AC 2011-440: REFERENCE DESIGNS FOR SENSORS USED IN MICROCONTROI BASED DESIGN PROJECTS

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Dr. Choi has genuine dedication in teaching and has earned a sustained record of excellence in it. His student evaluations have been among the best in his department and his college consistently. He has taught a wide spectrum of courses. His favorite ones include microprocessor applications, linear control systems, electromagnetic field applications, and capstone design projects. He has published his work in engineering education conferences regularly. He has received several teaching awards and was listed in the 2003-2004 Who's Who Among American Teachers. Dr. Choi's research interests include embedded control systems and computational algorithms. He has published over thirty papers in those areas. He is either the sole author or the first author in almost all of his publications. He prefers to do his own original work and to write the manuscripts by himself. Dr. Choi has completed a number of funded research projects and received significant amount of equipment and software grants before. Some of his funded research projects recently include interfacing of chemical and gas sensors to microprocessors and the subsequent control and signal processing. The project is a part of a grant funded by the U.S. Army. Dr. Choi could be reached at cchoi@unf.edu.

REFERENCE DESIGNS FOR SENSORS USED IN MICROCONTROLLER-BASED DESIGN PROJECTS

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Abstract

This paper describes a collection of tested reference designs that students can leverage into their microcontroller-based design projects with confidence. The collection is confined to common sensors such as accelerometers, digital compasses, infrared distance sensors, ultrasonic distance sensors, temperature sensors, pressure sensors, and Hall Effect sensors. These reference designs are useful for microcontroller applications and capstone design courses in our curriculum. The benefit of using these reference designs is the reduction of the time that students would have spent on re-inventing them by themselves. A website was developed for hosting these reference designs for students to download. The information for the reference designs in the website is presented in a manner that the students must do a little extra work in order to use them in their projects. Further, the code snippets provided in the website is intentionally condensed so that the students need to write extra codes for their applications. Some of the reference designs were part of our students' microcontroller-based projects. Some of these projects are briefly described in this paper. Also described are the merits and impact of these reference designs to our students in their engineering education. These reference designs promote hands-on experience. They can be easily adopted into laboratory and experimental courses. They are suitable for engineering curricula that emphasize on hands-on experience.

I. Introduction

This paper describes a collection of practical reference designs for adoption into microcontroller-based class projects. These reference designs are applicable to our microcontroller applications and capstone design courses. All these courses are at the senior level. The microcontroller unit

(MCU) in these reference designs was the MC9S12C32 microcontroller manufactured by Freescale Semiconductors [10], [11] (surfaced mounted on the Axiom's CSM-12C32 module). The reasons for choosing the MC9S12C32 are that the MCU is simple enough for the students to learn its functions quickly and that it has sophisticated enough on-chip peripherals for solving a wide range of embedded control problems. The integrated development environment used was CodeWarrior Development Studio for HCS12, which supports absolute assembly, relocatable assembly, C and C++ programming. A separate programmer is also required for flashing the firmware into the microcontroller. The one we used was from P&E Microsystems. The Freescale microcontroller and CodeWarrior IDE are covered in a number of references[1] through [11].

The reference designs described in this paper include an accelerometer, a digital compass, an infrared distance sensor, an ultrasonic distance sensor, a temperature sensor, a pressure sensor, and a Hall Effect sensor. Provided in each reference design are the description of the sensor, hardware interfacing techniques, circuit and wiring diagrams, code snippets in C language, and ordering information.

A website was developed for hosting the reference designs for students to download. The information for the reference designs in the website is presented in a way that the students need to do extra work in order to use them in their projects. This prevents the students from copying them straight into their projects without their own thinking. Further, the code snippets provided in the website are intentionally condensed so that the students need to write their own additional codes in their applications. The web versions of these designs are provided as hyperlinks in this paper.

Our microcontroller-based student projects contained some of the reference designs. Some of these projects are briefly described in this paper. Also described briefly are the merits and impact of these reference designs. These reference designs promote hands-on experience. They can be easily adopted into laboratory and experimental courses. They are suitable for engineering curricula that emphasize on hands-on experience.

