Unit 24, Assignment 1

Understanding Control Systems

George Hotten

January 11, 2023

Control Systems

Command Systems

A command system acts instantly based on commands/data inputted to the device. An example of command systems are TV remotes and drones. Commands for these devices can include the movement of the drone (i.e. up and down) and interacting with the TV's menu with its remote. Command systems are typically the most simplistic.

Programmable Systems

A programmable system allows the user to input code or parameters into a device, and that device performs the sequence of commands step-by-step. This means it can carry out its function mostly independently from the end-user as only a small amount of user input may be required once the program has started. Some examples of programmable systems are dishwashers, microwaves and washing machines. Programmable systems are predominantly found in domestic environments.

Sensing Systems

A sensing system detects changes in the environment around it, such as measuring the CO^2 in the atmosphere, reading how hot the air is, and detecting motion. Sensing systems often take in multiple complex inputs. Based on its readings, the system may trigger an alarm, open a door, etc. Some examples of sensing systems are fire alarms, burglar alarms, and cruise control systems such as line assist and park pilot.

Conditional Systems

A conditional system reacts based on a condition or situation. A conditional system is much simpler than a sensing system and usually only takes a single basic input. For example, central heating systems wait for the temperature to reach a certain threshold before turning the system on or off. Other examples include fridges and street lamps.

Control Systems and Signals

Different control systems may use either a digital or analogue signal. In the below comparison, I shall compare:

- Common uses
- Minimum and maximum values
- How each type is represented including diagrams

Analouge Signals

Analogue signals are continuous signals that can take any value within an infinite range. Analogue signals are most typically used for music, voice and video transmission and for controlling various mechanical mechanisms, for example, values and motors. Minimum and maximum values depend highly on what the system using the signal is. For example, if the signal was used for audio /music, the minimum value would be the quietest sound that can be produced and the maximum value would be the loudest sound that can be produced. For an example of an analogue signal, please refer to figure 1.

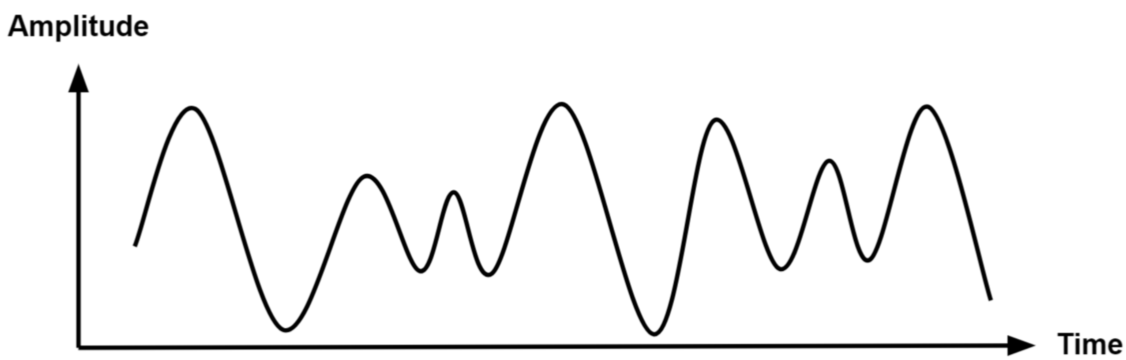

Figure 1: Analouge Signal Graph
`monolithicpower.com/en/analog-vs-digital-signal`

Digitial Signals

Digital signals are discrete signals that take any value within a finite range. Digital signals are most typically used for data transmission, networking and controlling electronic devices such as TVs. The minimum and maximum values depend on the number of bits used by the digital signal. For example, an 8-bit signal has a range of 0 to 255 and a 16-bit signal has a range of 0 to 65,535. For an example of a digital signal, please refer to figure 2.

