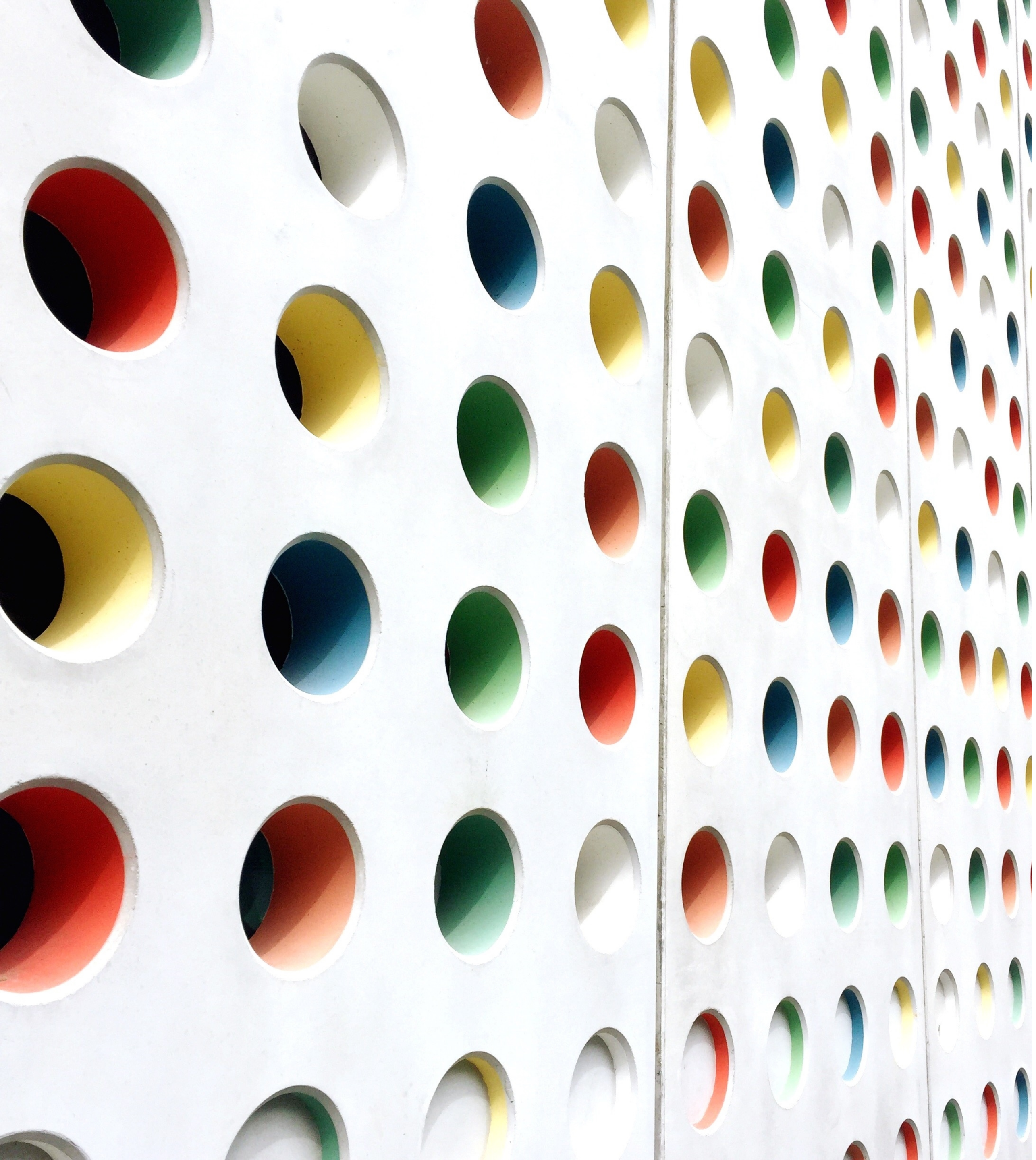

Things: The Technology of Connected Devices

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Agenda

- The different types of IoT device, and the technology they contain
- How sensors and actuators bridge the physical and digital worlds
- The challenge of powering IoT devices and how this shapes the technology

Issues to be addressed

- How the computer hardware and software technology inside specialized embedded devices—the novel devices of the Internet of Things—differs from multipurpose computers.
- How objects with no onboard computing power can nonetheless have an Internet presence.
- DESIGNING CONNECTED PRODUCTS • How sensors can be used to gather data from the physical world•
- How actuators can be used to translate digital commands into realworld actions
- Why energy conservation is at the root of many UX design constraints in IoT

