A Novel Attitude and Heading Reference System Algorithm with Momentum Correction Factor for Mobile Robotics

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Abstract— **In this paper, a novel Attitude and Heading Reference System(AHRS) algorithm for real time controlling of various mobile robots is presented. Such a control system is essential for real time mobile robots control applications, such as entertainment, business activities, industrial, domestic assistant and etc. New angles and vectors definition, system specification and Momentum Correction Factor(MCF) are proposed to compensate the motion time delay during an inertial action. A dedicated experimental setup is established to test the algorithm. Experimental results show that a low time dealy motion control can be maintained through the proposed algorithm.**

I. INTRODUCTION

Mobile robots have became more and more used in commercial and industrial environment. Many companies or individuals have been used mobile robots for entertainment, business survices, industrial,domestic assistant purposes and etc. Mobile humanoid robot motion control is important topic of the robotic research.A popular method of motion control for mobile robots is AHRS algorithm.

The AHRS algorithm consists of an accelerometer, a magnetic field meter and a gyroscope. It can provide yaw, roll and pich information for mobile robots. The real reference of AHRS are combined gravitational field and magnetic field of the earth.Its static final accuracy depends on the measurement accurcy of the magnetic field and gravity measurement. It's important to combine these two imformation and fuse them into an optimal solution taking into account the advantages of each information source[1].

Some latest AHRS algorithms in a large amount of literature that fuse gyroscope and accelerometer information[2,3]. However, both Madgwick and Mahony method only estimate the orientation correctly under ideal conditions, i.e. no significant accelerations and no magnetic disturbances [4,5], one of which is called Inertial Measurement Unit (IMU), The theoretical mechanics of the university tell us that a linear motion and a rotational motian can be make up the joint movements of robot arm. The inertial measurement unit measures both types of motion. Accelerometers and gyroscopes are used to measure accelerometers and rotational motion respectively[6].

Typically, the IMU includes three single-axis accelerometers and three single-axis gyroscopes. The accelerometer detects the independent three-axis acceleration signal of the object in the carrier coordinate system, which is equivalent to detecting the three-axis acceleration signal for robot, and the gyroscope detects the angular carrier relative to the speed coordinate signal of the navigation coordinate system. The detection of the speed signal of the robot is to use a gyroscope. In this way, the angular velocity and acceleration of the robot in three-dimensional space are measured and its posture is calculated. It has important application value in navigation. In order to improve reliability, it is also possible to equip each joint of the robot with a sensor. In general, the IMU will be installed at the center of gravity of the object being measured.

In fact, accelerometers and magnetic interference are inevitable in practical applications. There is still no algorithm exist that can compensate the motion time delay during transmission. Some researchers [7,8,9,10,11] have tried compensate the significant accelerations and magnetic disturbances.

This paper is organized as follows: In Section II describes the optimization of AHRS algorithm. The experiments and the rusults are discussed in Section III . Finally, the conclusions are given in Section IV.

II. OPTIMIZATION OF AHRS ALGORITHM

A new AHRS algorithm with momentum correction factor (MCF) to decrease the motion time delay due to the data transmission is proposed in this paper. Fig.1 shows the sensor's location of the motion detector.

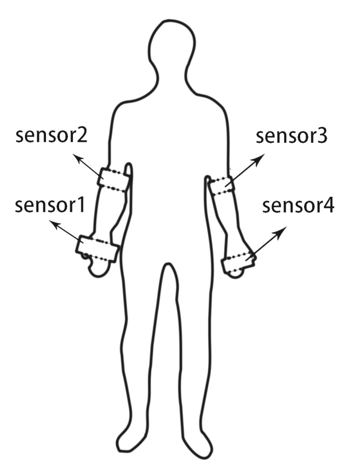

Fig. 1. Location of the motion detecter

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The very small sensor TDK MPU-9150 was used as the fundamental chip for the motion controller during the movement. The MPU-9150 contains 9-axis sensors in a small package: 3-axis gyroscope,3-axis digital compass and 3-axis accelermeter.

In this research, A humanoid robot arm mechanism was designed and the degree of freedom (DOF) defined in Fig.2. The robot arm contains 3 DOFs for shoulder,1 DOF for elbow and 2 DOFs for wrist. For motion detection, two motion detectors with one located in the palm of the controller and the other located in the upper arm of the controller were used for motion detection in the humanoid robot arm.

