10th ICSE 2019

ABSTRACT

Organized by

ရန်ကုန်နည်းပညာတက္ကသိုလ်
YANGON TECHNOLOGICAL UNIVERSITY

Sponsored by

JICA

December 7-8, 2019

ICSE2019-EE-1

Foot Trajectory Generation for Climbing Upstairs of a Biped Robot

Aye Aye Thant [#1], Myat Moe Khaing [*2]

[#] *Faculty of Computing, Myanmar Institute of Information Technology, Myanmar*
[1]aye_aye_thant@miit.edu.mm

[2]myat_moe_khaing@miit.edu.mm

Abstract - For a biped robot to be able to climb up and down stairs, the robot must be capable of various type of foot motion and high path curvature of trajectory planning will be needed. Basic requirement for the trajectory planning is to achieve smooth walking pattern for the biped robot. This paper presents the foot trajectory for climbing up stairs of the biped robot. In order to meet the requirement of smooth trajectory planning, the trajectory is generated by cubic spline interpolation method. The smooth trajectory of the present algorithm is verified with Matlab figures. The present algorithm is also applicable for climbing down stairs of the biped robot.

***Keywords* - Biped Robot, climbing upstairs, cubic spline interpolation, foot trajectory, smooth**

10th ICSE

2019

PROCEEDINGS

Volume 1

* Engineering Education
* Electrical and Electronics
* ICT
* Manufacturing and Automation

Organized by

YANGON TECHNOLOGICAL UNIVERSITY

Sponsored by

JICA

December 7-8, 2019

THE TENTH INTERNATIONAL CONFERENCE ON SCIENCE AND ENGINEERING, 2019 (10th ICSE 2019)

Scope

The Tenth International Conference on Science and Engineering, 2019 (10th ICSE 2019) has been organized by Yangon Technological University (YTU), Myanmar. The conference will be held in Yangon Technological University (YTU), Yangon, Myanmar from 7th to 8th December, 2019. The Tenth International Conference on Science and Engineering, 2019 (10th ICSE 2019) aims to bring together scientists, leading engineers, industry researchers, and candidates from postgraduate courses to share and exchange their knowledge, experiences, information, and research on science and technology.

The 10th ICSE 2019 will be held in accordance with the following objectives;

- ❖ To create opportunity for young generation scientists, engineers, technologists and technicians to gain international experience
- ❖ To get chance for gaining technical knowledge from the international experts who conduct seminars and workshops on science and technology
- ❖ To increase knowledge on science and technology by exchanging research information with international universities and research organizations
- ❖ To enhance research knowledge and experience contributing to the advancement of research capabilities in the country
- ❖ To gain experience in carrying out research activities in collaboration with international universities

A wide range of important themes in various fields of Science and Engineering will be addressed at the conference and those who are interested in science and technology are warmly welcome to participate in the 10th ICSE 2019. Participants are requested to submit a proposal of academic or research paper for a 15-minute presentation and 5-minute Q&A.

This international conference would encourage researchers and engineers to present and discuss recent advances in science and engineering. ICSE features paper presentation of the following science and engineering fields:

- ➢ **Electrical and Electronics**
  (EC, EP, CEIT, Mechatronics)
- ➢ **ICT**
  (CEIT, EC, Mechatronics)
- ➢ **Manufacturing and Automation**
  (Mechanical, Mechatronics, Chemical, Textile, Aero, Metallurgy)
- ➢ **Energy, Environment and Natural Sciences**
  (Civil, Biotechnology, Mining, Petroleum, Metallurgy, EP, EC, Nuclear Engineering, Geology, Mechanical, Textile, Chemical, Remote Sensing, Physics, Chemistry, Mathematics, Nuclear Engineering)
- ➢ **Natural Disaster Prevention**
  (Civil, Architecture, EP, EC, CEIT, Mechatronics)
- ➢ **Infrastructure**
  (Civil, Architecture, EP, EC, CEIT, Mechanical, Remote Sensing)

- **Engineering Education**
  (Civil, Biotechnology, Mining, Petroleum, Metallurgy, CEIT, EP, EC, Nuclear Engineering, Geology, Mechanical, Mechatronics, Textile, Chemical, Remote Sensing, Physics, Chemistry, Mathematics, English)

Organizing Committee

General Chair

U Win Maw Tun	Deputy Minister, Ministry of Education

Members

Dr. Thein Win	Director General, Department of Higher Education
U Win Khaing Moe	Director General, Department of Research and Innovation
Dr. Aye Myint	Director General, Department of Technical and Vocational Education and Training
Dr. Khin Maung Latt	Director General, Department of Technical Promotion and Coordination
Prof. U Nyi Hla Nge	Vice Chairman, National Education Policy Commission (NEPC)
Prof. Dr. Ba Myint	Member, Steering Committee for Technological Centres of Excellence
Prof. Dr. Kyaw Win	Member, Steering Committee for Technological Centres of Excellence
Prof. U Khin Maung Tin	Member, Steering Committee for Technological Centres of Excellence
Prof. Dr. Mya Mya Oo	Retired Rector, Yangon Technological University
Prof. Dr. Myint Thein	Rector, Yangon Technological University
Prof. Dr. Kay Thi Lwin	Rector, Technological University (Hmawbi)
Prof. Dr. Theingi	Rector, Technological University (Thanlyin)
Prof. Dr. Kyi Soe	Rector, West Yangon Technological University
Dr. Zaw Min Naing	Deputy Director General, Department of Research and Innovation

