

A Turning Model of Agricultural Robot Based on Acceleration Sensor

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Abstract: This paper develops a real-time turning angle acquisition method based on tri-axial acceleration sensor for an agricultural robot. And the radial and the tangent method are proposed to calculate the turning angle, which are different from existing algorithms. And the objective is to fulfil the automatic turning at end of the field or in uncropped land, and reduce the cost of the conventional inertial navigation system of agricultural robot. The moving filter is employed to improve the stability of output data of tri-axial acceleration sensor, the window size of which is set 15 or 27 points to produce good filtering effect. Furthermore, the velocity correction process is proposed to reduce the effect on the turning angle. The first set of data is collected through the simulation designed in this paper and used to obtain the error law of turning angle of the agricultural robot; the second set of data is collected to test the algorithms presented in this paper. Then the radial method and the tangent method are compared analytically. And the experimental results show that the error mean is 0.9517 degree with the standard deviation 2.4779 degree, and the time consumption being about 0.7ms for the tangent method. The error mean is 1.6268 degree with standard deviation 2.1703 degree, and the time consumption being about 0.5ms for the radial method. This research can provide a valuable reference for obtaining the turning angle based on tri-axial acceleration sensor for agricultural robot.

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Keywords: Agricultural robot; Navigation; Acceleration sensor; Turning angle

1. INTRODUCTION

Autonomous navigation is essential for the agricultural robot that can promote the sustainable production of food (Rovira-Más et al., 2015). The inertial navigation is an effective autonomous navigation system by using GPS (Global Positioning System) and DR (Dead-Reckoning) for agricultural robot (Mousazadeh, 2013). The acceleration sensor is one of the most important devices in DR because of its small size, low power and low cost (Diamant et al., 2014; Akula et al., 2011). In fact, these acceleration sensors are used in most robot navigation systems for obtaining robot speed and localization (Nistler et al., 2011). And also it has been widely used in MEMS (Micro-Electro-Mechanical Systems) (Yu et al., 2009; Händel et al., 2010; Zwahlen et al., 2012). For instance, an identification of transportation mode is proposed, in which the double integration of acceleration is used to get the distance and the gyroscope was used to get the patch angle (Feng et al., 2013). The roll and pitch angle detected in using a tri-axial acceleration sensor was used in standalone inertial pocket navigation system (Diaz et al., 2014). A low power MEMS acceleration sensor was used to measure vibration signals resulted from the track-terrain interaction about agricultural robot (Mahadhir et al., 2014). In Ref. (Madgwick et al., 2013), authors presented two schemes to provide the

measurement of translational and angular motion using a array of triple-axial acceleration sensors. Because of lightweight, low power, MEMS inertial sensors can also be in combination with knowledge of joint constraints to give measurements of knee joint flexion/extension angles of people during dynamic activity (walking & running) (Cooper et al., 2009). Bächlin et al. (2009) introduced the concept of a wearable assistant for swimmer, which consists acceleration sensors with micro-controllers and feedback interface modules that swimmer wore while swimming (Bächlin et al., 2009). Takeda et al. (2009) proposed a method for gait analysis using an acceleration sensor and a gyro, which could obtain the three-dimensional positions of joint centers of the hip, knee, and ankle during movement to provide important quantitative information for gait diagnosis. In Ref. (Rosli et al., 2013), GPS, the heart rate monitor and the tri-axial acceleration sensor were combined to assess physical activity of people. Kawahara et al. (2007) designed a recognizing user context using mobile handsets with acceleration sensors. And it can identify three walking patterns: horizontal walking, up and down staircase walking. Cooper et al. (2010) developed a travel mode of mapping the walk to school using acceleration sensor combined with a GPS, where the acceleration sensor provides physical activity of children walking to school and the location is determined with a GPS receiver. Most of these studies obtain the pitch

and roll angle of a moving object by using three-axial acceleration sensor, in which some algorithms also use expensive gyroscope to obtain the yaw angle of moving object. On the other hand, many existing agricultural robots use computer vision and other sensors to supplement GPS data when navigating (Hiremath et al., 2014; Jiang et al., 2013; Pérez-Ruiz et al., 2012), and some are also presented by using laser range finder for autonomous navigation of agricultural robot (Hiremath et al., 2014; Choi et al., 2014). This paper presents two algorithms to obtain the yaw angle as the turning angle of navigation system of agricultural robot by using only one tri-axial acceleration sensor instead of expensive gyroscope. And the radial acceleration along x-axis and the tangent acceleration along y-axis could be utilized to compute the yaw angle according to the principle of kinematics of circular motion. This is our main contribution.