Types of Connected Device

Connected devices can take a number of forms, and are typically one of the following:

- Multipurpose computers
- Specialized embedded devices
  - Embedded Hardware
  - Embedded Software
- Connected sensors
- Passively trackable objects

Types of Connected Device

Most systems will be composed of multiple types. For example, a connected home system may have:

- A control interface on a smartphone (multipurpose computer)
- Heating/ventilation/air conditioning (HVAC) controller, remote control door locks, and blind controllers (specialized embedded devices)
- Security sensors such as motion and contact sensors (connected sensors)

Summary of connected device types

	MULTIPURPOSE COMPUTER	SPECIALIZED EMBEDDED DATA	CONNECTED SENSOR	PASSIVELY TRACKABLE OBJECT
User interaction	Rich onboard interaction capabilities (e.g., through screens and keyboards)	May have limited inputs/outputs; advanced interactions handled via web/mobile apps	Via web/mobile apps	Via web/mobile apps
Functionality	Generalized; can run wide range of applications	Specialized for specific functions	Single task	Identity only
Processing	Powerful onboard processor	Onboard processor, with some functions provided by cloud service	Mostly in cloud service	In cloud service

Multipurpose Computers

- These are powerful computers designed to perform a variety of computing tasks.
- They are no longer just PCs, but also smartphones, tablets, and now arguably connected TVs, set-top boxes, and game consoles.
- They have *rich interaction capabilities*, via screens, audio, touch input, keyboards, mice, and sometimes voice and gestural interfaces, too.
- They *contain powerful microprocessors* with external chips for memory and peripheral interfaces, such as networking.
- We don’t think of these as belonging to the category of IoT devices, but they are often used to handle user interactions for IoT services

Embedded Devices

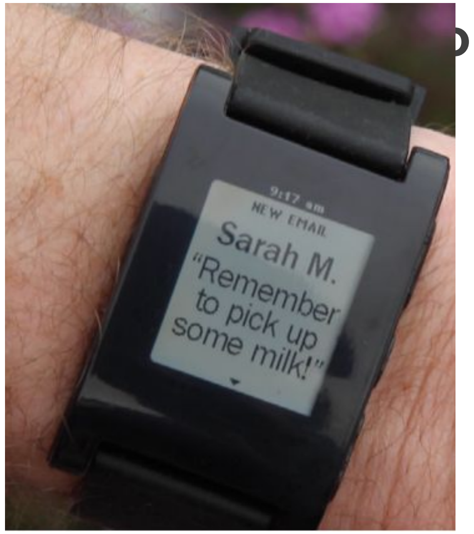
- The most novel and iconic devices of the Internet of Things: the *thermostats, bathroom scales, and even plastic rabbits.* These are all embedded devices.
- Because embedded devices are specialized to do specific jobs, they can do those jobs more reliably and more efficiently than a general-purpose computer system despite having less power.
- For example, an embedded computer controlling your car brakes can guarantee that it would release and activate the brakes at exactly the right intervals needed to prevent you losing control (this is an example of a real-time system).

Advantages – Embedded Devices

- Embedded systems may need to meet far more stringent operating criteria than general-purpose computers, especially if they are located in inaccessible places or controlling safety-critical systems.
- They may need to work in *harsh environmental conditions* (such as down an oil well), conserve electrical power very efficiently to run for years on a tiny battery (as in an environmental sensor), run for years without errors (as in anti-lock car brakes or a nuclear reactor), and potentially recover themselves from failures when human intervention isn't possible (as in an undersea cable).
- They are also often devices that we expect to set up and largely forget about, such as home boilers/furnaces, which we don't want to have to maintain or reboot regularly

Advantages - Embedded Devices

Embedded devices may connect directly to the Internet (as the Nest controller does, over WiFi). They may connect indirectly via a smartphone or hub/gateway device (as many home automation systems do). Gateways, and the different ways that