Steering Committee

General Chair

Prof. Nyi Hla Nge
Vice Chairman, National Education Policy Commission (NEPC)
The Government of the Union of Myanmar

Members

1. Prof. Ba Myint
   Member, Steering Committee for Technological Centers of Excellence, Yangon Technological University and Mandalay Technological University
2. Prof. Kyaw Win
   Member, Steering Committee for Technological Centres of Excellence, Yangon Technological University and Mandalay Technological University
3. Prof. Khin Maung Tin
   Member, Steering Committee for Technological Centres of Excellence, Yangon Technological University and Mandalay Technological University

4. Prof. Dr. Aung Kyaw Myat
   Chief Technical Advisor, Alliance Star Group of Companies
   Former Deputy Minister, Ministry of Science and Technology, Myanmar
5. Dr. Thein Win
   Director General, Department of Higher Education
6. U Win Khaing Moe
   Director General, Department of Research and Innovation (DRI)
7. Dr. Aye Myint
   Director General, Department of Technical and Vocational Education and Training
8. Dr. Khin Maung Latt
   Director General, Department of Technical Promotion and Coordination (DTPC)
9. Prof. Mya Mya Oo
   Rector (Retired), Yangon Technological University
10. U Aung Myint
    President, Myanmar Engineering Society (MES)
11. Prof. Nobuo Funabiki
    Department of Electrical and Communication Engineering Okayama University, Okayama, Japan
12. Prof. Keiji Iramina
    Kyushu University, Japan
13. Prof. Osamu Murao
    The University of Tokyo, Japan
14. Mr. Isamu HAMADA
    Projector Coordinator, Japan International Cooperation Agency (JICA)

Technical Program Committee

Aerospace Engineering

Dr. Kyi Thwin
Rector
Myanmar Aerospace Engineering University

Architecture

Dr. Theingi Shwe
Professor and Head
Department of Architecture
Yangon Technological University

Dr. Hnin Wuint Yi
Professor
Department of Architecture
Yangon Technological University

Dr. Pwint
Professor Department of Architecture
Yangon Technological University

Chemical Engineering

Dr. Tint Tint Kywe
Professor and Head
Department of Chemical Engineering
Yangon Technological University

Dr. Nwe Nwe Win
Professor
Department of Chemical Engineering
Yangon Technological University

Dr. Aung Thu Hein
Lecturer
Department of Chemical Engineering
Yangon Technological University

Civil Engineering

Dr. Nyan Myint Kyaw
Professor and Head
Department of Civil Engineering
Yangon Technological University

Dr. Win Win Zin
Professor
Department of Civil Engineering
Yangon Technological University

Dr. Khin Maung Zaw
Professor
Department of Civil Engineering
Yangon Technological University

Electrical Power Engineering

Dr. Okka
Professor and Head
Department of Electrical Power Engineering
Yangon Technological University

Dr. Aung Zeya
Professor
Department of Electrical Power Engineering
Yangon Technological University

Dr. Ohn Zin Lin
Professor
Department of Electrical Power Engineering
Yangon Technological University

Electronic Engineering

Dr. Hla Myo Htun
Professor and Head
Department of Electronic Engineering
Yangon Technological University

Dr. Hnin Si
Professor
Department of Electronic Engineering
Yangon Technological University

Dr. Yu Yu Lwin
Professor
Department of Electronic Engineering
Yangon Technological University

Computer Engineering and Information Technology

Dr. Nyein Nyein Oo
Professor and Head,
Department of Computer Engineering and Information Technology,
Yangon Technological University

Dr. Thanda Win
Professor,
Department of Computer Engineering and Information Technology,
Yangon Technological University

Mechanical Engineering

Dr. Mi Sandar Mon
Professor and Head
Department of Mechanical Engineering
Yangon Technological University

Dr. Yin Yin Tun
Professor
Department of Mechanical Engineering
Yangon Technological University

Dr. Thein Min Htike
Professor
Department of Mechanical Engineering
Yangon Technological University

Dr. Min Thaw Tun
Professor
Department of Mechanical Engineering
Yangon Technological University

Mechatronic Engineering

Dr. Hnin Thida Aye
Professor and Head
Department of Mechatronic Engineering
Yangon Technological University

Dr. Theint Theint Thu
Professor
Department of Mechatronic Engineering
Yangon Technological University

Dr. Aung Myo Thant Zin
Lecturer
Department of Mechatronic Engineering
Yangon Technological University