The rest of this paper is organized as follows: the reference designs are described the next section. Section III covers some of the microcontroller-based projects that contained these designs. The merit and impact of the reference designs are discussed in Section IV. Concluding remarks are provided in Section V.

Additional reference designs were developed and currently undergoing testing. They include DC Motor drivers, stepper motor drivers, GPS modules, keypads and switches interfacing, serial LCD, graphical LCD, organic LED displays, and Bluetooth modules. These new reference designs will be presented in future publications.

II. Reference designs

Seven reference designs are presented in this section. For the purposes of this paper, the materials developed for the first reference design are provided here. The materials include ordering information, description of the sensor, hardware interfacing information, wiring diagram, and C-code snippets. Same kind of materials were also developed for the other six reference designs but will not be included here so as to avoid excessive lengthy details. Hyperlinks to these reference designs are provided instead.

The code snippets for the reference designs are suitable for MC9S12C series of microcontrollers running at 8 MHz bus clock. The codes can be easily modified for other members of the MC9S12 family of 16-bit microcontrollers. Students were encouraged to modify these code snippets and to integrate them into their main programs.

A. Accelerometer

This section shows how to connect an accelerometer to the CSM-12C32 module and provide several C functions for initializing its analog-to-digital channels and for capturing the analog voltages from the sensor.

The accelerometer selected is Analog Devices ADXL203CE, which is a two axis, solid state MEMS accelerometer with analog outputs. Because of the particular E8 package of the accelerometer, a breakout board with the sensor mounted is recommended. The ordering information and the web link for the breakout board are shown in Table 1. The breakout board is shown in Fig. 1.

Table 1: ordering information.

Vendor	Part Number	Weblink for the part	Description	Unit Price
SparkFun Electronics	SEN-00844	http://www.sparkfun.com/commerce/product_info.php?products_id=844	Accelerometer Breakout Board with ADXL203CE +/-1.7g	$39.95

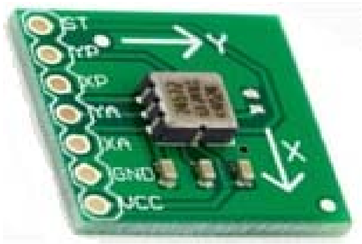

Fig. 1: ADXL203CE accelerometer and breakout board

The accelerometer is capable of the full scale of measurement of +/- 1.7g with typical noise floor of 110 µg/√Hz. The sensor is suitable for tilt sensing and for brute acceleration sensing.

Hardware interfacing to the Freescale 9S12C32 MCU

There are seven pins on the breakout board. When using the analog voltage output option, only four pins (VCC, GND, XA, and YA) are to be connected. The wiring diagram is shown in Fig. 2. The left half of Fig. 2 is the pinout diagram for the 9S12C32 MCU that is surface mounted on the CSM-12C32 module.

The signals XA and YA are the analog voltages corresponding to the acceleration in the x- and y-directions, respectively. The signals XP and YP are the corresponding PWM outputs, which are not used in this reference design. At zero g force the outputs XA and YA are 2.5 V. The sensitivity is 1000 mV/g. For example, at 1.5 g, the analog output voltage is 4 V.

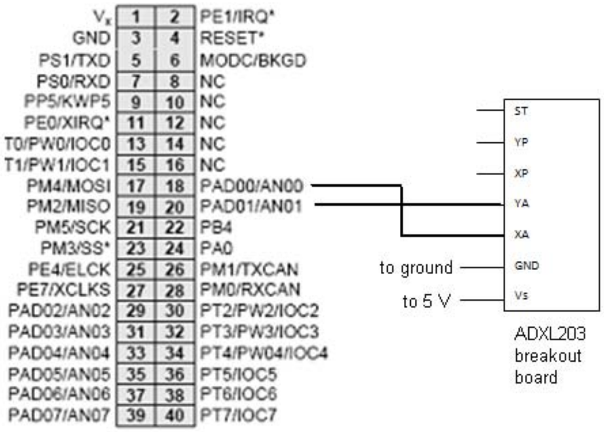

Fig. 2: accelerometer wiring diagram

Software development

The C function below can be used for initializing the ADC of the MCU. It is assumed that the analog voltages XA and YA are fed to the channels 0 and 1 of the ADC module. Other assumptions are included in the comment statements. The code snippet can be easily modified for other Freescale 16-bit microcontrollers.

```
void init_ADC(void) {
  ATDCTL2 = 0x80;  // turn on ADC
  ATDCTL3 = 0x10;  //  2 conversion/sequence
  ATDCTL4 = 0x01;  //  10-bit conv., 2MHz ADC clock
  ATDCTL5 = 0x90;  //right justify, unsigned, sample across channels.
  return;
}
```

