Mechatronics, Electrical Power, and Vehicular Technology 04 (2013) 109-116

Mechatronics, Electrical Power, and Vehicular Technology

e-ISSN:2088-6985
p-ISSN: 2087-3379
Accreditation Number: 432/Akred-LIPI/P2MI-LIPI/04/2012

www.mevjournal.com

CONTROL OF PAN-TILT MECHANISM ANGLE USING POSITION MATRIX METHOD

Hendri Maja Saputra [a,*], Arif Santoso [a], Midriem Mirdanies [a], Vikita Windarwati [b], Riastus Nayanti [b], Lukni Maulana [b]

[a] Research Center for Electrical Power and Mechatronics, Indonesian Institute of Sciences
Komp. LIPI Bandung , Jl. Sangkuriang, Gd. 20. Lt. 2, Bandung 40135, Indonesia
[b] Mechatronics Department, Faculty of Engineering - Yogyakarta State University
Colombo Street No.1, Yogyakarta, 55281 Indonesia

Received 15 October 2013; received in revised form 07 November 2013; accepted 11 November 2013
Published online 24 December 2013

Abstract

Control of a Pan-Tilt Mechanism (PTM) angle for the bomb disposal robot Morolipi-V2 using inertial sensor measurement unit, x-IMU, has been done. The PTM has to be able to be actively controlled both manually and automatically in order to correct the orientation of the moving Morolipi-V2 platform. The x-IMU detects the platform orientation and sends the result in order to automatically control the PTM. The orientation is calculated using the quaternion combined with Madwick and Mahony filter methods. The orientation data that consists of angles of roll (α), pitch (β), and yaw (γ) from the x-IMU are then being sent to the camera for controlling the PTM motion (pan & tilt angles) after calculating the reverse angle using position matrix method. Experiment results using Madwick and Mahony methods show that the x-IMU can be used to find the robot platform orientation. Acceleration data from accelerometer and flux from magnetometer produce noise with standard deviation of 0.015 g and 0.006 G, respectively. Maximum absolute errors caused by Madgwick and Mahony method with respect to X-axis are 48.45° and 33.91°, respectively. The x-IMU implementation as inertia sensor to control the Pan-Tilt Mechanism shows a good result, which the probability of pan angle tends to be the same with yaw and tilt angle equal to the pitch angle, except a very small angle shift due to the influence of roll angle.

Key words: Pan-Tilt control, x-IMU sensor, quaternion, position matrix, Morolipi-V2.

I. INTRODUCTION

Inertial measurement unit (IMU) sensor is being used to determine position and orientation of an object. Therefore, this sensor can be applied for platform stabilization system [1, 2] and hand-operated remote control replacement [3]. One example of the widely used IMU sensors is the brand of x-IMU. The first generation of IMU sensor only consisted of a gyroscope (measuring rotation) and accelerometer (measuring translation), but then evolved with the addition of a magnetometer (measuring flux).

Quaternion method, as well as Euler, and Direction Cosine Matrix (DCM) can be used to represent the IMU sensor parameters. The advantages and disadvantages of the three methods are being discussed by Phuong [4]. An IMU sensor research with a particular filter method has been done by Madgwick [5] and Mahony [6]. Their research described an algorithm to obtain the value orientation of data that acquired from the IMU sensor using a quaternion representation where IMU consisting of tri-axis gyroscopes, accelerometers, and magnetometers. Control of pan-tilt mechanism (PTM) camera with IMU sensor 3/3/3 PhidgetSpatial brand has been done by Saputra [7].

In this research, it explained how to acquire the orientation angles with a simple method which is derived geometrically. A similar study with a PTM on a 2-DOF robot and a 2-DOF camera-equipped gimbal has been done by Sarwar [8], where the mechanism of the robot arm two degrees of freedom (2-DOF) is used for mounting the camera. Dynamic model of the mechanism derived using Newton-Euler's

