Context-Aware Energy Saving in Smart Home

台大電機系/資工系
傅立成

Outline

- Backgrounds
  - Smart Home Technologies and Applications
- Main Topic
  - Energy Saving in Smart Home
- Course Activity
  - Designing Home Energy Saving Scenarios
- Conclusion

History of Smart Home Technologies

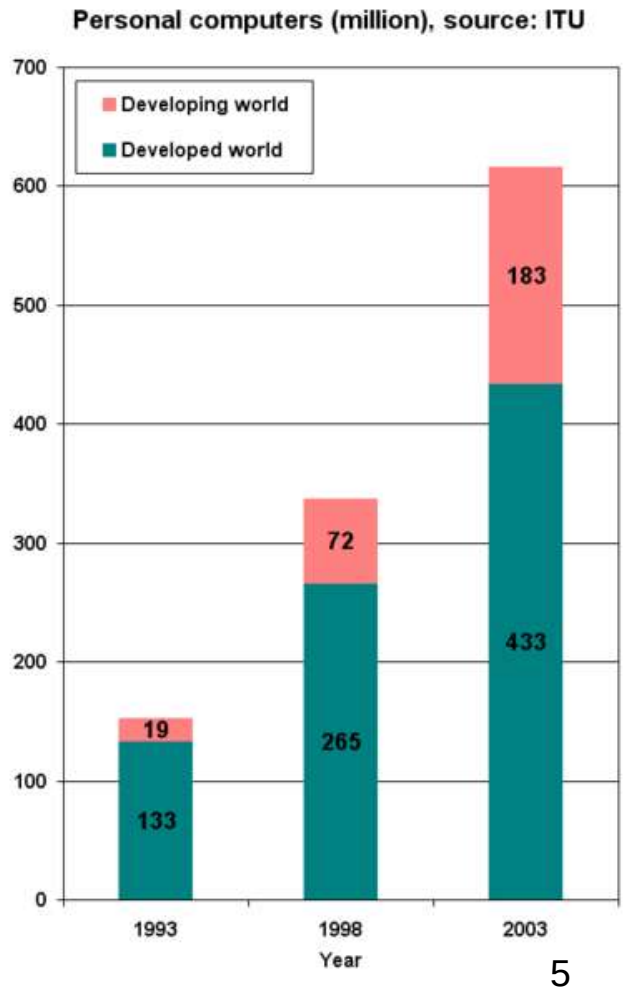
- Before 1940: Smart Home is a “dream”
  - “House of Tomorrow” in Chicago World’s Fair
  - 12 sides, 3 stories (層), built-in dishwasher, electric lights, central air conditioning, passive solar heating, car and plane garage.

History of Smart Home Technologies

- 1960: TV and electronic appliances become popular in all homes

History of Smart Home Technologies

- 1980s: The coming of information age
  - Widespread use of personal computers in home

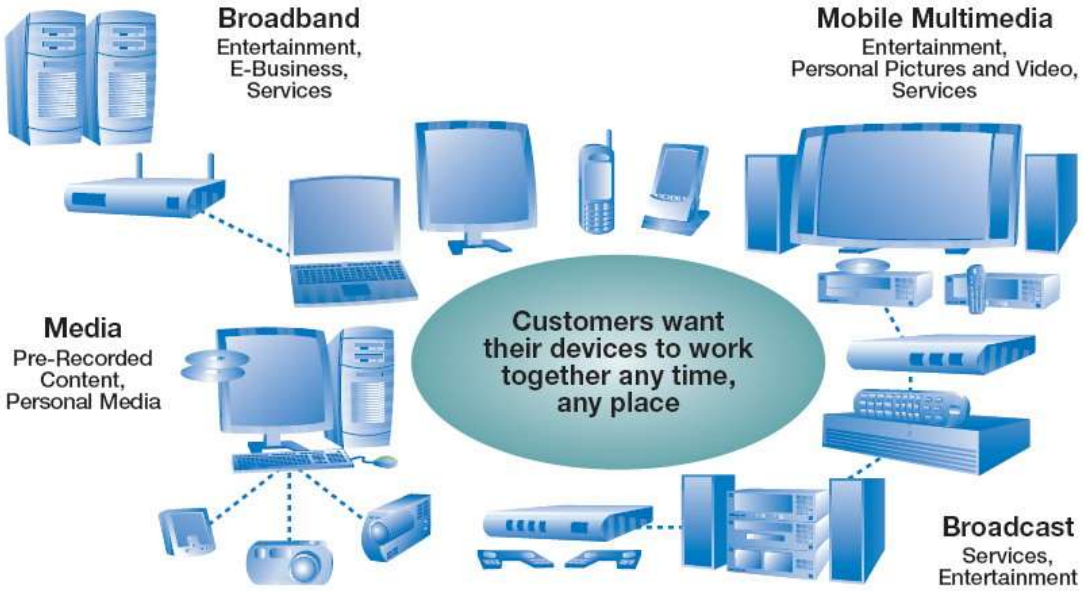


History of Smart Home Technologies

- 1980s – 1990s: Home Automation
  - Appliances are made controllable, programmable, or even schedulable
  - A great deal of standards and protocols are proposed
    - E.g. X.10, LonWorks, UPnP, …etc.

History of Smart Home Technologies

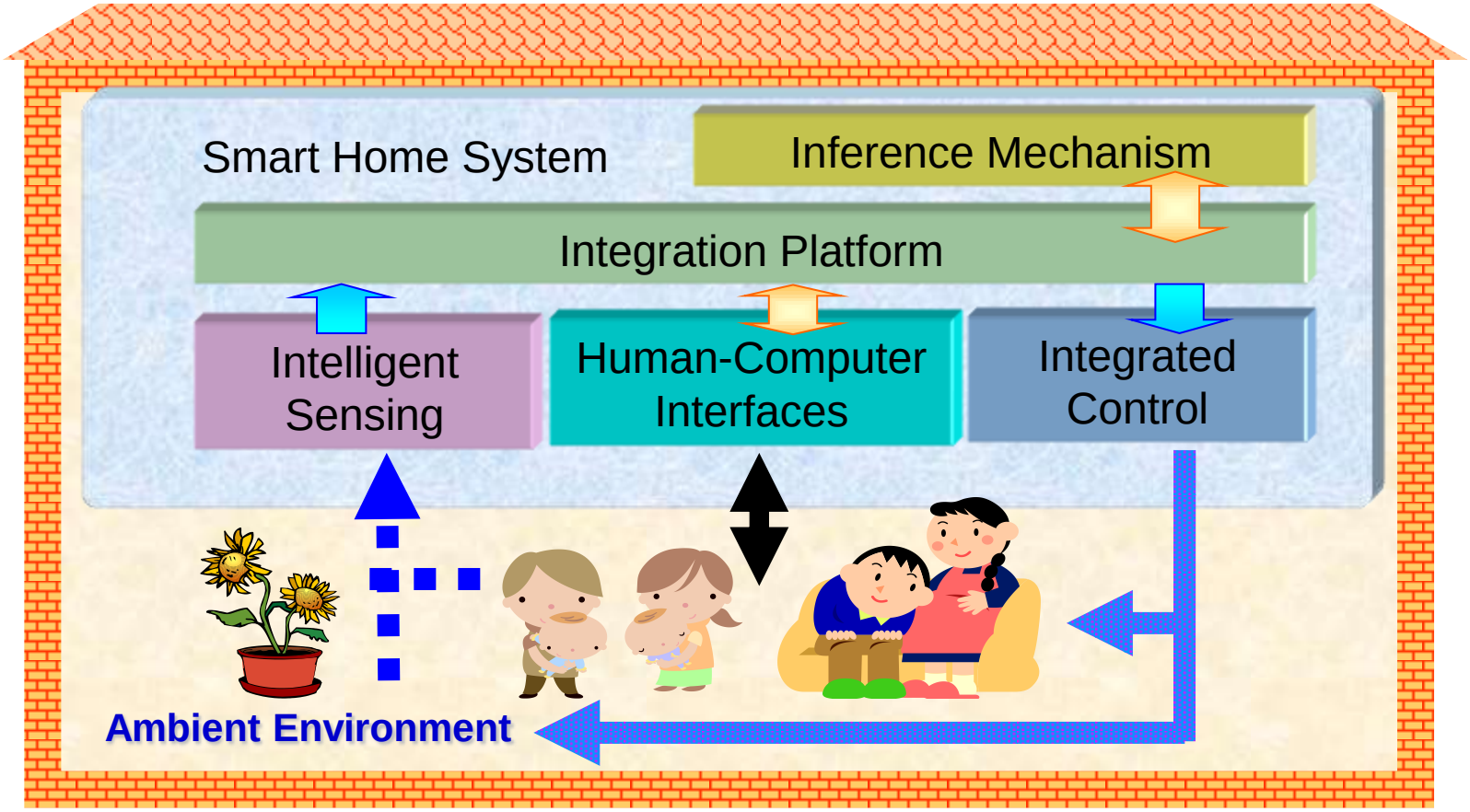
- 2000s: Digital Home (driven by network technologies)
  - All appliances are interconnected by home network
  - Facilitating remote access of digital content



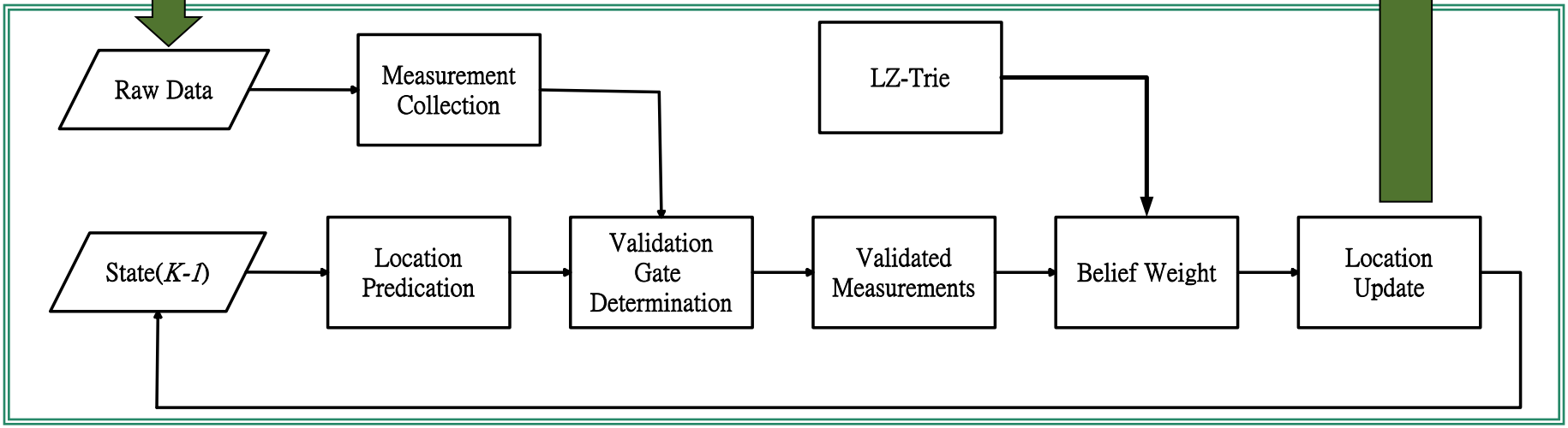
Current Trend: Smart Home

- Key Features
  - Context-Aware
    - Gather ambient information using sensors
    - Deduce contexts from sensor data
    - Infer users' needs from contexts
  - Adaptive
    - Adjust appliance states to fulfill users' needs
  - Interactive
    - Interact with inhabitants based on natural user interfaces such as speech, gesture, …etc

