Chapter 1: Introduction to microprocessor system design

1.1 Overview

1.1.1 List of the techniques you will learn from this course

I. Structure and working principles of microprocessor systems

II. Microcomputer hardware and software development techniques.

III. Interfaces between real world data and microprocessors.

IV. Process and analyse signal using microprocessors.

V. Software interfaces to hardware systems.

1.2 Descriptions of the course

1.1.1 What is this course about?

This course is about how to use microprocessors to build useful applications. Since the microprocessor is the core of a computer system, so we will also study the structure of a computer and how the components are related.

A microprocessor or Central Processor Unit (CPU) is a very complex machine and its internal structure will be dealt with in other courses. Here in this course we will treat it as a black box and see how it can be used to build useful systems. As you can see from Figure 1 , the internal architecture of a computer has many components, for example the memory system and other peripheral devices. We will show how the CPU is connected to these components, and this kind of interfacing can be called internal interfacing.

Moreover, we will study how a microprocessor based computer interfaces with the real world. Since a computer is essentially a computational machine, but it also required to get data from its user and its environment. Also it can be used to control other machines such as motors and speakers through peripheral interfacing devices. This kind of interfacing can be called external interfacing.

These interfacing techniques will be discussed in details in the course.

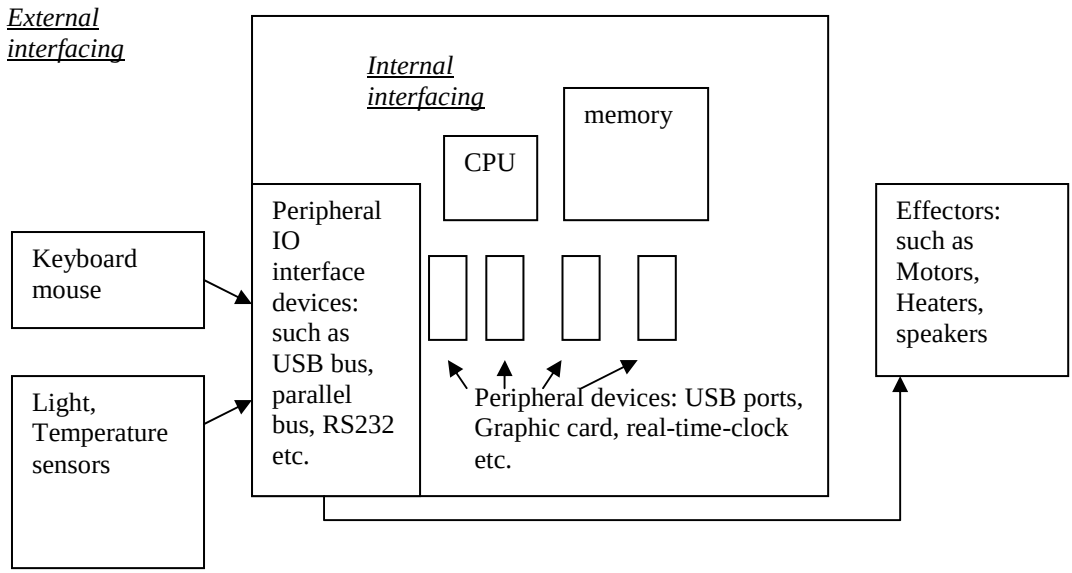

Figure 1-- A computer system with external devices

1.1.2 Why do we need to learn microprocessor system design

The microprocessor is the core of a computer system. However, the knowledge of microprocessor engineering is not limited to building computers, Nowadays many communication, digital entertainment and portable devices are controlled by microprocessors (called microcontrollers). Knowledge of microprocessor engineering is essential to design these products. In particular an engineer should know what types of components he needs, ways to reduce production cost and product reliable. These are the techniques to be discussed in this course.

1.1.3 What are the main contents?

1.1.3.1 Internal interface: Hardware Interface of the CPU and other peripheral devices

A CPU is a very complex machine, but it cannot live by itself, it also needs to work with a memory system and input/output sub-systems to build up a computer. We will discuss how to interface these devices. First, we will study how the hardware components are connected. Then we will look at the interfacing processes which are described by the writing and reading timing diagrams of the address, data and control signals.