* Corresponding Author.Tel: +62-22-2503055
E-mail: hendri_maja@ yahoo.co.id/ hend018@lipi.go.id

doi: 10.14203/j.mev.2013.v4.109-116

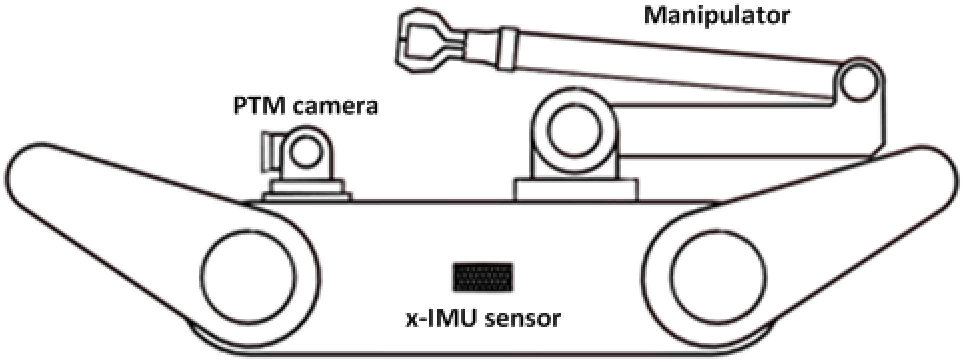


Figure 1. PTM camera and x-IMU in Morolipi-V2

equation. The study was conducted to obtain the motion controllers for the pan and tilt mechanisms (PTM) based on dynamical model. In Sangveraphunsiri [9] paper presents PTM to be installed in the aircraft.

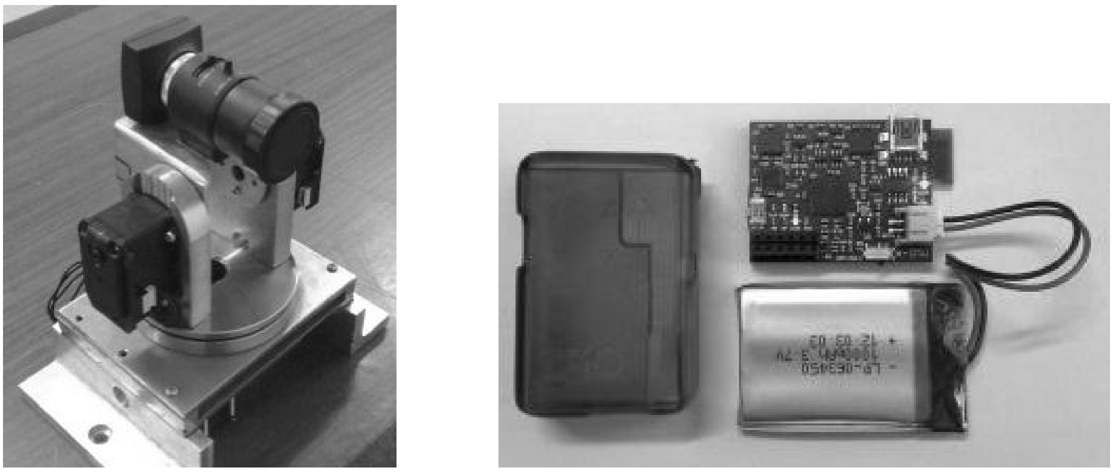
IMU sensors mounted on the base to detect the orientation of the plane which refers to the fixed reference frame. Control of PTM is needed to overcome the nonlinearities, the error dynamics modeling, friction and disturbances from the outside environment. A method to change the orientation angle (3-DOF) of IMU sensor into the PTM angle (2-DOF) has been conducted Saputra [10] by giving a term 'inverse-angle'. The simplest method to calculate inverse-angle is position matrix method.

This paper discusses experiment of controling a PTM camera angles using x-IMU sensor that has been done in the laboratory of mechatronics Indonesian Institute of Sciences (LIPI). This study that was conducted to evaluate the ability of x-IMU sensors in order to detect orientation through specific produce angles calculations is used to drive PTM camera as compensation.

II. Equipment and Methodology

Mechatronics laboratory at the Research Center for Electrical Power and Mechatronics-LIPI has been conducting several studies related to robotics. Robot prototypes which have been developed, among others, named Morolipi-V1 and Morolipi-V2. Morolipi-V1 is a bomb disposal robot equipped with a static camera. Morolipi-V2 is the later generation of the previous version designed to have a moveable PTM camera. The PTM camera is designed to be moved using manual remote control (potentiometer) and some active sensors (IMU or computer vision). They are mounted on the bomb disposal robot Morolipi-V2 as illustrated in Figure 1. The x-IMU serves as an inertial sensor which sends information to the PTM camera of Morolipi-V2 during its operation.

