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The Data Acquisition and Processing Based on MEMS Accelerometer

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ABSTRACT:A data acquisition module is designed based on the ADXL345 of MEMS accelerometer.The Cortex-M3 communicates with the ADXL345 via the internal IIC bus to acquire the output data of accelerometer. Have a curve fitting because of the output signal of MEMS accelerometer with a large noise. ADXL345, as an input component, takes advantage of analyzing the relationship between the attitude of input component and gravitational acceleration to eliminate the influence of gravity on the trajectory. As a result, acceleration of the movement of the input component is collected,and displacement is got through the secondary integral of the acceleration,so the trajectory can be simulated by MATLAB. Calculating the deflection angle of the input component in the space,and data processing in the MATLAB.

Keywords-*MEMS,Data Processing,IIC,Simulate,Curve fitting*

I. INTRODUCTION

For a long time, using the body's movements to interact with a computer has been one of the targets the human-computer interaction technology in pursuit of perfection. At the present ,There are two main kinds of human-computer interaction technologies: action recognition technology in the video and action recognition technology of inertial devices[1] .

With the development of Micro-Electro-Mechanical Systems(MEMS) and the development of micro processing technology, MEMS acceleration,MEMS gyroscope, magnetometer sensor, micro sensor input control unit, can meet the higher requirements of the input terminal. Using MEMS acceleration sensor to measure speed and get the displacement can be applied to hard disk pedometer, fall protection, rotation angle measurement, rotation detection, shaking detection, and click, double-click detection as well as other intelligent detection function and the control component of the game[2-4].

The ADXL345 is a small, thin, ultra-low power, 3-axis accelerometer with high resolution (13-bit) measurement at up to ±16 g. Digital output data is formatted as 16-bit twos complement and is accessible through either a SPI (3- or 4-wire) or I2C digital interface. The ADXL345 is well suited for mobile device applications. It can measures the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion or shock. Its high resolution (3.9 mg/LSB) enables the measurement of inclination changes less than 1.0° .[4]

This article designs the ADXL345 of MEMS accelerometer as an input control component, and discusses the data acquisition, data processing and simulation, and puts forward the prospect of the application of ADXL345.Data processing and simulation is the most important part of this article which mainly includes:curving fitting of the output signal, analyzing the relationship between the attitude of input component and gravitational acceleration to eliminate the influence of gravity on the trajectory, acquiring the acceleration of the output of X axis and Y axis, simulating the trajectory through the secondary integral of the acceleration in the MATLAB environment. Analyzing the acceleration of X axis, Y axis and Z axis and calculating the deflection angle of the input component in the space.

II. THE DESIGN OF THE DATA ACQUISITION SYSTEM

2.1 Hardware Design

The data acquisition unit of the hardware circuit is composed of a microprocessor module and an acceleration sensor module. The STM32F103ZE chip which is based on Cortex-M3 kernel is used as the microprocessor. Acceleration measurement module applies ADXL345 of MEMS accelerometer. The ADXL345 chip has an IIC interface, communicates with the IIC serial bus of microprocessor. The sensor data can be acquired through the IIC serial bus interface [5-6].

The hardware circuit is shown in Figure-1; STM32F103ZE chip is used as the data-processing systems and ADXL345 is used as input component. The SDA and SCL interface link STM32F103ZE with ADXL345 through the IIC serial bus.

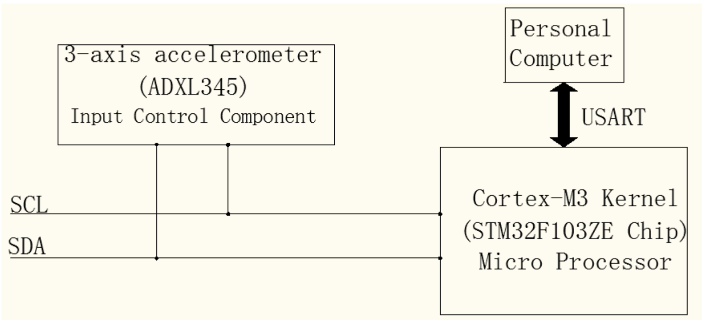

Figure-1:Schematic Diagram of Hardware Circuit

STM32F103ZE microprocessor communicates with personal computer through serial port USART. STM32F103ZE read the data of ADXL345 registers DATAX, DATAY, DATAZ (register address:0X32 - 0X37) and communicate with the personal computer through USART to save the X-axis, Y-axis, Z-axis acceleration data.