Metallurgical Engineering and Material Science

Dr. Kyaw Win Tun
Professor and Head
Department of Metallurgical Engineering
Yangon Technological University

Mining Engineering

Dr. Aung Lay Tin
Professor and Head
Department of Mining Engineering
Yangon Technological University

Petroleum Engineering

Dr. Zaw Htet Aung
Professor and Head
Department of Petroleum Engineering
Yangon Technological University

Textile Engineering

Dr. Swe Swe Hnin
Professor and Head
Department of Textile Engineering
Yangon Technological University

Dr. Nyi Nyi Htoo
Professor
Department of Textile Engineering
Yangon Technological University

Engineering Chemistry

Dr. Marlar Than
Professor and Head
Department of Engineering Chemistry
Yangon Technological University

Engineering Geology

Dr. Tun Naing
Professor and Head
Department of Engineering Geology
Yangon Technological University

Daw Khin Soe Moe
Lecturer
Department of Engineering Geology
Yangon Technological University

Engineering Mathematics

Dr. Khaing Khaing Aye
Professor and Head
Department of Engineering Mathematics
Yangon Technological University

Engineering Physics

Dr. Mya Hnin Su
Professor and Head
Department of Engineering Physics
Yangon Technological University

English

Daw Phyu Phyu Sein
Associate Professor and Head
Department of English
Yangon Technological University

Remote Sensing and GIS

Dr. Sao Hone Pha
Director and Head
Remote Sensing and GIS Research Center
Yangon Technological University

Dr. Kyaw Zaya Htun
Director
Remote Sensing and GIS Research Center
Yangon Technological University

General Information and Communication Committee

Chair

Dr. Mi Sandar Mon
Professor and Head
Department of Mechanical Engineering
Yangon Technological University

Deputy Secretary-General

Dr. La Pyae Lynn
Professor
Department of Mechatronic Engineering
Yangon Technological University

Dr. Min Thaw Tun
Professor
Department of Mechanical Engineering
Yangon Technological University

Members

U Kyaw Kyaw
Lecturer
Department of Metallurgical Engineering and Material Science
Yangon Technological University

Daw Khin Soe Moe
Associate Professor
Department of Engineering Geology
Yangon Technological University

U Lin Thura Aung
Lecturer
Department of Chemical Engineering
Yangon Technological University

Daw Ngwe Zar Chi Win
Lecturer
Department of Engineering Chemistry
Yangon Technological University

Dr. Kyaw Zayar Tun
Director
Remote Sensing and GIS Research Center
Yangon Technological University

Dr. Ei Ei Khaing
Assistance Lecturer
Department of Civil Engineering
Yangon Technological University

Daw Phyo Khaing Zar Oo
Assistance Lecturer
Department of Mechatronic Engineering
Yangon Technological University

Daw Moe Win Khaing
Assistance Lecturer
Department of Electronic Engineering
Yangon Technological University

Daw May Thu Win Sein
Assistance Lecturer
Department of Mechatronic Engineering
Yangon Technological University

Daw Khaing Zin Wint
Assistance Lecturer
Department of Architecture
Yangon Technological University

U Thaw Aung
Demonstrator
Department of Architecture
Yangon Technological University

U San Gar Daung
Demonstrator
Department of Architecture
Yangon Technological University

U Wai Yan Maung
Demonstrator
Department of Architecture
Yangon Technological University

Daw Zar Zar Myint
Accountant (2)
Department of Architecture
Yangon Technological University

Secretary

Dr. Htin Lin
Professor
Department of Mechatronic Engineering
Yangon Technological University

Finance Committee

Chair

Dr. Mar Lar Than
Professor and Head
Department of Mechanical Engineering
Yangon Technological University

Members

Dr. Khaing Khaing Aye
Professor and Head
Department of Engineering Mathematics
Yangon Technological University

Dr. Mya Hnin Su
Professor and Head
Department of Engineering Physics
Yangon Technological University

Daw Phyu Phyu Sein
Associate Professor and Head
Department of English
Yangon Technological University

Secretary

U Kyaw Kyaw
Lecturer
Department of Metallurgical Engineering and
Material Science
Yangon Technological University

Fundraising Committee

Chair

Dr. Nyan Myint Kyaw
Professor and Head
Department of Civil Engineering
Yangon Technological University

Members

Dr. Win Zaw
Professor,
Department of Computer Engineering and Information Technology,
Yangon Technological University

Dr. Htin Lin
Professor
Department of Mechatronic Engineering
Yangon Technological University

Dr. Myo Myint Han
Lecturer
Department of Engineering Geology
Yangon Technological University

Secretary

Dr. Zaw Htet Aung
Professor and Head
Department of Petroleum Engineering
Yangon Technological University

Invited Talks

Keynote Speaker

World record efficiency of solar to hydrogen conversion by combining photovoltaic modules and electrochemical cells

