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A FUZZY TECHNIQUE TO CONTROL ATTITUDE AND POSITION OF A STEWART PLATFORM

Mateus Moreira de Souza
Fabio Toledo Bonemer de Salvi
Sergio Ricardo Carlos
Emilio Eduardo Tressoldi Moreira
Gabriel Scherer Schwening
Eduardo Morgado Belo
Escola de Engenharia de São Carlos, Universidade de São Paulo, Av. Trabalhador São Carlense, 400, Pq Arnold Schmidt, São Carlos – SP.
mateusmoreiradesouza@yahoo.com.br; fabiodesalvi@yahoo.com; sergiorc@gmail.com; emilio.eduardo@gmail.com; gabrielschs@gmail.com; belo@sc.usp.br;

Ricardo Breganon
Instituto Federal do Paraná, Av. Dr. Tito, s/n, Jardim Panorama, Jacarezinho – PR.
ricardo.breganon@ifpr.edu.br

Rodrigo Cristian Lemes
Instituto Federal de São Paulo, Rodovia Washington Luís, km 235, São Carlos – SP.
professorlemes@yahoo.com

Abstract. *A 6-6 configuration Stewart platform was developed in the Aerospace Control Laboratory of the Escola de Engenharia de São Carlos – USP. This platform has 6 electromechanical actuators connecting 2 platforms. Actuators' lengths were estimated utilizing encoders in the engine's shaft of the actuator and calibration curves. To control the relative attitude and position between the two platforms a fuzzy logic controller was developed. Square signals of voltage were sent to the actuator's engine with different amplitude and time to create the fuzzy sets utilized in the controller. The fuzzy controller receives the desired position and attitude and calculates the actuator's lengths utilizing the platform's inverse kinematic. The actuator with the highest difference between actual and desired lengths receives the highest amplitude square signal and is utilized to determine the time to reach the desired length and then, the inputs for the other actuators are determined utilizing the sets. This fuzzy controller can reduce undesired movement of the platform caused when one actuator could reach its desired length before the others.*

Keywords: *Stewart Platform, Position Control, Attitude Control, Fuzzy Logic Controller.*

1. INTRODUCTION

Stewart Platforms are composed of two platforms connected by six parallel linear actuators and the relative position between the two platforms can be changed by extending or retracting the actuators. It can be used in flight simulators, for docking aircraft in space, as submarine rescue docking device and other applications (Bo, Zhongcai and Zhiyong, 2011).

Attitude and position control of Stewart platforms are real complex problems in several areas of study. The reference model for this mechanism can be split in two categories, hydraulic or eletromechanical actuators. For hydraulic actuators it is utilized Newton's law for translation and rotation movements considering a base platform and a moving platform, since the system is non linear and is linearized near an equilibrium point (Qiang, Juan and Zhiyong, 2008) and (Rémillard and Boukas, 2006). Eletromechanical actuators utilize the inverse kinematic of the platform and the actuators mathematical models. Inverse kinematic of the Stewart platform is obtained utilizing linear algebra.

Position control of Stewart Platforms has been obtained utilizing PID controllers with gains found by cooperative co-evolution algorithms (Sun, Ding and Hao, 2008), fuzzy PID and feedback controllers with gains defined in reference points and selected in other points by fuzzy algorithms (Bo, Zhongcai and Zhiyong, 2011) and (Rémillard and Boukas, 2006) PD controllers with gains varying with adaptive algorithm (Nguyen, Antrazi, Zhou, and Campbell, 1993), and other different techniques.

In this paper, a fuzzy logic controller was designed for a real Stewart platform with electromechanical actuators. It utilizes the inverse kinematic of the Stewart Platform to obtain the required actuators length to reach the desired attitude and position between the two platforms, and then utilizes fuzzy sets to determine the input for each actuator.

2. THE STEWART PLATFORM

A Stewart platform designed in the Aerospace Control Laboratory of the Escola de Engenharia de São Carlos – USP was utilized in this work. Figure 1 shows the Stewart platform utilized. It has six electromechanical actuators that are utilized to control the position and attitude of the movable platform. To measure the variation of the actuators' lengths encoders in the shaft of the actuators' engines were utilized to measure the number of rotations of the engine, and then a calibration curve was applied to obtain each actuator variation length.