2.2 Software Design

The whole development system can be programmed in two software tool; The programming software of STM32F103ZE chip is MDK Keil4 and the data receiving software is Serial Debugging Assistant. Programming in the MDK environment and generated .HEX file. Downloading the .HEX file to the STM32F103ZE chip through J-Link. When receiving the acceleration ,the environment could be set as 38400 baud rate, serial number COM, 8 data bits,no parity, and 1 stop bit. After the Assistant print out the DATAX, DATAY, DATAZ register data of ADXL345,serial communication succeeds. As shown in the Figure-2, the software realization process.

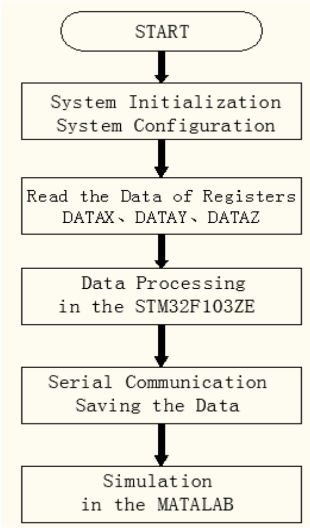

Figure-2:The Software Realization Process

In the initialization process of ADXL345:

Reading the ADXL345 device address, setting the ID 0xE5 because the DEVID register holds a fixed device ID code of 0xE5 (345 octal), Not self-check, low level output terminal, 13 for full resolution to range 16g. The data output rate of 100Hz and link enable, measurement mode interrupt enable. X, Y axis offset calibration is 0x00. The Z axis offset calibration is 0xF9 according to the measured data.

The DATA_FORMAT register (Address 0x31) controls the format of the data. It is recommended that a multiple-byte read of all registers be performed to prevent a change in data between reads of sequential registers. Reconstruct the data after acquiring the acceleration it from the data register. DATAX0 is the low byte register of the X-axis acceleration and DATAX1 is the high byte register. DATAY0 is the low byte register of the Y-axis acceleration, high byte register is DATAY1. DATAZ0 is the low byte register of the Z-axis acceleration, high byte register is DATAZ1. ADXL345 uses binary data format and under the 13 bit mode, 1LSB is on behalf of 3.9mg. So the X-axis acceleration can be calculated as:

$$a_x = XTemp = DATAX \times 3.9\text{mg}\,; \qquad (1)$$

In the formula, a_x is the measurement acceleration;The calculation of a_y, a_z are similar to the process of calculating the a_x.

III. THE DATA PROCESSING

The input component slowly rotated around the X axis a circle and then rotated around the Y axis in three-dimensional space. The data output shows as Figure-3;

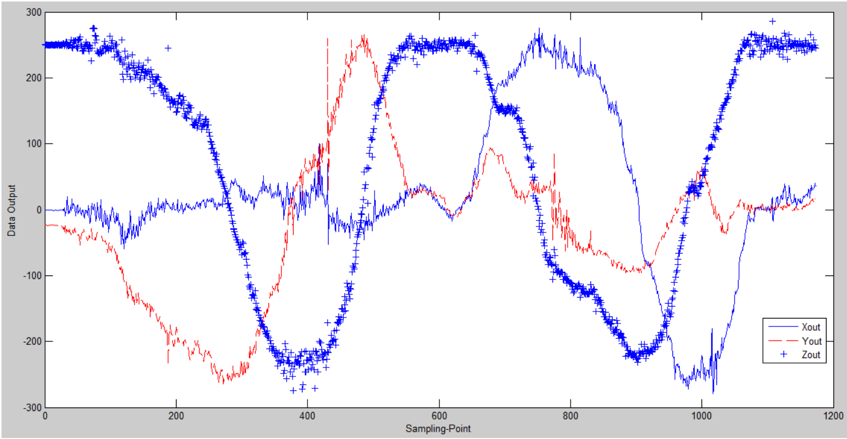

Figure-3:The Acquiring Original Data

3.1 Curve Fitting

The basic idea of curve fitting constructs the polynomial function and approaching the measurement data(x_i , y_i)(i=1,2,3……).[7]Constructing a polynomial function:

$$f(x) = a_1 x^n + a_2 x^{n-1} + \ldots\ldots + a_n x + a_{n+1} \tag{2}$$

For measuring a set of metrical data y, obtain an expression $f(x)$ which reflects the relationship with the measurement value y, then reach the minimum value E.

$$E = \min \sum_{i=1}^{n} | y_i - f(x_i) |^2 = \sum_{i=0}^{n} (y_i - a_i x^{n-i})^2 \tag{3}$$

E equals to the smallest valve of the square of the measurement value minus the polynomial function of curve fitting .