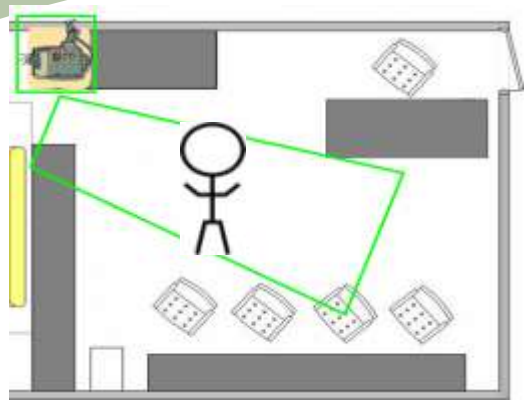
A Typical Smart Home Architecture



Intelligent Sensing: Smart Floor

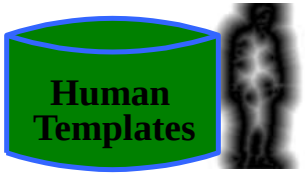


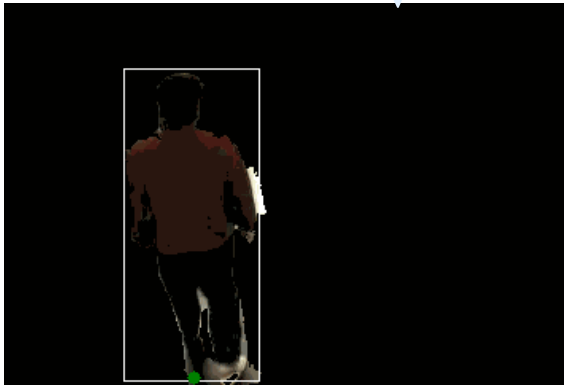
Intelligent Sensing: Camera-based Human Tracking



Foreground Detection

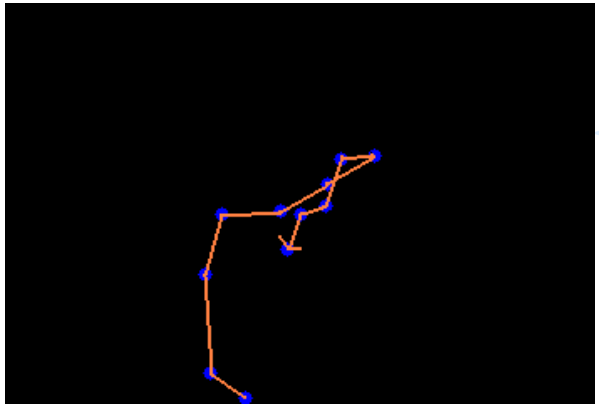
Human Recognition





Perspective Transformation

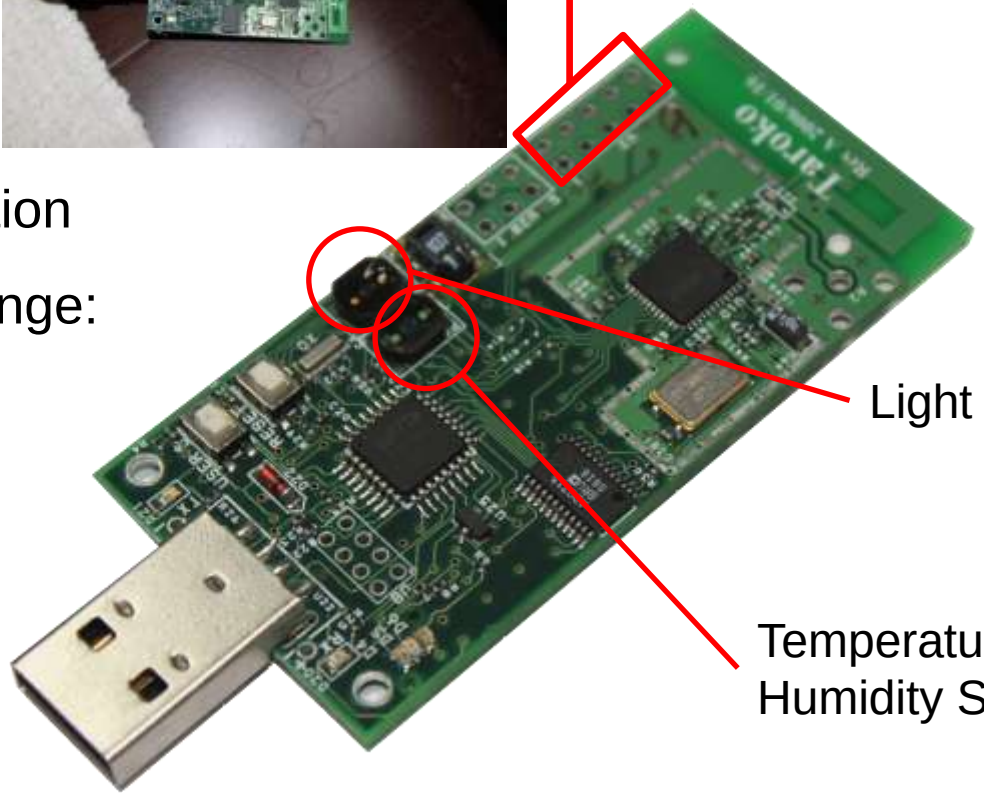
Camera Calibration



Wireless Intelligent Sensing Device

- NTU Taroko
  - MSP430
  - CC2420-802.15.4
  - 250kbps 2.4GHz
  - Low energy consumption
  - Radio transmission range:

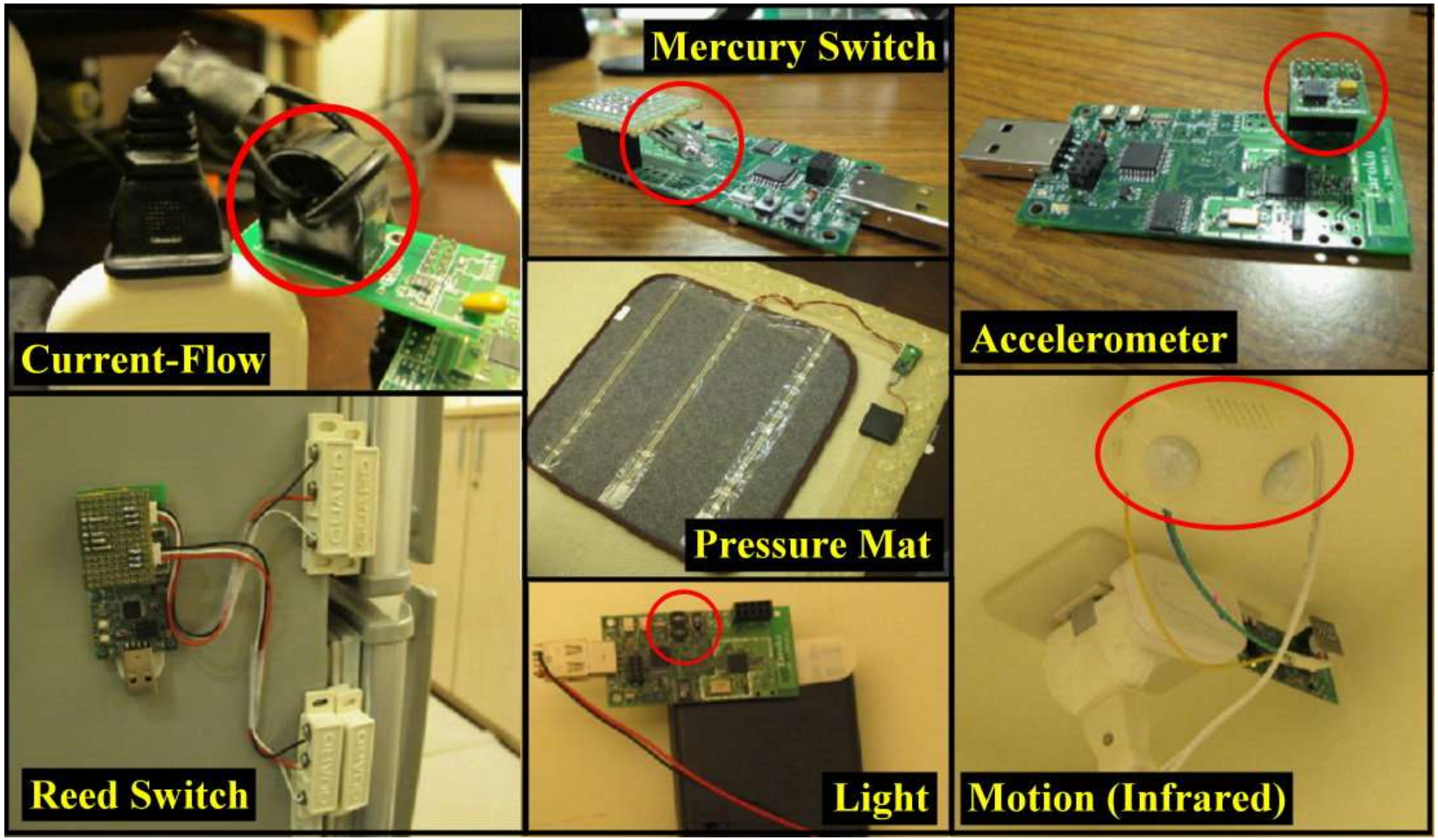
    20m~30m



Intelligent Sensors

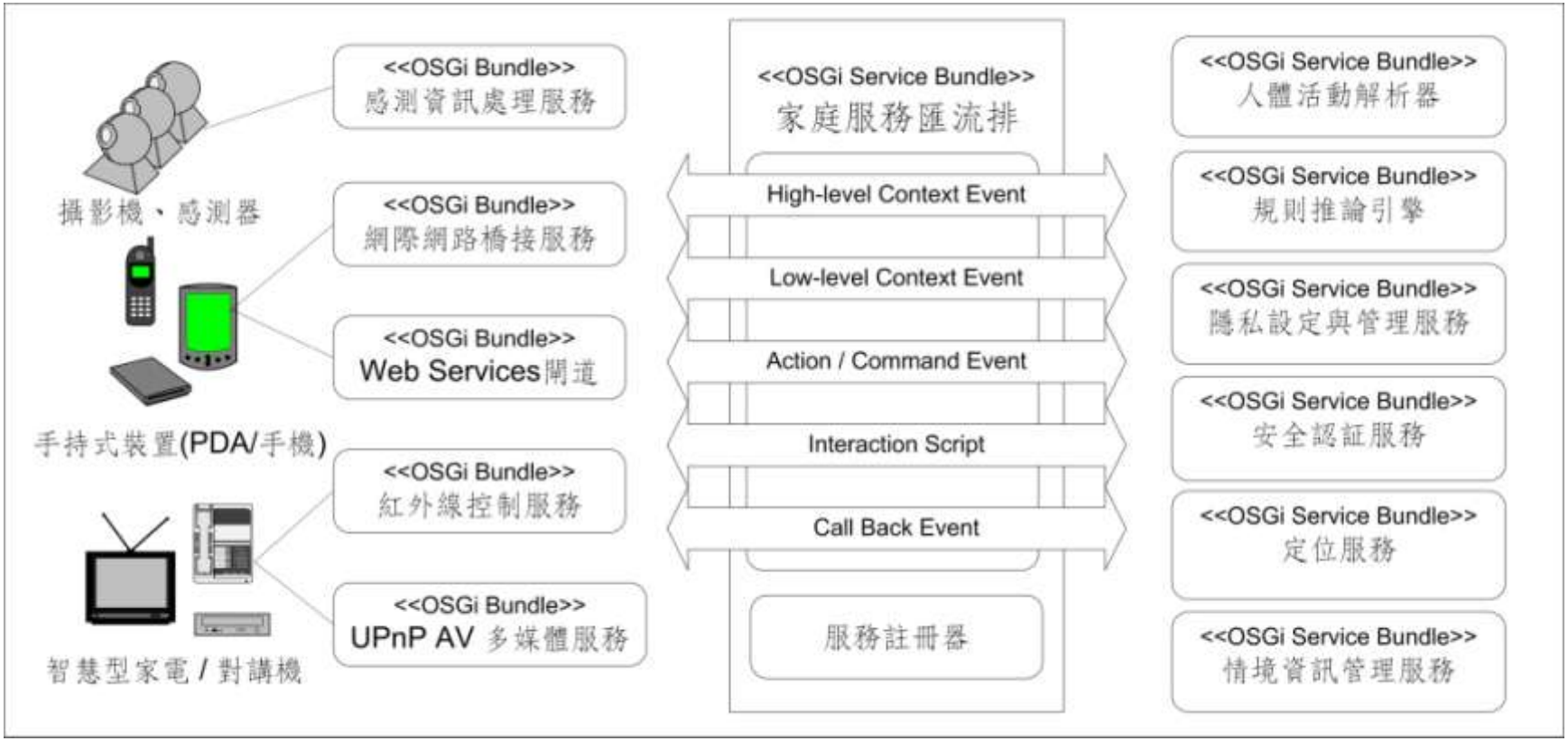
無線智慧元件 / 感測器		用途	佈建數量	佈建地點
壓力地板		室內人員追蹤，定位	35	主臥室
壓力座墊		室內人員定位	6	客廳與主臥室的椅子以及床墊上
壓力地墊		室內人員定位（可隱藏在一般地毯下，安裝機動性較壓力地板高）	1	主臥室的門口
電流、電壓感測器		家庭電器之使用	2	與電視、電扇串連
溫度、濕度、光度、二氧化碳、一氧化碳		生活環境偵測	2	客廳與主臥室
磁簧開關、接觸開關		偵測門窗之開閉或家電、物品之使用	4	客廳與主臥室的門窗上
三軸加速器		偵測室內物品之使用或當作人機介面	2	客廳窗戶上
紅外線活動感測器		人員或物體活動偵測	2	客廳與洗手間的天花板
物品定位器		透過聲音找出特定物品的位置	4	與特定物品繫在一起（鑰匙、智慧卡等）