In this study, the robot platform was not used for data collection. Instead, the experiment uses only the PTM camera and the x-IMU sensor. Both components can be seen in Figure 2. The PTM consists of two servo motors and one camera. Generally, the basic concept of this study



(a) (b)

Figure 2. Components for experiment: (a) PTM camera; (b) x-IMU sensor

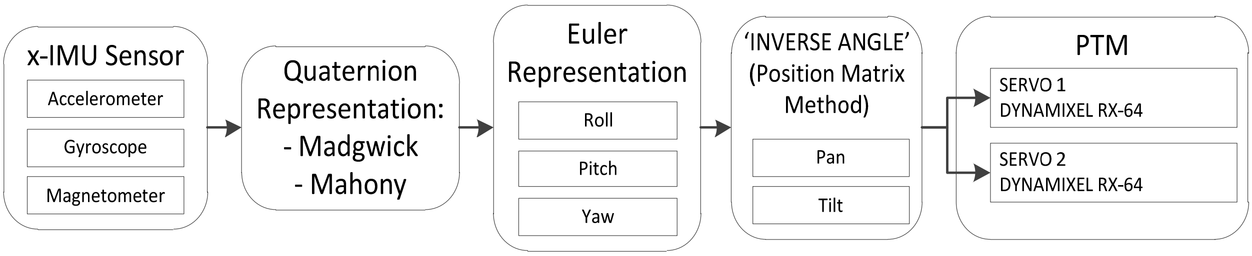


Figure 3. The basic concept of pan-tilt determination

can be seen in Figure 3. The x-IMU sensor is an integration of three sensors, namely accelerometer which issues acceleration data, a gyroscope which issues angular velocity data, and magnetometer sensor which issues flux (magnetic field) data. The datas are then filtered and transformed into quaternion representation. The quaternion representation then modified to the form of Euler angle representation (roll-pitch-yaw) to calculate the inverse-angle that has been formed by the PTM camera.

The methods were described by Madgwick [5] and Mahony [6] use quaternion representation to update orientation data. Therefore, the quaternion representation is then converted into the form of Euler angles as shown in equations (1-3) [5]. Then the result is calculated to get pan and tilt joint angles with a particular method.

$$\gamma = A\tan 2\,(2q_2q_3 - 2q_1q_4, 2q_1^2 + 2q_2^2 - 1) \quad (1)$$

$$\beta = -\sin^{-1}(\,2q_2q_4 + 2q_1q_3) \quad (2)$$

$$\alpha = A\tan 2\,(2q_3q_4 - 2q_1q_2, 2q_1^2 +\, 2q_4^2 - 1 \quad (3)$$

Where Atan is the inverse tangent (arctangent), sin-1 is the inverse sine, [q1 q2 q3 q4] are component of quternions, γ is the roll which is a rotation on the X-axis, β is the pitch which is a rotation on the Y-axis, and α is the yaw which is a rotation on the Z-axis.

The method used to determine the angle to be set up by the pan-tilt mechanism (inverse-angle) is the position matrix method as described by Saputra [10]. The method takes advantage of the total homogeneous transformation position matrix,P = [P_x P_y P_z] P = [Px, Py, Pz] as follows.

$$P_x = (\cos\alpha\cos\beta)(L_2 + L_x)\cos\theta_1\cos\theta_2 + (\cos\alpha\sin\beta\sin\gamma - \sin\alpha\cos\gamma)(L_2 + L_x)\sin\theta_1\cos\theta_2 + (\cos\alpha\sin\beta\cos\gamma + \sin\alpha\sin\gamma)(L_1 + (L_2 + L_x)\sin\theta_2) + bx, \quad (4)$$

$$P_y = (s\alpha\cos\beta)(L_2 + L_x)\cos\theta_1\cos\theta_2 + (\sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma)(L_2 + L_x)\sin\theta_1\cos\theta_2 + (\sin\alpha\sin\beta\cos\gamma - \cos\alpha\sin\gamma)(L_1 + (L_2 + L_x)\sin\theta_2) + by \quad (5)$$

$$P_z = (-\sin\beta)(L_2 + L_x)\cos\theta_1\cos\theta_2 + (\cos\beta\sin\gamma)(L_2 + L_x)\sin\theta_1\cos\theta_2 + (\cos\beta\cos\gamma)(L_1 + (L_2 + L_x)\sin\theta_2) + bz \quad (6)$$

Where [θ_1, θ_2] represent default position of pan-tilt joint angles, L_1 represents the distance between the end of the camera and object detected by camera, L_2 represents the distance from the joint to the tip of tilt camera, L_x represents the distance from the tip of the object to the camera on the trail, [bx, by, bz] is the position of PTM camera base where x-IMU sensor attached.