The above function fitting problem can be regarded as the extreme valve problem of multivariate function, therefore, solves the Equation:

$$\frac{dE}{da_n} = 0; (N = 0, 1, 2\ldots\ldots) \tag{4}$$

It could get n+1 linear equations consisted of equation.

$$\sum_{i=0}^{n} a_i \sum_{j=0}^{m} x^{j} = \sum_{i=0}^{n} y_i x_i^{n} \tag{5}$$

It is Known that acquiring the output data of X-acceleration, Y-acceleration, Z-acceleration is discrete points. Obtaining an analytic function y=f (x) according to the collected data. $f(x)$ can keep the $X_{out}, Y_{out}, Z_{out}$ get close to the curve fitting of Fx, Fy, Fz as far as possible. Least square method is the most commonly used method of Curve fitting and the fitting results can make mini the square deviation. It is to find the optimum Fx:

$$\min \sum_{i=1}^{n} | Fx - Xout |^{2} \qquad (6)$$

Similarly, Fy, Fz abide by the same principle. Obtain the Curve fitting of X-axis, Y-axis, Z-axis output from the above principle solution.Get each of them is shown in Table 1.

Table 1.The Polynomial of n Degree of F_x, F_y, F_z

	Polynomial of n Degree (the valve of n)
F_x	55
F_y	55
F_z	71

According to this method, getting the optimal curve fitting and simulating in the MATLAB. The curve fitting is Shown as Figure-5.

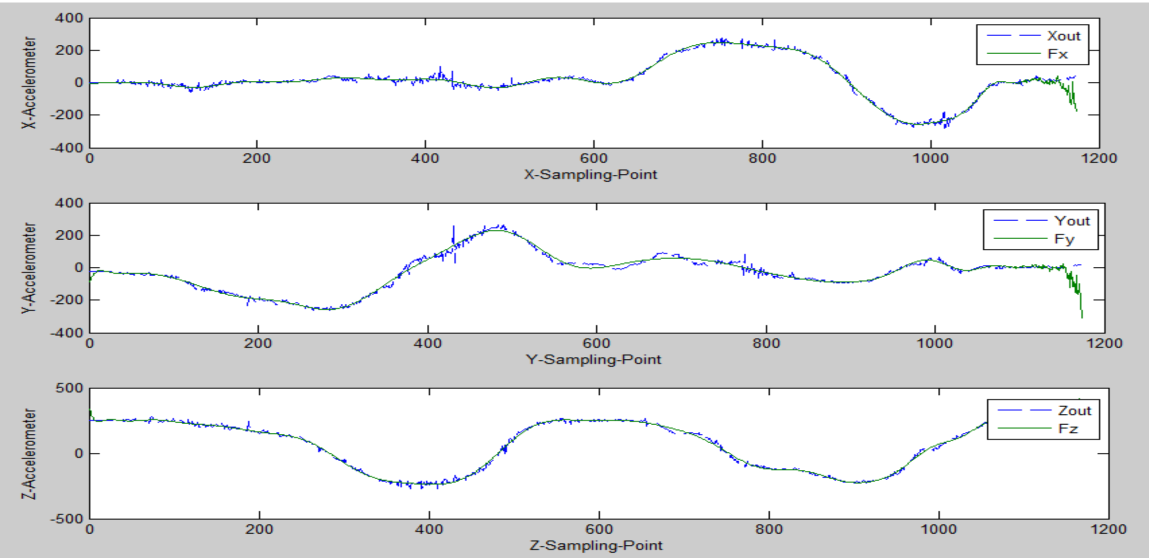

Figure-4:The Simulation of the Curve Fitting

3.2 Space Angle Conversion

In the three-dimensional space,measuring the acceleration of each axis which contains acceleration of component gravity and motion acceleration, therefore, it cannot be directly calculated the displacement by the measured acceleration valve. The MEMS accelerometer measurement value is relative to the carrier coordinates, when the input component is not in the horizontal coordinates, it creates a acceleration of component gravity in the X-axis, Y-axis, Z-axis. Three axis in the space coordinates system project on the horizontal plane and get the horizontal value of acceleration. In horizontal plane, remove the gravitational acceleration (Z axis) to get the horizontal acceleration of motion for calculating displacement.The relationship between horizontal coordinate system and space is showed as Figure-5.