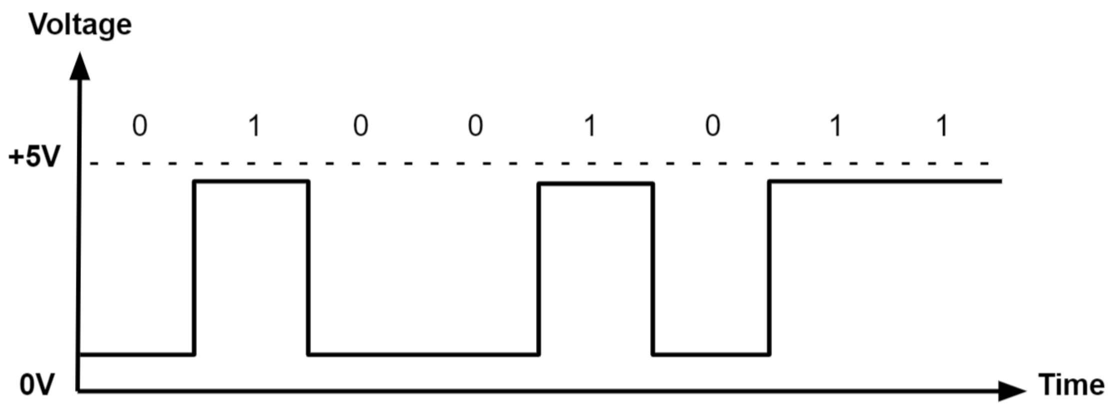

Figure 2: Digitial Signal Graph
`monolithicpower.com/en/analog-vs-digital-signal`

The Key Differences

Digital signals are represented by discrete values, whilst analogue signals are continuous. To be specific, digital signals are represented by zeros and ones, meanwhile analogue signals are represented by a continuous but varying electric signal.

Compatibility

Digital signals are becoming more and more compatible with newer devices as analogue is starting to be phased out. Most modern devices are incompatible with analogue signals and require analogue-to-digital converters before they can process the data.

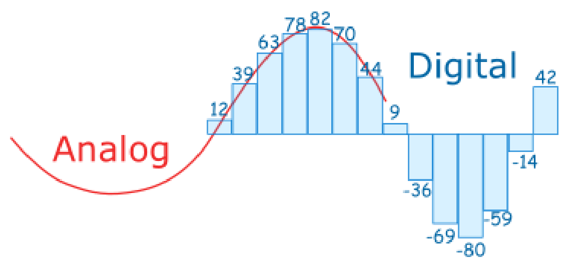

Figure 3: Basic example of an analogue signal being quantised into a digital signal
`mathsisfun.com`

Reliability

As analogue signals use electric waves to transmit data, they can be subject to interference and distortion from the environment around them causing degraded signal quality. Digital signals on the other hand can transmit data without loss of quality or missing data as they have error-checking built-in. This means if data didn't arrive, it can be sent again until received successfully.

Signal Processing

As digital signals use bits of data, it is simple for a computer to receive and understand the data as they both communicate in the same way: binary. Analogue signals on the other hand use electric signals making it impossible for a device to understand without the above-mentioned ADC, analogue-to-digital converter. The ADC can take an analogue signal and convert it to a digital signal for a computer to understand.

The Need for Signal Conversion

Signal conversion is important to maintain compatibility between older and newer hardware. Older hardware utilizes analogue signals whilst newer hardware uses digital signals. However, not all modern hardware use digital signals. For example, a vast amount of modern music equipment still utilizes analogue signals for mixing and manipulation.

Digitial to Analogue

A common example of needing to convert a digital signal to an analogue signal is when streaming audio to a speaker. When a computer wants to play audio from speakers, a DAC (digital-to-analogue converter) is used to process the data and transform it back into an analogue signal the speaker can understand and play.

