Micro-Controllers

Module 3: Process Control

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IAT Curriculum Unit

August 2008

Module 3: Process Control

Module Objectives

1. Introduce Process Control
2. Learn Flowcharts
3. Introduce Open Loop Prcoss Control,
4. Introduce Closed Loop Pricess Control.
5. Explain PID Control Elments.

Module Contents

1 Process Control
2 Flowcharts to Represent Processes
3 Open Loop Process Control
4 Closed Loop Process Control
5 PID Control

Process Control

Process control term is extensively used in the world of engineering, but what dos term mean?

Process control can be considered as short for automated control of an industrial process where the creation of a final product is based on a continuous series of processes being applied to raw materials.

Process control is used extensively in oil refining, chemical processing, electrical generation, and the food and beverage industries.

In the process one or more system parameters such as temperature, pressure, humidity, flow or level will be controlled.

Processes to control can be very simple or very complex, however, no matter what the complexity level is, all have the same structure that is shown in figure 3.1. All processes consist of inputs being monitored by a processing device such as Micro-Controller, PLC or even a PC. Based on the inputs, the processing device will decide the outputs values.

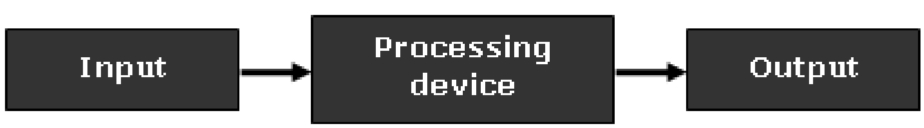


Fig 3.1: Process Control elements

Do you like chocolates?
Well, who does not?
Did you ever wonder how chocolates are made? Or where they come from?

Fig 3.2: Chocolate bars are made of cocoa seeds

Chocolates are made of cocoa seeds. Cocoa trees are shade loving trees that grow in the rain forests of tropical areas. Although a cocoa tree must be older than five years to start flowering, it flowers all year long. A cocoa fruit called "pod" requires 5 months to ripen fully. Once Cocoa pods ripen, they will be harvested, fermented, and then dried.

Fig 3.3: Cocoa tree and cocoa pods

Fermentation means leave the cacao seeds heat up naturally causing chemical changes that will alter the look and the flavor.

Once the cocoa seeds are ready they will be shipped to factories; we will have a look at chocolate making process. The process is far complicated than mixing seeds, with sugar and milk.

Roasting

The first step at the factory is to roast the cocoa seeds in roasting ovens that are heated to 250F temperatures. The roasting might take 30 minutes to 2 hours.

Fig 3.4: First step in chocolate making is roasting

Winnowing

Second, the cocoa seeds will go through a machine that is called a winnow machine. This machine will crack open the seeds, blow away the shells and sort the nibs, remaining centre part of the seeds, by size.

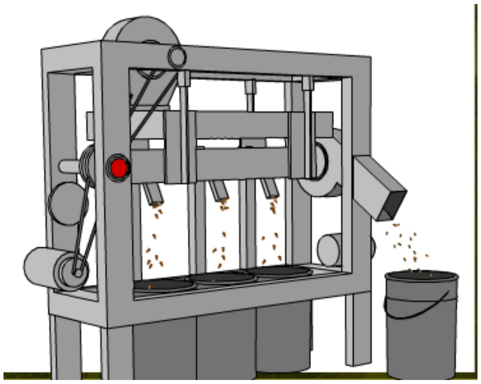


Fig 3.5: 2^{nd} step is winnowing

Grinding

The third step is to grind the chocolate nibs in to thick paste called Chocolate liquor. Don't be fooled by the name, it is totally alcohol free. Heavy metal discs like the one shown in figure 3.6 will do the grinding work.

Pressing

Part of the chocolate liquor will be pressed to separate cocoa butter from cocoa powder; the remaining part will be used as is in the process.

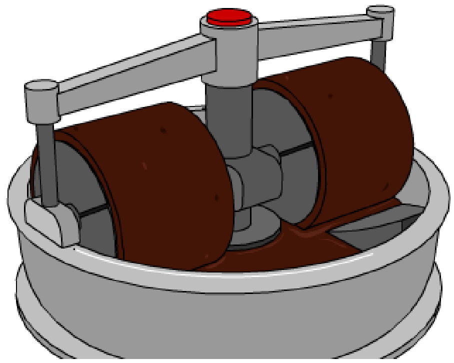


Fig 3.6: The product of grinding is chocolate liquor.