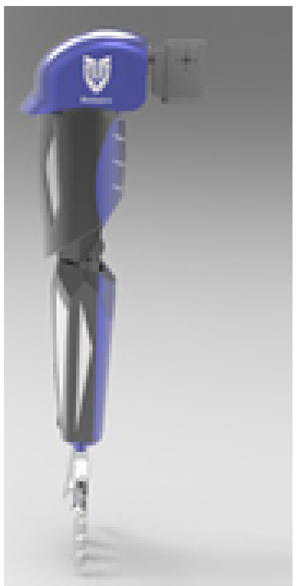


Fig. 2. The mechanism design of the humanoid robot arm

The motion path of this work is planned to move from degree $\sigma = 90^\circ$ to $\sigma = -90^\circ$ in a clockwise direction movement, then $\sigma = -90^\circ$ to $\sigma = 90^\circ$ in a anticlockwise direction movement. While the angle between the upper arm and lower arm is remain constant with $\rho = 180^\circ$. The angular velocity of σ from the controller is kept at $120^\circ/s$. Fig.3 shows the motion path of robot arm.

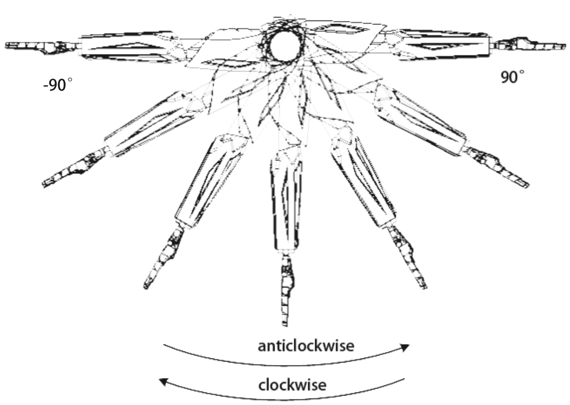


Fig. 3. Motion path of robot arm

A. New AHRS angle definition and system specification

In order to shorten the calculation cycle time, the traditional AHRS angel definition θ , ψ and φ are ignored. The axes are followed by relatively angel form the motion sensor $X-\alpha$, $Y-\beta$, $Z-\varphi$. The angles of Euler can be obtained through q^{nb}. R_x, R_y, R_z are R vector on $X-\alpha$, $Y-\beta$, $Z-\varphi$ respectively.

$$R_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c(\alpha) & -(\alpha) \\ 0 & s(\alpha) & c(\alpha) \end{bmatrix} \tag{1}$$

$$R_y = \begin{bmatrix} c(\beta) & 0 & s(\beta) \\ 0 & 1 & 0 \\ -s(\beta) & 0 & c(\beta) \end{bmatrix} \tag{2}$$

$$R_z = \begin{bmatrix} c(\varphi) & -s(\varphi) & 0 \\ s(\varphi) & c(\varphi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3}$$

Where $s = sin$, and $c = cos$. M is the optimized motion path equation.

$$M = \begin{bmatrix} c\beta c\varphi & -c\beta s\varphi & s\beta \\ s\alpha s\beta c\varphi + c\alpha s\varphi & -s\alpha s\beta c\varphi + c\alpha c\varphi & -s\alpha c\beta \\ -c\alpha s\beta c\varphi + s\alpha s\varphi & c\alpha s\beta s\varphi + s\alpha c\beta & c\alpha c\beta \end{bmatrix} \tag{4}$$

Fig.4 shows the vector and angle definition of new AHRS system.

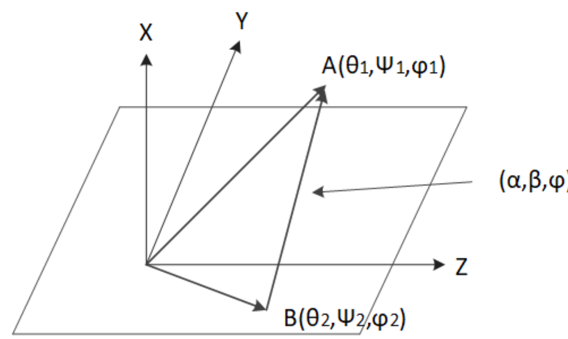


Fig. 4. Vector and angle definition of new AHRS system

Through the vector and angle definition, the state $\hat{X}$can be estimated by the fellowing equation[12].

$$\hat{X} = \begin{bmatrix} q^{nb} & \omega^b & x_g \end{bmatrix} \tag{5}$$

where q^{nb} is an unit quaternion representing the orientation, x_g is the gyro's bias of the device. ω^b is the velocity's bias.

The angular rate y_g of the robot arm can be written as.

$$y_g = \omega^b + x_g + v_g \tag{6}$$

where v_g is the Gaussian noise.

The measurements of the accelerometers of the device can be given by.

$$y_a = a^b - g^b + \omega_a + v_a \tag{7}$$

where g^b is the gravity vector and ω_a is the accelerometer's bias, and v_a is the vector of Gaussian with zero-means.

the magnetic vevtor m^b expressed in the humanoid frame as y_n can be simplified by.

$$y_n = m^b + x_n + v_n \tag{8}$$

where v_n is the noise and Magnetometer bias x_n is the magnetometer bias.