Sensing Device Deployment

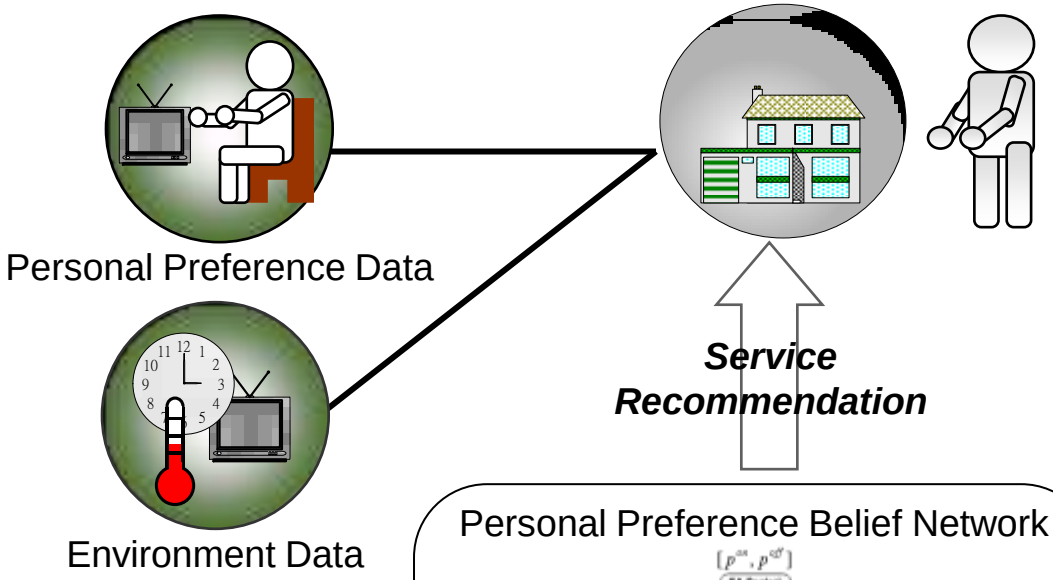


Integration Platform

- OSGi-based service integration platform



Inference Mechanism



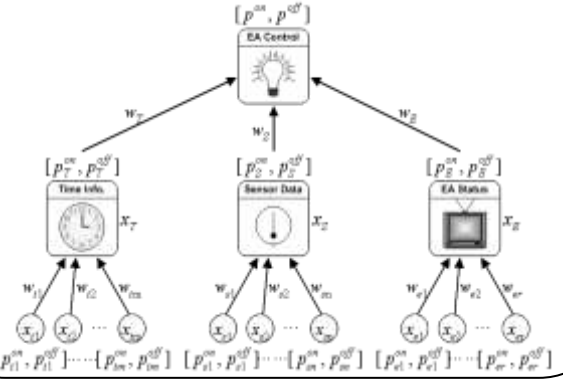
Service Recommendation

Data Collection

Database

Data Preprocessing

Personal Preference Belief Network

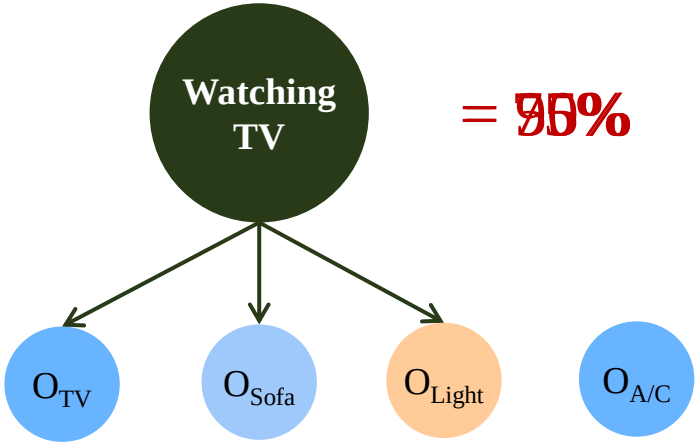


Personal Preference Learning

Inhabitant's Information

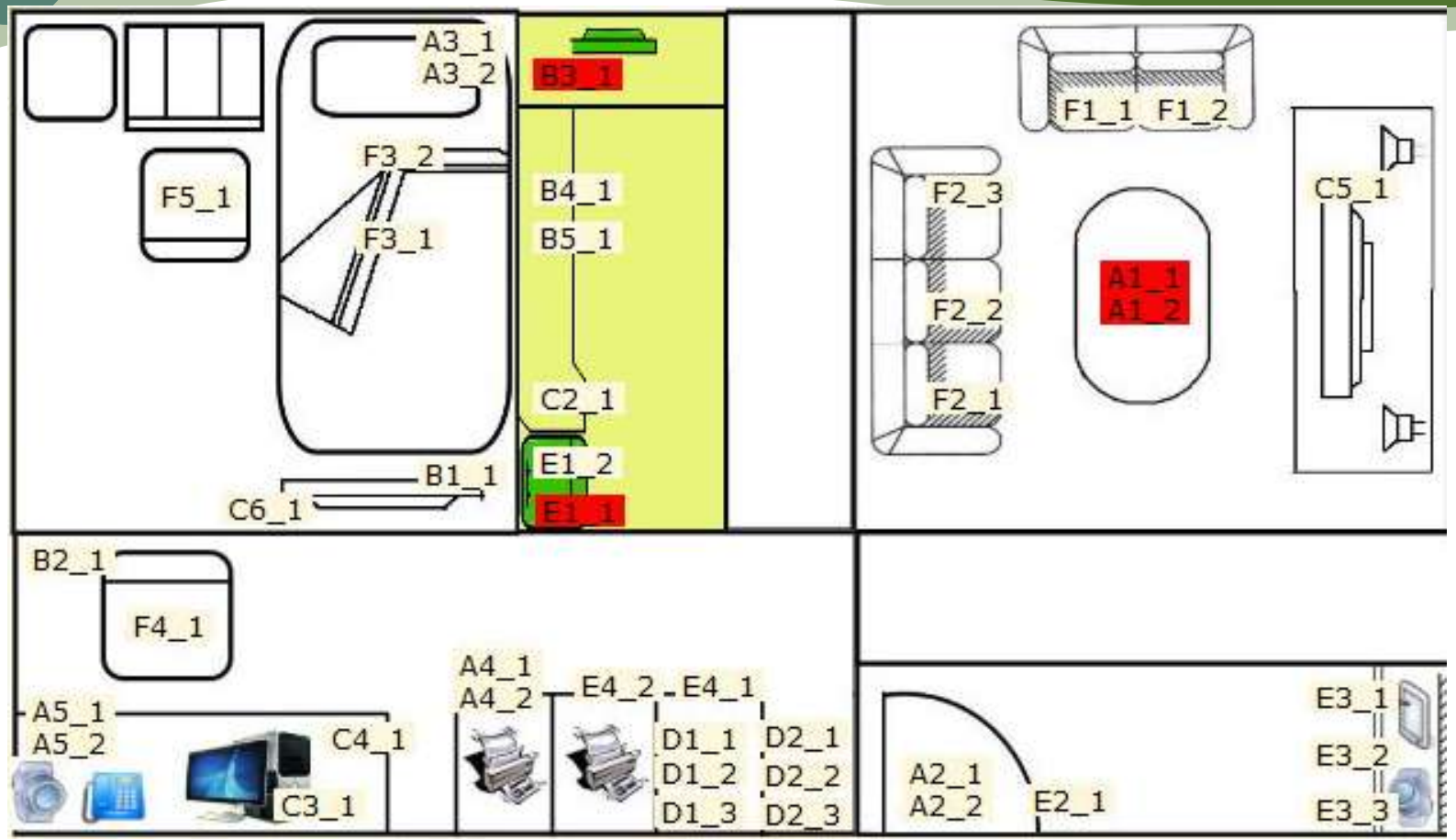
Activity Recognition

- Dynamic Bayesian Network (DBN)



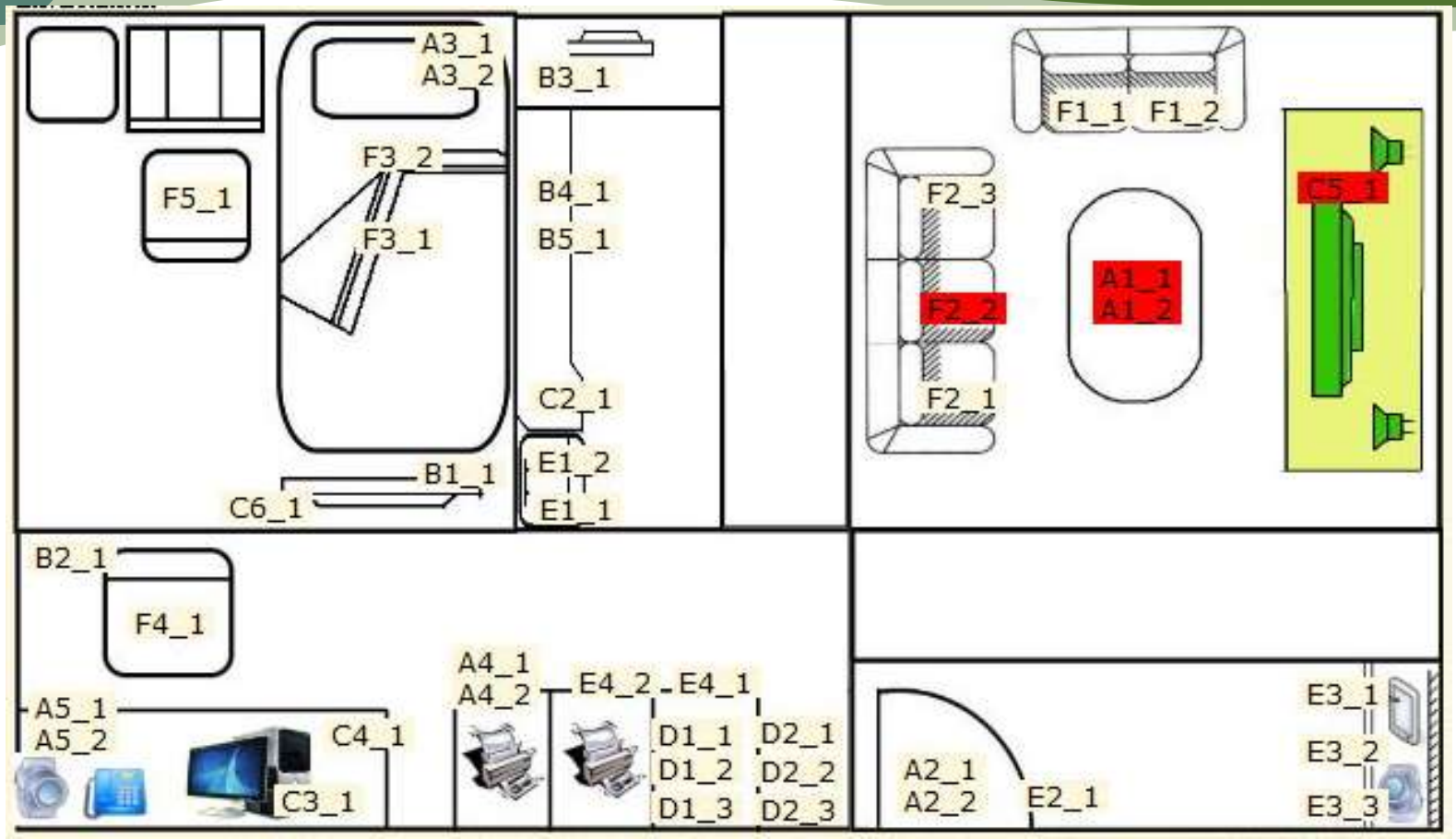
: current-flow sensor
: pressure sensor
: light sensor