Based on research is conducted by Saputra [10], the inverse-angles (θ1 and θ2) derived using position matrix method generates equations as shown by equation (7) and (8), where the values of z and r are calculated by equation (9) and (10).

$$\theta_1 = tan^{-1}\left(\frac{P_y}{P_x}\right) \quad (7)$$

$$\theta_2 = tan^{-1}\left(\frac{z}{r}\right) \quad (8)$$

$$z = P_z - L_1 \quad (9)$$

$$r = \sqrt{P_x^2 + P_y^2} \quad (10)$$

III. RESULT AND ANALYSIS

Data collection was done in three phases: (1) data collection of x-IMU sensor output consisting of the acceleration, angular velocity, and flux; (2) data collection of roll-pitch-yaw (RPY) angles obtained through filters and calculation using Mahony and Madgwick methods; and (3) data collection of pan-tilt angles obtained through corner angle calculation using position matrix method.

A. Data Collection of x-IMU Sensor

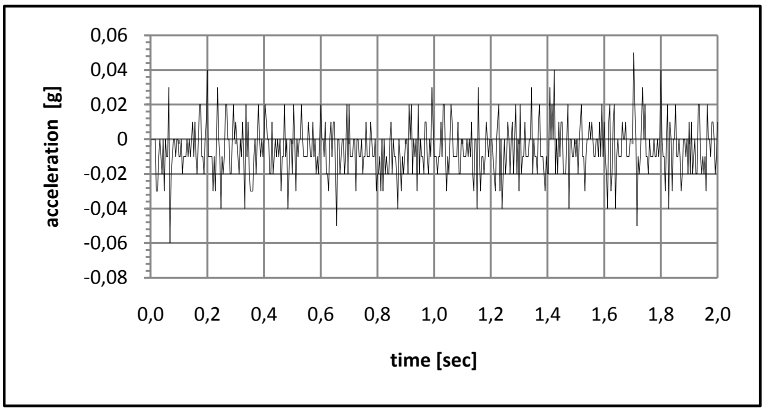
The output of x-IMU sensor actually consists of data on the X-axis, Y-axis and Z-axis, but in this paper, only data on the X-axis are shown. The data is taken at the time when the sensor does not move. It is shown in Figure 4. This figure shows that the data of acceleration (accelerometer) and flux (magnetometer) contain noise with standard deviation of 0.015 g (average value is 0.006 g) and 0.006 G (average value is -0.072 G), respectively. While noise of the angle-speed data (gyroscope) is compensated using window discrimination so value is zero of all time.

Offsets that occur in data shown in Figure 4 are eliminated by subtracting the sensor data with the average value. Sensor calibration to see the accuracy or precision as well as in-depth research related to the dynamic characteristics is not performed in this study because it is assumed that it has been done by the manufacturer of the sensor itself.

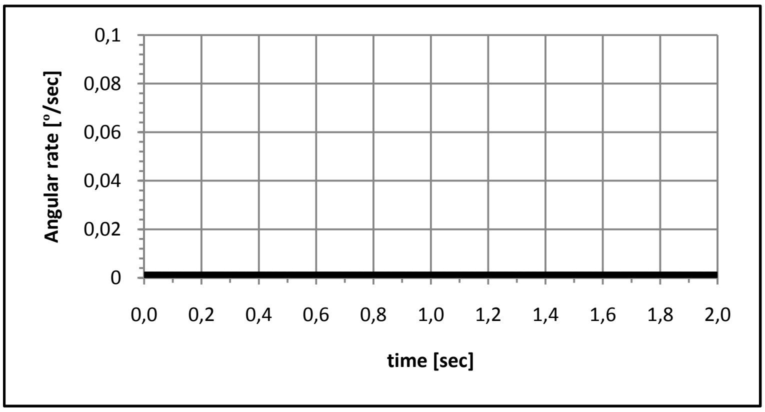
B. Data Computation of RPY Angles

Roll-pitch-yaw (RPY) angles taken are Euler angles converted from quaternion representation. RPY measurement data obtained through the filter and calculation using Madgwick and Mahony methods can be seen in Figure 5 and Figure 6. In the Madgwick method, a value of 0.1 is given for Beta while for Mahony, a value of 5 is given for Kp. These values were selected based on "trial and error" method.