A C function for computing the acceleration in g based on the corresponding analog voltage is shown below.

```
void read_Acceleration(void) { // this function returns the x- and y-
                               // acceleration (in g force) through global
                               // variables x_acc and y_acc
  int d_XA, d_YA;
```

```
  ATDCTL5 = 0x90;  // initiate ADC conversion
  waitms(1);       // waitms(1) is a delay function of
                   // 1 ms allowing time for ADC conversion,
  d_XA = ATDDR0;    // read 10-bit x-acceleration
  d_YA = ATDDR1;    // read 10-bit y-acceleration

  x_acc = (d_XA/1024)*5-2.5;  // x_acc and y_acc are float type global
  y_acc = (d_YA/1024)*5-2.5;  // variables
  return;
}
```

If the signed option of the ADC is used, the code snippets above can be simplified. With signed option, the 2.5 V for the case of 0 g is converted to decimal 0 instead of decimal 512, which is the case for unsigned option. If signed option is used, the init_ADC and read_Acceleration functions are revised as follows:

```
void init_ADC(void) {
  ATDCTL2 = 0x80;  // turn on ADC
  ATDCTL3 = 0x10;  //  2 conversion/sequence
  ATDCTL4 = 0x01;  //  10-bit conv., 2MHz ADC clock
  ATDCTL5 = 0b11010000;  //right justify, signed, sample across channels.
  return;
}

void read_Acceleration(void) { // this function returns the x- and y-
                               // acceleration through global variables
                               // x_acc and y_acc
  signed int d_XA, d_YA;
  ATDCTL5 = 0b11010000;  // initiate ADC conversion
  waitms(1);       // waitms(1) is a delay function of
                   // 1 ms allowing time for ADC conversion,
  d_XA = ATDDR0;    // read 10-bit x-acceleration
  d_YA = ATDDR1;    // read 10-bit y-acceleration
  x_acc = (d_XA/1024)*5;  // x_acc and y_acc are float type global
  y_acc = (d_YA/1024)*5;  // variables
  return;
```

```
}
```

A few details of the code snippet above are intentionally left out for the students to figure out. This way will prevent the students from cut and paste without their own thinking. The above materials including the pictures, ordering information, web link for the breakout board, hardware interfacing, wiring diagrams and code snippets are provided in the hyperlink http://www.unf.edu/~cchoi/Sensors/Main.html.

B. Digital Compass

This reference design shows how to connect an inexpensive digital compass to the CSM-12C32 module and provide several C functions for initialization and for capturing the compass information. The compass module under consideration is Hitachi HM55B, which is a dual-axis magnetic field sensor with a 6-bit (64-direction) resolution. It is sensitive to microtesla (μT) variations in magnetic field strength. It takes 30 to 40 ms between start measurement and data-ready with SPI interface. The module measures angle in the clockwise direction from the magnetic North. Pictures, ordering information, web link for the breakout board, hardware interfacing, wiring diagrams and code snippets are provided in the hyperlink http://www.unf.edu/~cchoi/Sensors/Main.html.

C. Infrared Distance Sensor

This reference design shows how to connect an infrared distance sensor to the CSM-12C32 module and provide the C-codes for initializing one of its analog-to-digital channels for capturing the analog voltage from the infrared sensor and for converting the analog voltage into numerical distance. A typical infrared distance sensor is Sharp GP2D12, which is a general purpose type distance measuring sensor. Pictures, ordering information, hardware interfacing, wiring diagrams and C-code snippets are provided in the hyperlink http://www.unf.edu/~cchoi/Sensors/Main.html.