Dr. Kensuke NISHIOKA

Professor
Vice Dean, Faculty of Engineering
Director, Research Center for Sustainable Energy & Environmental Engineering
University of Miyazaki, Japan

Invited Speakers

Measurement of prefrontal cortex activity to attention conflicts in working memory by NIRS

Mr. Keji IRAMINA

Department of Informatics, Faculty of Information Science and Electrical Engineering
Graduate School of Systems Life Sciences, School of Interdisciplinary Science and Innovation,
Kyushu University, Fukuoka, Japan

Post-Mining a holistic approach

Dr.-Ing. Stefan Möllerherm
Forschungszentrum Nachbergbau, Technische Hochschule Georg Agricola
Staatlich anerkannte Hochschule
Herner Straße 45
44787 Bochum

Water Cleaning System Using Polysaccharides Fibers

Prof. Hiroshi Tamura
Department of Chemistry and Materials Engineering
Faculty of Chemistry, Materials and Bioengineering
Kansai University, Suita, Osaka 564-8680, Japan

Deposition of permanent magnet powders applied to miniaturized motors

Prof. Masaki Nakano
Trustee of MSJ (Magnetics Society of Japan)

A Proposal of Element/Code Fixing Problem in Java Programming Learning Assistant System

Prof. Nobuo Funabiki
Department of Electrical and Communication Engineering Okayama University, Okayama, Japan

Volume 1

ICSE2019-EE-1

Foot Trajectory Generation for Climbing Upstairs of a Biped Robot

Aye Aye Thant #1, Myat Moe Khaing *2

Faculty of Computing, Myanmar Institute of Information Technology, Myanmar
1aye_aye_thant@miit.edu.mm
2myat_moe_khaing@miit.edu.mm

Abstract - **For a biped robot to be able to climb up and down stairs, the robot must be capable of various type of foot motion and high path curvature of trajectory planning will be needed. Basic requirement for the trajectory planning is to achieve smooth walking pattern for the biped robot. This paper presents the foot trajectory for climbing up stairs of the biped robot. In order to meet the requirement of smooth trajectory planning, the trajectory is generated by cubic spline interpolation method. The smooth trajectory of the present algorithm is verified with Matlab figures. The present algorithm is also applicable for climbing down stairs of the biped robot.**

Keywords - **Biped Robot, climbing upstairs, cubic spline interpolation, foot trajectory, smooth**

I. Introduction

Biped robot is two legged robot and is expected to eventually evolve into one with human-like body. The biped robot has higher mobility than conventional wheeled robots especially when moving on rough terrain, steep stairs and in environments with obstacles [1]. Climbing up and down stairs is the typical common action of biped robot.

Since the biped robot tends to tip over easily, it is necessary to take stability. Stable walking can be achieved by centre of gravity (CG) control and Zero Moment Point (ZMP) control. The CG trajectory control can guarantee the stability of static walking while the ZMP trajectory control can realize stable dynamic walking. The ZMP is the point on the ground which the sum of all the moments of the active forces equals zero. In order to achieve stable dynamic walking, the ZMP must be kept the inside the support region [9].

The walk of the biped robot can be determined by controlling the hip and foot trajectories. In the single support phase, cubic polynomial is used to generate the hip and swing foot trajectories which satisfy the ZMP criterion [1]. The swing foot should follow the desired trajectory to avoid obstacles and to satisfy the landing constraints. In some research, cubic spline interpolation method is better than cubic polynomial for trajectory planning of biped robot [6].

Some other international and domestic academics have also relevant studies about the biped robot actions of climbing up and down stairs or slopes [2]. Based on the analysis of the actions of biped robots, in this paper we present the foot trajectory for climbing up stairs of biped robot. This paper organized as follows. Mathematical background of applied method is introduced in section II. In section III, the algorithm for foot trajectory are proposed and generated. Resulting trajectories are demonstrated with Matlab in Section IV. And finally, a conclusion is given in section V.

II. MATHEMATICAL BACKGROUND

The mathematical interpolation is one of the simplest methods utilized for obtaining the suitable curves with respect to the given break points that the robot must undergo. When there are various constraints such as ground conditions and various foot motions, the order of polynomial is too high, its computation is difficult and the trajectory may oscillate. To avoid this problem, cubic spline interpolating polynomial is used to generate the swing foot trajectory [6].

1. Cubic Spline Interpolation

In this section, theoretical concept of cubic spline interpolation is discussed. The cubic spline interpolation will be applied to find the trajectory planning of biped walking.

The fitting of polynomial curve to set data points has applications in trajectory planning of the biped walking. To be able to draw a smooth curve through data points that are not subject to error, mathematically, it is possible to construct cubic functions on sub interval. The resulting piecewise curve and its first and second derivatives are all continuous in the larger interval. The continuity of first derivative means that the graph will not have sharp corners. The continuity of second derivative means that the radius of curvature is defined at each point [4].