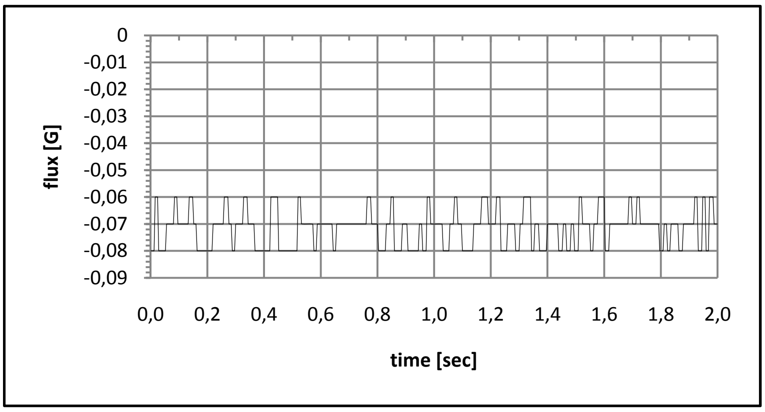
The Euler angle comparison of the two methods can be seen in Figure 5. Figure 5(a), Figure 5(b), and Figure 5(c) show that the



(a)

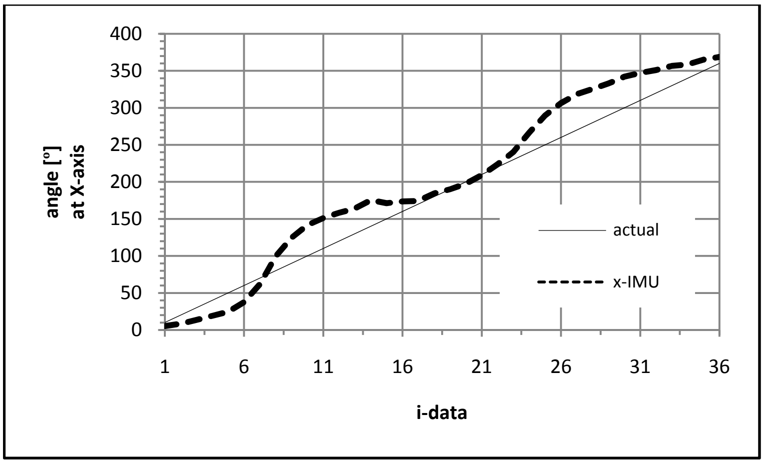


(b)

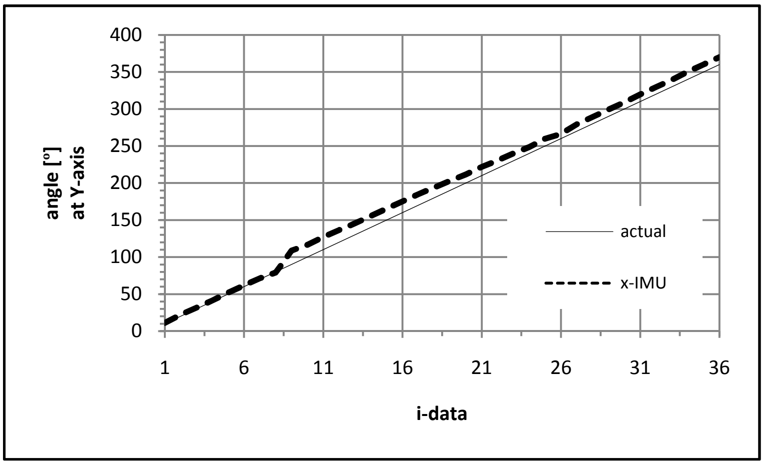


(c)

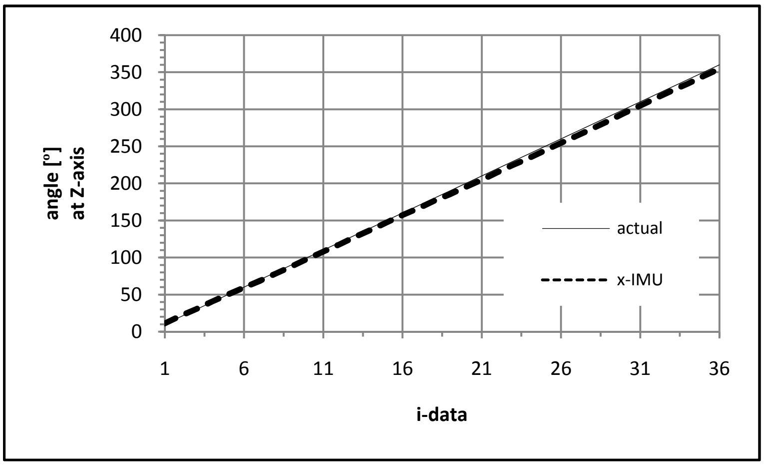
Figure 4. The results of X-axis of x-IMU sensor measurement: (a) accelerometer; (b) gyroscope; (c) magnetometer