Example 1: Preparing Food



B3_1 : 移動偵測(Motion)
E1_1 : 冰箱開啟(磁簧)
A1_1 : 燈(照度-可見光)
A1_2 : 燈(照度-不可見光)

Example 2: Watching TV



C5_1 : 電視(電流)
F2_2 : 沙發(壓力)

A1_1 : 燈(照度-可見光)
A1_2 : 燈(照度-不可見光)

UPnP-based IA Control

IR

IR

RF

RF

Smart Appliance Controller

UDP

UPnP

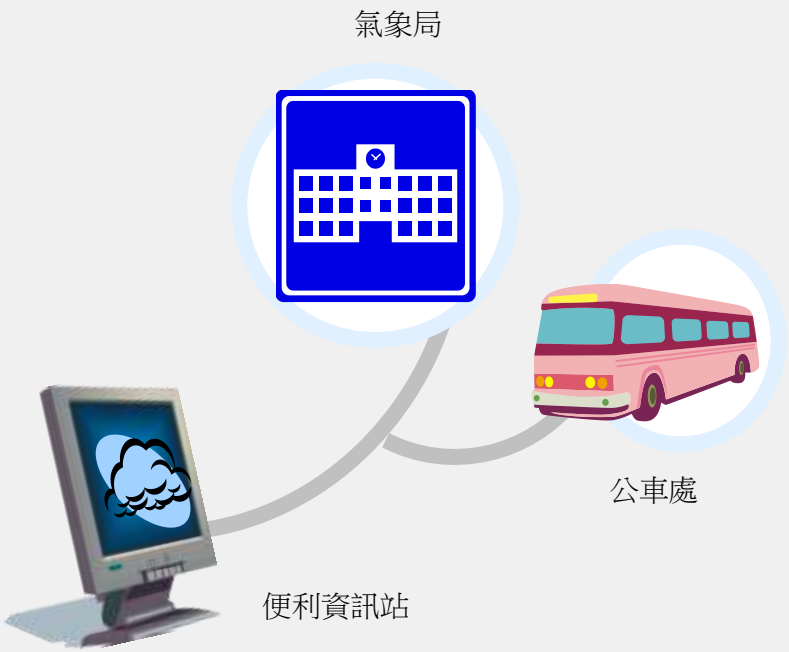
Home Server

Smart Home Applications

- The Attentive Home
  - Located at 博理-313
- Some deployed applications
  - 便利資訊站
  - 遠端監控
  - 媒體如影隨形
  - 智慧聲控
  - 入侵偵測

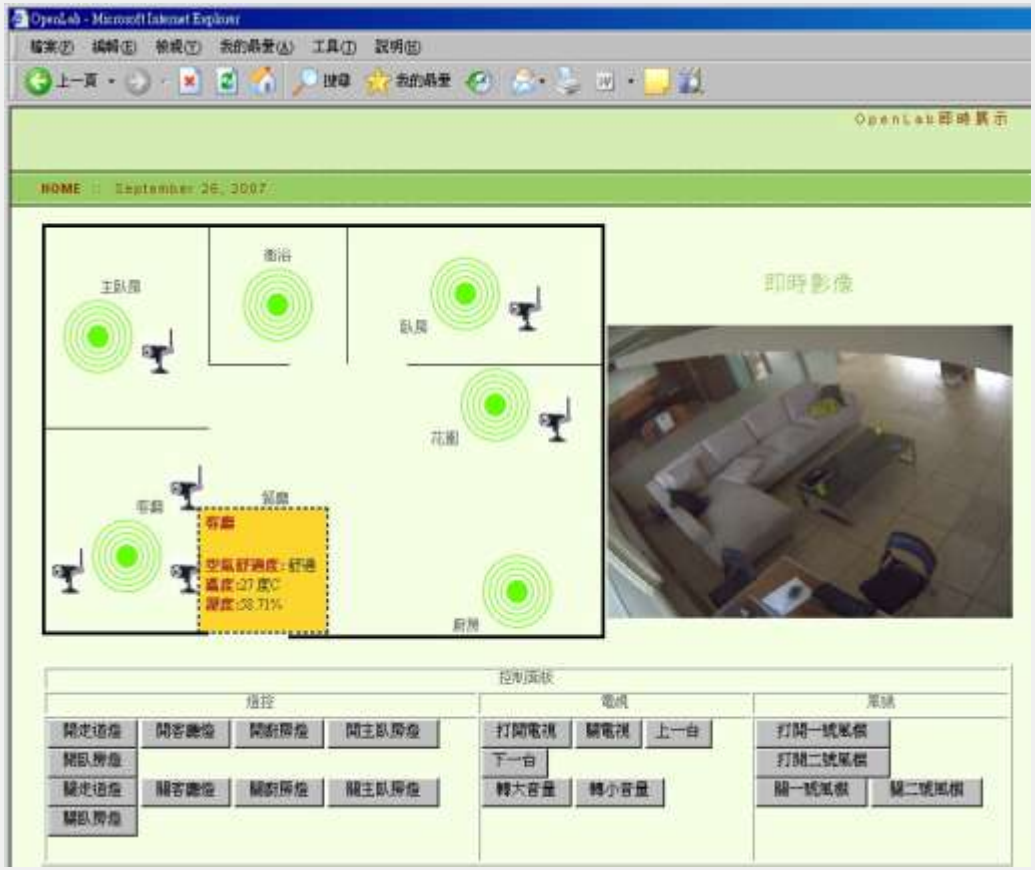
便利資訊站

便利資訊站通常設置在門口或玄關附近，居住者在出門前可透過它查詢今天的天氣以及附近的公車資訊。



遠端監控

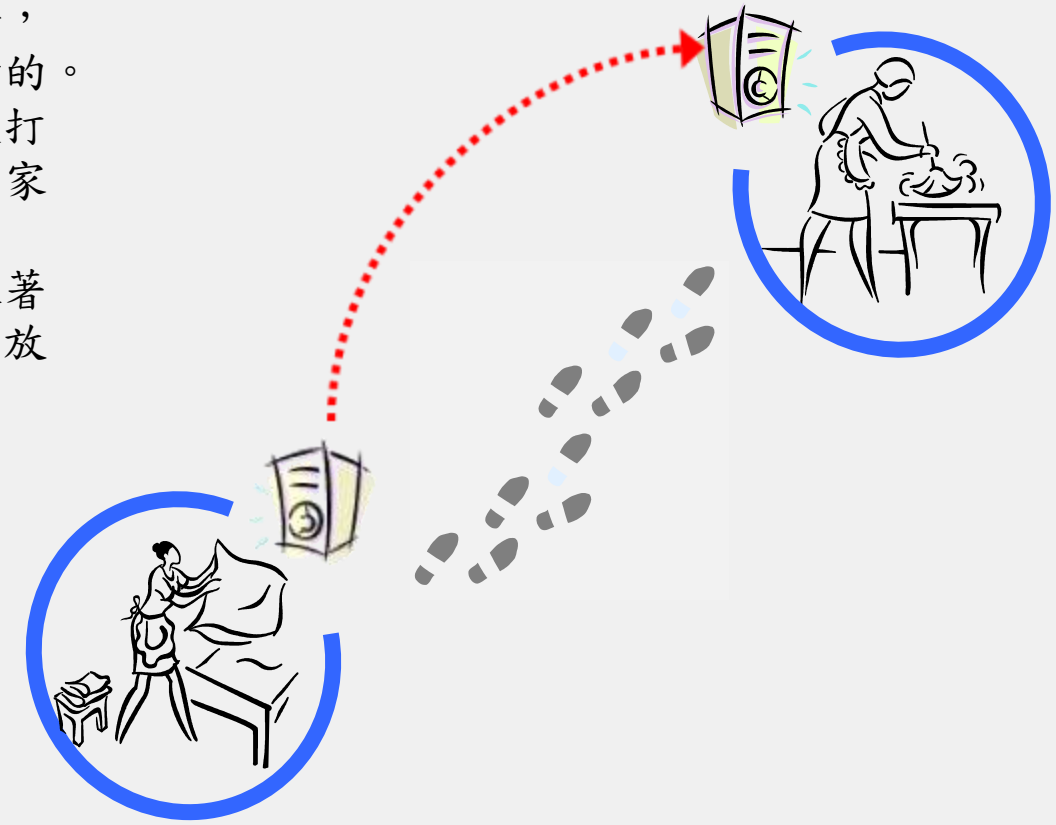
使用者可以從遠端透過Web介面進入系統，觀看自己家中的相關資訊(如監控畫面、溫濕度資訊)並操作家電。