2. *Piecewise Cubic Splines*

Suppose that $\{(t_j, f_j)\}_{j=1}^{n}$ are n points, where $t_1 < t_2 < \cdots < t_n$. The function $S(t)$ is called cubic spline if there exist $n-1$ cubic polynomials $S_j(t)$ with coefficients $a_{j,0}$, $a_{j,1}$, $a_{j,2}$ and $a_{j,3}$ that satisfies the following properties:

$$I.\ S(t) = S_j(t) = a_{j,0}\,(t-t_j)^3 + a_{j,1}\,,(t-t_j)^2 + a_{j,2}\,(t-t_j) + a_{j,3}$$
$$\text{for } t \in [t_j, t_{j+1}] \text{ and } j = 1,2,\cdots,n-1$$
$$II.\ S(t_j) = f_j \text{ for } j = 1,2,\cdots,n.$$
$$III.\ S_j(t_{j+1}) = S_{j+1}(t_{j+1}) \text{ for } j = 1,2,\cdots,n-2.$$
$$IV.\ S_j'(t_{j+1}) = S_{j+1}'(t_{j+1}) \text{ for } j = 1,2,\cdots,n-2.$$
$$V.\ S_j''(t_{j+1}) = S_{j+1}''(t_{j+1}) \text{ for } j = 1,2,\cdots,n-2.$$

Property I states that $S(t)$ consists of piecewise cubies. Property II states that piecewise cubies interpolate the given sets of data points. Property III and IV require that the piecewise cubic represents a smooth continuous function. Property IV states that the second derivatives of the resulting function are also continuous.

A piecewise function is constructed as follows [4].

$$S(t) = \begin{cases} S_1(t) & if \quad t_1 \le t \le t_2 \\ S_2(t) & if \quad t_2 \le t \le t_3 \\ \vdots \\ S_{n-1}(t) & if \quad t_{n-1} \le t \le t_n \end{cases}$$

where $S_j(t)$ is a cubic polynomial defined by

$S_j(t) = a_{j,0}\,(t - t_j)^3 + a_{j,1}\,(t - t_j)^2 + a_{j,2}\,(t - t_j) + a_{j,3}$, $j = 1,2,\cdots,n-1$.

By using the properties, I, II, III and IV, we can get the coefficients of cubic spline interpolation as follow:

$$a_{j,0} = \frac{m_{j+1} - m_j}{6h_j},$$

$$a_{j,1} = \frac{m_j}{2},$$

$$a_{j,2} = a_{j,3} - \frac{h_j(2m_j + m_{j+1})}{6},$$

$$a_{j,3} = f_j$$

where $m_j = S_j''(t_j)$ and $h_j = t_{j+1} - t_j$.

Construction of natural spline interpolation

There exists a unique cubic spline with the free boundary conditions $m_1 = m_n = 0$ [3]. The linear system equations for finding $m_2, m_3, \ldots, m_{n-1}$ connected with natural spline condition are

$$2(h_1 + h_2)m_2 + h_2 m_3 = u_2$$

$h_{j-1}m_{j-1} + 2(h_{j-1} + h_j)m_j + h_j m_{j+1} = u_j$ for $j = 3,4,\ldots,N-2$

$$h_{n-2}m_{n-2} + 2(h_{n-2} + h_{n-1})m_{n-1} = u_{n-1}$$

where $u_j = 6(d_j - d_{j-1})$, $j = 2,3,\ldots,n-1$ and $d_j = \frac{f_{j+1} - f_j}{h_j}$.

3. Function imitation: Cubic splines are not necessary to be simple to determine a well-behaved function to fit any data set. This is, however, usually not the case. Thus, the cubic spline technique is used to generate a function to fit the data. Moreover, it can be shown that the data generated by a particular function is interpolated by a spline which more or less like the original function. This is testimony to the consistency of spline [4].

III. Foot Trajectory for Walking Upstairs of a Biped Robot

An anthropomorphic biped robot is considered as a reference model where each leg consists of a thigh, a shank and a foot. The under study model has six degree of freedom in sagittal plane including three degree of freedom (DOF) in the hip joint, one in each knee joint, and two in each ankle joint. If both foot trajectories and hip trajectory are known, all joint trajectories of the biped robot will be determined by kinematic constraints. The climbing up stairs pattern can therefore be denoted by uniquely by both foot trajectories and hip trajectory. In this paper, we only discuss the swing foot trajectory in the sagittal (*XZ*) plane.

For a sagittal plane, each foot trajectory can be denoted by a vector

$X_a = [x_a(t), z_a(t)\theta_a(t)]^T$ where $(x_a(t), z_a(t))$ is the coordinate of the ankle position, and $\theta_a(t)$ denotes the angle of the foot [1].

If the biped robot climbs up stairs, the foot trajectories can be obtained by varying the values of start and end positions [2]. For example, $x_{fe} = x_{fs} + 2L_s$, $z_{fe} = z_{fs} + 2S_h$ where (x_{fs}, x_{fe}) and (z_{fs}, z_{fe}) are initial and final position of one climbing cycle, L_s is stair length and S_h is stair height shown in Fig 2.