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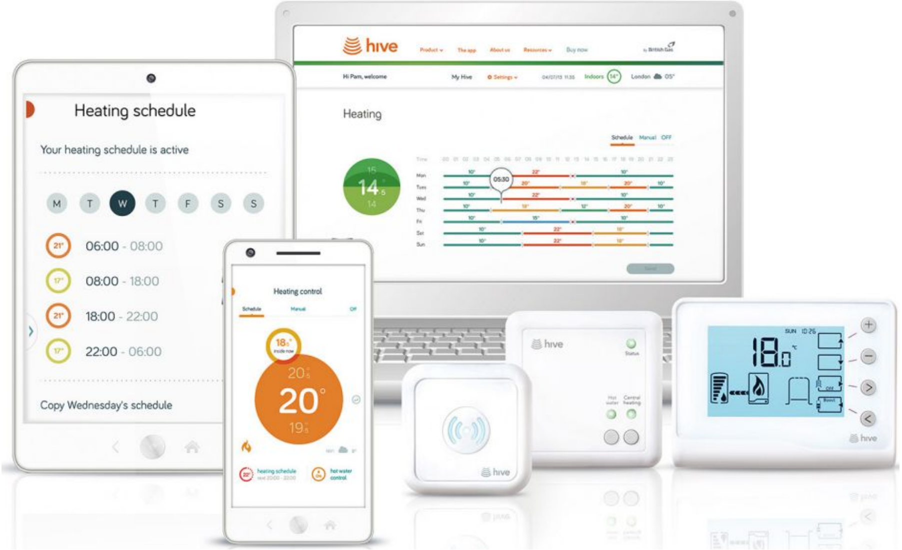


The Pebble Smartwatch connects to a smartphone to display app notifications on the wrist; it can also run apps of its own, such as displaying Evernote notes

The Hive thermostat can be remotely controlled by mobile and web apps; it connects to the Internet via a dedicated gateway device

Embedded Devices

Nest's thermostat learns how the home's occupants set their heating manually, uses motion and light sensors to detect when the home is occupied, and uses, this data to optimize the heating schedule and settings; controls are available on the device or via a smartphone app and web service

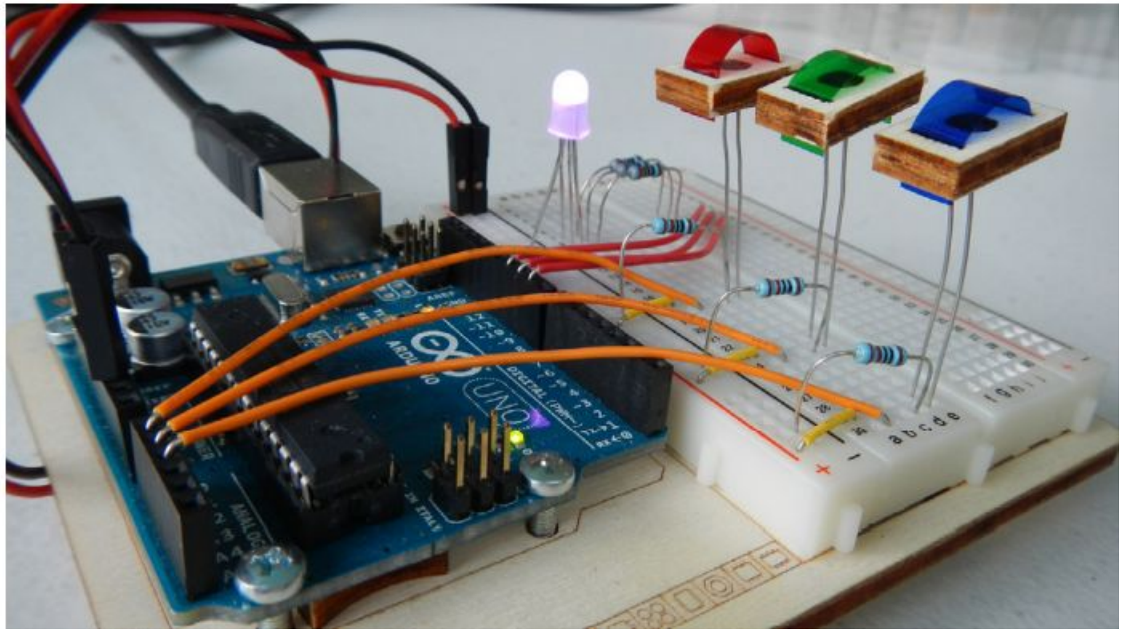
Embedded Devices

The Withings Smart Body Analyzer bathroom scales transmit weight readings over WiFi to an Internet service for users to track their weight using a smartphone app

The Nabaztag—one of the earliest consumer IoT devices—was a rabbit-shaped ambient device that could read out email and information from Internet services