媒體如影隨形

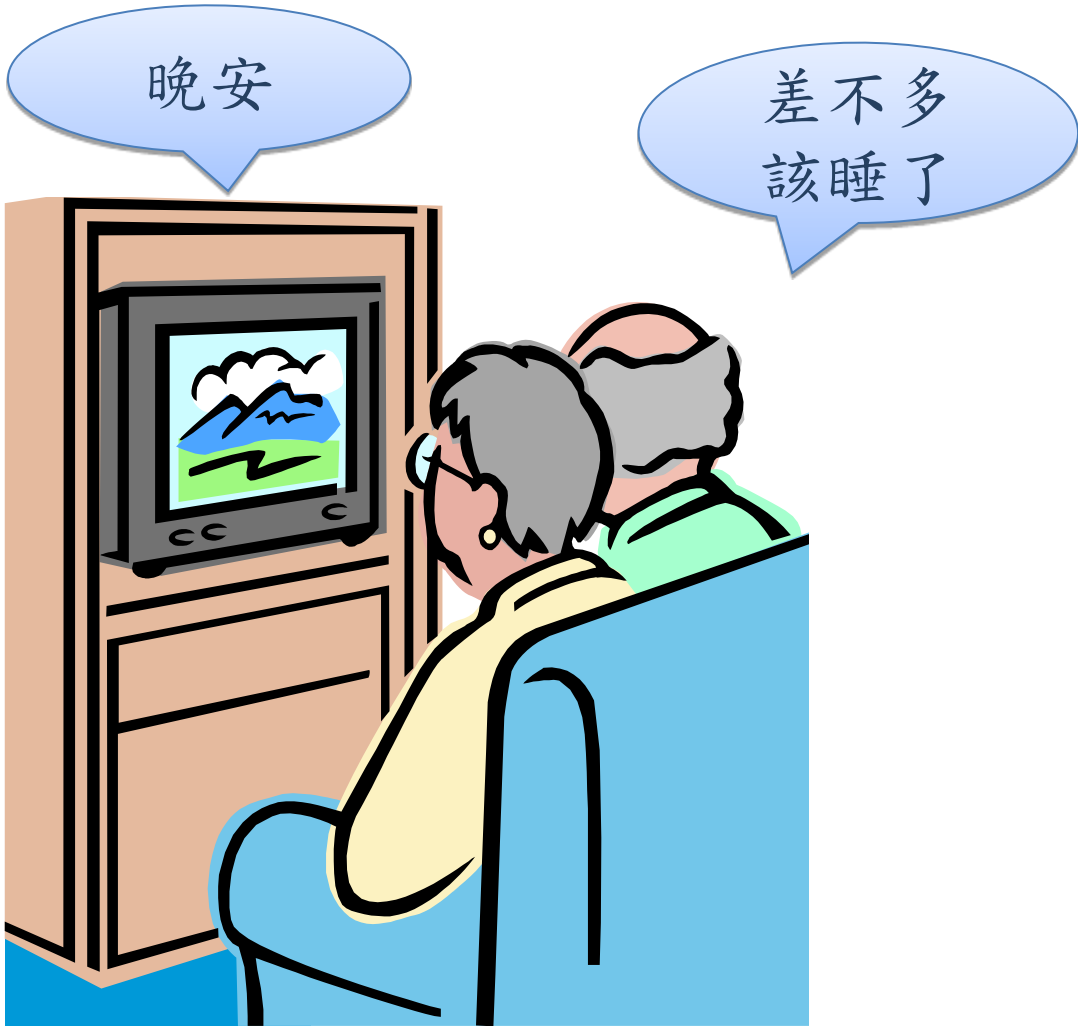
家中的成員在家中享受媒體時，有時會希望這個服務是不間斷的。例如，媽媽在家中邊聽音樂邊打掃時，會希望音樂能隨著她到家中不同的區域。

透過室內定位系統，媒體能跟著使用者，在離使用者最近的播放器播放。



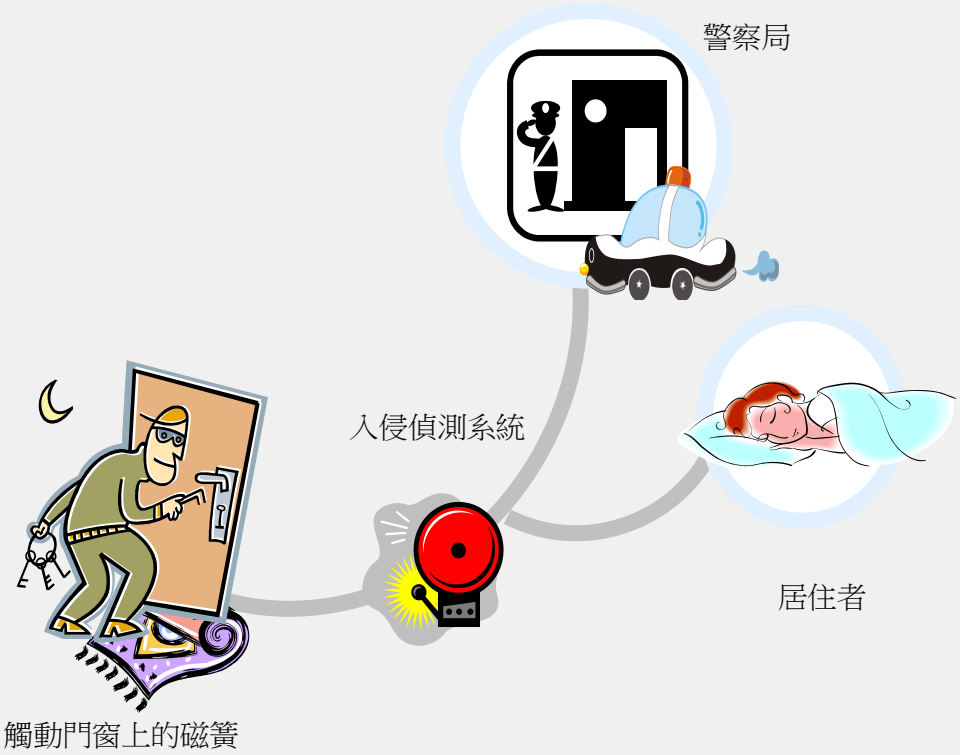
智慧型聲控系統

語音是人和人之間最自然的溝通方式，語音系統提供了一個比傳統搖控器更親切的家電控制介面。例如：當準備就寢時，利用語音告知系統，系統將自動關閉電器、檢查門窗是否關好等等，使屋子進入睡眠的情境，方便使用者不必一一關閉、檢查。



入侵偵測系統

就寢時間到, 家中的門窗無故被開啟。透過門窗上的磁簧可立即偵測門窗被開啟, 經由入侵偵測系統傳送訊息出去, 當門窗無故被開啟，系統便發出警報聲, 並通知社區保全或警察單位的來協助。



Video Demonstration

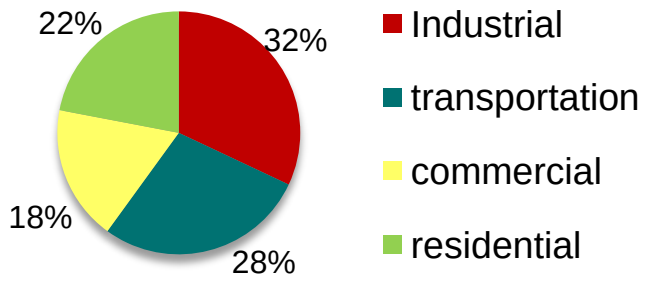
Outline

- Backgrounds
  - Smart Home Technologies and Applications
- Theme
  - Energy Saving in Smart Home
- Activity
  - Designing Home Energy Saving Scenarios
- Conclusion

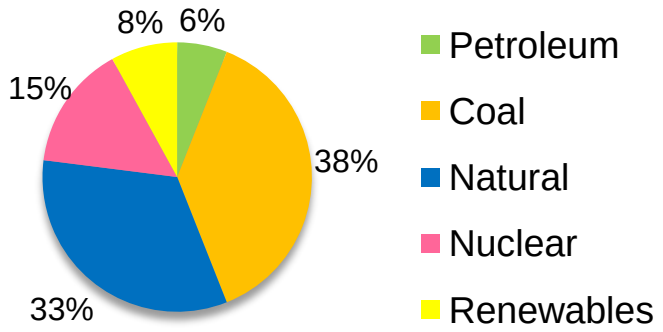
Global Energy Saving Trends

- Draining of energy resources and rapidly changing climates are believed to be caused by the overly consumed energy
- Reducing energy consumption and improving energy efficiency is a global concern

U.S. Energy Consumption



U.S. Buildings Sector



Approaches for Energy Saving

- Energy saving can be achieved by
  - Enforcement of government laws
  - Increasing energy efficiency
    - Use rechargeable batteries instead of ordinary ones
  - Decreasing energy consumption
    - Turn off appliances not currently used, or use alternative energy
    - Can be assisted by M2M technologies
      - To automatically control appliances based on context and energy usage

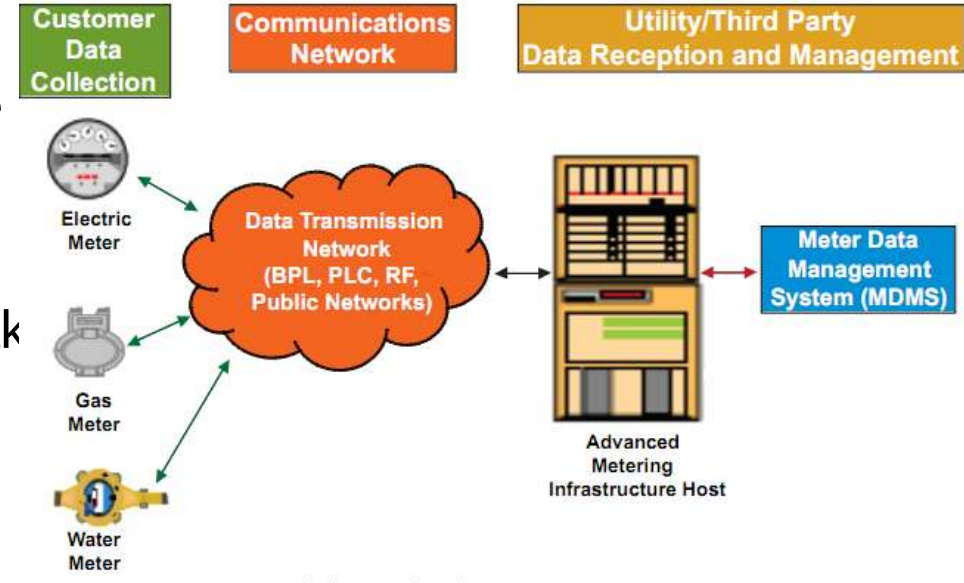
Home Energy Monitoring and Feedback

- Advanced Metering Infrastructure (AMI)
- Nonintrusive Appliance Load Monitoring (NALM)
- Energy-aware feedback design

Advanced Metering Infrastructure (AMI)

- AMI integrates metering, control and feedback among energy providers and household appliances

- Advantages
  - Enable real-time energy usage measurement
  - Enable fine-grained pricing designed to encourage off-peak use
  - Provide user information for saving strategy



Advanced Metering Infrastructure (AMI)

- AMI has been deployed in the following countries
  - Italy (completed in 2009)
  - Sweden (completed in 2009)
  - Netherlands (expected to be completed in 2013)
  - England (expected to be completed in 2017)
- The result of deployments in US 800 households (Hazas et al.'10)
  - Achieve financial savings in 90 percent of household
  - Achieve energy-use reductions of up to 25 percent in the summer using peak-rate pricing

M. Hazas, A. Friday, and J. Scott, "Look Back before Leaping Forward: Four Decades of Domestic Energy Inquiry," in *IEEE Pervasive Computing,* Vol.10, No.1 , pp. 13-19, 2010.

Appliance Load Monitoring

- Two ways of load monitoring
  - Intrusive Load Monitoring
    - Deploy lots of sensor to measure the power consumption at every power outlet
    - Hard to deploy in existing home
  - Non-intrusive Load Monitoring (NALM)
    - Use one meter to learn and process energy information from whole house
    - Easy and seamless for installation

Nonintrusive Appliance Load Monitoring

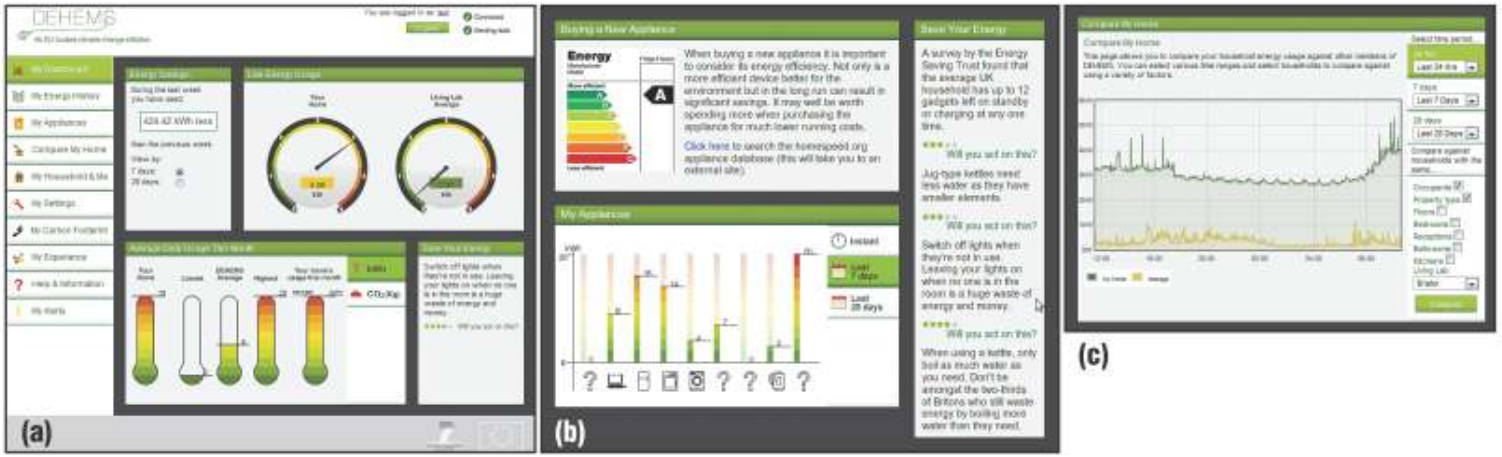
- NALM analyzes power line transients and their power signatures to identify appliances in use
  - Invented it at MIT in the early 1980s (Hart '92)
  - Can be improved by machine learning techniques to achieve success rate of 85 to 90 percent (Patel et al. '07)
- Input and output of NALM
  - Input: transient current (瞬變電流) form appliances
  - Output: the states of possible appliances

G. Hart, "Nonintrusive Appliance Load Monitoring," in Proc. IEEE, vol. 80, no. 12, pp. 1870–1891, 1992.

S. Patel et al., "At the Flick of a Switch: Detecting and Classifying Unique Elec-trical Events on the Residential Power Line," Proc. 9th Int'l Conf. Ubiquitous Computing (Ubicomp 07), ACM Press, pp. 271–288 , 2007.