The Proposed Trajectory Planning Algorithm

1. The time interval for the breakpoints of one climbing step is previously specified.
2. The position constraints for the breakpoints of one climbing step is formulated.
3. The whole trajectory between the breakpoints of one climbing step is derived by applying cubic spline interpolation.

Algorithm step 1: Time interval for One Climbing step

Assuming that the entire sole surface of the right foot is in contact with the stairs at $t = 0$ and $t = T_c + T_d$. T_c, T_d and T_m are the interval of single support phase, the double support phase and the foot swing over the middle stairs. The time interval for one climbing step as shown in Fig 1 is specified as follows:

1. Place (entire sole contact) $(t = 0)$
2. Deploy (heel off) $(t = T_d)$
3. Swing (lift on the air) $(t = T_m)$
4. Deploy (heel contact) $(t = T_c)$
5. Place (entire sole contact) $(t = T_c + T_d)$

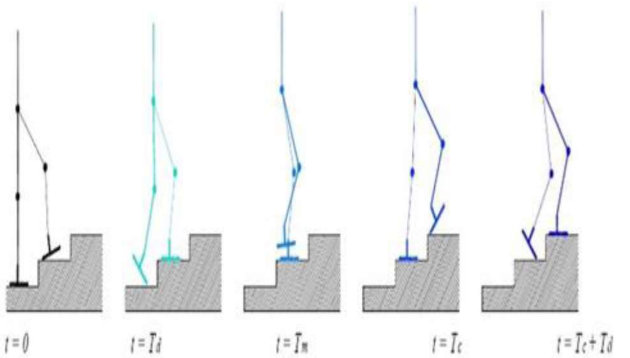

Fig. 1 Time interval for one climbing step

Algorithm step 2: Position constraints for the breakpoints of one climbing step

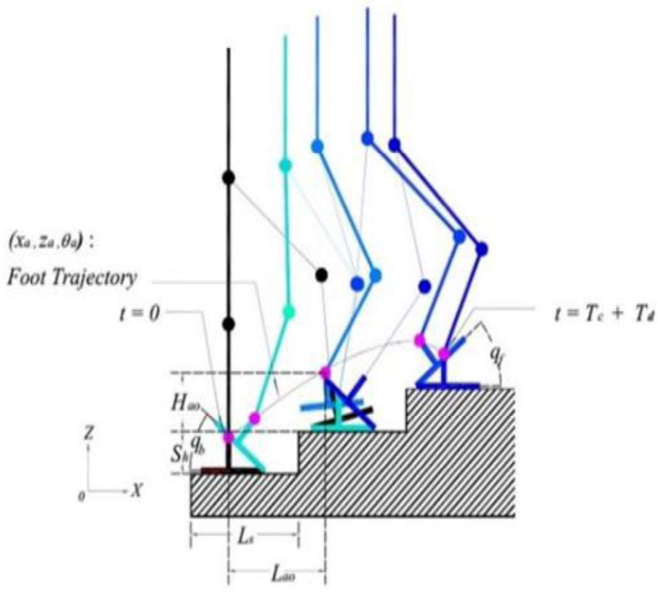

Fig. 2 One climbing stairs cycle of the biped robot

Letting l_{an} be the height of the foot, l_{af} is the length of the ankle joint to the toe and l_{ab} is the length of the ankle joint to the heel. Letting q_b and q_f be the designated angles of the swing foot as its leaves and lands on the stairs.

The position constraints for breakpoints of one climbing cycle are described by following [7]:

$$x_a(\mathrm{t}) = \begin{cases} 0, & t = 0 \\ l_{an} sinq_b + l_{af}(1 - cosq_b), & t = T_d \\ l_{ao,} & t = T_m \\ 2L_s - l_{an} sinq_b - l_{ab}(1 - cosq_f), & t = T_c \\ 2L_s, & t = T_c + T_d \end{cases}$$

$$z_a(t) = \begin{cases} l_{an}, & t = 0 \\ l_{af} sinq_b + l_{an} cosq_b, & t = T_d \\ H_{ao+}S_h, & t = T_m \\ 2S_h + l_{ab} sinq_f + l_{an} cosq_f, & t = T_c \\ 2S_h + l_{an}, & t = T_c + T_d \end{cases}$$

$$\theta_a(t) = \begin{cases} 0, & ,t = 0 \\ q_{b,} & t = T_d \\ q_{f,} & t = T_c \\ 0, & t = T_c + T_d \end{cases}$$

Algorithm step 3: The whole trajectory between the break points of one climbing cycle

The cubic spline interpolation method is applied to find the trajectory planning of biped robot. Firstly, the values of parameters for one climbing step are proposed in Table 1.