The acquisition, transmitting, and processing system dSPACE was utilized in combination with the speed controller drive RoboClaw 2 to send signal of voltage in the range of 10 V to -10 V to the actuators' engines.

Figure 1. The Stewart platform of the Aerospace Control Laboratory.

3. THE INVERSE KINEMATICS

Once defined the desired position and attitude of the Stewart platform, the length of the six actuators can be obtained utilizing the inverse kinematics of the platform. Joints of actuators are known for a given platform, and their relative positions can be written in relation to the center of each platform in two coordinate systems shown in Fig. 2. The base platform coordinate system utilizes the center of the base platform F as origin, the xf-axis pointing between joints with actuators 1 and 6, zf-axis is perpendicular with the platform plane, and yf-axis completes the right hand rule. The movable platform coordinate system center M and its axis xm, ym, and zm are defined in a similar way. The positions of joints of the base and movable platforms in its coordinate systems are represented in Eq.s (1) and (2), respectively.

$$\{F_i\}^F = \{F_{i1} \quad F_{i2} \quad 0\}^T, i = 1,2,...,6 \tag{1}$$

$$\{M_i\}^M = \{M_{i1} \quad M_{i2} \quad 0\}^T, i = 1,2,...,6 \tag{2}$$

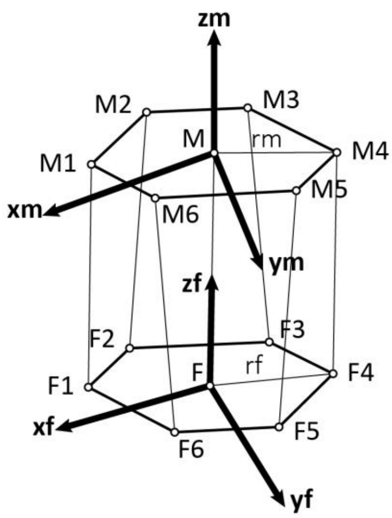

Figure 2. Base and movable platforms coordinate systems.

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The transformation matrix [T^{MF}] to obtain coordinates from movable coordinate system to base coordinate system can be obtained utilizing three rotations in sequence. The first rotation is applied in xm-axis until ym-axis is parallel to the base platform plane; this angle of rotation φ is known as roll angle. Then it is applied a rotation in the ym-axis until the movable platform is parallel to the base platform; the pitch angle θ is obtained. And the last rotation is applied in the zm-axis generating the yaw angle ψ. The transformation matrix is show in Eq. (3).

$$\left[T^{MF}\right]=\begin{bmatrix} c\varphi * c\theta & c\varphi * s\theta * s\psi - s\varphi * c\psi & c\varphi * s\theta * c\psi + s\varphi * s\psi \\ s\varphi * c\theta & s\varphi * s\theta * s\psi + c\varphi * c\psi & s\varphi * s\theta * c\psi - c\varphi * s\psi \\ -s\theta & c\theta * s\psi & c\theta * c\psi \end{bmatrix} \quad (3)$$

where c is the cosine and s is the sine function.

The position of the movable platform can be written in the base platform system as shown in Eq.(4) and the length vectors V_i of the six actuators can be obtained utilizing Eq.(5).

$$\{M\}^F = \{x \quad y \quad z\}^T \quad (4)$$

$$\{V_i\}^F = \{V_{i1} \quad V_{i2} \quad V_{i3}\}^T = \{M\} + \left[T^{MF}\right] * \{M_i\} - \{F_i\}, i = 1,2,...,6 \quad (5)$$

The actuator's length l_i is the module of the vector $\{V_i\}$ as shown in Eq.(6).

$$l_i = \left(V_{i1}^2 + V_{i2}^2 + V_{i3}^2\right)^{0.5}, i = 1,2,...,6 \quad (6)$$

4. THE FUZZY CONTROLLER

The position and attitude control of the movable platform in relation to the base platform is executed by controlling the six actuators lengths. A small variation in the response of each real eletromechanical actuator is expected and can cause undesired movement of the movable base, in the case of an actuator reaches the desired length before others. To avoid this situation, a fuzzy logic controller was designed to control all the actuators with only one controller.