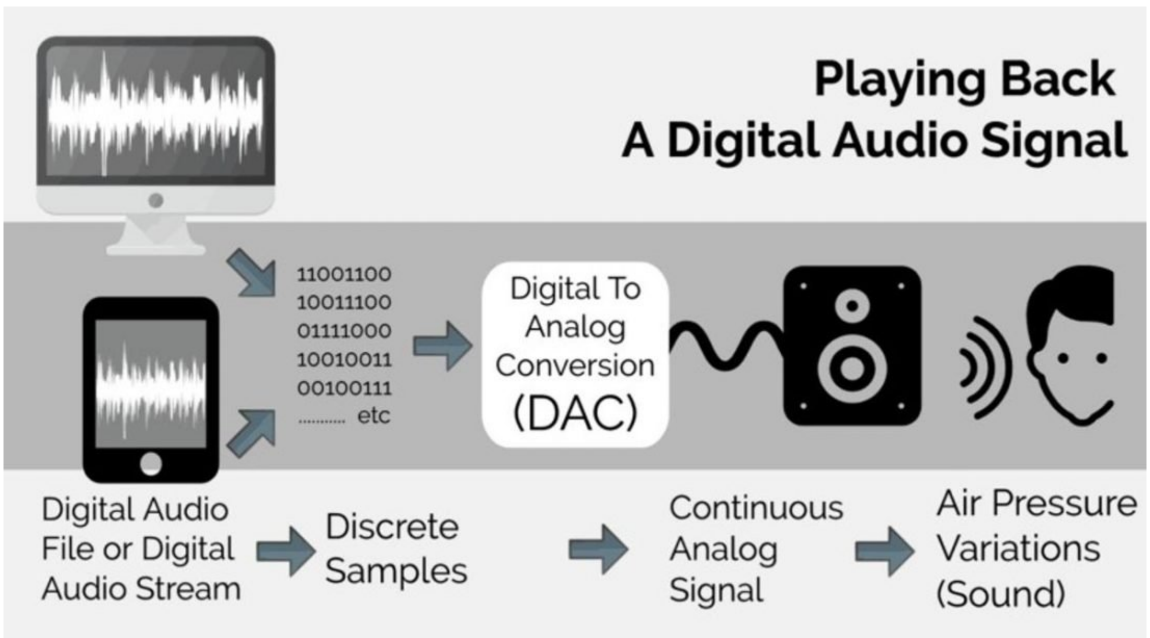

Figure 4: Basic example of how digital audio is played on an analogue speaker
headphonesty.com/2019/12/dacs-guide-part-1

Analogue to Digital

A common example of needing to convert analogue back to digital is when recording audio from a microphone. This allows the user to convert sound waves (analogue) into a digital signal to save and use on a device. This conversion is done via an ADC (analogue-to-digital converter), which uses pulse code modulation. Pulse code modulation has three steps: sampling where the amplitude of the wave is measured at exact intervals, quantization where each sample is quantized to reach a normalized value, and encoding which digitizes the analogue signal.

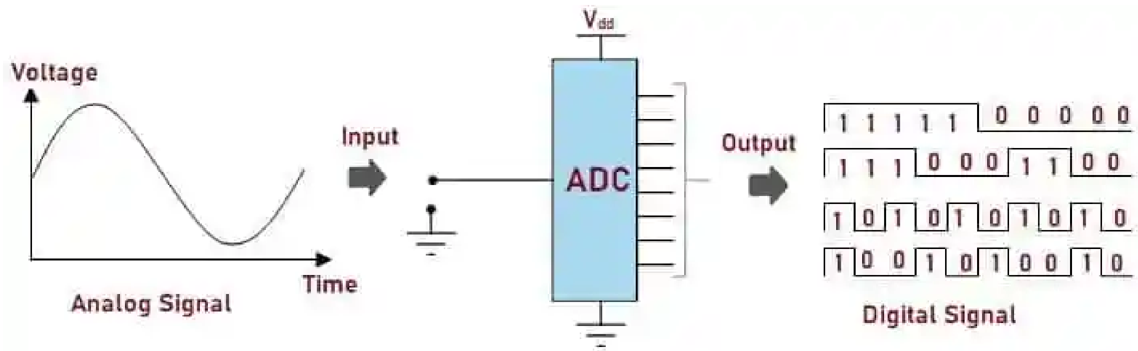

Figure 5: Basic example of how an analogue signal is converted to be digital
`electricalfundablog.com/analog-to-digital-converter-adc`

The Operation of Sensors and Output Devices

Input Devices

Temperature

There are two main types of temperature sensors: contact and non-contact. A common contact temperature sensor is a Thermocouple which is comprised of two different wires made of two different metals. The voltage between both wires shows the temperature change. It has a typical range of -100 to 1750 degrees Celcius.