TABLE 1
PARAMETERS OF ONE CLIMBING CYCLE

parameter	value
T_d	0.18 s
T_m	0.4 s
T_c	0.9 s
l_{an}	10 cm
l_{ab}	10 cm
l_{af}	13 cm
D_s	50 cm
l_{ao}	40 cm
H_{ao}	15 cm
L_s	39 cm
S_h	13 cm
q_b	0.7 rad
q_f	0.7 rad

By applying the cubic spline interpolation in section II, finally we get the complete one climbing step foot trajectory is obtained as follows:

$$x_a(t) = \begin{cases} 512.16t^3 + 36.18t, & t \in (0,0.18) \\ -638.29(t-0.18)^3 + 276.57(t-0.18)^2 + 85.96(t-0.18) + 9.50, & t \in (0.18,0.4) \\ 103.17(t-0.4)^3 - 144.70(t-0.4)^2 + 114.97(t-0.4) + 35, & t \in (0.4,0.9) \\ -18.63(t-0.9)^3 + 10.06(t-0.9)^2 + 47.65(t-0.9) + 69.21, & t \in (0.9,1.08) \end{cases}$$

$$z_a(t) = \begin{cases} 169.67t^3 + 27.97t + 10, & t \in (0,0.18) \\ -210.22(t-0.18)^3 + 91.62(t-0.18)^2 + 44.46(t-0.18) + 16.02, & t \in (0.18,0.4) \\ -26.01(t-0.4)^3 - 47.12(t-0.4)^2 + 54.25(t-0.4) + 28, & t \in (0.4,0.9) \\ 159.53(t-0.9)^3 - 86.15(t-0.9)^2 - 12.39(t-0.9) + 40.09, & t \in (0.9,1.08) \end{cases}$$

For the pre-swing phase and post-swing phase,

$$\theta_a(t) = \begin{cases} -8.57t^3 + 4.17t & t \in (0,0.18) \\ 8.57(t-0.9)^3 - 4.63(t-0.9)^2 - 3.33(t-0.9) + 0.7 & t \in (0.9,1.08) \end{cases}.$$

IV. SWING FOOT HIP TRAJECTORY BY MATLAB PROGRAM

In this section the numerical result of swing foot trajectories that have been derived in section III are checked by drawing graphs with Matlab figures. So that all the results we obtained are correct can be checked to see whether they are correct or not.

In Fig.3, the resulting trajectory of *X*-axis is demonstrated. It can be clearly seen that the demonstrated trajectory is smooth and continuous.

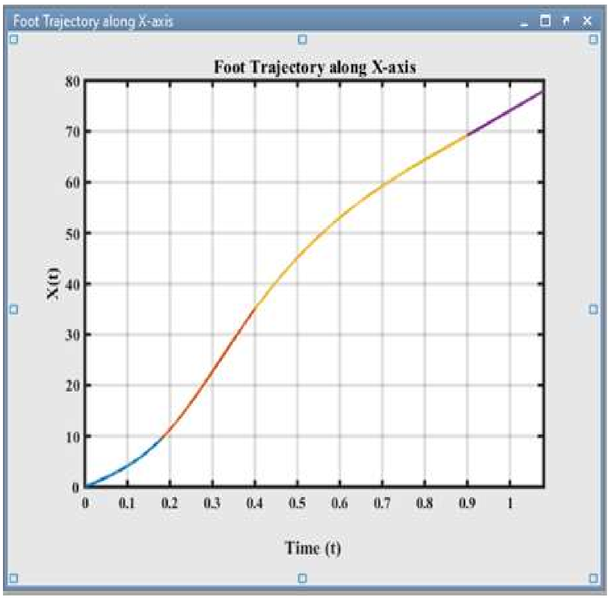

Fig. 3 Swing foot trajectory along *X*-axis

In Fig.4, the resulting trajectory of Z-axis is demonstrated. The demonstrated trajectory is a smooth curve through data points that are not subject to error as in Fig.3.

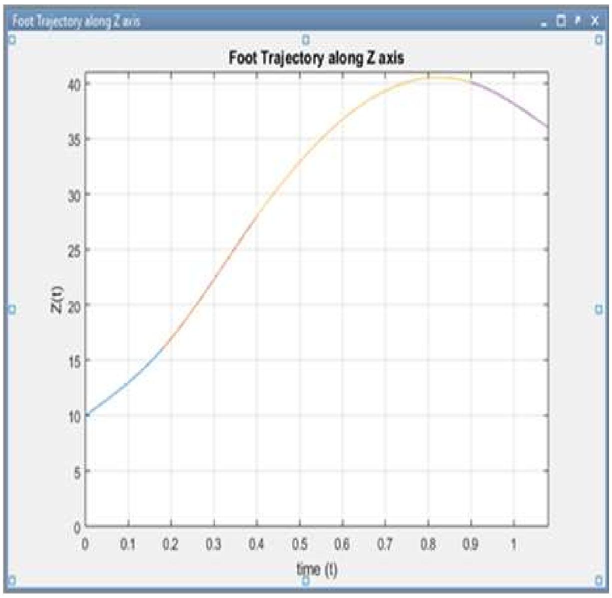

Fig. 4 Swing foot trajectory along *Z*-axis

In Fig.5, the resulting trajectory of along angle for pre-swing foot and post-swing foot is demonstrated. This trajectory is a smooth curve as in Fig.3 and 4.

