Journal of Theoretical and Applied Information Technology
20th January 2013. Vol. 47 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

DATA ACQUISITION SYSTEM OF A SELF-BALANCING ROBOT BASED ON FPGA

[1]DAODE ZHANG, [2]QIANG WANG, [1]CHENG XU
[1]School of Mechanical Engineering, Hubei University of Technology Wuhan, China
[2]Nanjing Research Institute of simulation technology Nanjing, China
hgzdd@126.com

ABSTRACT

For inverted pendulum principle of two-wheeled self-balancing robot, this paper describes the use of FPGA controller for attitude sensor data acquisition system design. Using Verilog HDL hardware description language data acquisition module and A / D converter module, it can have the attitude sensor data of the FPGA control system collected early and accurately , and the way is given to solve the multi-sensor data collection, using the area reuse and reconfiguring idea of FPGA .The results show that the system is stable, reliable, accurate data collection.
Keywords: *Self-Balance Robot ; FPGA ; Data Acquisition ; Verilog HDL*

1. INTRODUCTION

To be accompanied by continuous and rapid development of science and technology, FPGA embedded systems with function of two-wheeled self-balancing robot have got wide application. While the wheeled mobile robots in all walks of life have broad application prospects for development, it has become an important branch in the robot research field. At present, under the background of the embedded technology, image processing and recognition algorithm and robot technology rapid development, the precise machine vision automatic tracing function has a strong application, in transport, emergency services and space exploration, battlefield, dangerous goods transport, fire fighting, intelligent robot cooperation, wheelchair, control theory test and teaching platform. It has better economic benefits and value. FPGA have powerful parallelism and the reconstruction，other chip can't be compared with it. So in this paper, FPGA embedded hardware platform instead of traditional single-chip, ARM, DSP and other hardware platform as a controller.

2. ATTITUDE SENSORS SELECTION

The two-wheeled self-balance robot using stair inverted pendulum principle can be self-balancing and stable stand. It belongs to a kind of intrinsic unstable wheeled mobile robots, with many variables, nonlinear, owe drive, and strong coupling and incomplete constraint system characteristics[1]. This system is a part of attitude sensor data acquisition system in two-wheeled self-balancing robot, and the system can provided the follow-up data source for it.

The self-balancing robot system using attitude sensors as proper perception component has an important effect. when the attitude sensors in two-wheeled self-balance robot detects body posture to produce angle of inclination, FPGA controller take reference to measured angle of inclination data to create a corresponding PWM signal, by controlling the DC motor to drive two wheels toward the body movement in the direction of the fallen, to keep the dynamic balance of the robot itself. The self-balance robot essence is that the attitude sensors collects itself the dip angle data in real-time and accurate PID control. Figure 1 has given mechanical structure of the two-wheel self-balance robot, attitude sensors require Angle data collected as shown in figure 1.

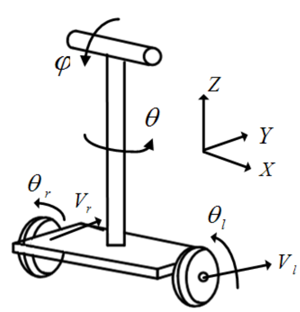

Figure 1. Structure Diagram

As mechanical structure diagram shown, the physical parameters of the self-balancing robot

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

system during run is illustrate well. Parameter description: The X axis represents the direction of robot wheel axle. The Y axis represents the robot moving direction. The Z axis represents axial direction of robot body. Vl and Vr represent the straight-line speed of left wheel and right wheel respectively. θl and θr represent the angular velocity of wheels. θ represents of the angle between the robot and the reference surface of Z axis .Different mechanical structure of self-balancing robots have different kinematic and dynamic mathematical model. But the same substance is PID feedback control on the dip angle data from gesture sensor. When robot is moving, robot body will has a certain dip angle. And the gesture sensor will get the dip angel in time , as shown in figure 2.

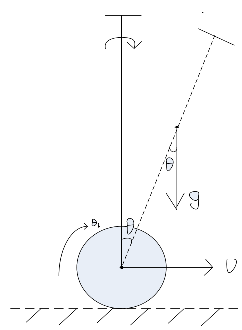

Figure 2. Two-wheeled Self-balancing Robot Motion Model

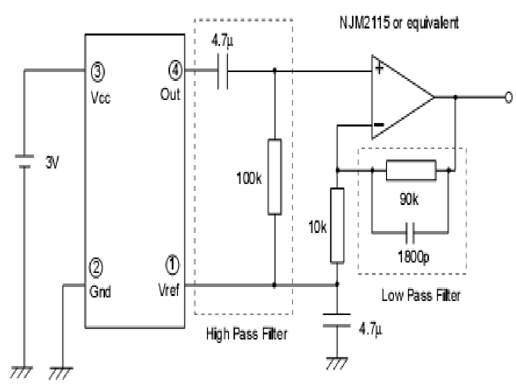

Figure 3.Typical Hardware Filter Circuit

The sensors use by two-wheeled self-balancing robot system is gyroscope ENC-03MA and accelerometer MMA7260Q[2][3] .