Embedded Hardware

In IoT forums, you may often hear the names of some of the common microcontrollers/systems used in prototyping and building IoT devices, such as *Arduino, Beaglebone, Electric Imp, Raspberry Pi and ARM mBed.*



Arduino is a popular range of microcontrollers used in IoT prototyping and is designed to be accessible to newcomers to hardware prototyping; this image shows an Arduino Uno used to create a color-mixing lamp

Embedded Hardware

http://www.arduino.cc

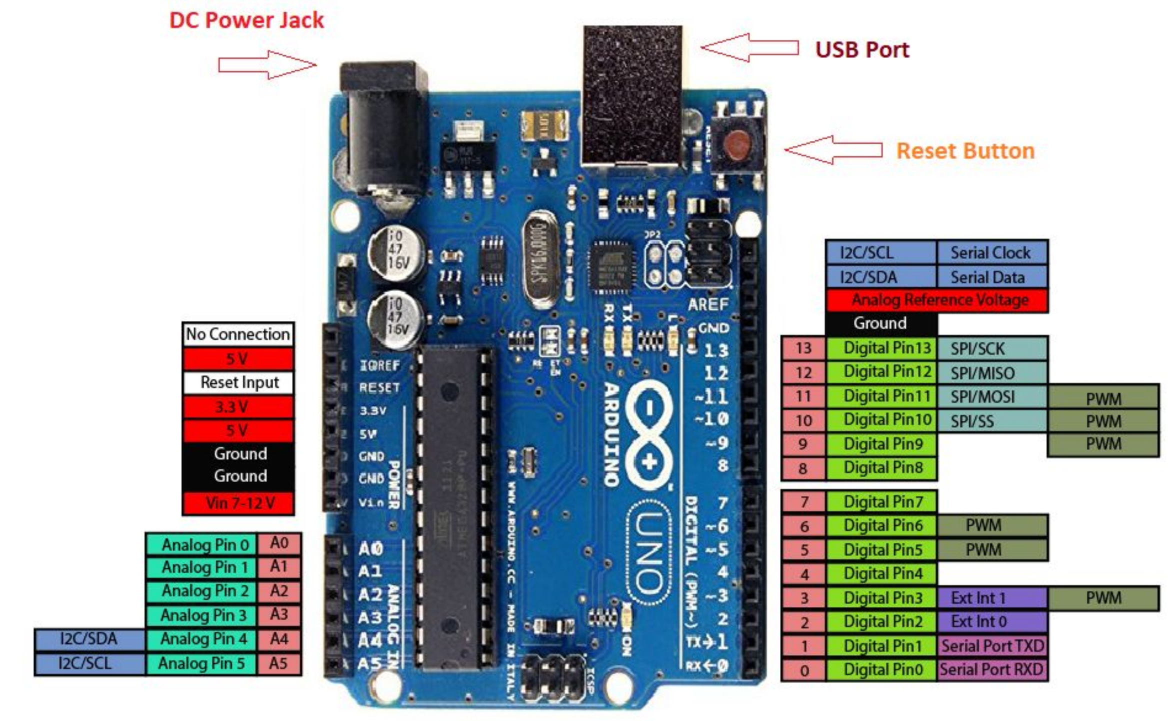
http://beagleboard.org/bone

https://electricimp.com

https://www.raspberrypi.org

https://mbed.org

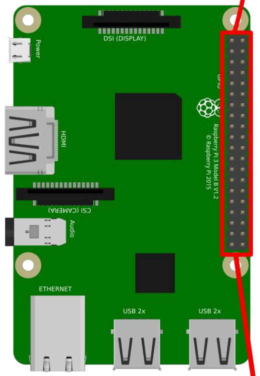
Arduino



Arduino Uno Pinout

www.TheEngineeringProjects.com

Raspberry pi



3.3V PWR	1	2	5V PWR
GPIO2 (SDA1 , I2C)	3	4	5V PWR
GPIO3 (SCL1 , I2C)	5	6	GND
GPIO4 (GPIO_GCLK)	7	8	(UART_TXD0) GPIO14
GND	9	10	(UART_RXD0) GPIO15
GPIO17 (GPIO_GEN0)	11	12	(GPIO_GEN1) GPIO18
GPIO27 (GPIO_GEN2)	13	14	GND
GPIO22 (GPIO_GEN3)	15	16	(GPIO_GEN4) GPIO23
3.3V PWR	17	18	(GPIO_GEN5) GPIO24
GPIO10 (SPI0_MOSI)	19	20	GND
GPIO9 (SPI0_MISO)	21	22	(GPIO_GEN6) GPIO25
GPIO11 (SPI0-_CLK)	23	24	(SPI_CE0_N) GPIO8
GND	25	26	(SPI_CE1_N) GPIO7
ID_SD (I2C EEPROM)	27	28	ID_SC (I2C EEPROM)
GPIO5	29	30	GND
GPIO6	31	32	GPIO12
GPIO13	33	34	GND
GPIO19	35	36	GPIO16
GPIO26	37	38	GPIO20
GND	39	40	GPIO21