Mixing

Then the chocolate liquor will be mixed with milk, sugar and extra cocoa butter in huge mixers like the one shown in figure 3.7 for hours to ensure creamy smooth texture in the end product. However the outcome of this step is coarse brown dough called "crumb".

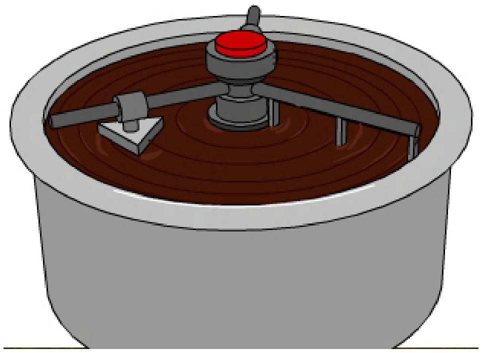


Fig 3.7: Mixing chocolate liquor with cocoa butter, milk and sugar

Refining

The crumb will be refined by means of giant steel rollers to make the chocolate even silkier.

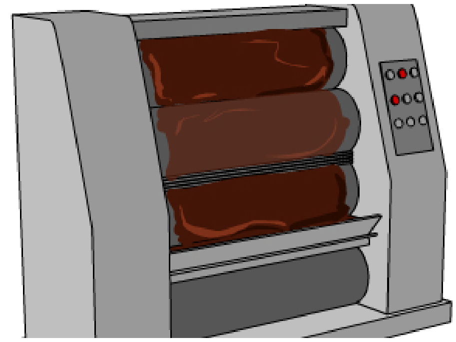


Fig 3.8: Refining step

Tempering

This step is referred to as tempering, which simply means stirring the chocolate slowly, heating and cooling it repeatedly to temperatures between 105F and 85 F.

Fig 3.9: Tempering Step

Molding

The final step is to mold the chocolates into the bars you know. Industrial machines will do that at rates of several hundreds per minute.

Now you can enjoy your chocolate

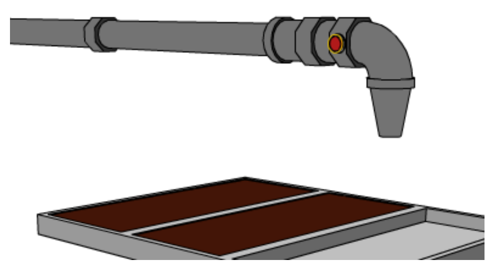


Fig 3.10: Molding chocolate into bars

Looking back at chocolate manufacturing process, every mentioned step can be thought of a process that can be automated and controlled.

At roasting step, for example the row cocoa seeds will be processed to produce roasted seeds.

In terms of control, you will need a start switch as in input, the processing device will control time, the key control task in this step; remember that the oven has to be on 30 minutes to two hours, and the output is the oven actuator.

Feed in product of step	**Finished product**
Row cocoa seeds	Roasted seeds

Table 3.1: Roasting product analysis

Input devices	**Control task**	**Output devices**
Start switch	Time control	Oven heating element

Table 3.2: Roasting automation elements

Winnowing is bit complicated process; the roasted seeds will be the fed in this step to produce the cocoa nibs.

A typical input device would be a start switch, the controlling tasks are cracking, blowing shells and sorting. Outputs devices could be motors and blowers

Feed in product of step	**Finished product**
roasted seeds	Cocoa nibs

Table 3.3: Winnowing product analysis

Input devices	**Control task**	**Output devices**
Start switch	Cracking Blowing shells sorting	Motors blowers

Table 3.4: Winnowing automation elements

Can you analyze the remaining chocolate making steps in the same manner? Fill in the tables for the steps:

- Grinding

Feed in product of step	**Finished product**

Table 3.5: Grinding product analysis

Input devices	**Control task**	**Output devices**

Table 3.6: Grinding automation elements

- Mixing

Feed in product of step	**Finished product**

Table 3.7: Mixing product analysis

Input devices	**Control task**	**Output devices**

Table 3.8: Mixing automation elements

- Tempering

Feed in product of step	**Finished product**

Table 3.9: Tempering product analysis

Inputs	Control task	outputs

Table 3.10: Tempering automation elements

- Molding

Feed in product of step	Finished product

Table 3.11: Molding product analysis

Inputs	Control task	outputs

Table 3.12: Molding automation elements

Flowcharts to represent processes

A flowchart is a graphical representation of steps and decisions used to arrive at a logical outcome. It can be used to arrive at management decisions, system troubleshooting decisions, and other processes that involve well-defined steps and outcomes. It is still an excellent tool when planning program flow. Flowcharting is particularly useful in process control because it can be used to visually represent the steps and decisions required to perform control of the system.