1.1.3.2 External interface: Hardware Interface to the real world

One of our main concerns is how to interface microprocessors to the real world. First, it is about sensing the world; it is about capturing the activities of the real world and transforming them into data to be understood by computers. For example, in speech recognition, the first step is to turn the change of pressure caused by speech sounds into a sequence of data for further processing. Another example is temperature sensing, we need a transducer to turn temperatures into digital values before the computer can understand.

Another important aspect is about controlling the effectors to produce useful outputs. Producing computer printout by a mechanical laser printer is an example. Another

example is the production of sound or music on you computer. They all involve the transformation of information into energy. Due to the fact that most real world signals are analog, therefore we will also discuss the conversion processes: namely analog-to-digital and digital-to-analogue conversions, which are essential elements in external computer interfacing.

1.1.3.3 Software for interfacing

Apart from the hardware requirement of interfacing we will also look at the software side of the problem. When dealing with signals of the real world, no matter in sensing and controlling, the concept of real time processing is very important. That means it is not just what data you receive or produce, the ordering and the timing of dealing with these signals are also important issues. For example, for printing a document, you must print the characters in a correct sequence; in the case of producing computer music, time control must be accurate otherwise music may become noise.

For a more general system, real-time software can be centralized under the control of a Real-Time-Operating-System (RTOS), which coordinates different tasks using timer interrupts. Using timer interrupt is a special topic we will elaborate in this text.

1.1.3.4 Digital signal processing and analysis

Most real world interfacing problems can be solved by digital signal processing techniques. For example, for the problem of speech recognition, the microphone captures speech signals as well as noise from the environment; we need to remove noise before recognition can be made accurate. In analogue processing, low-pass analog filters built from op-amps, capacitors etc. are used, but the cost is high. Using Digital Signal Processors (DSP), noise filtering can be achieved by only manipulating (multiplying, adding etc.) the digitized data by software. Another example is the mobile phone you use everyday, digital processing is a must to compress the speech signal to fit into the channel you are subscribing to.

1.1.4 How to achieve our goal

In this course, we will concentrate on using a particular microprocessor device to illustrate the design procedures, we chose the 8051 microcontroller (a type of microprocessor) and the reasons are as follows.

- It is low cost; the minimum configuration is HK$10 each and is ideal for students.
- It is one of the most popular microcontroller devices worldwide. Many hardware and software resources are available publicly from the Internet. Although new 8051 based controllers are being designed for the market, however, the software is still compatible with order products.

In particular we will show how to make use of an 8051 microprocessor chip to build a useful computer system. We will concentrate on the following topics.

- Internal Interfacing: The relation of the microprocessor and the memory devices (Random Access Memory RAM, Read Only Memory ROM etc).
- External Interfacing: The relation of the microprocessor and the world (e.g. the printer, mouse, keyboard and display).
- Control and sensing: We will also study microprocessor based real time control. For example, we will use a design of a mobile robot to illustrate various aspects of

control engineering, such as how to control mechanical devices, wheels and sensors of a robot in real time.

1.1.5 Our experiments on robot building

In order to make the course more interesting we will use mobile robots as our examples. Each student is required to build and program a mobile robot. It is hoped that essential computer interfacing techniques can be grasped. Our robot will have the following features:

1. It has two power wheels to move itself around.
2. It has infrared and ultrasonic sensors to sense obstacles ahead, and the sensors can measure the distances of the robot from the left and right walls. It is quite useful for a micro mouse in a maze.
3. It has a servo motor (positional control motor) to carry the ultrasonic sensory system to point to a particular position that the robot is interested
4. It has certain intelligence for some reflex actions, e.g. not bump into the walls.
5. It has a communication link (wired or wireless) with a host computer for receiving commands from users.
6. It has a power system containing a battery to fuel its motion. In the future we can add intelligence to it so that it can search for battery recharging units in its living space. Hence it can run without stopping.