Beaglebone

Beaglebone Black Pinout Diagram

P9

Function	Physical Pins		Function
DGND	1	2	DGND
VDD 3.3 V	3	4	VDD 3.3 V
VDD 5V	5	6	VDD 5V
SYS 5V	7	8	SYS 5V
PWR_BUT	9	10	SYS_RESET
UART4_RXD	11	12	GPIO_60
UART4_TXD	13	14	EHRPWM1A
GPIO_48	15	16	EHRPWM1B
SPIO_CSO	17	18	SPIO_D1
I2C2_SCL	19	20	I2C_SDA
SPIO_DO	21	22	SPIO_SLCK
GPIO_49	23	24	UART1_TXD
GPIO_117	25	26	UART1_RXD
GPIO_115	27	28	SP11_CSO
SP11_DO	29	30	GPIO_112
SP11_SCLK	31	32	VDD_ADC
AIN4	33	34	GND_ADC
AIN6	35	36	AIN5
AIN2	37	38	AIN3
AIN0	39	40	AIN1
GPIO_20	41	42	ECAPWMO
DGND	43	44	DGND
DGND	45	46	DGND

LEGEND
Power, Ground, Reset
Digital Pins
PWM Output
1.8 Volt Analog Inputs
Shared I2C Bus
Reconfigurable Digital

P8

Function	Physical Pins		Function
DGND	1	2	DGND
MMC1_DAT6	3	4	MMC1_DAT7
MMC1_DAT2	5	6	MMC1_DAT3
GPIO_66	7	8	GPIO_67
GPIO_69	9	10	GPIO_68
GPIO_45	11	12	GPIO_44
EHRPWM2B	13	14	GPIO_26
GPIO_47	15	16	GPIO_46
GPIO_27	17	18	GPIO_65
EHRPWM2A	19	20	MMC1_CMD
MMC1_CLK	21	22	MMC1_DAT5
MMC1_DAT4	23	24	MMC1_DAT1
MMC1_DATO	25	26	GPIO_61
LCD_VSYNC	27	28	LCD_PCLK
LCD_HSYNC	29	30	LCD_AC_BIAS
LCD_DATA14	31	32	LCD_DATA15
LCD_DATA13	33	34	LCD_DATA11
LCD_DATA12	35	36	LCD_DATA10
LCD_DATA8	37	38	LCD_DATA9
LCD_DATA6	39	40	LCD_DATA7
LCD_DATA4	41	42	LCD_DATA5
LCD_DATA2	43	44	LCD_DATA3
LCD_DATA0	45	46	LCD_DATA1

Embedded Software

Software for embedded systems is *designed to make efficient use of limited resources*. If you want to change the way the device works, you need to *overwrite* the firmware.

**Some Whirlpool laundry appliances featured USB ports to enable users to
upgrade the firmware and add new wash programs**

Embedded Software

- **A more complex device may have a *specialist embedded operating system* and be able to run multiple programs, as desktop operating systems are used to run applications.**
- **For example, an OS can manage access to system resources, like the processor or network, if different applications may require them at the same time.**
- **An OS also provides flexibility to change the functionality of the device without reinstalling all the software.**
- **Real-time operating systems, such as VxWorks, QNX and RTLinux, are used where time-sensitive processing is needed.**

Connected Sensors

- Connected sensors are small embedded devices used for *capturing data from the physical world, and passing this to a networked service.*
- Although technically a class of embedded device, they tend to be used and experienced in a different way as part of the Internet of Things.
- They generally have no onboard user input or output capabilities. So there are no knobs or pushbuttons, and the only way to know what they are doing is via a display on another devi

Connected Sensors

The focus of the UX is not on the devices, but on the data that is captured and the service that the data enables

The NetAtmo Weather Station sensors measure temperature, humidity, air quality, and atmospheric pressure; there are no onboard user interaction capabilities on the sensors, but data can be viewed via smartphone or web apps

Connected Sensors

They are often deployed in networks of multiple sensors (in which they may be called “sensor nodes”).