Energy-aware Feedback Design

- According to a study in the mid-1970s, even as simple as daily notes can have 5 to 20 percent of energy saving
- Good feedback design helps users to set pre-defined conservation goal and lead to more powerful and longer-lasting energy saving effects



Energy-aware Feedback Design

- Case study (Amft et al. ‘11)
  - Amft et al. conduct an experiment that monitors real-time energy consumption in homes across Queensland
  - In their experiment, the mobile phone displays comparative feedback on energy consumption
  - The mobile application also lets users review and compare their energy consumption with friends in Facebook

O. Amft, R. Medland, M. Foth, P. Petkov, J. Abreu, F. C. Pereira, P. Johnson, R. Brewer, J. Pierce, and E. Paulos, "Smart Energy Systems," *Pervasive Computing, IEEE,* vol. 10, pp. 63-65, 2011.

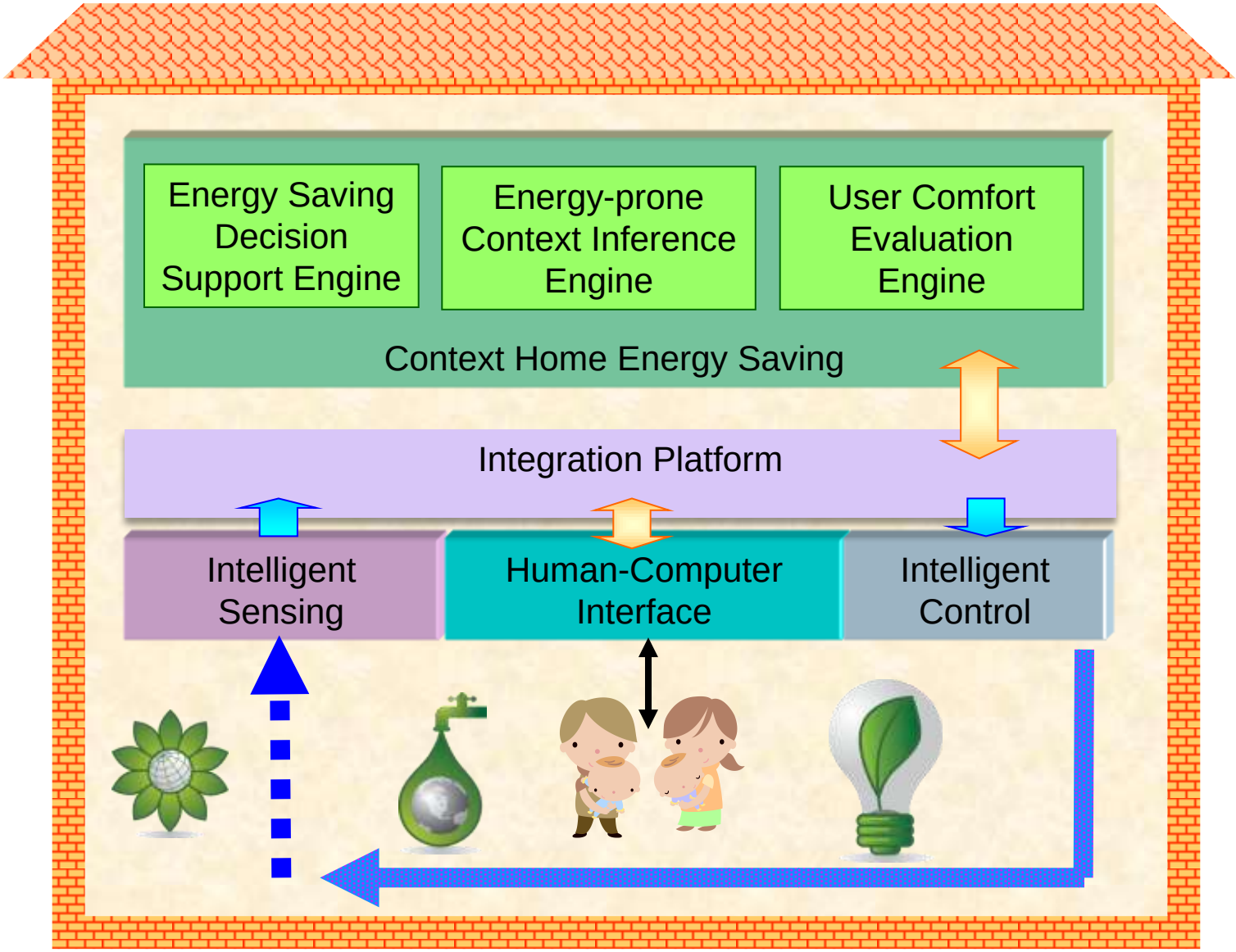
Barriers of Current Approaches

- Limited to single user context
  - Non-scalable to multi-user, real-life ES scenarios
- Ignoring energy consumption information
  - ES decisions are likely to disturb users' tasks
- Implausible user comfort evaluation
  - e.g. "misery-to-dollars conversion" is hard to realize
- High cost and difficulty of deployment
  - Impeditive to public acceptance

Project Overview

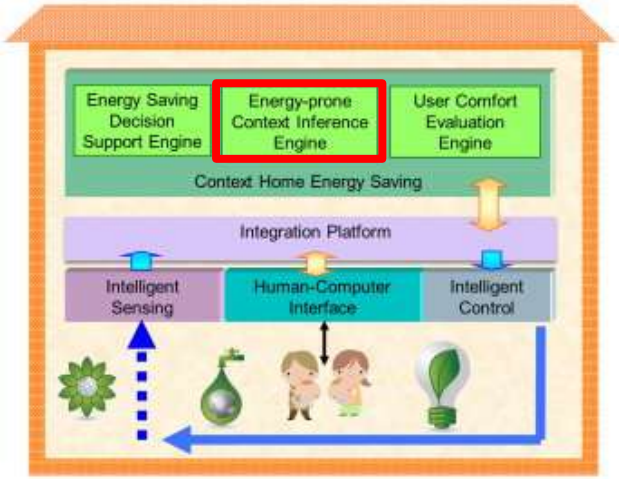
- Name: “M2M-Based Context-Aware Home Energy Saving System”
- Objectives
  - We design a home energy saving system for:
    - Multiple-user contexts and their associated energy consumption information
    - Standard-based and quantifiable user comfort
    - Optimized energy saving decisions without compromising user comfort

System Architecture



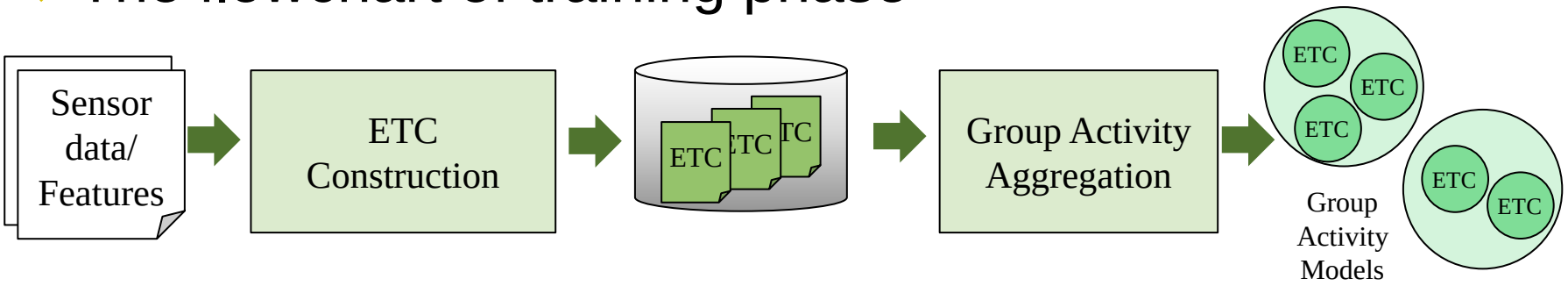
Energy Prone Context (EPC) and EPC Inference

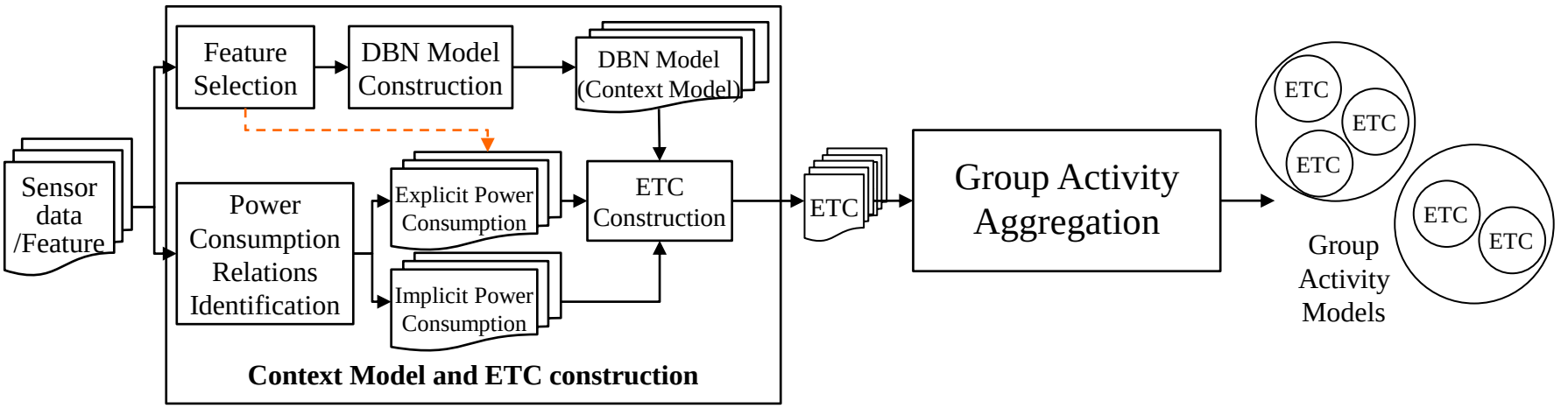
- Energy Prone Context
  - A context (ex: activity) that is apt to cause energy consumption
  - Energy Tagged Context (ETC) is used to represent the energy information of Energy Prone Context (EPC)
- Energy Prone Context Inference
  - Training phase:
    ETC construction and group activity aggregation
  - Testing phase:
    Group activity inference



