Sensing, Actuating and Processing in the Built Environment - A Beginners Guide to Physical Computing Tools

Original Author: Viswanathan Kumaragurubaran (Autumn, 2011)
Contributions by: Brian Johnson (varies)

Introduction

This document details the commonly available sensing (inputs), actuating (outputs) and processing mechanisms employed in a physical environment in order to sense and react to events in real time. While the conventional applications of these feedback control systems are in consumer and industrial applications, the document primarily concentrates on those tools that may find use in the built environment.
(Ref - http://www.arduino.cc/playground/Main/InterfacingWithHardware)

Vocabulary

Signal: An aspect of the physical environment that changes over time or characterizes a locale. Mostly electromagnetic radiation (light, infra-red, radio). Covers both intentional (cell-phone, GPS) to unintentional (EM radiation from normal wiring) radiation.

Resolution: How much or how often a physical phenomenon changes or can be detected to have changed. Also, how finely something is measured: in wood frame construction dimensions are generally only accurate to ¼ inch, whereas in machining metal parts, dimensions may be accurate to 1/1000 inch.

Sensing Proximity

Definition: Proximity is a measure of how close an object is to a reference or test point. In a typical case, the test or reference point is static in space and the object is dynamic.

Example: Smartphone devices such as the iPhone employ a Proximity sensor near the phone’s ear piece to detect how close your phone is to your ears, enabling or disabling the touch mechanism on the screen surface. This ensures that when the phone is held to the ear, accidental touch inputs are not sent to the phone.

Sensing: Any signal that can be controlled during generation and reception is theoretically capable of detecting proximity. It is important to note that signal resolution is a crucial factor in accurately tracking proximity. Signal resolution is also a factor affecting the scale of proximity sensing. Proximity sensing can vary from a few millimeters to several hundred meters from the reference point.

The output of a proximity sensor is usually a presence (in range) or absence (out of
range). Proximity sensors do not calculate the physical quantity of distance as a number. The “range” value depends on the sensing mechanism. Some common sensing mechanisms are:

1. Infra-red light emitters and sensors
2. Radio Frequency Identification (RFID)
3. Bluetooth
4. Zigbee
5. WiFi
6. GPS
7. Special imagers such as RGBD sensors (Microsoft Kinect)

Each of the above listed sensing methods has various configurations and techniques involving detection of proximity. Some are straightforward implementations (as provided in the Arduino Playground website) or hacks. Through a combination of the above sensors, it is possible to achieve great control and accuracy in detecting proximity.

**Sensing Location**

**Definition:** Location identification is mostly done on a latitude-longitude scale with resolutions of few meters. More recently, a combination of satellite based GPS and mobile network signal assisted positioning known as Assisted GPS positioning has greatly improved performance and accuracy of GPS devices. It is important to note that GPS based location awareness is based on line-of-sight to the satellites and hence do not perform as accurately indoors.

(Ref - http://support.google.com/chrome/bin/answer.py?hl=en&answer=142065  
http://www.docomolabsresearchers-usa.com/~iguvenc/MELT_Workshop_Presentation_v2.pdf)

**Example:** GPS devices are commonly embedded in mobile smart phones. When combined with a maps systems such as Google maps, real time location aware systems are widely used as car navigation systems.

**Sensing:** Location sensing is either static or dynamic in nature. Static location sensing is preferable where one-time access of the test object’s co-ordinates are retrieved based on fixed sensing systems. An example is location sharing feature in modern web browsers. This is achieved by gaining access to the computer’s IP address and surrounding WiFi signal characteristics such as signal strength which is then associated with a database from the browser’s vendor. Dynamic location sensing is important for tracking objects under motion such as vehicles, people, devices etc. Currently, GPS devices and associated electronics are the norm. Depending on the level of accuracy expected, some of the common ways of detecting location are:

1. WiFi
2. GPS
Location sensing is ambiguous in nature owing to the scale of the application. While GPS devices are the most common instruments for outdoor location sensing, it is not certain if there is a reliable method of calculating highly precise indoor location. Approaches combining GPS, WiFi, internal sensor networks to building such as Zigbee and mobile networks are being investigated as one method for indoor positioning and location sensing in real time.

**Sensing Things and People (Presence, Absence and Occupancy)**

*Definition:* This class of sensing is based on object and pattern recognition - both static and dynamic. While proximity sensors may detect the presence or absence of anything capable of reflecting IR light, they are unable to distinguish between the subjects being sensed. Sensing objects and people hence sometimes require special sensors.

*Example:* Sensing presence and absence may take the form of occupancy detection, sensing objects such as furniture, detecting people or objects for the purpose of security etc.

*Sensing:* Since the idea behind sensing presence and absence is to identify unique shapes in the vicinity, a vision based system is the most commonly implemented sensing mechanism. While it is possible to use proximity sensors, the solution may only work under specific circumstances (such as objects of certain shape or size). More generic sensing methods include:

1. Activity logging (such as computer login events)
2. Camera based pattern recognition (including RGBD, thermal and conventional video camera)
3. WiFi
4. Mobile networks
5. RFID - Radio Frequency Identifiers
6. Biometric features (weight, retinal patterns, finger-prints, etc.)