The next sections of this paper are organized as follows. In Section 2, the turning model of agricultural robots based on acceleration sensor is designed. And two algorithms are proposed to obtain the yaw angle by processing the radial and tangent acceleration data. Section 3.1 is acquisition of experimental data; Section 3.2 is data procession and analysis, where the size of moving filter is analyzed to remove the noise. Section 4 is the conclusions.

2. TURNING MODEL OF AGRICULTURAL ROBOTS BASED ON ACCELERATION SENSOR

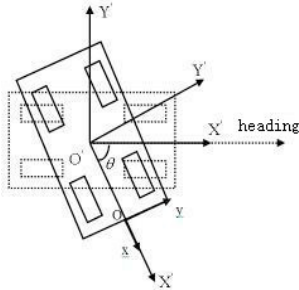


Fig. 1. Turning angle model of agricultural robot.

Generally, four-wheel steering robot can be used in field operations such as automatically spraying water, or fertilization etc. in field (Jeon et al., 2009; Jensen et al., 2012; Dutta et al., 2014), which only can turn at end of field or in uncropped land, in order to avoid crushing crops. This requires that the agricultural robot can rotate around its centre to achieve turning ability to reduce turning space. Fig.1 shows the turning model of an agricultural robot. We assume the robot turns in two-dimensional horizontal plane about X' and Y' , and the axis of Z' is perpendicular to the ground. The agricultural robot travels along the direction of X' . O' is its instantaneous rotating center. (Both the center and the radius are both unchanged in the time interval Δt). O is the center of the mounted device with tri-axial acceleration sensor in this robot model. x and y in Fig.1 denote the sensing axes. Undoubtedly, the velocity of the agricultural robot starting from zero, gradually increases, and then reduces to zero in the whole turning process according to the literatures (Maalouf et al., 2006; Yin et al., 2013; Lin et al., 2013). Therefore,

the turning angle can be expressed according to the model of agricultural robot, shown as

$$\theta = L/R, \quad (1)$$

Where, R is turning radius of the model, which is determined by the length of the robot model. L is the turning arc length of the model. Obviously, the turning process is a circular motion. Therefore, there are two methods for the turning angle acquisition based on the model of agricultural robot.

1) Acquisition of turning angle through tangent acceleration along axis y (called tangent method)

As Fig.1 shown, the model of agricultural robot moves in a circle in an interval Δt . When Δt is small, the arc L can approximately be substituted by a straight line segment, shown as

$$L_i = v_i \Delta t + 0.5 a_{yi} \Delta t^2, \quad (2)$$

Where, L_i is the i th ($i=0,1,2,\dots$) arc, v_i and a_{yi} are the i th tangent velocity and tangent acceleration, respectively. And the whole arc L is:

$$L = \sum_{i=0}^{n-1} L_i. \quad (3)$$

In the experiment, the arc L and the velocity v_i can also be expressed as formula (4) respectively, which is obtained by

$$\begin{cases} L = \Delta t^2 \sum_{j=0}^{n-1} (\sum_{j=0}^i a_j - 0.5 a_j) \\ v_i = v_{i-1} + a_{i-1} \Delta t, \end{cases} \quad (4)$$

using the formula (2) and (3), where, a_i denotes the i th acceleration; a_j denotes the j th acceleration ($0 \leq j \leq i$). Obviously, the arc L is related to the interval Δt , the sampling times n and the tangent acceleration a_i (or a_j). Besides, the larger the sampling times n is, the more the L is approaching the actual trajectory.

2) Acquisition of turning angle through radial acceleration along the axis x (called radial method)

When the Δt is small, we assume that the velocity is uniform changing (in the applications, the velocity can be controlled). Therefore, in the interval Δt , the velocity can be expressed, shown as

$$v_i = \sqrt{a_{xi}} R, \quad (5)$$

Where v_i denotes the linear velocity, a_{xi} is the radius acceleration, R is the turning radius. In the interval Δt , the arc

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