A common non-contact temperature sensor is an infrared sensor. The infrared sensor is used to determine temperatures at a distance. A heat source emits thermal radiation which the infrared sensor measures. This is most typically used in hazardous environments where distance is required to stay safe.

Figure 6: K-Type Thermocouple Sensor
`naradaelectronics.rw`

Voltage Sensors

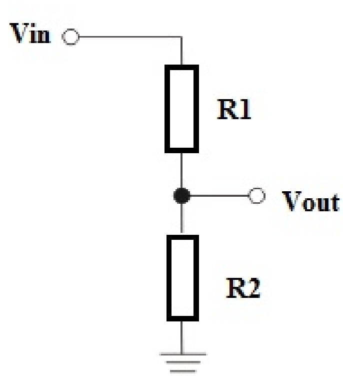

Figure 7: Resistive-Type Voltage Sensor
`elprocus.com`

There are two main types of voltage sensors: resistive and capacitive. Resistive-type sensors include two circuits: a voltage divider and a bridge circuit. Inside the circuit, there is a resistor which acts as the sensing element. Once the voltage is supplied to the circuit, the amount can be calculated by the amount of resistance within the circuit.

A capacitor-type sensor uses a capacitor within the circuit which is powered with 5 volts and has the flow of the circuit going through it. This creates a revulsion of electrons within the capacitor, with the difference in capacitance indicating the voltage.

Montion Sensor

The most common type of motion sensor is a Passive Infrared Sensor (PIR). A PIR sensor utilises pyroelectric sensors that detect levels of infrared radiation. A PIR contains two slots that measure the radiation levels. If a change is detected between the two, an electronic pulse is created, which activates the sensor showing that there was movement.

Another common type of motion sensor is a Microwave motion sensor which, similar to devices such as speed cameras, emits high-frequency waves and measures the reflection sensing a frequency shift. This causes a pulse which triggers the sensor showing that there was movement.

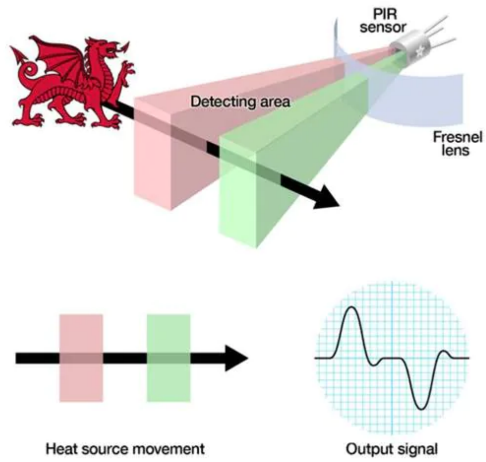

Figure 8: Example of a PIR sensor
adafruit.com

Output Devices

Motors

Motors are comprised of multiple magnets that are used to create motion. This is because of the law of magnets that opposites attract and likes repel. For example, if there are two magnets the left side of one magnet will attract the right side of the other magnet while the left side of the magnet repels from the other's left. These forces create rotational motion.

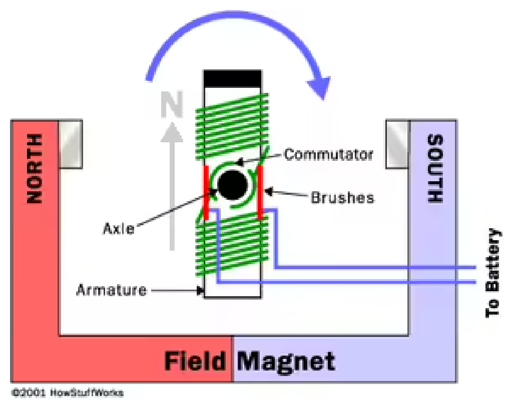

Figure 9: Example of a DC motor
howstuffworks.com

A common type of motor is a DC motor. A DC motor contains a permanent magnet on its outside that does not move. On the inside, there is a rotor which is what moves. When DC power goes through the rotor, a temporary electromagnetic field is created that interacts with the permanent magnet. Within the magnet, there is a communicator which keeps the polarity of the field flipping which keeps the rotor rotating.