(1) Gyroscope sensor ENC-03MA which use to measure angular velocity can output varying voltage corresponding to angular velocity. And the faster it rotates，the greater voltage it outputs. Conversely, the smaller voltage it outputs. It can get angle value by integral operation in the processor. But, the integral operation has serious accumulative errors, and this can contribute to a increasing accumulation error after a long run until the system can not work property. So, the processor need to correct data drift regularly. Therefore, it can simply summarized as: the gyroscope is accurate at short time and is not accurate at long time. In addition, it has wally dynamic performance. Hardware Filter Circuit Shown in Figure 3

(2) Accelerometer Sensor MMA7260 which is used to measure linear motion can output speed variation. The faster the greater voltage it output and the smaller voltage it output inversely. However all the objects on earth are restricted by gravitation, similarly, the self-balancing robot has a vertical downward acceleration and which size is g. Therefore, the angle between the accelerometer and the direction of gravity can be computer by arc sine in the FPGA processor. But accelerometer is a liner motion sensor and this makes it very sensitive to quake. However the quake from running motor can not be ignore， and the outputs while the accelerometer is running is mixed data of kinetic acceleration and gravitational acceleration. This can badly effects accuracy of angle calculation without doubt. Therefore，it can be summarized as that the accelerometer has a fine static property，and shows a good long-term precision but a poor short-term precision.

The performance contrast of three kinds of commonly inertial sensors shown in table 1[4] which including inertial sensors’ property， advantages and disadvantages，etc. Our system adopts the gyroscope ENC-03MA and accelerometer MMA7260 as inertial sensor，and the most reason that we choose this adoption is according to the cost. If not for this reason, the better inertial sensor can be chosen and this will greatly improve the stability and reliability of system.

3. MUTUAL COMPENSATION OF THE DATA FROM GYROSCOPE AND ACCELEROMETER

Now, we give recertification to these two sensors. The gyroscope , with a fine dynamic property， shows a good short-term precision but a poor long-term precision. However, the accelerometer, with a fine static property， shows a good long-term precision but a poor short-term precision. So these two sensors enable mutual compensation[5]. Analysis the gesture sensor, using any single inertial sensor to collect the gesture angle data of self-

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

balancing system can not reach a desirable outcome. For this reason, the system use two or more gesture sensor to mutual compensate and correct the disadvantage of single sensor. And this can improve the accuracy of data, make the system more accurate, prepare for data fusion and filtration. To acquire more accurate and long-term stable angle data, the two sensors are both necessary. This is the basic idea of the whole data acquisition process-mutual compensation[6].

4. THE REALIZATION OF DATA ACQUISITION SYSTEM OF GESTURE SENSOR

Because the two-wheel self-balancing robot belongs to Unstable body to itself, the robot can't stand without gesture sensor, which can collect real-time, accurate data and post them to FPGA controller for feedback control. Therefore, in order to achieve standing stably and reliably of the two-wheel self-balancing robot, we must collect real-time, accurate data through gesture sensor, which not only provides accurate status information for data fusion, but also provides FPGA controller with real-time, accurate feedback gesture data.

Table1. Contrastive Performance

Inertial sensors	Inclinometer	Accelerometer	Gyroscope
Measuring physical quantities	angle	acceleration	angular velocity
Advantage	good static performance	good static performance	good dynamic performance
Disadvantage	dynamic response slowly, unsuitable for tracking dynamic angle motion	dynamic response slowly , unsuitable for tracking dynamic angle motion	exist in cumulate drift error, work alone is not suitable for long

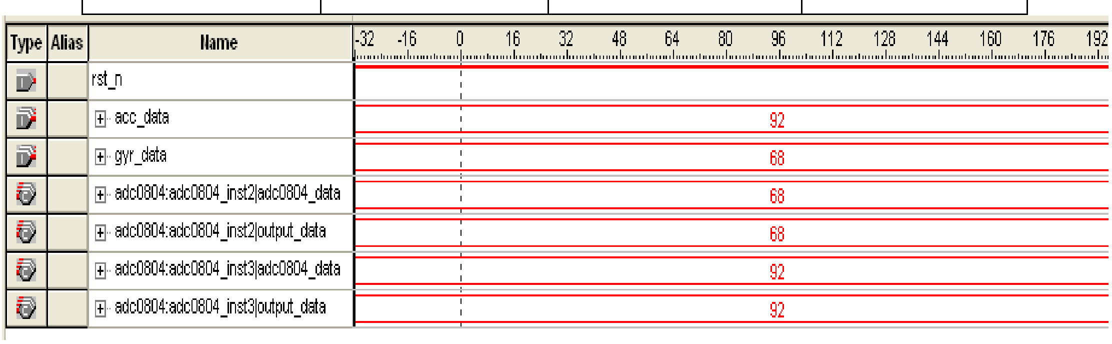

Figure 5.Data Signal was Collect by SingalTap Ⅱ inside FPGA

The collection of gesture data through inertial sensor of self-balancing robot system is drawn as a flowchart and shown in Figure 4. The output of inertial sensor both gyroscope and accelerometer is analog voltage, but the FPGA controller only can receive digital value. Therefore, we add a analog to digital converter ADC0804 in this data acquisition system of gesture sensor. The ADC0804 converts the analog voltage output by the gesture sensor to digital value, and transfers it to the data I/O of FPGA, waiting for the control signal of sensor data acquisition module inside FPGA becoming effective, then, that it collects real-time and accurate data. Analog to digital converter ADC0804 can connect with the data I/O of FPGA controller directly, as to the chip pin diagram and read-write timing diagram, please refer to the datasheet of ADC0804.