B. Motion phase delay optimization

During normal AHRS transmission, there will be an absolute delay between motion input and motion output. In order to compensate the response time of robotic arm, two correction factors are considered.

The first one is displacement correction factor C which is expressed by the equation, it is proposed to compensate the length different between sensors corresponded to the length of the humanoid robot arm. The displacement of motion detection controllers and the length of robot arm is in one to one scale, therefore the displacement correction factor is not considered.

$$C = \begin{bmatrix} 1 & C_{xy} & C_{xz} \\ C_{xy} & 1 & C_{yz} \\ C_{zx} & C_{zy} & 1 \end{bmatrix} \tag{9}$$

The later one is momentum correction factor S, it is proposed to compensate the robot motion time delay during an inertial action, while S_x, S_y, S_z are the MCFs corresponding to different x, y and z axes. V_x, V_y, V_z are the motion velocity along the inertial motion in x, y and z axes, the function relationships are expressed by the equations.

$$S_x = \frac{\int_o^x V_x^2(B_x d_x)}{V_x^2 B_x d_x} \tag{10}$$

$$S_y = \frac{\int_o^y V_y^2(B_y d_y)}{V_y^2 B_y d_y} \tag{11}$$

$$S_z = \frac{\int_o^z V_z^2(B_z d_z)}{V_z^2 B_z d_z} \tag{12}$$

The optimized motion path result O can be evaluated by the equation.

$$O = \begin{bmatrix} C & S & M \end{bmatrix} \tag{13}$$

III. EXPERIMENT AND RESULTS

To validate and test the algorithm of AHRS, a dedicated experimental platform setup is established in Fig.5.

A humanoid robot, which every arm has 5 DOFs, and also has 5 DOFs in every palm. the parameters of robotic arm are as follows: $2*300kg/cm$ servos for shoulder movement; $2*70kg/cm$ servos for arm movement; $6*20kg/cm$ servos for palm and fingers movement.

The experiment test platform is shown in Fig.6. A comparative data is measured, the proposed algorithm can not output the estimated momentum normal output correction factor AHRS algorithm are compared.

The sensors are mounted on every arm of the humanoid robot , as shown in Fig.7.

Fig. 5. The humanoid robot

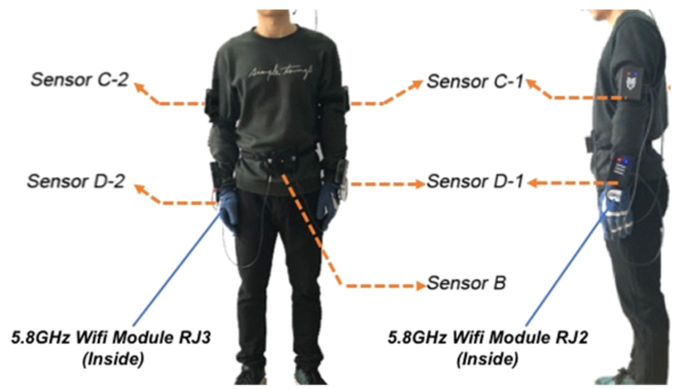
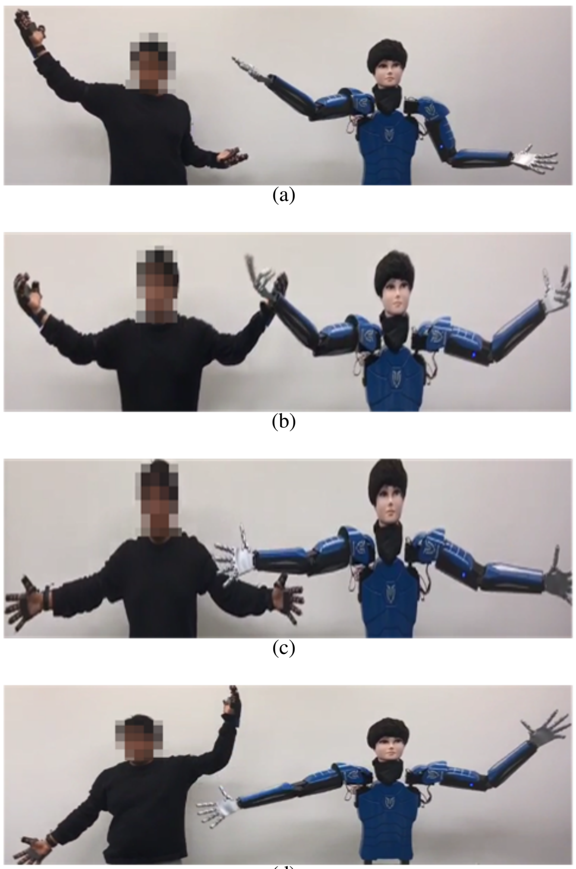


Fig. 6. The system of experiment platform

Fig. 7. The sensors of humanoid robot

For each test, while holding the rotating movement of about 10 meters from the motion detection controller. The original data was obtained through data acquisition card.