(a)



(b)



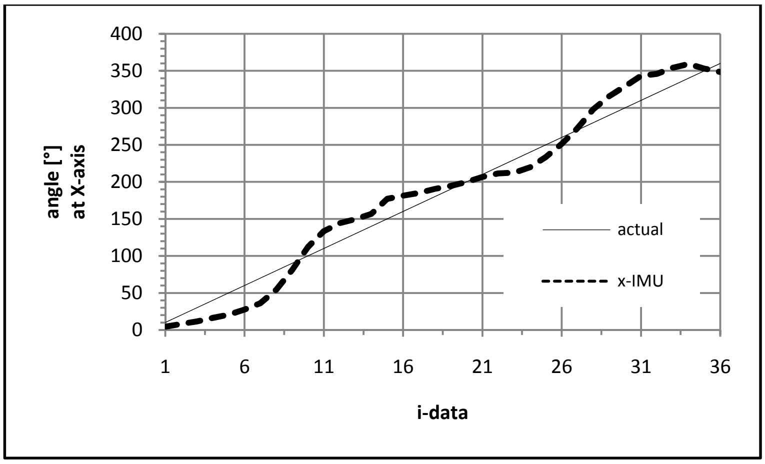
(c)

Figure 5. Comparison of the computed angles to actual angles measurement with Madgwick method for (a) X-axis; (b) Y-axis; (c) Z-axis

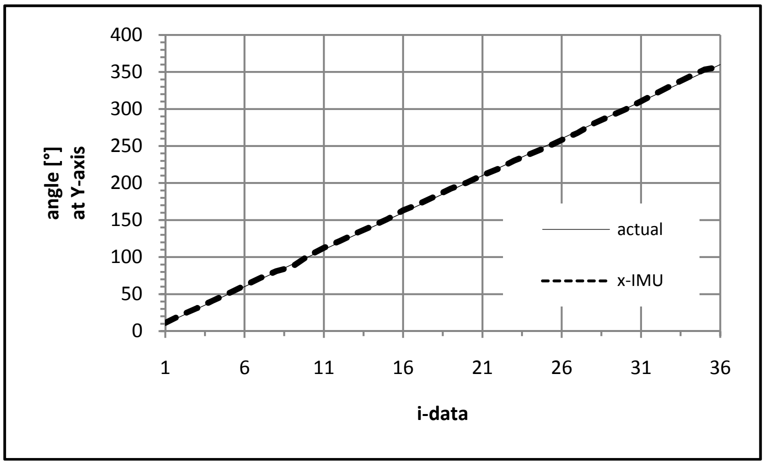
greatest absolute error of maximum angle for Madgwick method with respect to X-axis, Y-axis and Z-axis are 48.45º, 18.75º, and 5.81º, respectively. From Figure 6(a), Figure 6(b), and Figure 6(c) it can be seen that the greatest absolute error for the Mahony method with respect to X-axis, Y-axis and Z-axis are 33.91º, 3.41º, and 8.51º, respectively. From Figure 5, it can be seen that the largest absolute errors of the two methods occur in the X-axis. It can be concluded that Mahony method results smaller average error.

C. Data Computation of Pan-tilt Angles

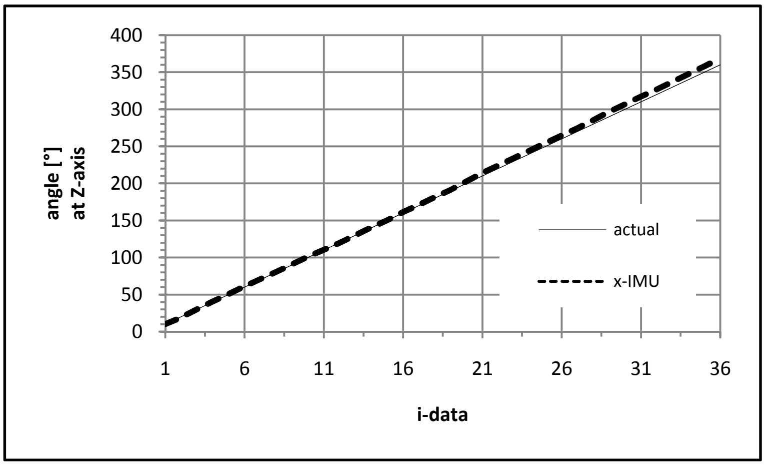
Data computation of RPY angles is processed to obtain pan-tilt angles using matrix position method. After that, the pan-tilt angles are used to drive the PTM. The actual measurement data of