A large-scale example such as a network of air quality sensors may have hundreds or thousands of nodes; a smaller-scale example might be a set of home alarm motion/contact sensors. Single sensors may also be practical in some circumstances, such as the Proteus in-body pill sensor, which can be used to detect whether a patient is taking their medication.

Connected Sensors

It may be possible to pass simple instructions to the sensor over the network (e.g., to control how frequently readings are sent), or the sensor may only be capable of pushing data to the network and may not be able to receive instr

The Proteus smart pill contains a tiny sensor—it has no battery, but is activated by contact with stomach acid, sending a small transmission to a Bluetooth enabled skin patch, which in turn connects to a mobile phone and notifies relatives or doctors via an Internet service that a pill was taken

Passively Trackable Objects

A “thing” can have a simple presence on the Internet without actually having an Internet connection. Passively trackable objects have a unique identity that is associated with information about them online, but are not themselves connected to the Internet.

RFID and NFC Simple objects, which need not have any onboard computing at all, can be identified via radio-frequency identification (RFID) or a quick response (QR) code. This unique ID allows the user to access information about the object online.

In terms of data storage, there are two types of RFID:

Read-only RFID tags These tags have just enough storage for a unique identifying number, which is associated with more detailed product information in a database, probably on the Internet. If you want to change any of the product information, you'll have to do so in the database, as you can't overwrite the data on the tag.

A read-only RFID tag of the type used in pet ID chips

Read/write tags These can be overwritten with changing information, so you don't necessarily require Internet access to retrieve meaningful information from the tag.

RFID tags can operate on different radio frequencies:

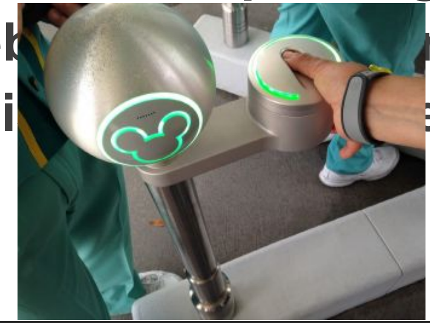
- Higher-frequency tags are capable of transmitting over a longer range, lower-frequency tags transmit over a shorter range.
- A shorter range is preferable when the tag should be read as the result of an explicit user interaction, such as swiping a smart card or scanning a product label. You don’t want to read the same tag twice, or accidentally read another nearby tag instead.
- A longer range … suited to tracking a number of items over a larger area

The London Oyster travelcard uses short-range read/write RFID to store local information about the cash or tickets stored on the card

Applications of RFID

- RFID is commonly used in inventory management, to track stock levels in stores and at suppliers. For example, the UK department store Marks and Spencer was an early pioneer of RFID for inventory tracking, using it to keep track of the numbers of each item in each store with the aim of matching supply to customer demand.

- RFID is also commonly used for contactless ticketing and payments, such as debit and credit cards. Disney theme parks issue RFID tickets and wristbands, which visitors swipe to gain access to attractions. The tickets can store data about preb ns and track the movement of visitors around the parks, helping Di erstand visitor behavior.



The Disney MagicBand wristband, which provides access to attractions and can be used to pay for purchases in the park, helps Disney better understand visitor behavior

Near field communication [NFC]

- Near field communication (NFC) uses the same standard as some shorter-range RFID tags, but evolves it. An NFC-enabled device (e.g., a smartphone) can behave both like an RFID tag (and be read by a reader) or like a reader.
- RFID uses many different data formats, so different RFID devices cannot necessarily interoperate. A key advantage of NFC is that it provides a single common data format—the NFC Data Exchange Format, or NDEF—which can allow all kinds of NFC enabled devices and tags to share data

Near field communication [NFC]

NFC-enabled smartphones are often used for contactless payments from mobile devices. NFC permits two-way communication between devices, and a potentially interesting application for IoT is in making it easier to set up network connections between other devices. Android Beam uses NFC to streamline the process of setting up a temporary Bluetooth connection between two devices to share data such as a photo or contact

