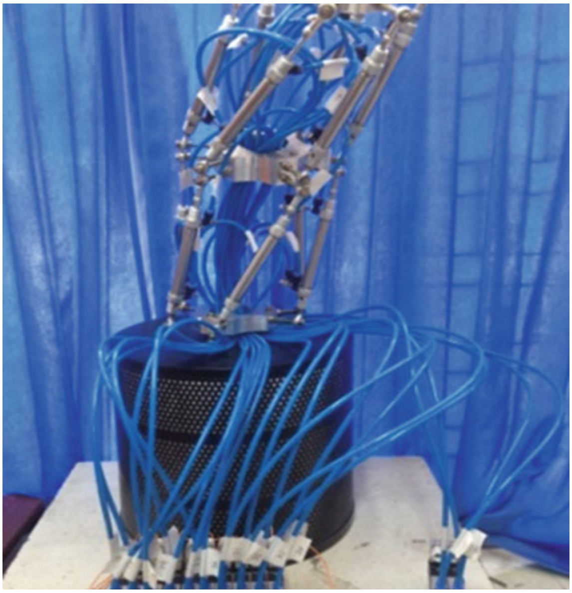

**Fig. 4.2** Implementation of Discrete Manipulator with 12 Discrete Actuators

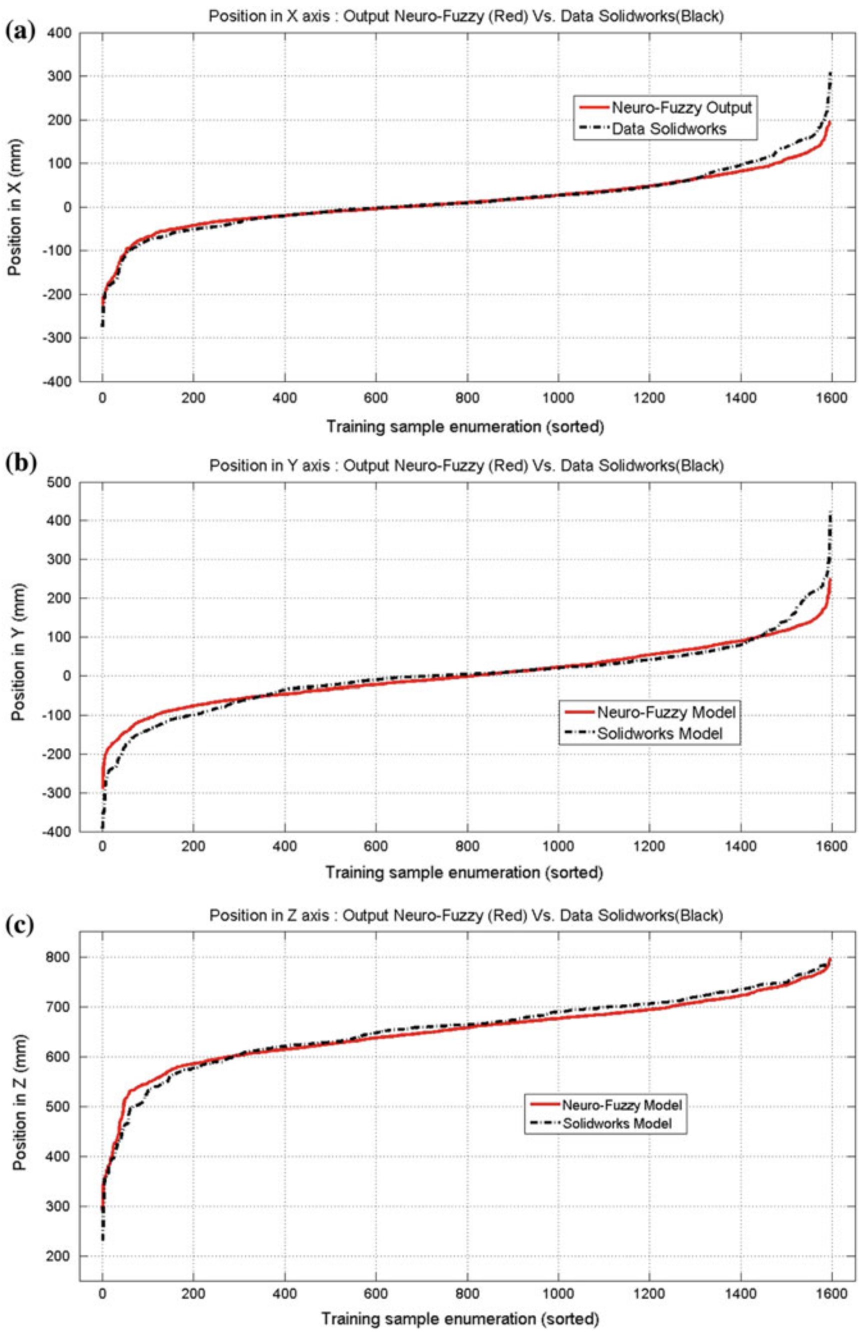


**Fig. 4.3** Data graph showing comparison between software simulation result and manipulator measurement process result. **a** Position along the X axis, **b** Y axis, **c** Z axis

## 4.4 Conclusions

As conclusion, this paper presented: (1) twelve discrete actuators two-six three-state discrete actuators with six DOF; (2) Neuro-Fuzzy methods type Takagi Sugeno for the solution of inverse static analysis of the considered manipulator. The prediction of the XYZ coordinates and its relevant states via neuro-fuzzy methods is used as control mechanism for the 12 actuators manipulator. The simulation result obtained using SW software shows that the reference point on the moving platform can move along the X, Y, and Z axis, which indicated the position of the point along each axis. RMS error of the manipulator obtained by comparing software simulation data and the results of neuro-fuzzy method shows quite small values on the X, Y and Z axis, which are less than 2 % Therefore it is most likely that neuro-fuzzy network can be used as an ISA solution on this manipulator.

**Acknowledgments** We would like to thank Ministry of Research, Technology and Higher Education of Indonesia for supporting this research under two years Research Grant 2014-2015, with the Number: 25/SP2H/LPPM-UKP/IV/201.

## References

1. Pasila, F.: Inverse static analysis of massive parallel arrays of three-state actuators via artificial intelligence. PhD Dissertation, University of Bologna (2013)