Table 3.13 shows the most popular symbols used in flowcharting. These blocks, connected with flow lines, are used to describe the actions and flow of the program.

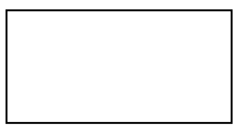
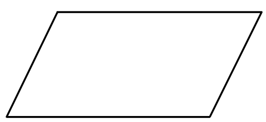
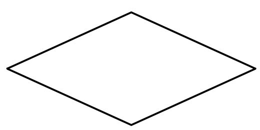
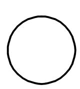
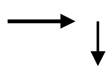
Symbol	Function
	**Start/Stop: Indicates beginning of a program**
	**Process task: Indicates task, such as delay or calculations, or declarations**
	**I/O control: read external input or write to external output (writing to PC included)**
	**Evaluation symbol: used to decide flow direction in one or more pathways.**
	**Predefined process: indicates a process without details**
	**Connector: indicates connection between two locations in the chart**
	**Flow lines: indicates direction of flow in the chart**

Table 3.13: Flowchart symbols

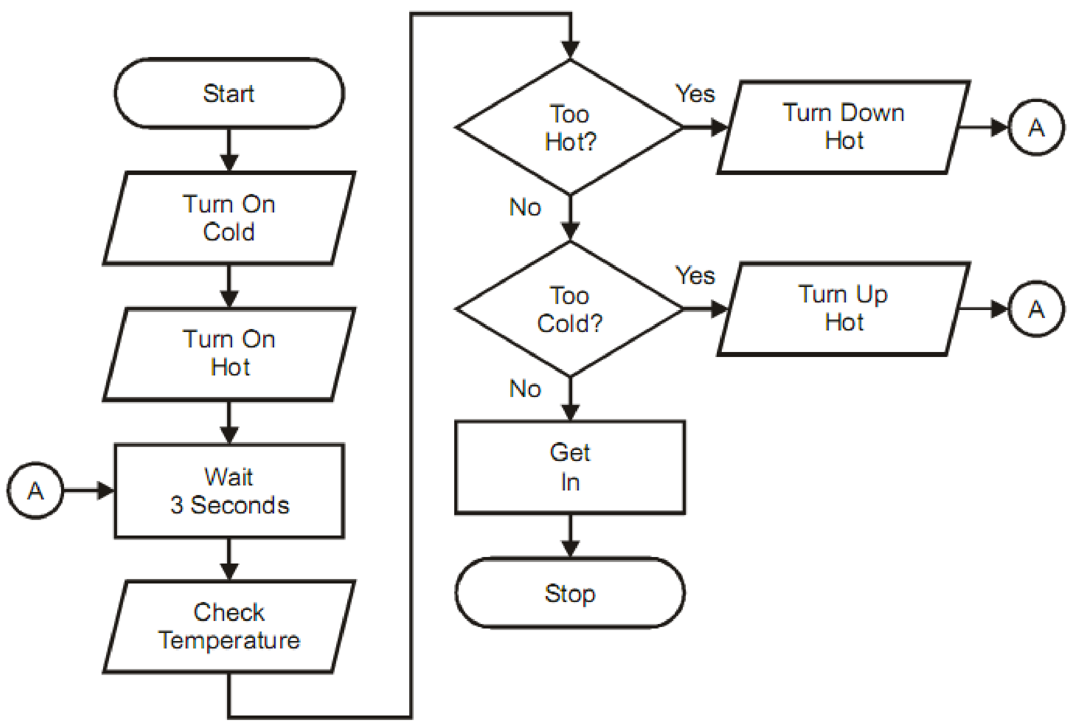
Let's look at the following daily life example of adjusting shower water temperature:

1. Turn on cold water
2. Turn on hot water
3. Wait for some time (let's say 3 seconds) for temperature to stabilize.
4. Test water temperature:
5. If too hot, turn hot water down, and return to step 3.
6. If too cold, turn cold water down, and return to step 3.
7. if temperature ok, get in shower

Although this is a silly task not a process, we still can use flowcharts to represent the same

Note how each symbol is used:

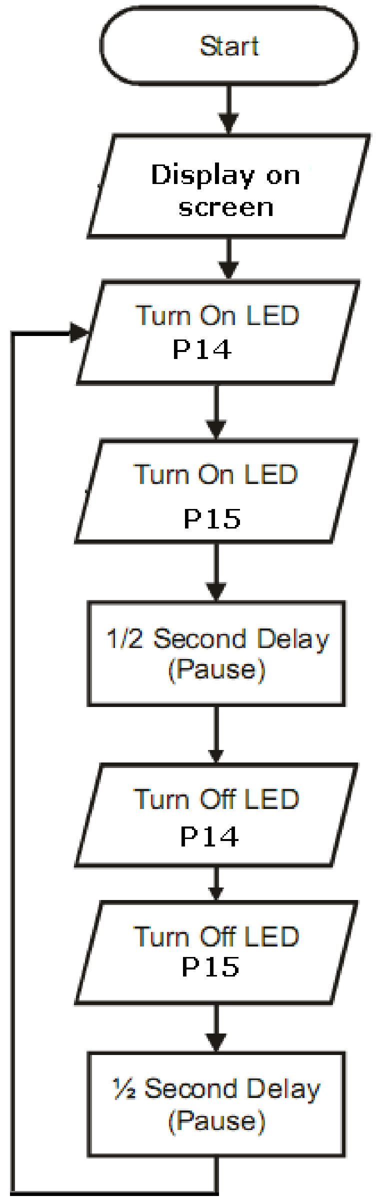
- **I/O control symbols are used to read input (temperature) or write outputs (Turn on/off hot or cold water tubs).**
- **Evaluation symbol is used to guide the flow direction based on evaluation result.**
- **Process task symbol is used when performing a certain processing task such as delay or calculations.**



Flowcharts can also be used to represent more serious applications, processes and even programs like the example below:

This was the program you used in module 2 to program two LEDS; the same can be graphically represented by means of a flow chart.

```
DEBUG "Program Running"
DO
HIGH 14
HIGH 15
PAUSE 500
LOW 14
LOW 15
PAUSE 500
LOOP
```

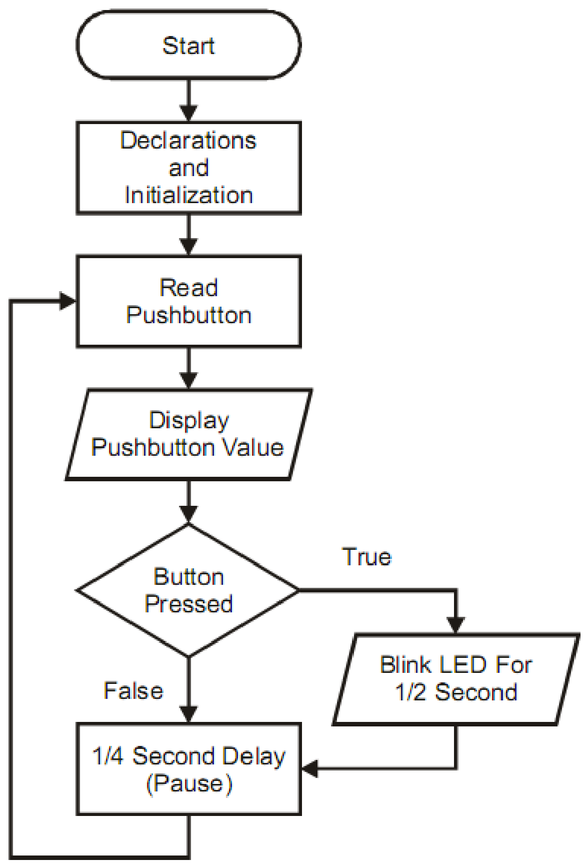


Remark: pay attention that displaying on the screen is I/O control symbol.

Can you draw the flowchart for the following program?