Projector

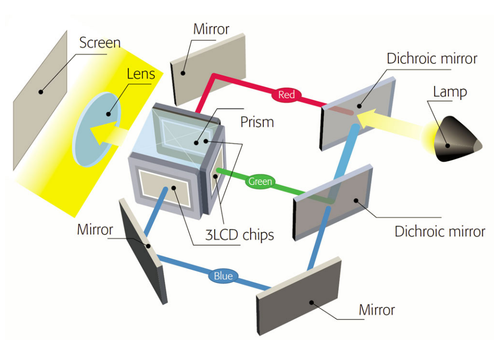

Figure 10: Internals of an LCD projector
extremetech.com

The most common type of projector is a Liquid Crystal Display (LCD) projector. LCD projectors used polarized light which shone through three liquid crystal panels. Each panel represents a different primary colour. After the light is shone through a prism, a lamp and a filter are projected through a final lens.

In more detail, the first panel displays the image and using dichroic mirrors the light is split up into its primary colours. After the light has been separated, it is passed through another LCD panel which recombines the colours by separating light into a spectrum. Each panel shines either red, blue or green which is sent through the final LCD panel which bends the light. Finally using dichroic mirrors, the colours are combined, magnified by an onboard lens and projected.

Printer

A common type of printer is the Ink Jet printer, which works by using a series of nozzles to spray drops of ink onto the paper. A stepper motor is used to move the print head back and forth across the paper. More modern printers also have another motor to park the print head when not in use to prevent it from accidentally moving and becoming damaged. To create the droplets of ink used by the print head, two different methods can be used: thermal bubbles and piezoelectric.
Thermal bubbles printers use resistors to generate heat which is used to vaporize ink to create a bubble. When the bubble expands it is pushed out of the nozzle onto the paper. When the bubble collapses, a vacuum is created which pulls more ink from the cartridge into the ink head.
Piezoelectric printers use piezo crystals which are found in the back of the ink reservoir for each nozzle. The crystal uses a tiny electric charge which causes it to vibrate. When it vibrates outwards, ink is pulled into the reservoir. When it vibrates inwards, ink is forced out of the nozzle.

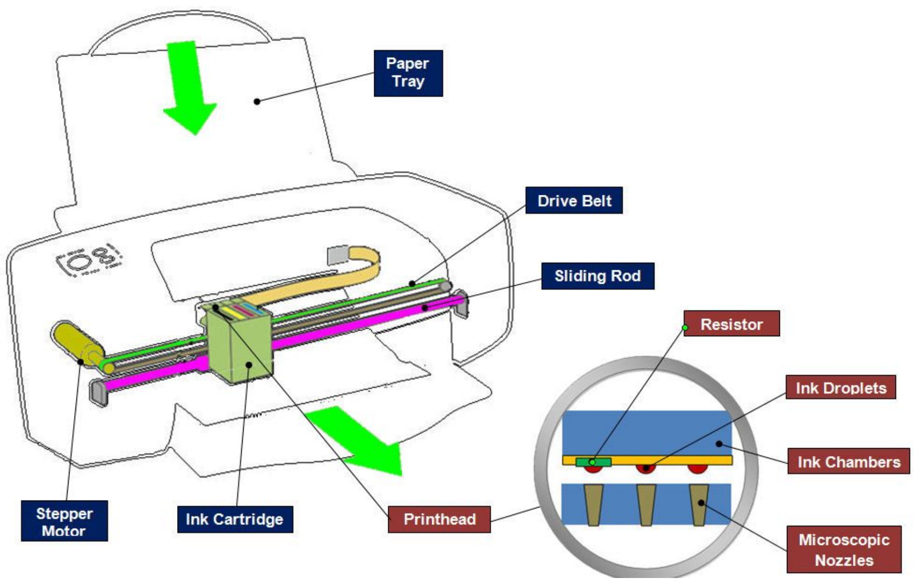

Figure 11: Internals of an Inkjet printer
`pintrest.com`

Data Representation

Binary

Binary is known as a base-2 number system, meaning it is comprised of 0s and 1s. In denary—base-10—, numbers are represented in units by 10^x, creating the tenths, hundredths, and thousandths we know. Instead of using 10, binary uses 2^x. To convert 101 from binary to denary, you must multiply the bit by the appropriate power of 2. For example, 101 can be calculated by $(1 \times 2^0) + (0 \times 2^1) + (1 \times 2^2) = 5$.
To convert 5 back to binary, create a grid with the power of two. As our number is small, I will use 4 bits.