Energy Prone Context Inference

- The flowchart of training phase

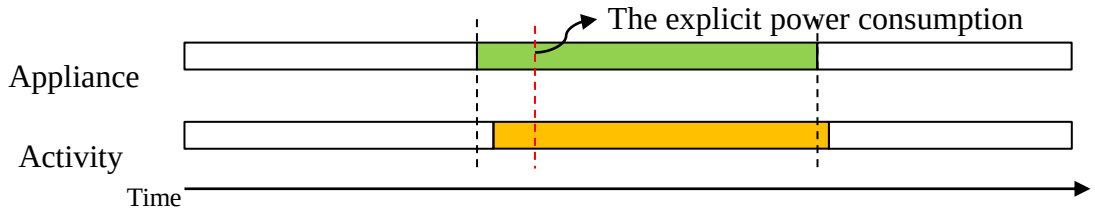




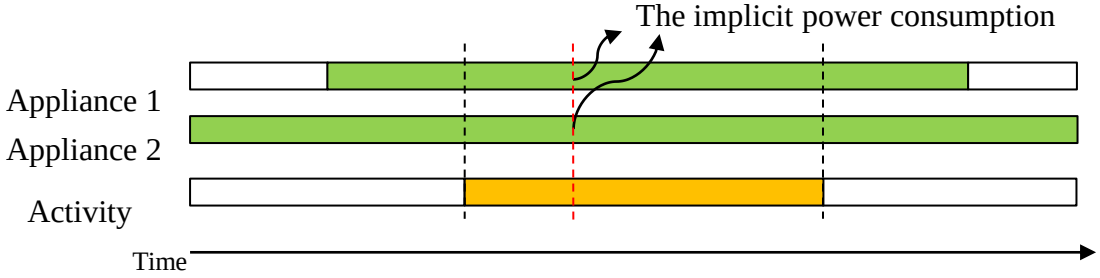
ETC: Energy Tagged Context

Energy Prone Context Inference

- The two types of power consumption:
  - Explicit power consumption
    - the power consumption that is directly triggered by the context

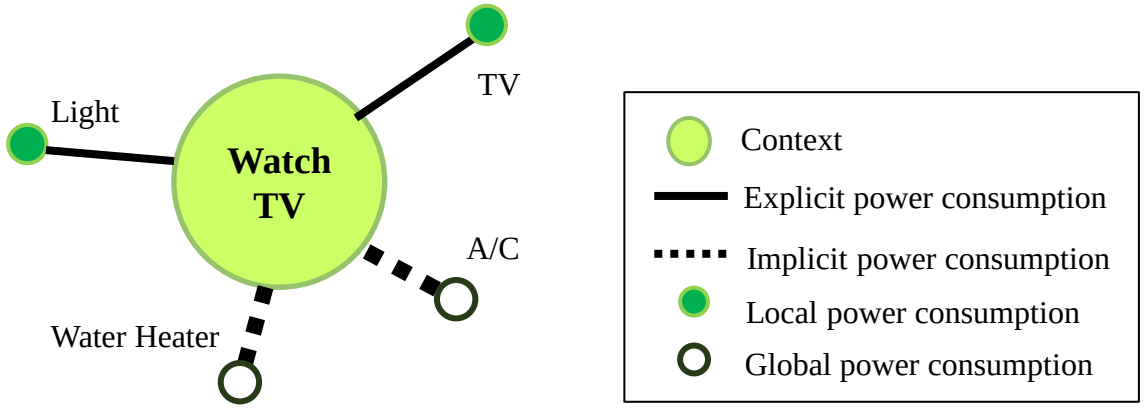


  - Implicit power consumption
    - the power consumption that is indirectly triggered by the context
    - the operating period is longer than time period of the context



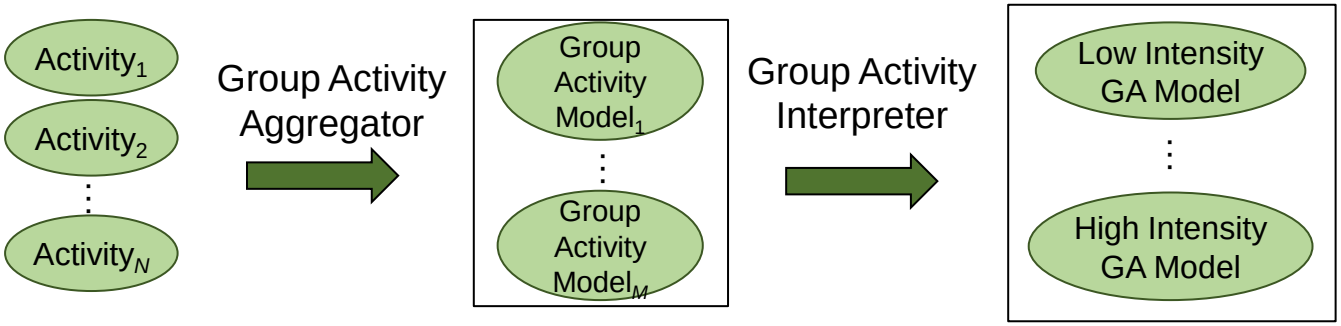
Energy Prone Context Inference

- Energy tagged context (ETC) is used to represent the context and its associated power consumption
- ETC can be illustrated as a graph:
  - The node is the context
  - The edge is the correlation between context and power consumption
    - Length of edge: the power consumption level
    - Width of edge: the confidence of the correlation



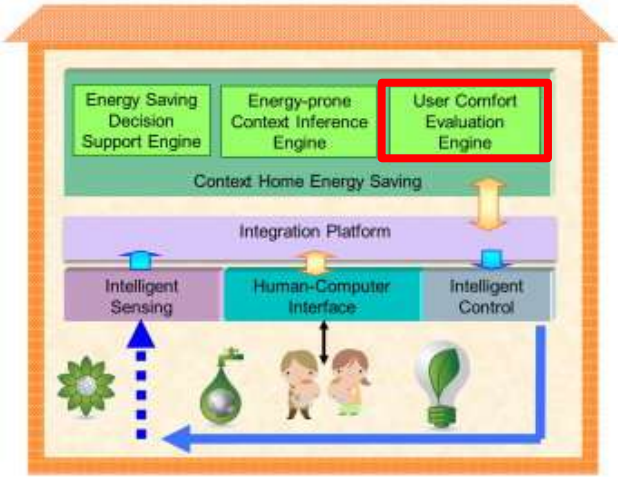
Energy Prone Context Inference Engine

- Definition of group activity
  - One or more than one people doing the same thing in the same area
  - More than one people doing different things in the same area
- Group activity aggregation
  - Contexts with similar attributes are aggregated into the same group
  - The aggregated attributes:
    - intensity of activity
    - the combination of power consumption



User Comfort Evaluation Engine

- Adopt a comprehensive and quantifiable user comfort index for realizing a fine-grained energy saving control
- Two sub-indices of comprehensive user comfort index
  - Thermal-sub index:
    - Evaluate the human thermal sensation to adjust the indoor temperature. (*e.g.* air conditioner)
  - Illumination-sub index:
    - Evaluate the human light perception to find the best light composition according to the activity

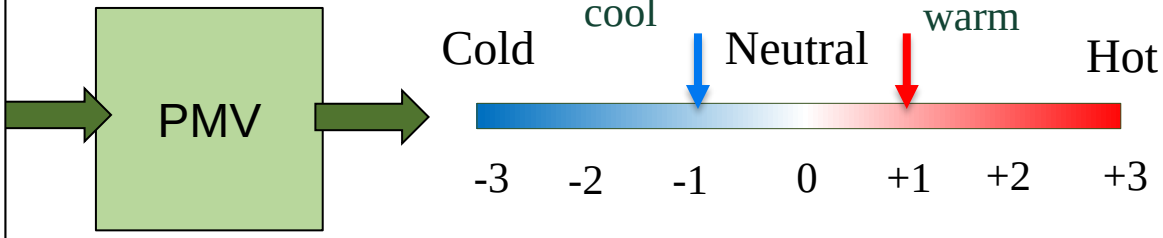


User Comfort Evaluation Engine

- Thermal sub index
  - Predicted mean vote (ISO 7730) is for evaluating the thermal sensation of a large population of people

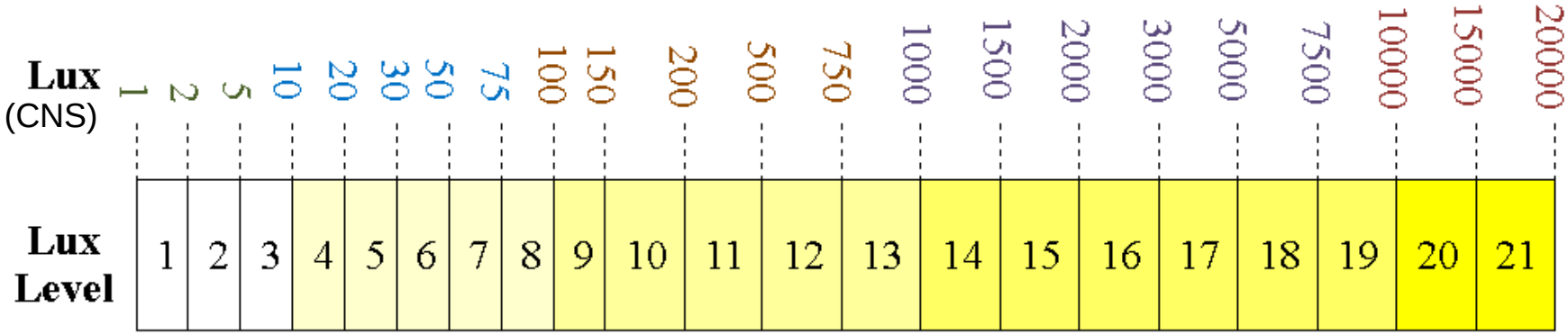
4 environment factors:
- air temperature
- air velocity
- mean radiant temperature
- air humidity

2 personal factors:
- clothing insulation
- activity level



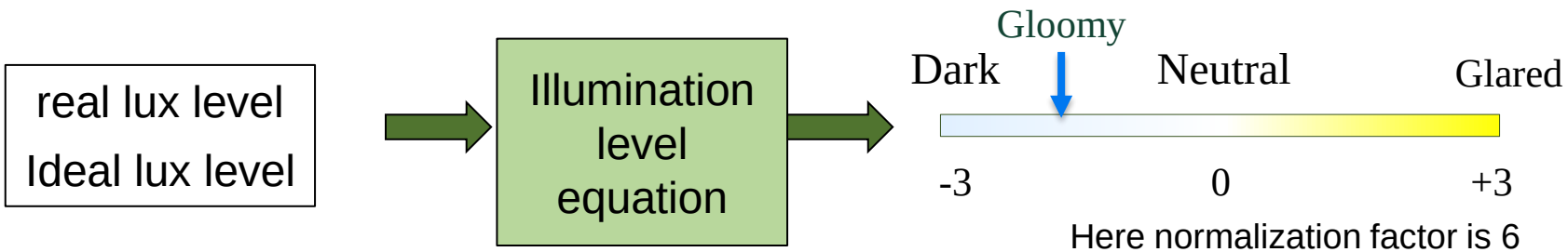
User Comfort Evaluation Engine

- Illumination sub index
  - The Chinese National Standards (CNS) defines the discrete illumination rank by giving each rank a specific lux of illumination.



User Comfort Evaluation Engine

- Similar to PMV, we use a 7-scaled illumination level to measure the distance between real and ideal lux level of an activity.