The controller receives the desired position and attitude of the movable platform, utilizes the inverse kinematic to obtain desired lengths for the six actuators, and utilizing two fuzzy sets it send square signals of voltage to the electric engine of each actuator. To define the amplitude and time of application of each signal, it utilizes the procedure described next.

First, the difference between the desired lengths and the actual lengths are calculated for all actuators and are the inputs of the fuzzy logic controller. These inputs are normalized utilizing the variation of the actuator´s length when applied a tension of 10V in its electric engine during 1 second. The normalized inputs are utilized to define the actuator that will take longer to reach the desired length. Utilizing difference of this actuator the time of application of the signal is obtained.

Fuzzy sets with different variations on the actuator length were created utilizing experimental tests in the Stewart platform. In these tests, square signals with 10V were sent to the electric engines of the actuators with different times of application and the variations in the actuators lengths were measured. These values are presented in Tab. 1. Utilizing the triangular membership presented in Eq.(7), the application time of the square signal is obtained utilizing Eq.(8).

Table 1. Variations in actuators' lengths caused by application of square signals of voltage to the actuators' engines with different time of application and amplitude of 10V and -10V.

Time [s]	Variation in the actuator length [mm]											
	Actuator 1		Actuator 2		Actuator 3		Actuator 4		Actuator 5		Actuator 6	
	10 V	-10V	10 V	-10V	10 V	-10V	10 V	-10V	10 V	-10V	10 V	-10V
0,1	3,86	-4,08	4,36	-3,85	3,89	-3,92	3,93	-3,83	4,34	-4,29	3,79	-4,42
1,0	45,9	-49,61	54,01	-50,23	45,54	-47,44	47,56	-47,14	51,34	-49,86	44,71	-51,45
2,0	91,17	-100,73	99,48	-98	94,87	-96,18	96,28	-94,32	101,25	-102,31	91,37	-105,15
2,5	114,51	-127,37	124,31	-122,48	118,88	-120,52	120,22	-117,86	128,1	-127,66	115,11	-131,66

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$$\mu^t{}_{ij} = \begin{cases} \max\left(\dfrac{\Delta l_{i+1,j} - \Delta l}{\Delta l_{i+1,j} - \Delta l_{i,j}}, 0\right), i = 1, j = 1,2 \\ \max\left(\min\left(\dfrac{\Delta l - \Delta l_{i-1,j}}{\Delta l_{i,j} - \Delta l_{i-1,j}}, \dfrac{\Delta l_{i+1,j} - \Delta l}{\Delta l_{i+1,j} - \Delta l_{i,j}}\right), 0\right), i = 2,3, j = 1,2 \\ \max\left(\dfrac{\Delta l - \Delta l_{i-1,j}}{\Delta l_{i,j} - \Delta l_{i-1,j}}, 0\right), i = 4, j = 1,2 \end{cases} \quad (7)$$

where Δl is the higher input, Δl_{ij} are the lengths in Tab.1 for the actuator with the high input in the *i-th* line and *j-th* column, and $\mu^t{}_{ij}$ is the membership value for the fuzzy set Δl_{ij}.

$$t = \sum_{i=1}^{4} \sum_{j=1}^{2} \mu^t{}_{ij} * t_i \quad (8)$$

where t is the time of the applied signal and t_i is the time in the i-th line of Tab.1.

The amplitude of the signal for each actuator is obtained in a similar way. Square signals of voltage of 10 V, 5 V, -10 V, -5 V and minimum values of voltage that cause rotation of the actuator's engine with 0,1 s, 1 s, 2 s and 2,5 s of time of duration were sent and then the actuators lengths were measured. Table 2 shows variations of actuator's 1 length for each combination of voltage and time of application. The amplitude of the signal for each actuator is obtained utilizing Eq.(9), where triangular membership functions are utilized to correlate the required variation in the length of the actuator with the amplitude voltage the controller will send to the actuator's engine.

Table 2. Variation in actuator's 1 length caused by application of square signals of voltage in the actuator' engine with different times of application and amplitudes.