8	**4**	**2**	**1**
-	-	-	-

We must start at the left-most end of the table with our initial number of 5. We then go down each column, if we can subtract our number by the power of 2, we do so and put a 1 in that column, else we put a 0 and move on to the next one.

We shall start by doing $5 - 8$, which will take us below 0. This means we put a 0 into the 8's column and move on.

8	**4**	**2**	**1**
0	-	-	-

Next, $5 - 4$. As this does not take us below 0, we put a 1 in the 4's column. We now repeat this with $1-2$ and then $1-1$ until we reach the end of the table with the binary number 101.

8	**4**	**2**	**1**
0	1	0	1

ASCII

ASCII, the American Standard Code for Information Interexchange, is the standard that assigns different letters, numbers and symbols to a number within an 8-bit range (0-255). The ASCII standard is divided into three sections: non-printable (0-31), lower ASCII (32-127) and higher ASCII (128-255). Lower ASCII contains the basic symbols along with the characters and numbers from the English language. Higher ASCII is programmable and includes characters based on the language of your OS or program.

Hex	Dec	Char		Hex	Dec	Char	Hex	Dec	Char	Hex	Dec	Char
0x00	0	NULL	null	0x20	32	Space	0x40	64	@	0x60	96	`
0x01	1	SOH	Start of heading	0x21	33	!	0x41	65	A	0x61	97	a
0x02	2	STX	Start of text	0x22	34	"	0x42	66	B	0x62	98	b
0x03	3	ETX	End of text	0x23	35	#	0x43	67	C	0x63	99	c
0x04	4	EOT	End of transmission	0x24	36	$	0x44	68	D	0x64	100	d
0x05	5	ENQ	Enquiry	0x25	37	%	0x45	69	E	0x65	101	e
0x06	6	ACK	Acknowledge	0x26	38	&	0x46	70	F	0x66	102	f
0x07	7	BELL	Bell	0x27	39	'	0x47	71	G	0x67	103	g
0x08	8	BS	Backspace	0x28	40	(	0x48	72	H	0x68	104	h
0x09	9	TAB	Horizontal tab	0x29	41	)	0x49	73	I	0x69	105	i
0x0A	10	LF	New line	0x2A	42	*	0x4A	74	J	0x6A	106	j
0x0B	11	VT	Vertical tab	0x2B	43	+	0x4B	75	K	0x6B	107	k
0x0C	12	FF	Form Feed	0x2C	44	,	0x4C	76	L	0x6C	108	l
0x0D	13	CR	Carriage return	0x2D	45	-	0x4D	77	M	0x6D	109	m
0x0E	14	SO	Shift out	0x2E	46	.	0x4E	78	N	0x6E	110	n
0x0F	15	SI	Shift in	0x2F	47	/	0x4F	79	O	0x6F	111	o
0x10	16	DLE	Data link escape	0x30	48	0	0x50	80	P	0x70	112	p
0x11	17	DC1	Device control 1	0x31	49	1	0x51	81	Q	0x71	113	q
0x12	18	DC2	Device control 2	0x32	50	2	0x52	82	R	0x72	114	r
0x13	19	DC3	Device control 3	0x33	51	3	0x53	83	S	0x73	115	s
0x14	20	DC4	Device control 4	0x34	52	4	0x54	84	T	0x74	116	t
0x15	21	NAK	Negative ack	0x35	53	5	0x55	85	U	0x75	117	u
0x16	22	SYN	Synchronous idle	0x36	54	6	0x56	86	V	0x76	118	v
0x17	23	ETB	End transmission block	0x37	55	7	0x57	87	W	0x77	119	w
0x18	24	CAN	Cancel	0x38	56	8	0x58	88	X	0x78	120	x
0x19	25	EM	End of medium	0x39	57	9	0x59	89	Y	0x79	121	y
0x1A	26	SUB	Substitute	0x3A	58	:	0x5A	90	Z	0x7A	122	z
0x1B	27	FSC	Escape	0x3B	59	;	0x5B	91	[	0x7B	123	{
0x1C	28	FS	File separator	0x3C	60	<	0x5C	92	\	0x7C	124	|
0x1D	29	GS	Group separator	0x3D	61	=	0x5D	93	]	0x7D	125	}
0x1E	30	RS	Record separator	0x3E	62	>	0x5E	94	^	0x7E	126	~
0x1F	31	US	Unit separator	0x3F	63	?	0x5F	95	_	0x7F	127	DEL