(a)



(b)

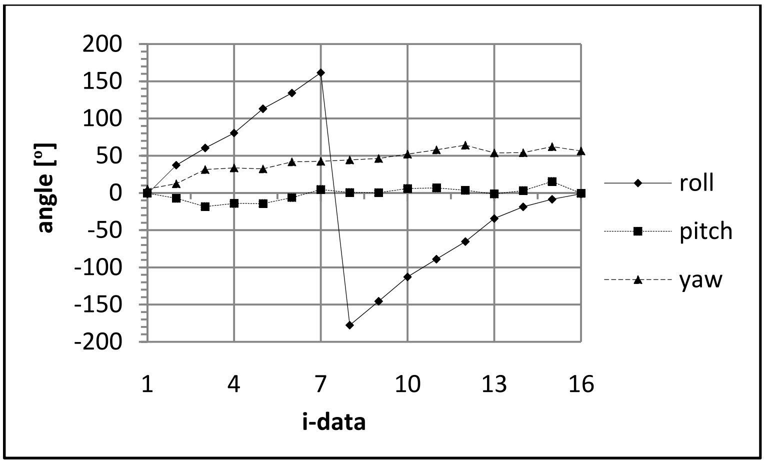


(c)

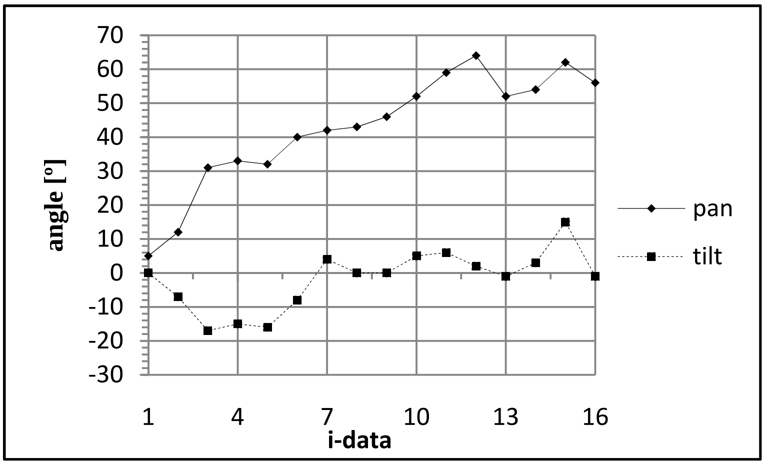
Figure 6. Comparison of the computed angles to actual angles measurement with Mahony method for (a) X-axis; (b) Y-axis; (c) Z-axis

the PTM angles (pan-tilt) based on output from x-IMU sensor (RPY angles) can be seen in Figure 7. RPY values were obtained through Madgwick method with a beta value of 0.1.

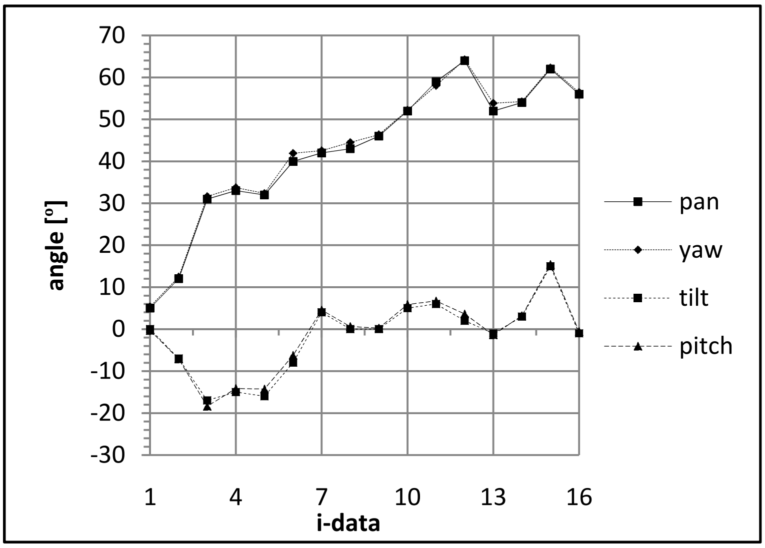
The angles formed by the PTM camera (pan and tilt angles) in the experiment fit with the results of research that conducted previously [10]. The application of the position matrix method as inverse-angle will produce pan angle that tends to be the same with yaw angle. In the same way, the tilt angle is likely to be the same with the pitch angle except a very small angle shift due to the influence of roll angle. The accuracy and precision of the results shown in Figure 7(c) cannot be demonstrated experimentally in this paper because it requires a fairly complicated instrument.