D. Ultrasonic Distance Sensor

This reference design shows how to connect an ultrasonic sensor to the CSM-12C32 module and provide the C-codes for initializing the SCI port, for capturing the serial data from the sensor and for converting the serial data into numerical distance. The selected sensor is Maxbotix LV-MAXSONAR-EZ1. Pictures, ordering information, web link of the datasheet, ordering information, hardware interfacing, wiring diagrams and code snippets are provided in the hyperlink http://www.unf.edu/~cchoi/Sensors/Main.html.

E. Temperature Sensor

There are several common types of temperature sensors, namely, semiconductor (silicon) type, thermistors, resistive temperature devices, and thermal couples. The output signals of the sensors can be in various formats such as analog voltage output, SPI output, I2C output, 1-wire bus or logic output. A semiconductor type temperature sensor with analog voltage output is considered. The particular temperature sensor is LM34CZ, which is for general purpose applications. Pictures, ordering information, hardware interfacing, wiring diagrams and code snippets are provided in the hyperlink http://www.unf.edu/~cchoi/Sensors/Main.html.

F. Pressure Sensor

There are several types of pressure sensors in the market such as mechanical pressure sensors, semiconductor-based and MEMS-based devices. The latter two types are characterized with high sensitivity and long-term repeatability. Their output signals can be in various formats such as analog voltage output and serial (SPI or I2C) output. A semiconductor type pressure sensor with analog voltage output was considered. The particular pressure sensor was Freescale's MPXA6115A. This is an integrated silicon pressure sensor for measuring absolute pressure. This sensor is on-chip signal conditioned, temperature compensated and calibrated.

This reference design shows how to connect the pressure sensor to the CSM-12C32 module and provide the C-codes for initializing the on-chip analog-to-digital converter for capturing the analog output voltage from the temperature sensor. Pictures, ordering information, web link for the breakout board, hardware interfacing, wiring diagrams and code snippets are provided in the hyperlink http://www.unf.edu/~cchoi/Sensors/Main.html.

G. Hall Effect Sensor

A common magnetic field sensor is a Hall Effect sensor, which is a transducer with output voltage changes with the strength of the magnetic field at the sensor. Hall sensors have been used as speed sensor, position sensor, rotation sensor, and other applications. The particular Hall Effect sensor chosen is Panasonic's DN6848SE. The datasheet states that "the sensor consists of an amplifier circuit, a Schmidt circuit, a stabilized power supply, and a temperature compensation circuit all integrated into a single IC. The Hall element output is amplified by the amplifier circuit, and converted into the corresponding digital signals through the Schmidt circuit that can drive TTL and MOS IC." Description of the Hall Effect sensor, web link of the datasheet, pictures, ordering information, hardware interfacing, wiring diagrams and code snippets are provided in the hyperlink http://www.unf.edu/~cchoi/Sensors/Main.html.

III. Example projects that contained the reference designs

In this section two microcontroller-based student projects that contained some of the reference designs are briefly described. The first project [12], selected from our senior level microcontroller applications course, was the measurement of the acceleration of a free swinging pendulum by using the ADXL203 accelerometer. The accelerometer was mounted on the pendulum as indicated in Fig. 3 below. The acceleration signals were sent to the ADC of the MC9S12C32 MCU. A proximity sensor (OPB745) was used to trigger the capturing of the acceleration signals. The accelerations were displayed on a terminal program running on a PC through the microcontroller's UART. The acceleration of the pendulum was successfully captured in this project. The project was accomplished by utilizing the resources- ADC, UART, and GPIOs, on the MCU. This project utilized all of the information learned throughout the semester in the class and laboratories.

The second project [13], selected again from our senior level microcontroller applications course, was using Hitachi HM55B digital compass for measuring the angular position from the true North. It is the earth's magnetic field strength in the x and y directions being reported by the digital compass. The magnetic field strength for each axis is represented by a 11-bit signed number. If the value of the 11-bit number is equal to n, that means the field strength is n microtesla (μT) in the north direction. If the value of the 11-bit number is equal to -n, that means the field strength is n microtesla (µT) in the south direction. However, there is measurement error with the value the compass retrieves for a 1, ranges from 1 to 1.6 microtesla.