Figure 12: ASCII Table from 0-127
brainaspinall.com

Integer

An integer is a wholly positive or negative number, including 0. Integers are written without a fractional component. Z represents the set of all the possible integers. Integers are commonly used in mathematical calculations, counting, measuring and computer programming for variable types. Integers can be represented in various ways, for example in base-10, base-2 and base-16. In base-10, integers are represented by a sequence of digits, such as 2701.

Hexadecimal

Hexadecimal—base-16—is a number system that is made up of 16 total symbols: 0-9 and A-F. The letter A represents 10, B represents 11, etc. To convert a hexadecimal number to denary, you must multiply the digit by the appropriate power of 16 (for example, the left-most digit would be 16^0.). To convert $3F$ to denary, $(3 \times 16^1) + (15 \times 10^0) = 63$.
Hexadecimal is often used in programming thanks to its compact nature and because it can represent binary data easier. It is also used for web-safe colour codes.

Control Loop Operations

Control loops are an important part of control systems as they are used to automatically adjust the behaviour of a system to reach a desired outcome. Control loops contain sensors that measure the current state of the system, a control algorithm that uses the measurement and determines the correct action to take, and an actuator to perform the action.

Open Loop Systems

An open loop system does not use feedback from the system to adjust the control action. These systems use a hard-coded algorithm to determine the action to take, ignoring the state of the system. This makes its actions independent of the output of the system. The accuracy of the system depends on how experienced the user is. For example, using an immersion water heater, the heater will keep heating the water regardless of its temperature and it is up to the user to decide when to take it out.

Advantages

- Simple to design and create
- Easier to implement with difficult-to-measure outputs
- More economic

Disadvantages

- Doesn't react to disturbances and changes to what is being measured
- Not reliable

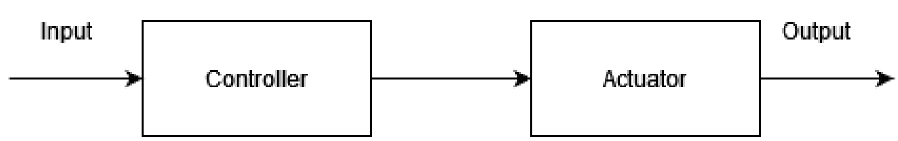

Figure 13: Flowchart of an Open Loop System

Closed Loop Systems

A closed-loop system continuously measures the output and feeds it back to the input to adjust the control action. The control system compares the desired state of the system with the actual state of the system and uses this to adjust the control action. Because of this, the system can react to disturbances and improve its accuracy. For example, using an air conditioner, a temperature sensor is used to turn on or off the cooler depending on how hot or cold the area is.

Advantages

- Better accuracy
- More robust to disturbances
- Flexible responses to the data it is measuring

Disadvantages

- More complex to design and implement
- Sensitive to errors and misreading the factor being measured