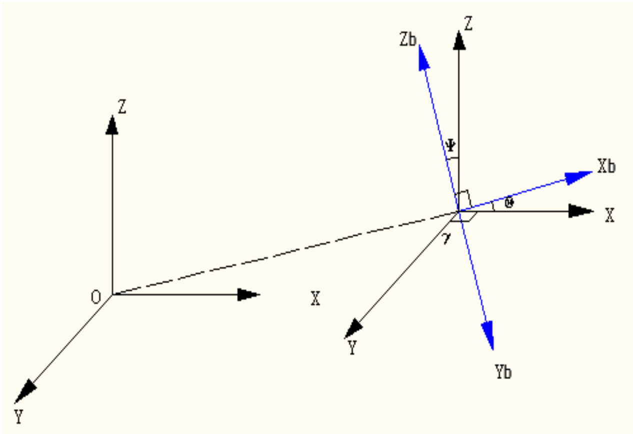

Figure-5:The Relationship Between Horizontal Coordinate System and Space

According to the measured MEMS values of accelerometers, calculate the attitude of input control terminal. The calculated angle θ、γ、ψ (Ignoring the effect of acceleration):(The angel θ、γ、ψ show in Figure-5)

$$\theta=\frac{XTemp}{\sqrt{YTemp^2+ZTemp^2}} \quad (7)$$

$$\gamma=\frac{YTemp}{\sqrt{XTemp^2+ZTemp^2}} \quad (8)$$

$$\psi=\frac{ZTemp}{\sqrt{XTemp^2+YTemp^2}} \quad (9)$$

MEMS accelerometer coordinate transform between vector coordinates and horizontal coordinates:

$$C_b^n=\begin{pmatrix} \cos\gamma & \sin\gamma\bullet\sin\theta & -\cos\theta\bullet\sin\gamma \\ 0 & \cos\theta & \sin\theta \\ \sin\gamma & -\cos\gamma\bullet\sin\theta & \cos\theta\bullet\cos\gamma \end{pmatrix} \quad (10)$$

It can calculate the acceleration according to the projection transformation matrix in the horizontal coordinate system.so as to eliminate the influence of acceleration of gravity acceleration in horizontal coordinate, the calculation formula is as follows:

$$a_{nx}=a_x\bullet\cos\gamma+a_y\bullet\sin\gamma\bullet\sin\theta-a_z\bullet\sin\gamma\bullet\cos\theta \quad (11)$$

$$a_{ny}=a_y\bullet\cos\theta+a_z\bullet\sin\theta \quad (12)$$

$$a_{nz}=a_x\bullet\sin\gamma-a_y\bullet\sin\theta\bullet\cos\gamma+a_z\bullet\cos\theta\bullet\cos\gamma \quad (13)$$

In the formula: a_{nx}, a_{ny}, a_{nz} is the accelerated speed of X-axis,Y-axis,Z-axis.

3.3 Motion Trajectory

Based on the principle of mathematical physics, motion displacement can be calculated by the double integral of accelerated speed. Regarding an output component as gravity acceleration, have the accelerated speed double integral to track and accumulate space trajectory.Calculate the displacement by double integrating the processing data of acceleration.

Firstly,integrating the valve could get the move speed,the formula is:

$$V_m(t) = \int a_m(t)dt = \sum_{i=1}^{N} a_{mi}(t) \bullet \Delta t \qquad (14)$$

Secondly,double integrating the valve could get the trajectory,the formula is:

$$S_m(t) = \int V_m(t)dt = \sum_{i=1}^{N} V_{mi}(t) \bullet \Delta t \qquad (15)$$

In the formula, $V_m(t)$ is the move speed. $a_m(t)$, $a_{mi}(t)$ is the acquisition of the processed data. $S_m(t)$ is the distance of the input component moved.

Using the X-acceleration valve and Y-acceleration valve, double integrating ,then simulate the trajectory in MATLAB. It gives us the Figure-6.The trajectory in the picture is similar with the path of input component.

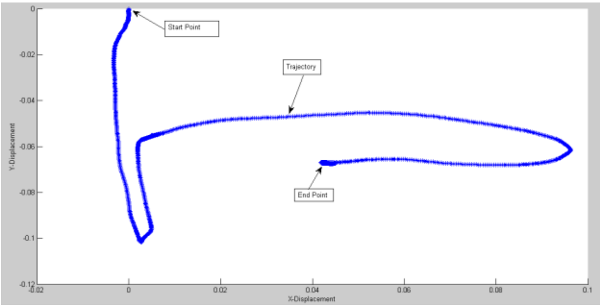

Figure-6:The Motion Trajectory of the Input Component

IV. CONCLUSION

The STM32F103ZE chip which is based on Cortex-M3 core can acquire the ADXL345 data of MEMS accelerometer . This article simulate the output data of ADXL345 to get the trajectory of the input component in MATLAB. It also analyzes the relationship between the output data and the acceleration of gravity,which can get control devices attitude.The input control terminal can be used to optimize the current input control technology in 3-D game; It can be used in anti-human fall detection device, can obtain the real-time attitude of people.

V. Acknowledgements

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