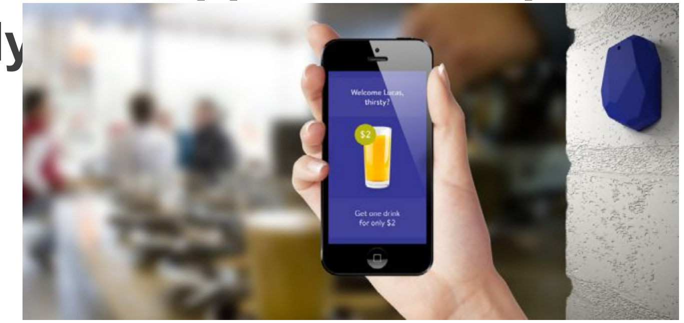
Samsung S Beam uses NFC to establish WiFi connections between smartphones

QR codes

QR codes are a very basic way to give a physical device a digital identity. These are two-dimensional barcodes, which can be read by any imaging device able to extract the data encoded in the image, such as a smartphone. Like read-only RFID tags, QR codes rely on the code being mapped to more extensive product information in a database

Beacons

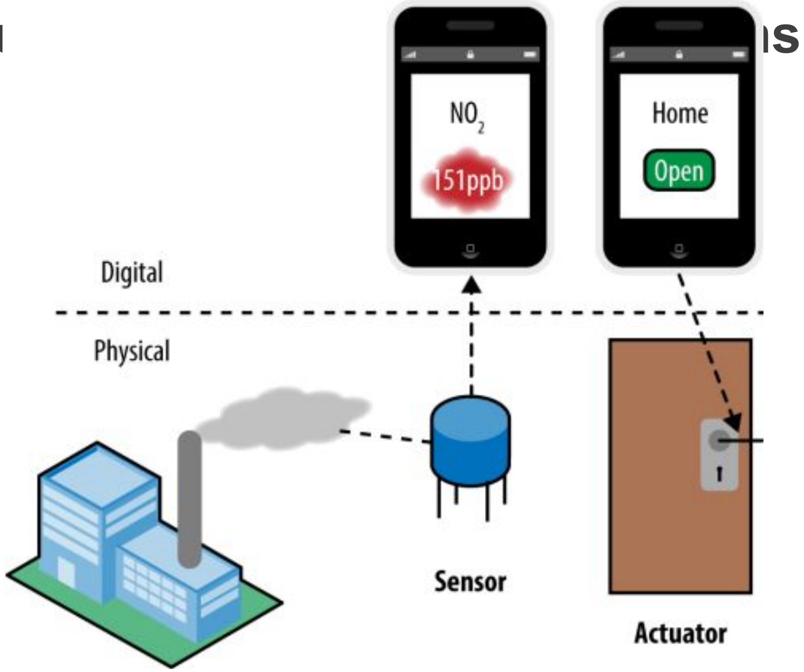
- Beacons use Bluetooth Low Energy to broadcast a unique ID that can be received by nearby Bluetooth-enabled devices, such as smartphones.
- The phone looks up the beacon’s ID in an online database, which provides information such as who owns the beacon, and exactly where it is. The strength of the radio signal between the beacon and phone helps determine how far the phone is from the beacon.
- Beacon-enabled apps on the phone can then use that information to provide contextually



entering a favorite department store might trigger the loyalty app on your phone to notify you of a special offer or discount voucher

Bridging Physical and Digital: Sensors and Actuators

Sensors and actuators are the device components that bridge the Internet and the physical world. Sensors convert energy readings from the physical environment into numeric values that can be transmitted digitally. Actuators convert digital instr ns.



Sensors convert readings from the physical environment into digital information; actuators convert digital instructions into mechanical actions

SENSORS

Sensors receive inputs from the physical world (e.g., motion, light, air quality, contact, location, proximity, humidity, orientation, etc.). They detect the presence of energy or changes in energy and quantify it, producing a numeric value.

A digital thermometer usually converts heat energy to a voltage, and then quantifies the voltage as a temperature reading. Similarly, a photosensor might convert light energy to a voltage then output a numeric reading

Types of Sensors

Two types of Sensors:

- **Active Sensors**
- **passive Sensors.**

Active sensors

Active sensors inject energy into the environment to detect changes of some sort.

The Samsung Galaxy S5 has an active sensor that can be used to measure heart rate; it fires a red light through the user's finger, using changes in light level to measure changes in blood flow that indicate a pulse

Passive sensors

Passive sensors detect energy that is already there. The motion detection systems used in stores (or to protect priceless museum exhibits in heist. movies) use beams of light shone across a room at photosensors: when something (such as a robber) breaks the beam, the sensor measures the loss of light.