**Sensing Light**

*Definition:* Sensing and measuring light is an extremely complex and elaborate science. It can vary from detecting light intensity to measuring photometric quantities such as luminance or illuminance. For the purpose of documentation, we provide a generic overview of the typical accessible sensing mechanisms.

*Example:* Modern notebook computers and smartphones employ a light sensor that
can measure the brightness of light around the device and attempt to adjust the display brightness. The motivation for this is to achieve a balance between display and ambient brightness so as to provide the best visual comfort for the user. **Sensing:** Depending on the accuracy, resolution and light frequency, the following methods of light sensing are popular:

1. Photocell based sensors
2. Camera (1D and 2D)
3. IR camera (point, 1D and 2D)
4. Photometers

### Sensing Electrical Energy

**Definition:** Energy in the form of transformed and transmitted electrical voltage/current that is used in buildings for industrial, domestic or commercial purposes is broadly defined as electrical energy. This includes alternating current or direct current.

**Example:** Any measurement device that can record electrical units such as voltage, current and thereby the energy and power is an example of electrical energy sensing. This may include simpler analog meters to more modern sensors such as the Opto EMU that have built-in data communication hardware. For more information on a similar system, refer ([http://lmnts.lmnarchitects.com/featured/energy-monitoring-101-open-standards/](http://lmnts.lmnarchitects.com/featured/energy-monitoring-101-open-standards/))

**Sensing:** Electrical energy measurement systems are constructed from a variety of electrical and electronic instruments that work as a control and sensing system. Some common ways of measuring electrical energy are:

1. Manual measurements using voltmeter, ammeter etc.
2. Electronic digital meters
3. Opto EMU
4. Pulse energy
5. Energy hub

### Sensing Sound

**Definition:** Any signal that falls under the category of ‘acoustics’ maybe termed as sound. This may include audible or inaudible (to the human ear) sound.

**Example:** Audible sound energy is ubiquitous. It is usually generated as a vibration of matter - solid, liquid or gas (including air) and detected electrically through microphones. Inaudible sound energy may take the form of ultra-sound or infra-sound. Ultra-sound sender/receiver pairs are highly specialized systems capable of transmitting and detecting ultrasound.
Sensing: Most systems capable of sensing sound are electro-mechanical in nature (those that translate vibration of a medium into electrical signals - also known as transducers). Commonly used sensors are:

1. Microphones - standalone, built-in PCs or Phones
2. Specialized transceivers for ultra-sound and infra-sound

One of the main challenges in sensing audio or sound is to isolate noise from meaningful signal and processing the signal. This is a separate science in itself (Digital Signal Processing).

Sensing Odor/Gas/Chemicals/Fire

Definition: This may include detecting the presence (and sometimes the absence) of certain chemicals or gases that may be infer a hazard.

Example: The most commonly seen sensor in this category is for Carbon monoxide (also sometimes incorrectly referred to as the smoke detector and alarm). Carbon monoxide sensors are mandatory for most buildings and help in detecting harmful and toxic carbon monoxide presence within built spaces.

Sensing: Various sensing mechanisms exist for detecting gases, odor and chemicals. This includes opto-chemical, biomimetic and semiconductor based sensors. Fire detectors or flame detectors are usually optics based with an addition of a thermocouple sensor. Some common sensors for this category are:

1. Gas detectors and analyzers (Optical, Chemical, semiconductor based)
2. Image/Video based
3. IR light based
4. Thermocouple based detectors

Sensing Touch

Definition: Any contact between human skin directed at an arbitrary surface for the purpose of creating a response from the surface maybe classified as touch.

Example: The most popular example of touch screen displays as seen in smartphones, tablets and other similar displays is an example of touch sensing.

Sensing: While capacitive and resistive touch sensing on glass is common, it may be useful to understand and identify techniques that detect touch on arbitrary surfaces. Touch sensing methods may include:

1. Proximity (using IR sensors)
2. Thermal imaging
3. Vision/Camera
4. Capacitive/resistive sensing on glass
5. Depth (using devices such as the Kinect)
6. Microphone
Sensing Temperature

**Definition:** Temperature maybe defined (in this context) as the property of a material to exchange heat with its surroundings. For built environments, ambient temperature sensing is of significant importance to study the effect of occupant comfort and safety.

**Example:** Automatic thermostats include a temperature sensor that automatically evaluates and sets the correct heating or cooling factors in built spaces.