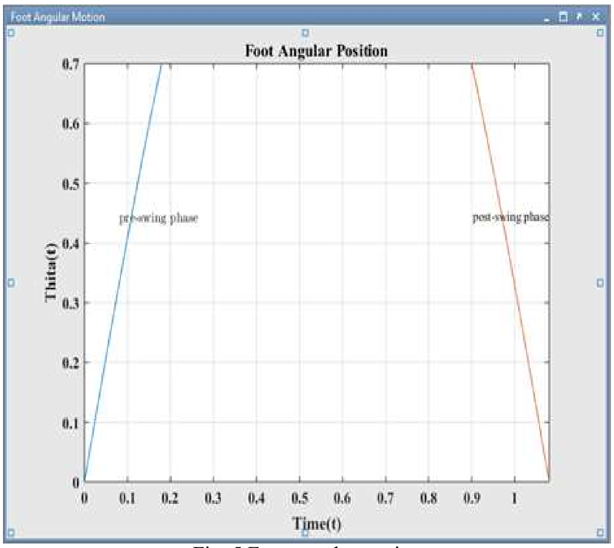

Fig. 5 Foot angular motion

It is clearly seen that the resulting trajectories are smooth and continuous due to the properties of cubic spline interpolation.

V. CONCLUSIONS

In this paper, foot trajectory for climbing upstairs of a biped robot has been generated. As mathematical background of this paper, cubic spline interpolation has been described. And then, theoretical background of climbing up stairs trajectory has been discussed. Finally, the goal of this research, the climbing upstairs trajectory generated by cubic spline interpolation, has been approached and derived. The resulting trajectories for applying this interpolation method are smooth and continuous. Future study will focus on stable hip trajectory for climbing upstairs of the biped robot from the mathematical point of view.

ACKNOWLEDGEMENT

Thanks and gratitude goes to my respectable teachers Dr. Khaing Khaing Aye, Dr. Myint Htay, Dr. Ni Ni Win and Dr. Yin May, Heads of Department of Engineering Mathematics at YTU, MTU, MIIT and TU (Magway) who directly or indirectly contributed towards the success of this work. I also wish to express my deepest gratitude to my adorable benefactor parents for their support and encouragement. Finally I want to recognize my deep appreciation to my husband for his assistance in AutoCAD drafting for this paper.

REFERENCES

[1] Huang, Qiang, Kazuhito Yokoi, Shuuji Kajita, Kenji Kaneko, Hirohiko Arai, Noriho Koyachi, Kazuo Tanie.: "*Planning walking patterns for a biped robot*". IEEE Trans. Robot. Auto vol.17, no.3 pp.1-2, (2001)

[2] Zhang, R. and Vadakkepet, P. "*Motion Planning of Biped Robot Climbing Stairs*". Department of Electrical and Computer Engineering, National University of Singapore at 4 Engineering Drive 3, Singapore 117576 pp. 1.

[3] Mathews, J.H. and Fink, K.K. 2004, "*Numerical Methods Using Matlab*". 4th ed. U.S.A: Prentice-Hall pp. 281-284.

[4] Mckinley, S. and Levine, M." *Cubic Spline Interpolation*" Math45: Linear Algebra. Niku, S.B pp. 1-9, 2001.

[5] Tang, Z., Zhou, C, and Sun, Z, "*Trajectory planning for smooth transition of a Biped Robot*". Proceedings of IEEE, International Conference on Robotics and Automation Taipei, Taiwan, pp.1, September, 2003.

[6] Thant, A. and Aye, K. "*Application of Cubic spline interpolation to walking patterns of biped robot*". Proceedings of World Academy of Science, Engineering and Technology, pp. 1, 2009

[7] Bagheri, A., Minpour, B. and Naseradinmousavi, P. "*Mathematical Modelling and Simulation of Combined Trajectory paths of a Seven Link Biped Robot*" The University of Guilan, Faculty of Engineering, Iran, pp.2, March 2010.

[8] Ranjbar, M., and Mayorga, R. "*A Seven Link Biped Robot Walking Pattern Generation on Various Surfaces*" Wise& Intelligent Systems& Entities (WISE) Lab, Faculty of Engineering and Applied Science, University of Regina, CANADA. Vol 16, pp.305, 2017.

[9] Bachor, Y. "*Developing Controllers for Biped Humanoid Locomotion*" School of Informatics, University of Edinburgh, pp.24-26, 2004.

[10] Cuevas, E., Zaldivar, D., Perez-Cisneros, M. and Ramirez-Ortegon, M. "*Polynomial Trajectory Algorithm for a Biped Robot*" International Journal of Robotics and Automation 25 (4), pp.7-9, 2010.