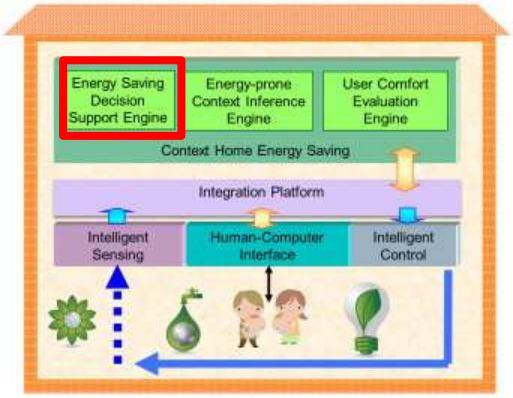
$$\frac{real\ lux\ level - ideal\ lux\ level}{normalization\ factor}$$

Energy Saving Decision Support Engine

- The decision engine uses ETC and CI to make context-aware energy saving decisions to:
  - minimize total power consumption
  - adjust the status of appliance or its power consumption level

$$TPC_{\min} \mid_{\text{ETCs+CIs}} = \underset{s_i \in S,\, d_i \in D}{\arg\min} \sum_{i=1}^{N} (L(s_i) + d_i) \mid_{\text{ETCs+CIs}},\ |\text{CIs}| \le T$$

where TPC is the Total Power Consumption
L is the Power Consumption Level
T is the threshold of comfort
$D = \{d_1, d_2, \ldots d_i, \ldots, d_N\}$, $S = \{s_1, s_2, \ldots s_i, \ldots, s_N\}$
d_i = Adjustment of Appliance$_i$, s_i = Status of *Appliance*$_i$

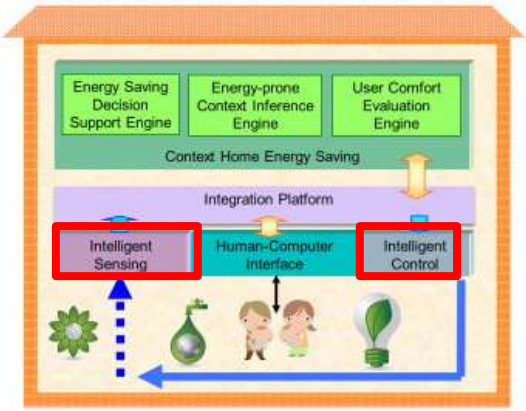


Energy-aware Sensing and Control

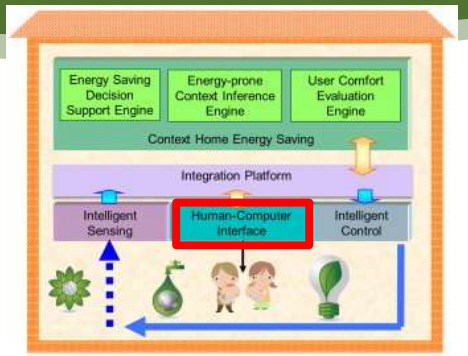
- Devices for energy-aware sensing and control
  - Smart meters

Intel WEST Sensor

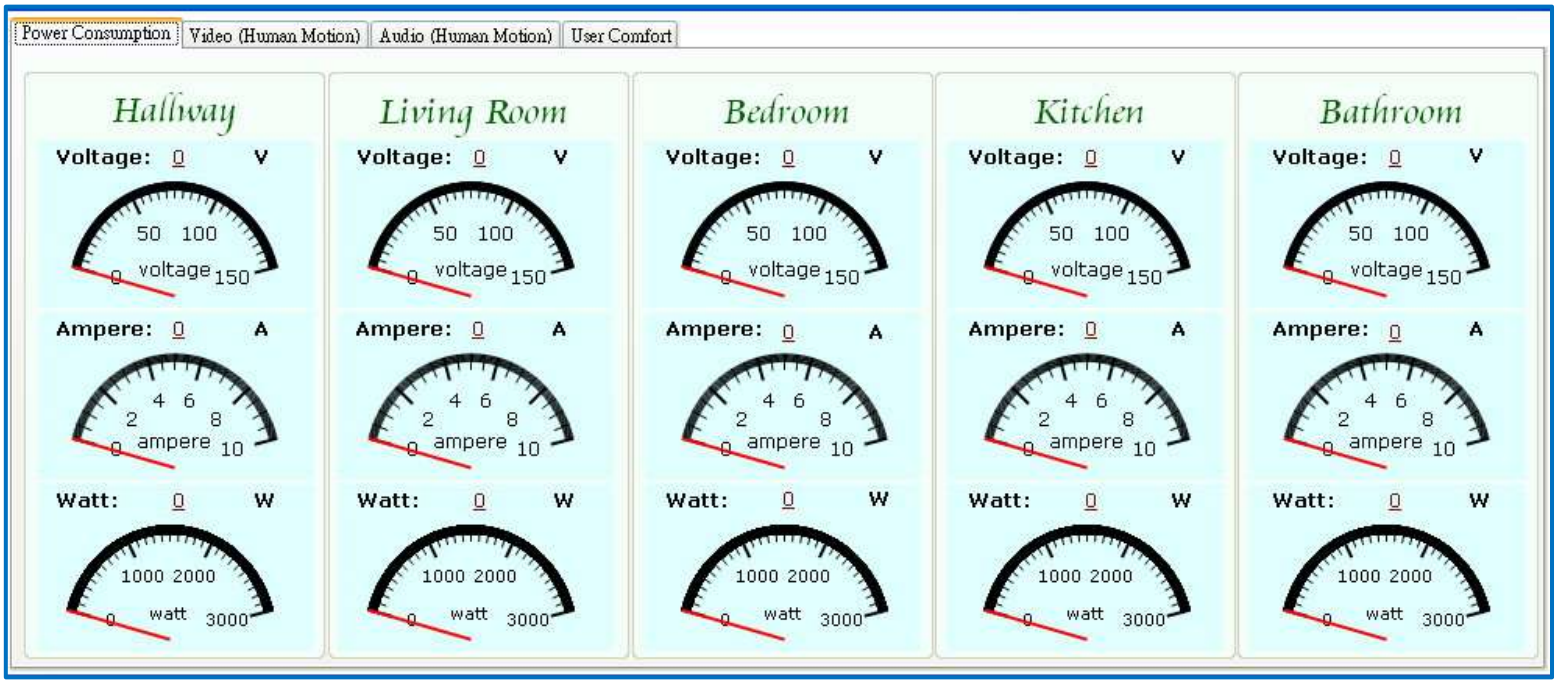
  - Wireless Control Relay (WCR)



Human computer Interaction-Smart Meter

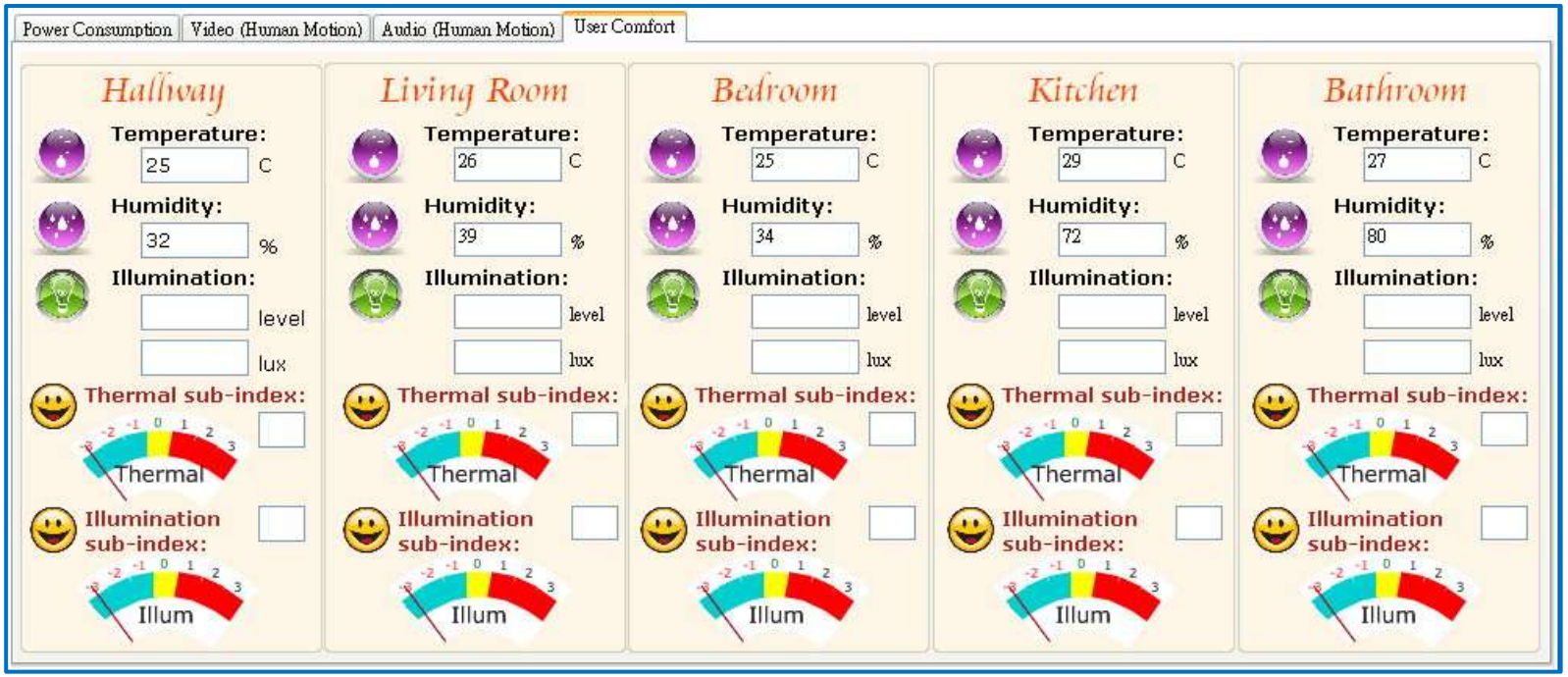


- Smart meter energy consumption
  - Show by the home location



Human Computer Interaction-PMV

- Humidity/Temperature/Illumination
- Comfort of illumination/Thermal



1. Playing Xbox - comfort

- Mary is playing Xbox in the living room.

Motion module (PIR + camera)
detects there is one person in the living room


Kinect on


TV on


Accelerometer high

→ Use the **"on" state of kinect and TV** and **high activity level (acc.)** to infer that Mary is playing kinect.
→ **decrease light level**

---

temperature
humidity
illumination


Accelerometer high

→ Use the parameters of environment (temperature, etc.) and activity level (acc.) to evaluate Mary's comfort.
→ **turn on the fan**

2. Chatting - Group-Activity

- Mary and her friend John are chatting in the living room.

Motion module (PIR + camera)
detects there are two persons in the living room

Microphone (audio)
detects the activity “chatting” is performed

temperature
humidity
illumination

Accelerometer
low

Use the parameters of environment (temperature, etc.) and activity level (acc.) to evaluate Mary’s comfort.
→ **turn off the fan**

3. Sleeping – Energy Saving

- John leaves the house and Mary goes to sleep.

Motion module (PIR + camera)
detects John leaves and Mary goes to bedroom to sleep
(*i.e.* there is no person in the living room)

Accelerometer
low

Use the camera in bedroom and her low activity level to infer that Mary is sleeping.
→ No activity, turn off A/C and the standby power (ex: TV, Kinect and PC) and switch th water heater into energy-saving mode

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- Turn off standby power:
  - TV: 1W (1W to 0W)
  - PC: 2W (2W to 0W)
  - Kinect: 6W (6W to 0W)
- Turn off A/C:
  - A/C: 650W (650W to 0W)
- Switch into energy-saving mode:
  - Water heater: 1500W (2000W to 500W)

About 18% energy saving

Outline

- Backgrounds
  - Smart Home Technologies and Applications
- Theme
  - Energy Saving in Smart Home
- Activity
  - Designing Home Energy Saving Scenarios
- Conclusion

小組活動

- 請以小組為單位，依據課程內容，設計此Context-Aware Home Energy Saving系統可能的應用場景，包含
  - 所需軟、硬體
  - 場景動機、使用案例(劇情)及結果
  - Context-Aware Home Energy Saving系統發揮效果的地方
  - 和M2M科技的關係
- 討論時間30 minutes，每組報告時間5 minutes

Q and A