(a)



(b)



(c)

Figure 7. Result of inverse-angle experiment: (a) x-IMU angle as input; (b) pan-tilt angles as output; (c) sim ilarity between pan-tilt with yaw-pitch

IV. CONCLUSION

The x-IMU sensor can be used to determine the orientation of the robot platform using Madwick and Mahony methods. Acceleration data (from accelerometer) and flux data (from magnetometer) contain noise with a standard deviation of 0.015 g and 0.006 G, respectively. The greatest absolute errors of maximum angle of Madgwick and Mahony methods with respect to X-axis are 48.45º and 33.91º, respectively. The implementation of the x-IMU as inertial sensor attached to a camera-equipped with pan-tilt mechanism, which is also collaborated with position-matrix method shows a good result.

Further research is needed to test the PTM camera that is integrated with robot platform. When robot moves through terrain steps, camera is expected to lead into the desired direction because PTM angles automatically moving continually in opposite orientation to compensate for the platform.

ACKNOWLEDGEMENT

Authors would like to thank to the Research Center for Electrical Power and Mechatronics - Indonesian Institute of Sciences (LIPI) that has supported research and development of Morolipi bomb disposal robots. Especially to Budi Prawara, Pudji Irasari, Estiko Rijanto, Roni Permana Saputra, Aditya Sukma Nugraha, Rizqi Andri Ardiansyah, Vita Susanti, Anwar Muqorobin, and Tinton Dwi Atmaja for their effort.

REFERENCES

[1] H. M. Saputra and E. Rijanto, "Analisis Kinematik dan Dinamik Mekanisme Penggerak 2-DOF untuk Antena Bergerak pada Komunikasi Satelit," *Teknologi Indonesia*, vol. 32, pp. 21-29, 2009.

[2] H. M. Saputra, "Simulasi Sistem Kendali Penggerak 2-DK untuk Antena Komunikasi Satelit," Master Thesis, Fakultas Teknik Mesin dan Dirgantara, Institut Teknologi Bandung, Bandung, 2012.

[3] N. Tran, et al., "*Wireless Data Glove for Gesture-Based Robotic Control,*" in Human-Computer Interaction. Novel Interaction Methods and Techniques. vol. 5611, J. Jacko, Ed., ed: Springer Berlin Heidelberg, 2009, pp. 271-280.

[4] N. H. Q. Phuong, et al., "A DCM Based Orientation Estimation Algorithm with an Inertial Measurement Unit and a Magnetic Compass," *Journal of Universal Computer Science*, vol. 15, pp. 859-876, 2009.

[5] S. O. H. Madgwick, "*An Efficient Orientation Flter for Inertial and Inertial/ Magnetic Sensor Arrays*," University of Bristol University, UK, Technical report, 2010.

[6] R. Mahony, et al., "Nonlinear Complementary Filters on the Special Orthogonal Group," *IEEE Transactions on Automatic Control,* vol. 53, pp. 1203-1218, 2008.

[7] H. M. Saputra, et al., "IMU Application in Measurement of Vehicle Position and Orientetion for Controlling a Pan-Tilt Mechanism," *Mechatronics, Electrical Power, and Vehicular Technology*, vol. 04, pp. 41-50, 2013.

[8] I. S. Sarwar and A. M. Malik, "Stability analysis and simulation of a two DOF robotic system based on linear control system," in *Mechatronics and Machine Vision in Practice, 2008. M2VIP 2008. 15th International Conference on,* 2008, pp. 263-268.

[9] V. Sangveraphunsiri and K. Malithong, "Control of Inertial Stabilization Systems Using Robust Inverse Dynamics Control and Sliding Mode Control," presented at *The 6th International Conference on Automotive Engineering (ICAE-6) BITEC,* Bangkok, Thailand, 2010.

[10] H. M. Saputra, et al., "Analysis of Inverse Angle Method for Controlling Two Degree of Freedom Manipulator," *Mechatronics, Electrical Power, and Vehicular Technology*, vol. 03, pp. 9-16, 2012.