**Sensing:** Multiple methods exist depending on the application for temperature sensing.

1. Thermometers
2. Semiconductor based thermistors
3. Thermostats
4. Thermocouples

Sensing Acceleration

**Definition:** Acceleration is defined as the time rate of change of velocity. It is often related to “g” which is the unit of acceleration equal to the earth’s gravity at sea level. (Ref - [http://www2.usfirst.org/2005comp/Manuals/Acceler1.pdf](http://www2.usfirst.org/2005comp/Manuals/Acceler1.pdf))

**Example:** The most commonly available sensing system for acceleration is the accelerometer built in many smartphones such as the iPhone. While several applications are available that use the accelerometer (such as for gaming), the most obvious example of use is to detect impact. Impact detection is useful when built in laptops that sometimes encounter accidental damage to the hard disk on impact. A built in accelerometer/motion sensor detects such potential impacts and attempts to lock the hard driver so the damage is minimized. (Ref - [http://support.lenovo.com/en_US/research/hints-or-tips/detail.page?LegacyDocID=MIGR-53167](http://support.lenovo.com/en_US/research/hints-or-tips/detail.page?LegacyDocID=MIGR-53167))

**Sensing:** In most cases, it may not be useful to determine an actual absolute value of acceleration. Rather, it is useful to provide a relative measurement of acceleration with respect to the enclosed system. Some sensing methods include:

1. Accelerometers/Tilt sensors
2. Motion sensors
3. Shock sensor

Sensing Flexure (bending)

**Definition:**

**Example:**

**Sensing:**

Sensing Pressure

**Definition:**

**Example:**

**Sensing:**
Scenario of Usage

In order to build a system consisting of one or more combinations of sensors with actuators such as drives and motors it is useful to understand the implementation of a system as applied to a real world scenario.

Objective: To remote control one or many home appliances or gadgets based on an event that maybe determined by an occupant.

Sample Task: Imagine you own a smartphone and drive a car. Every day, when you get back from work at 5:00PM, you like to brew a pot of coffee to get your evening started. Since this is a routine task, consider automating this task as follows:

1. You drive your car from work back home and trigger the garage door to open.
2. This trigger may also initiate a signal (Bluetooth or WiFi) to your smartphone - the content of this signal maybe as simple as an ON or OFF command.
3. The smartphone runs an application that is capable of turning ON or OFF, the coffee pot.
4. Assuming that the smartphone has access to the internet, the ON/OFF command may be transmitted over the network (a possible network interface would be Pachube).
5. This command is received by the always on home network where the coffee machine is ‘hacked’ to turn on or off from the network. (Google turns up several tutorials and examples on how to achieve this with almost no cost).
6. As you enter home, be welcomed by the smell of fresh coffee!

Implementation Guidelines: This may be divided into 3 segments:

1. Sensing
2. Processing and translating information
3. Actuating

The sensing portion of this example is not a conventional signal sensing mechanism. Rather, it is a detection of a click event on the garage door opening remote controller. Many experiments can be tried to achieve this. (Note: These methods assume that the coffee machine is controlled over the internet/LAN)

Hack the remote controller by removing the case and extracting the electrical signal from an OPEN event. This electric signal can be fed as an input to an Arduino controller which hosts a Bluetooth module. Using this combination, it is possible to transmit the OPEN command as a Bluetooth command to the smartphone (which in turn may communicate the command over the internet to the coffee machine).

Hack the garage door opening mechanism (the motors, electronics etc.) and include a custom Bluetooth or WiFi receiver hosted on an Arduino controller - which may in turn issue commands to the coffee machine over WiFi/wired LAN connections. This
shield may accept any custom commands from a remote device. The garage door opener remote controller maybe replaced by the smartphone (your smartphone is the door opener) which may transmit commands over Bluetooth or WiFi to the hacked garage door opening mechanism and eventually also transmit similar commands over the internet to the coffee machine.

Hardwire a communication channel from the door electronics to the coffee machine over Ethernet. By hacking the electronics on the garage door with an Arduino + Ethernet shield and tracking a ‘door open’ command, the Ethernet shield may transmit commands to the coffee machine (through wired or wireless interface). One the signal has been detected, it is necessary to process and translate this into a meaningful communication protocol. An easy and convenient method is to use Pachube.com service (also known as the internet of things). Pachube is an internet based database storage and data translation service targeting energy monitoring and building sensor networks. (Other similar services include ioBridge.com, open.sen.se, Homesense: Keyword for search – internet of things). Once the registration process is complete, the Pachube Dashboard is a possible app that can be used in this context (http://apps.pachube.com/dashboard/create.php). The Dashboard provides a ‘cloud’ based switch that can be controlled from anywhere (in this case, the Pachube inputs arise from the phone). The switch status can be accessed from any location and device that is aware of the Pachube feed details.

In order to access the Pachube feed from home, the coffee maker must be connected virtually to the Pachube switch. A hardware translation is required from the internet based switch status signal and the coffee machine. This can possibly be achieved through an Arduino controller and the Pachube-Arduino interface (http://community.pachube.com/arduino). The Arduino is capable of receiving the switch status and using a digital IO control to a relay switch (or FET based switch), the coffee machine can be turned ON or OFF.

Resources

http://store.arduino.cc/ww/index.php; Amazon.com;