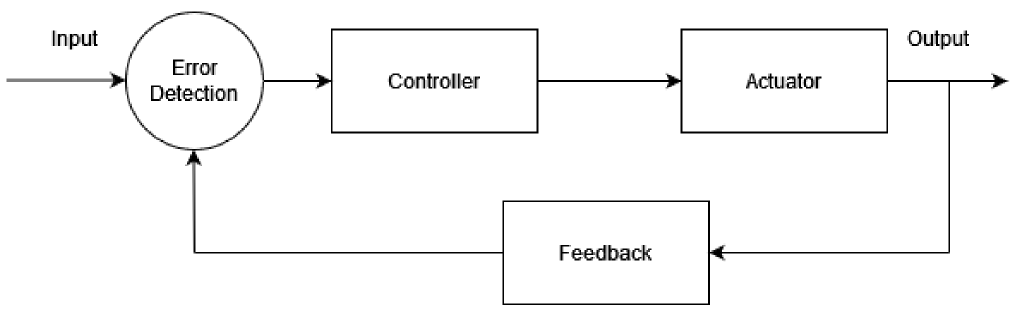

Figure 14: Flowchart of a Closed Loop System

Stages of Control Loops

Step 1: Measurement

A sensor measures a process variable, for example, temperature or pressure.

Step 2: Comparison

The measured value is compared to a set point, which is the desired value of the process variable.

Step 3: Calculation

The error, which is the difference between the measured value and the set point, is calculated.

Step 4: Correction

The control system uses the error to adjust the process in order to reduce the error and bring the process variable closer to the set point.

Step 5: Repeat

The control system repeats the processes continuously to reach the desired set point.

Principles and Uses of Proportional Control

Proportional control is a control strategy that uses a relationship between the control action and the error signal, the difference between the current output and the desired output. The larger the error, the greater the adjustment needed by the system. A common example of a system that uses proportional control.

An example of a system using proportional control is a central heating system. The system is continuously measuring the temperature in a building. If the temperature goes below a certain threshold, the system can automatically turn the heating on and automatically turn off when another threshold is reached. However, this can cause undesired effects such as oscillations and output fluctuation depending on how quickly the temperature is changing.

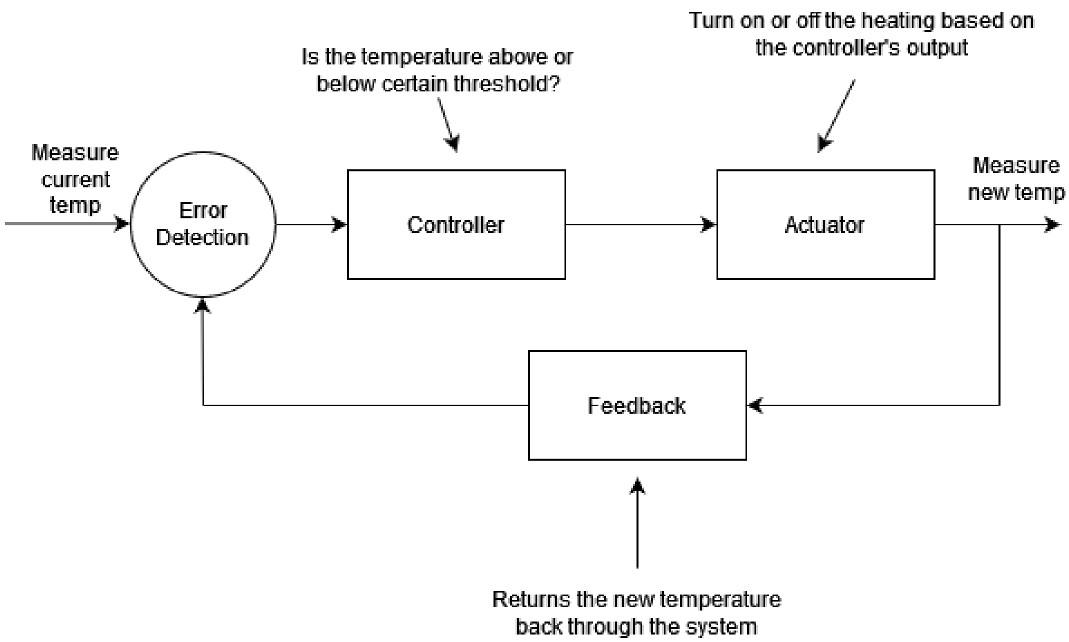

Figure 15: Flowchart of a Central Heating Proportional Control System

Advantages

- Reacts to the factor that is being measured
- Helps reduce a steady-state error

Disadvantages

- The system can have a slow reaction time
- The error can not be eliminated (for example, the temperature cannot be perfectly maintained)