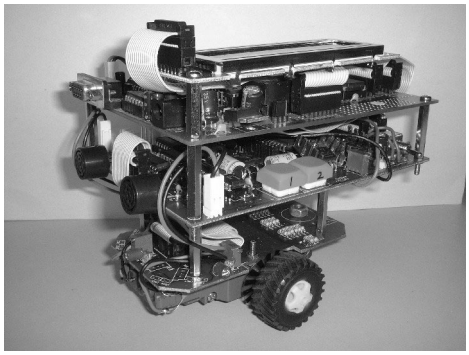

Figure 2--The Ceg3430 robot.

Figure 3--A more complex robot.

An autonomous mobile robot is a system that acts on its own according to some predefined rules to achieve certain functions.
In a way a robot is a model of a living creature. It is a mobile unit to move itself around. It has a brain to control its movements and has certain machine intelligence. We have come across these creatures such as R2D2 in the film “Star Wars”. Though imaginary now, but with the necessary research it is possible to realise this dream in future.

1.1.6 Why mobile robots?

The reasons of using mobile robots as teaching tools are as follows:

1. A robot is like a living creature; it needs to interface the real world in real-time. First it needs to control its wheels efficiently to move around. Therefore we will learn how to control motors.
2. It needs real time responses. In order to make effective motion it needs a real-time operating system to control it. Thus we need to investigate real-time operating system designs and applications.
3. It is a good case study for system noise removal. Because the motor is generating electrical noise, hence a good power delivery scheme must be installed to make the system stable.
4. To coordinate the system well we need an intelligence software system to coordinate various parts. However, even after years of research, a robot still cannot find its way in an office with the accuracy and flexibility comparable to human. Surely our experiments on robots only give you some taste of the difficulties and by no means demand you to solve the whole problem of artificial intelligence. Nevertheless you are free to explore ways to apply your robots, and hopefully it will arouse your interest for further research.

1.1.7 Applications of smart robots

- Home robots: It is forecasted at the end of this century or even much earlier robots would be helping human in many different areas at home. They can act as domestic helpers to clean up our rooms or to cook. And they can be drivers to drive us to work and even as teachers to teach children skills and facts.
- Entertainment robots: Sony's dog robots AIBOs (the picture is taken from http://www.sony.net/Products/aibo/) and their successors are examples of an attempt to make robots as pets.

Figure 4--The Sony AIBO

- Space or hazardous exploration: Exploration of areas hazardous to human is suitable for robots. The examples are exploratory robots in space, under-water, volcanoes and nuclear plants etc.

1.2 Work plan

1. Learn the design of a micro-controller (8051) based single board computer (SBC)
2. Learn to use the SBC and how to program it in "C".
3. Learn to use Interrupt and IO interface techniques.
4. Learn to generate pulse width modulation signals from the SBC, which are useful for Direct Current (D.C.) motor interfacing.
5. Learn to control the D.C. motors (motion control) and servo (positional control) motors for the robot.
6. Learn to build sensors for the robot

7. Learn to write PC interface software (e.g. using VC++ Windows programming).

8. Discuss the artificial intelligence techniques used in the robot.

1.3 Structure of this manuscript

In chapter 2 we will discuss the fundamentals techniques of computer system design, especially the interfacing techniques of the CPU and memory devices. In chapter 3, we will discuss the basic architecture of a microprocessor system based on a micro-controller chip 8051. Also memory and peripheral chips interfacing with the 8051 will be discussed. In chapter 4 we will discuss the programming techniques for the microcomputer system. Language C is used because it is one of the standard programming languages for low-level real-time systems. In chapter 5 we use a number of experiments to illustrate the operations of a microcomputer system. In particular, interrupt programming; serial and parallel input/output interface techniques will be introduced. Chapter 6 and 7 are dedicated to the discussion of robot motor control. In chapter 6 the concept of pulse-width-modulation for controlling the speed of a Direct Current (DC) motor will be discussed. And in chapter 7 we will talk about methods of how to control the speed of the motors accurately using feedback control. In chapter 8, we will discuss various sensory techniques for a mobile robot. The power supply system of a robot and real time system will be discussed in chapter 9.

END OF CHAPTER