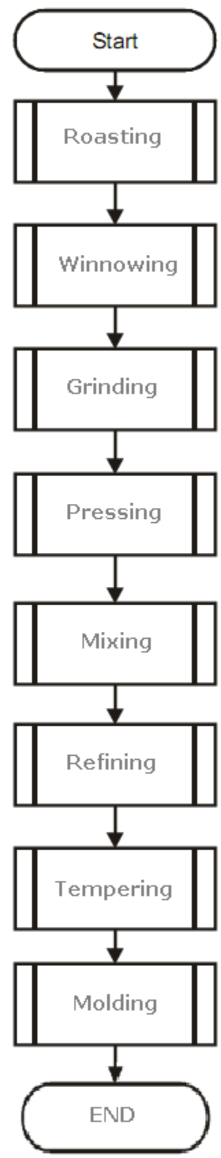
```
DO
DEBUG HOME
DEBUG ? IN3, CR
DEBUG ? IN4, CR

IF (IN3=1) THEN
HIGH 14
PAUSE 50

ELSEIF (IN4=1) THEN
HIGH 15
PAUSE 50

ELSE
PAUSE 50

ENDIF

LOW 14
LOW 15

LOOP
```

On the other hand, can you write a program from the flowchart? Consider pushbutton connected to pin 3, LED connected to pin 5.



As you know by now, chocolate manufacturing is a long complex process that consists of many smaller processes. Can we represent it by flowcharts as well?

The answer is yes, and the key symbol to use is **"predefined process".** A symbol used to indicate a full process without details. Each predefined process can be represented by flowcharts in details in other locations.



Open Loop Process Control

Process control can be categorized in two types: Open loop control and closed loop control. Control engineers must decide which type of control to be implemented when designing a new control system.

Let's say you are a control engineer in the municipality, your current task is to design an automatic irrigation system for all the gardens in your area.

You can design the sprinkler systems to be automatically on at certain times of the day such as 5:00 am, 5:00 pm, and 11:00 pm. Do you think this is a good design? Why?

How would the sprinkle systems operate in rainy winter day?

Let's say you have modified your design by adding a moist sensor that measures humidity level in the soil; if the sensor detected soil humidity, the sprinkler systems will not operate.

In the first design, you have applied **open loop process control**. The second design is called **closed loop process control** and it will be covered in details in the next section.

So what do we exactly mean by open loop control?

Open loop system is a silent system that provides no feedback, and therefore it does not auto-correct itself. In other words this means that the system does

Do you think 5:00 am is a suitable time? Why?

Do you think 5:00 pm is a suitable time? Why?

Do you think 11:00 pm is a suitable time? Why?

not observe the output of the processes to correct any errors that occur.

Another example of open loop control is the washing machine, which is purely time based control; depending of the selected wash cycle, the washing machine will operate for manufacturer pre-set time, and no washing machine as far as know will give a feedback such as "clothes not ready yet, wash for one more cycle", or "persisting stains, use a bleach" or even "wrong cycle for clothes' colors, use a mild one".

So when is the best time to use open loop control? It fits best in simple processes where feedback is not critical because of simplicity and low-cost implementation.

Open Loop Control Exercises:

Automatic Garage Door Control

Let's anticipate that you are a brilliant enthusiastic control engineer, your next assignment is to design an automatic garage door that can be opened by pressing ON button, and closed by pressing OFF button.

Fig 3.11: Automatd garage door

The door requires 60 seconds to fully open or fully close.

The used motor needs two signals to operate: ON/OFF signal and UP/DOWN signal. The motor has to be ON with direction UP so that door can open, and vise versa.

First: Determine the I/Os required for this process

Inputs	Outputs

Table 3.14: Garage door I/Os

Next: Draw the flowchart of the garage door control process.

Then: Can you write the process related Basic Stamp program

Now all you need to do is to test your program, how? Come on, Use your imagination. You have to build a representative circuit.

- Represent every output by an LED, but remember that you have to protect it with a resistor.
- Represent every input with a push button. Remember to use the one of the circuits shown in figures … and … when connecting the pushbutton.
- Decide I/O – pin connections and fill in the table below

Basic Stamp Pin #	**I/O**

Table 3.14: I/O pin mapping

- **Finally Draw the entire circuit schematic diagram in the box below, connect, and test it**.