Time [s]	Variation in the actuator's 1 length [mm]					
	2,3 V	5 V	10 V	-1,3 V	-5 V	-10 V
0,1	0,05	41,82	114,52	-0,06	-52,14	-126,38
1	0,21	34,32	91,18	-0,18	-41,87	-100,74
2	0,41	17,36	45,91	-0,40	-20,64	-49,62
2,5	0,46	1,36	3,86	-0,51	-1,80	-4,09

$$V_K = \sum_{i=1}^{6} \mu^V{}_i * V_i \quad (9)$$

where V_K is the amplitude of voltage of the square signal for the k-th actuator, $\mu^V{}_i$ is the membership value of the desired variation in the length of the actuator obtained for the time of application of the signal and the voltage in the i-th column and V_i is the voltage in the i-th column.

After the application of the square signal, this procedure is calculated again to correct for errors between the desired length and the actual length.

5. RESULTS

Two different displacement commands were sent to the controller. First the movable platform was commanded to move 50 mm in the axis zf and then to rotate 10° in the pitch angle. Figs. 3 and 4 show the variation in the actuator 1 length for the linear and angular motion of the movable platform, respectively, and Figs. 5 and 6 show the length error of each actuator at the same time. After the end of the first square signal, in linear motion, the actuator 4 has the highest length error being 0.92 mm, and in the angular motion, actuator 2 has 0.97 mm of error which is the highest error. When the movement is settled the highest length error occurs in the angular movement and is 0.47mm.

Since the errors in the actuators' lengths after the first square signal is less than 1mm in both cases, the fuzzy logic controller can reduce the undesired motion caused when an actuator reach its desired length before the others.

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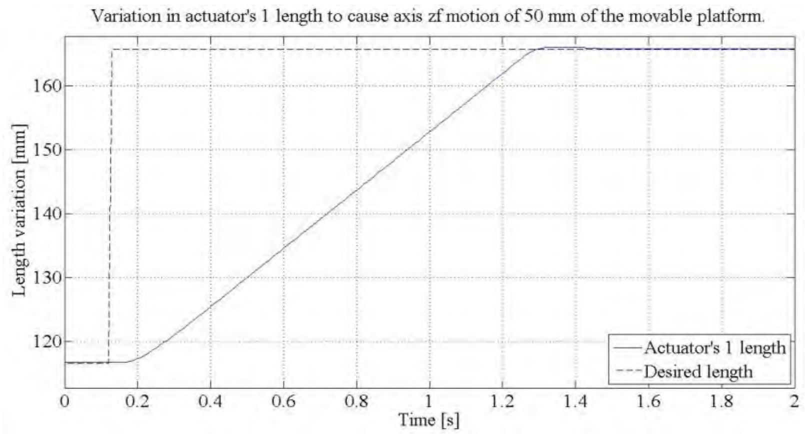

Figure 3. Variation in the length of the actuator 1 to cause motion in axis zf.

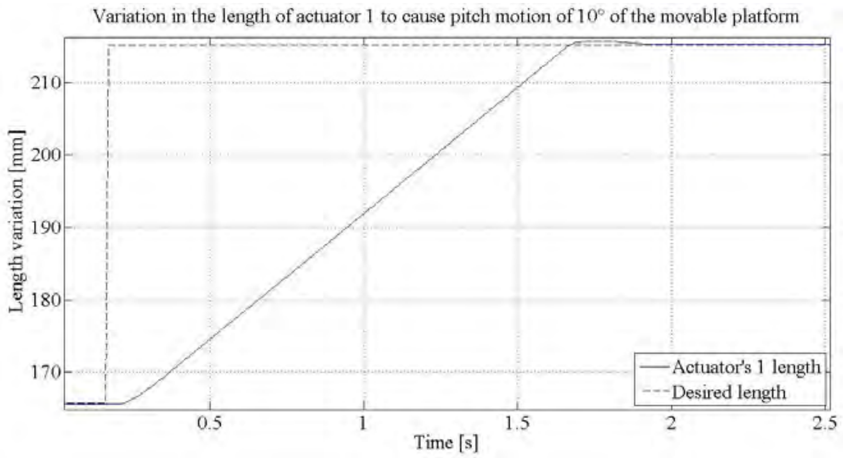

Figure 4. Variation in the length of the actuator 1 to cause pitch motion.