Applications of Sensors

Motion detectors used in home security alarms tend to be passive infrared sensors: human beings radiate infrared energy with a wavelength of around 9–10 micrometers, so alarm sensors are tuned to respond to rapid changes on this wavelength that indicate a person moving around. (Slower changes might simply mean that the room is warming up as the sun moves around.)

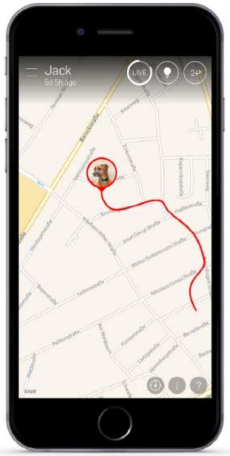
The Dropcam connected camera contains a passive infrared sensor to detect motion

Applications of Sensors

Some sensors measure the presence of chemicals. An air quality sensor might measure harmful volatile organic compounds (VOCs), such as benzene from car exhaust, by detecting changes in conductivity caused by the chemicals reacting with the surface of the sensor.

Applications of Sensors

Location sensing is commonly used in applications for mobile devices. A GPS receiver calculates its position by timing transmissions received from GPS satellites. The tiny compasses found in mobile phones use magnetic field sensing to tell which direction is north. Bluetooth beacons, described earlier, can be used to enable indoor location detection based on the proximity and signal strength of the beacons.



Tractive pet trackers track the location of your cat or dog using GPS

Applications of Sensors

Accelerometers measure acceleration based on vibration. They are often used in mobile phones and tablets to detect screen orientation and present the UI in landscape or portrait mode. Some alarm clocks use accelerometers to identify the best time to wake the user. The clock is placed on the mattress and detects differences in the sleeper's movement during different sleep phases, waking them during light sleep.

The Wii Remote uses an accelerometer to detect rotation; the WiiMotionPlus (the attachment on the bottom) adds a gyroscope for more accurate movement detection—this is used in many sports games and for more "realistic" sword fighting in "The Legend of Zelda: Skyward Sword"

ACTUATORS

Actuators provide the means for a digital system to act on the environment. They convert electrical energy into mechanical energy, producing movement in the real world. This might control a motor, or simply turn something on or off. Connected door locks, ceiling fans, and window shade motors are all examples of consumer actuators. Even bubble machines used as actuators

The Danalock connected door lock allows users to lock and unlock a door from
a smartphone

The Fortrezz water shutoff valve can be programmed and controlled remotely via a home automation app

The Bubblino Internet-connected bubble machine is a fun example of actuation: it watches Twitter and turns on the machine to blow bubbles when it sees a particular hashtag

The Challenge of Powering Devices

One of the key considerations in the technical design of a connected device is how it gets, and uses, power. This can have a fundamental impact on the functionality of the system and the user experience.

Conserving Battery Life

Many embedded devices and connected sensors run on batteries.

This may be because:

- **They need to be portable •**
- **They need to work where mains power is not available (e.g., outdoors or underwater) •**
- **It makes them easier to install (avoiding the need to rip holes in your walls or call out an electrician) •**
- **It's not safe to run mains power to their location (e.g., the device that takes readings from smart gas meters runs on a battery, as it's not safe to run a power line near a gas pipe)**

Conserving Battery Life

Many sensors are small, so will have only tiny batteries, capable of holding limited energy. As mentioned earlier, some devices may run on energy harvesting from the environment, such as solar or wind power, but this can be unreliable (it’s not always sunny or windy). A few may be able to generate enough power from a user interaction—for example, pressing a switch could generate a tiny amount of power from a piezo crystal that might be enough for a tiny data transmission

The Philips Hue Tap light switch is powered by kinetic energy generated when the switch is pressed

Conserving Battery Life

- Processing data and connecting to networks drains energy.
- Devices that need to conserve energy need to do as little processing and as little talking to the network as possible.

Powering Devices Creates Ux Challenges

- UX designers don't normally have to concern themselves with the electricity consumption of devices. But, in IoT, the secondary effects of trying to conserve energy consumption ripple all the way up to the UI level.
- Devices often connect only intermittently. That means that communications are essentially asynchronous: it may take time for a message to reach all the devices in a system. Some data may be out of date or missing, and in some cases, different devices will give you different information about the status of the system. Whether and how much this matters depends on the type of service you're building.
- Power consumption is often at the root of some of the responsiveness challenges that IoT services pose for UX designers: intermittent connectivity and asynchronous communications