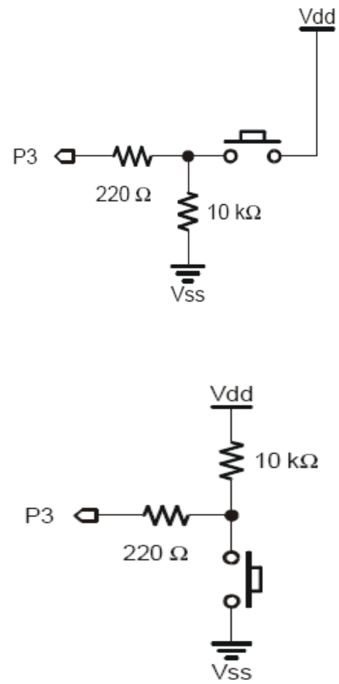


Fig 3.12: Pushbutton connection circuits

In the next exercise you will look at the **molding** process of the chocolate manufacturing.

Let's make some assumptions to make design task easier:

- The molding machine needs 20 seconds initialization time after pressing Start pushbutton.
- The mold of the chocolate bar consists of **4 blocks** (think of Kit Kat as an example); the required time to fill a block is .5 seconds. The filling valve shall be on during this time
- A conveyer motor operates for .25 second to correctly locate the filler to next block.
- After one full bar is filled, the conveyer
- To stop the machine you need to press Stop pushbutton, however the machine will complete filling the mold of a whole bar before it stops

Fig 3.13: Kit Kat bar consists of 4 blocks

First: Determine the I/Os required for this process in table

Inputs	Outputs

Table 3.15: Process I/O Table

Next: Draw the flowchart of the molding process.

Then: Can you write the process related Basic Stamp program

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Decide I/O – pin connections and fill in the table below

Basic Stamp Pin #	I/O

Table 3.16: I/O Pin mapping

Finally Draw the entire circuit schematic diagram in the box below, connect, and test it.

Closed Loop Process Control

In contrast to an open-loop control system, a closed-loop control system utilizes an additional feedback signal from the field (process) to compare the actual output with the ideal output response.

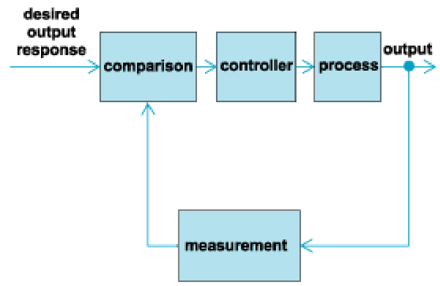

Fig 3.14: Closed Loop Control Illustration

Due to increased complexity of processes to be controlled and the interest in achieving optimum performance, i.e. increase system accuracy, closed loop control got more and more attention.

Closed loop process control can be illustrated as shown in figure 3.14. In addition to standard inputs such as start/stop switches and pushbuttons, the controller gets a measured feedback signal from the process. This feedback signal will be compared to the desired output response, normally refereed to a set-point, to measure how far the practical output signal from the desired one is. Based on that error measurement, the controller must perform corrective actions to keep that error as low as possible. The ideal case would be zero error of course.

We as human beings naturally utilize closed loop control all the time, in the case of the driver steering a car, the driver uses his or her sight to visually measure and compare the actual location of the car with the desired location. The driver then serves as the controller, turning the steering wheel. The same can illustrated as shown in figure 3.16

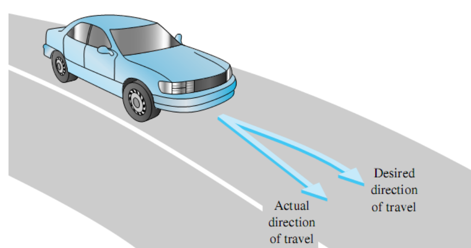

Fig 3.15: Closed Loop Control is utilized in car steering process

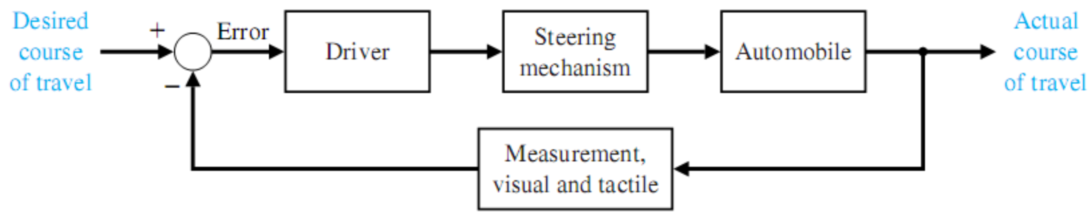

Fig 3.16: Car steering illustration

Closed Loop Control Exercises

Chocolate Tempering Process

Let's have a closer look at the tempering step in chocolate manufacturing process

Once you press the start pushbutton, the mixer will start operating.