Each capture lasts time about 3 minutes. The motion following expeirment as shown in Fig.8.



(a)

(b)

(c)

(d)

Fig. 8. The motion following experiment.(a)Right arm motion following. (b) Motion following with both arms.(c) straight both arms.(d) Left arm motion following.

To validate the time delay reusults, Fig.9 shows the results of the normal AHRS system. The angle indicated in the chart is corresponding to the motion path planned i.e. $\sigma = 90°$ to $\sigma = -90°$ in a clockwise direction movement and $\sigma = -90°$ to $\sigma = 90°$ in an anticlockwise direction movement by the motion detection controller. The first 10 seconds data captured had been shown. There is a consistent motion time delay of 0.16s during the whole experiment.

Fig.10 shows the results of the optimized AHRS system with momentum correction factor(MCF). The angle indicated in the chart is corresponding to the motion path planned i.e $\sigma = 90°$ to $\sigma = -90°$ in a clockwise direction movement and $\sigma = -90°$ to $\sigma = 90°$ in an anticlockwise direction movement by the motion detection controller.

The first 10 seconds data captured hand been shown. For the first cycle movement $t = 0s$ to $t = 0.5s$ the output is exactly the same as the normal AHRS system with a motion time delay of 0.16s. Once the MCF function is activated after $t = 0.5s$, the motion time delay is minimized to 0.04s

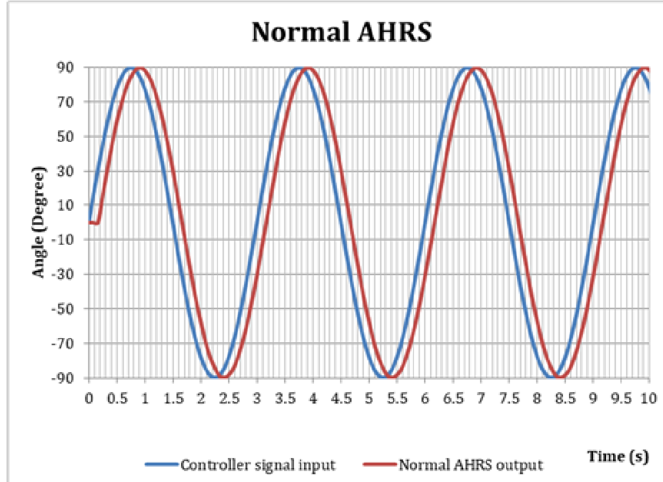


Fig. 9. Comparison between normal AHRS output and controller input

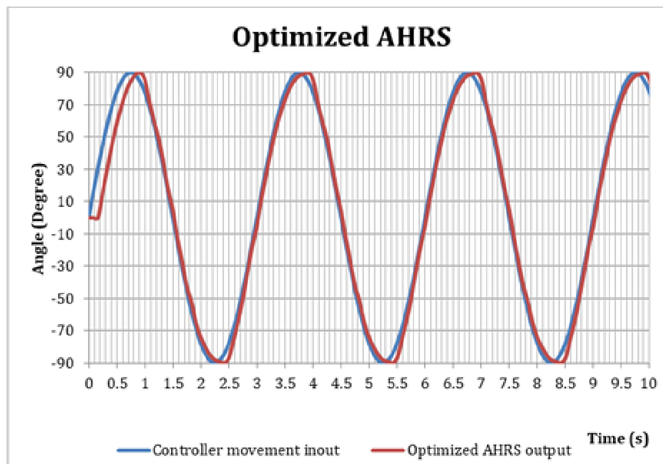


Fig. 10. Comparison between optimized AHRS output and controller input

in the interval from $\sigma = 70°$ to $\sigma = -70°$. In the interval $\sigma = [70, 90, 70]$ degree and $\sigma = [-70, -90, -70]$ degree, the motion delay is varied from 0.04s to 0.16s. While 0.16s delay happens when $\sigma = 90°$ and $\sigma = -90°$.

IV. CONCLUSION

In summary, a novel AHRS algorithm for real time controlling mobile robots is proposed by us. The proposed optimized system is essential for real time mobile robots control appli-cations. New angles and vectors definition, system specifi-cation and momentum correction factor (MCF) are proposed to compensate the motion time delay during an inertial action. Based on the experimental results, the optimized AHRS with MCF can decrease the motion time delay in an inertial motion by 80%.The significant implementation is highly recommended to mobile robots that is sensitive in transmission response time or delay-free motion control desired.

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