Data acquisition module is corresponding to inertial sensor. This acquisition is described by hardware description language——verilog HDL inside FPGA controller. The system uses two

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

channels inertial sensor to collect gesture data, so the FPGA use an idea that use the same inertial sensor acquisition module to realize the function of two-way sensor data acquisition, which we call it Area Reuse.

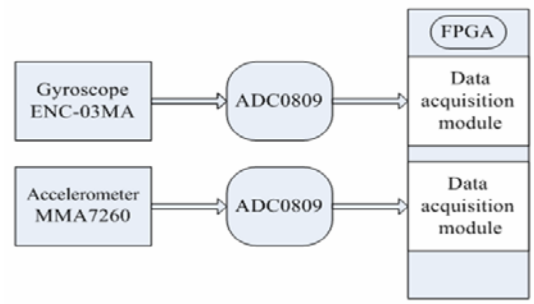

Figure 4.Flow Chart of Data Acquisition Through Inertial Sensor

The software builds environment and debugging tool used in our system is Quartus II 9.0, ModelSim II 9.0, VC++6.0 and SingalTap II 9.0. Software use Verilog HDL to achieve the module of gesture data acquisition, and data test interface of robot is adopt C++ to compile. The gesture data acquisition module of inertial sensor uses Verilog HDL to write.

5. EXPERIMENT OF SIMULATION AND SHOW OF DEBUGGING CONSEQUENCE

In order to verify the correctness of programmi and the accuracy of the data acquisition module,we use soft oscilloscope of SingalTap Ⅱinstead of hard oscilloscope to collect data signal inside FPGA controller, acc_data single is the digital acc_data single is the digital voltage that is collected by the accelerometer sensor and convertted by ADC0804. The measured value 92 is the digital voltage when the two-wheel self-balancing robot keeps in its equilibrium position. Similarly, the gyr_data is the digital voltage which is collected by gyroscope sensor and converted by ADC0804, this measured value 68 is the digital voltage when the two-wheel self-balancing robot keeps in its equilibrium position

The remaining few signals is output by the data acquisition module of sensor which connects with the inport of next data process module in FPGA. But in this system the rest signals are sent to the databus of NIOS and waiting for processing.

6. CONCLUSIONS

It has powerful advantage of reconfigurable hardware that we select FPGA controller to substitute MCU, ARM and DSP controller, etc of two-wheel self-balancing robot in the application environment. We can build a SOPC system to make use of soft processors of NIOS II for real-time control with C Language, in addition, it combine Verilog HDL with SOPC to complete the development of self-balancing robot system, and shorten the Development cycle. The idea which used in the system is that two kinds of data of sensor are complemented, and the paper introduces the characteristic and usage of two kinds of inertial sensor which are gyroscope ENC-03MA and accelerometer MMA7260. These two kinds of inertial sensors are good choices in low cost and low accuracy self-balancing system of motion control. The design realizes data acquisition with inertial sensor in self-balancing robot system which is based on FPGA controller. The system uses the idea of reuse area to solve the problem that several sensors collect data simultaneously and output Parallelly, it achieves early data acquisition with inertial sensors in FPGA controlling system. At last, Correctness and dependability of Data acquisition module are verified through the experiments and simulation, and we achieve the design of self-balancing robot with FGPA controller.

REFERENCES:

[1] Wang Xiaoyu. Research on Two-wheeled Self-balanced Robot. *Dissertation for the Doctoral Degree in Engineering*. Harbin Institute of Technology.2007.12, pp.1~2.

[2] *ENC-03MA Data Shee*t. Analog Device Inc.2006.6.pp.1

[3] *MMA7260QT Data Sheet*. Analog Device Inc.2008.3.pp.2

[4] Wu Jihua, Wang Cheng. Alter FPGA/CPLD Design（Advanced articles）.Posts & Telecom Press. 2005.7,pp.42

[5] WEI Yanhui, LIU Sheng, GAO Yanbin, ZHANG Hanzhi. Research on Integrated Posit ioning Method of T wo-wheeled Self-balancing Mobile Robot. *Machinery & Electronics* .2010.10,pp58~63

[6] Matsumo to O, Kajita S, Komoriya K. Flexible locomotion control of a self - contained biped leg- wheeled system. *Proceedings of the 2002 IEEE/ RSJ International Conference on Intelligent Robots and Systems*. 2002,pp.2599~26