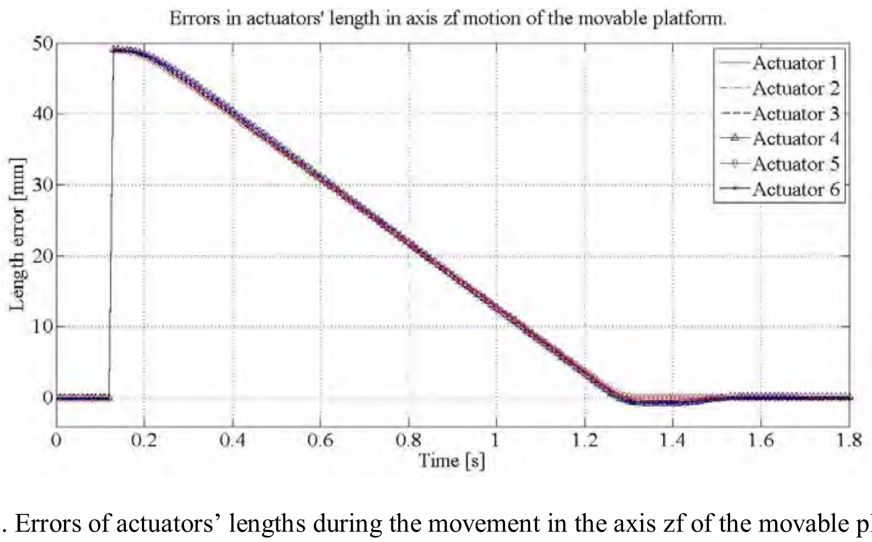

Figure 5. Errors of actuators' lengths during the movement in the axis zf of the movable platform.

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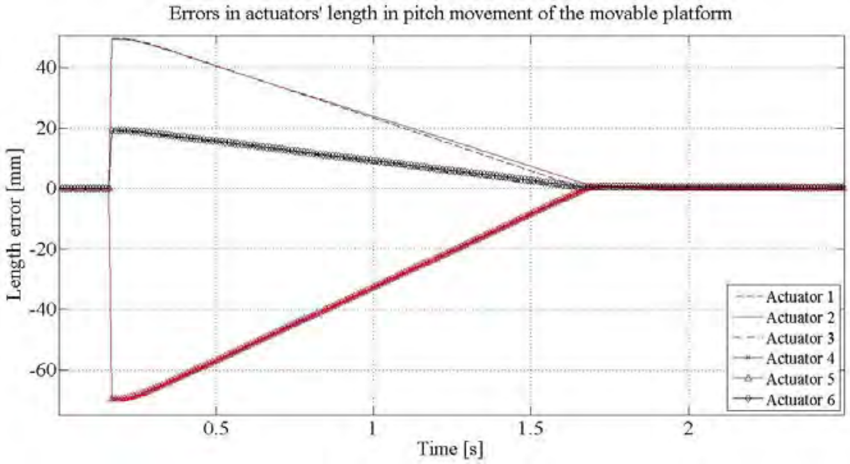

Figure 6. Errors of actuators' lengths during the pitch movement of the movable platform.

6. CONCLUSION

In the present work was proposed a fuzzy logic controller that reduces the undesired motion caused when an actuator can reach its desired position before the others. Since it utilizes the highest allowed input in the actuator that will take longer to reach the desired position to determine the time of application of the square signal of voltage in the actuator's engine, this controller has good response too.

This controller was designed to follow step inputs of position and attitude and can be easily applied to Stewart platforms with electromechanical actuators, since it needs only experimental data of the variation of lengths of each actuator when applied square signals with different amplitudes and times of applications. It can also be utilized in machinery tooling applications.

Future studies can increase the number of voltage amplitudes and times of applications to verify the benefits in the controller response, or can insert an additional fuzzy rule to increase or reduce the voltage amplitude during the application of the square signal to reduce the error after the end of the first square signal.

7. ACKNOWLEDGEMENTS

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9. RESPONSIBILITY NOTICE

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