Fig. 3: measurement of pendulum acceleration

The students stated in the conclusion of their project report that "The HM55B digital compass was a challenging project that offered a lot of experience working with Serial Peripheral Interface (SPI) and Serial Communication Interface (SCI). Knowledge of the functionality of both of these interfaces was gained. The digital compass will successfully return x and y bits. The compass best in buildings with limited electrical components such as computers, Televisions, radios, etc. This is a result of the magnetic fields produced by these objects. When the magnetic interference is limited, the digital compass will function consistently from a range of 90˚ to 330˚. Although readings from 0˚ to 360˚ have been achieved, the readings from 330˚ to 90˚ are very inconsistent. The HM55B can be incorporated in several meaningful devices such as robots, automobile and hand-held navigation products, weather vanes, and any other devices that use compass bearings. The applications for a digital compass are nearly endless. Overall, this project offered programming experience in C, experience with SPI and SCI, and problem solving knowledge that will last a lifetime." Fig. 4 shows the HM55B digital compass wired to the microcontroller.

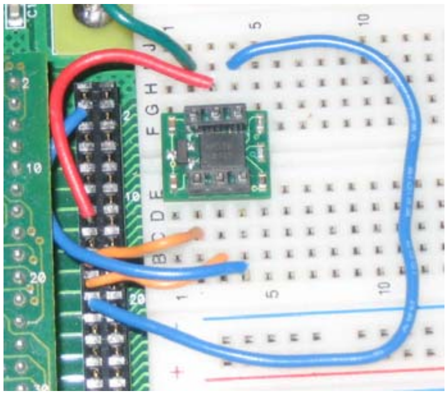

Fig. 4: taking compass reading

IV. Merit and impact of the reference designs

Many engineering students came up with good ideas for their engineering class projects and capstone design projects. Some students were able to complete the projects from concepts to prototypes without much technical assistance. At the other end of the spectrum were projects with good ideas also but the students were not able to realize fully their ideas into prototypes. Many times the problem was that the students failed to partition the total design into modules small enough that they could handle. They only had an overall vision of what the final system must do. For those who can partition their design into smaller modules, many of them often wasted much time in testing their own experimental solutions and failed to complete their projects by the end of the term. The first problem can be alleviated by proper coaching. The second problem can be solved by providing the students a collection of tested, practical reference designs. The use of reference designs will reduce the design burden on the part of the students and shorten their prototype development time.

An additional impact of the reference designs is that the students are more likely to realize their ideas into prototypes. The students need to partition their design into modules and for those modules that are in the list of reference designs, they can integrate the reference designs into their projects. The reference designs are not devised as complete solutions. The students will have some design work to do. The students evaluations of the projects were favorable. Their comments were that the coverage of the reference design materials in class greatly helped them in moving their projects forward.

V. Concluding remarks

The contents of the reference designs cover both hardware interfacing and software programming with emphasis on applications. The reference designs promote hands-on experience and can be easily adopted into laboratory and experimental courses. Minor details of the reference designs are intentionally left out in the website so that students still have to do their "homework" to make them work for their projects. The advantages of these reference designs are the shortening of the students' learning curve and the reduction of the starting "torque" of their microcontroller-based projects. The projects incorporated the reference designs were successfully completed with positive feedbacks as indicated in their project reports. The reference designs are suitable for engineering curriculums that emphasize hands-on experience and should continually be updated and expanded to include the latest in technology if budgets permit.

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Biographical information

Dr. Choi is a Professor in the Department of Electrical Engineering at the University of North Florida. He earned his Master's and Ph.D. degrees in electrical and computer engineering from the University of California, Santa Barbara. He has keen interest in engineering education and is active in research. Dr. Choi received his B.S. degree in electrical engineering from the University of Hong Kong. He worked for Norton Telecom and Mitel as a maintenance and a product engineer, respectively, for several years in Hong Kong. Dr. Choi holds a current and active professional engineer license issued by the State of Florida.

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