Assuming the actual temperature is less than 105F (40.56C), the heater will start after a delay of 1s. The heater will remain on until the high temperature is achieved, this will be indicated by the high temperature indicator (sensor)

After the heater is switched off, a delay of .5s is required before the cooling fan is on. The fan will remain operating until the low temperature of 85F (29.4C) is achieved; this will be indicated by the low temperature indicator (sensor).

After the cooler is off a delay of .5s is required before heart operates again. The same heating and cooling steps will be repeated 4 more times, before the machine stops.

Remember the mixer is on at all steps till the machine stops

First: Determine the I/Os required for this process in table

Inputs	Outputs

Table 3.17: Process I/O table

Next: Draw the flowchart of the tempering process.

Then: Can you write the process related Basic Stamp program

Decide I/O – pin connections and fill in the table below

Basic Stamp Pin #	I/O

Table 3.18: Process I/O mapping

Finally Draw the entire circuit schematic diagram in the box below, connect, and test it.

PID Control

PID stands for "proportional, integral, derivative." These three terms characterizes the behavior the error signal of closed loop control, which is Ideal output (setpoint) – feedback signal (practical output), and each of these elements performs a different task and has a different effect on the functioning of a system. As you can se in figure 3.17, your practical signal (dashed pink line) has to reach the setpoint signal (blue line).

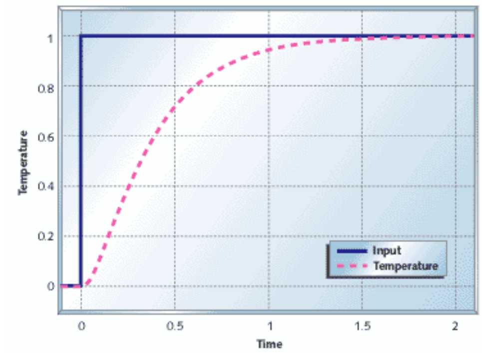

Fig 3.17: actual signal vs. setpoint signal over time

Error = setpoint- feedback

Proportional element

Let's assume you want to heat water in a boiler to a specific temperature of 76C to use in a scientific experiment, you filled the water form the tub in a cold winter day, the water temperature was 10C. The calculated error was found to be 66C, so the more the error, the more heating is required, that is the proportional term, which is in other words that error is proportional to the corrective action.

Error = setpoint- feedback

= 76 - 10

= 66

Corrective action α Error

Corrective action = K * Error

K is the proportional constant

The higher the constant K is, the more aggressive the corrective action becomes which means a faster response to error; the disadvantage may be overshooting, i.e. exceeding the setpoint value, in this example means the water temperature overshoots 76C to reach 100C.

A Low constant will decrease the speed of the corrective action, and may result in a less system accuracy.

Differential element

In order to improve process performance the proportional part alone is not enough, you need to predict or foresee the situation in advance, this can be done by analyzing the differential element, which means in very simple words analyze the error's rate of change i.e. how much the error changes in a certain time frame. For example if you are driving a car at constant speed for two hours, the rate of change is zero, because there was no change in the speed although the speed itself is not zero but could be 120 Km/hour if you are driving along a highway. If your speed in the first hour was 60Km/hour, and the next hour was 120Km/hour then the rate of change was 2 as you doubled your speed every hour. So knowing the rate of change helps the process not just to react to error value but calculate expected next error value and react accordingly.

This overcomes system response delays and relatively prevents overshooting cases. while the proportional element is computing when the error becomes small, The derivative signal lets the controller decide, "Whoa, we are getting very close to the setpoint, *and* the sensor's temperature is still rising pretty rapidly; time to cut back on the heater power".

Integral element

Now Let's say the experiment you are conducting is extremely critical where extreme accuracy is required, you need to consider the integral element, which analyze the total value of all recent errors to ensure that it does not exceed a certain value. The advantage of integral element is that it eliminates long term errors, however because it may be slower in response.

Good control designed systems utilize a combination of two elements or some times all three PID elements to achieve quick, efficient and accurate signals.