2. Pasila, F., Alimin, R.: Neuro-fuzzy architecture of the 3D model of massive parallel actuators. ARPN J. Eng. Appl. Sci. **9**(12) (2014)
3. Yang, P., Waldron, K.J.: Massively parallel actuation. In: 2001 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 868–873 (2001)
4. Chirikjian, G.S.: Inverse kinematics of binary manipulators using a continuum model. J. Intell. Rob. Syst. **19**, 5–22 (1997)
5. Lees, D.S., Chirikjian G.S.: A combinatorial approach to trajectory planning for binary manipulators. In: Proceedings of the 1996 IEEE International Conference on Robotics and Automation, pp. 2749–2754 (1996)
6. Sujan, V.A., Lichter D., Dubowsky S.: Lightweight hyper-redundant binary elements for planetary exploration robots. In: 2001 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 1273–1278 (2001)
7. Lichter, D., Sujan V.A., Dubowsky S.: Computational issues in the planning and kinematics of binary robots. In: Proceedings of the 2002 IEEE International Conference on Robotics and Automation, pp. 341–346 (2002)
8. Suthakorn, J., Chirikjian, G.S.: A new inverse kinematic algorithm for binary manipulators with many actuators. Adv. Robot. **15**(2), 225–244 (2001)
9. Ioannis, D., Papadopoulos, E.: Model-based control of a 6-dof electrohydraulic Stewart-Gough platform. Mech. Mach. Theory **43**, 1385–1400 (2008)
10. Sugeno, T.: Fuzzy identification of systems and its applications to modeling and control. IEEE Trans. Syst. Man Cybern. **SMC-15**, 116–132 (1985)