A Universal Implementation Model for the Smart Home

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Abstract

Since the emergence of the smart-home concept, many devices, interfaces and controllers have become available. However, there is a problem: each component usually performs a single function and there is no synchronization with other components. In order to exploit the great potential of the new technologies that these devices embody, as a base for synchronizing devices, interfaces and intelligent control systems, a universal model is required. The current paper offers a universal, comprehensive model for a smart home. Drawing upon existing protocols and technologies, it illustrates how to integrate different devices, software, and user interfaces to create a smart home. The model emphasizes four principles: A universal model can substantially lead to higher quality and usability of both devices and user interface; Production costs may be significantly reduced if manufacturers adopt a universal standard; The model synchronizes different groups of devices. This makes it possible to program complex scenarios leading to improved and enhanced smart-home utilization; Based on current available communication standards and infrastructure, the model can easily be installed in any house. Proposed smart-home architecture comprises - in addition to appliances and communication interfaces - a central management unit and a built-in database for smart equipment integration, for creating and implementing pre-programmed complex scenarios. The central management unit application and database store an up-to-date list of all connected devices. Any new integrated device is synchronized upon connection and removed when not in use. This is done automatically by sending any shared data (list of properties, commands, optional streaming, etc.) into the database upon initial connection.

Keywords: *Smart-home, Standardization, Universal Model*

1. Introduction

In Joel Garreau's book "Radical Evolution" [1], the author predicts major, order-of-magnitude advancements in the GRIN technologies (genetics, robotics, information technology and nanotechnology) over the next 15 years. These advancements will profoundly affect our lives, the way we work, modes of transportation, the environment, and our homes.

Not so long ago, smart houses seemed very futuristic. The notion that such mundane tasks as checking groceries' inventory, operating appliances or feeding the dog could be programmed or remotely controlled from long distance seemed unthinkable. Smart homes have now become a reality, and we can currently program our house or use our mobile phone to ensure that the smell of fresh coffee and bread fills the air when we wake up, and that the hot tub awaits us when we get home from work [2].

1.1. Purpose

Since the emergence of the smart-home concept, many devices, interfaces and controllers have become available. However, each component, usually performing a single function, can't be integrated with others. For example, home security systems can't make use of available equipment, such as digital cameras or home entertainment speakers. In order to exploit the great potential of new technologies, and to integrate devices and create an intelligent environment, a new universal smart home model is required.

1.2. The Lack of an Adequate Model

In order to figure out the lack of a universal model in spite of the smart-home phenomenon, we should look at the history of the wireless network before IEEE (Institute of Electrical and Electronics Engineers) announced the wireless network standard.
In 1990, a new IEEE[1] committee was set up to look into getting a standard started. However, it wasn't until 1997 that this new standard was published, though pre-standard devices were already being used. These devices were very expensive, and didn't allow for broad usage of wireless communication. Equipment manufacturers tried creating their own devices using different communication protocols, connections and frequencies.
Existing smart-home devices and interfaces reflect the same situation, which is typical to rapidly growing new technologies, when early adopters don't mind paying high prices for the newest inventions.
Yet, in order to expand the usage and popularity of the smart-home environment and exploit its great potential, a universal model is mandatory.

The comprehensive model that we present in this paper illustrates the integration of different devices, software, and user interfaces in the smart home, based on existing protocols and technologies. This model is universal, introducing a common infrastructure for both hardware and software that will enable the wide variety of available devices and systems to become an integral and unified part of the smart-home environment.
The suggested model comprises an artificial Intelligence module, featuring a pre-programmed set of scenarios, cases and responses, and intra-home communication with neighbors, friends, etc.

1.3. Statistical background

1.3.1 Technology adoption: In order to elucidate the need for a universal smart-home model, one must first determine the potential growth and adoption of smart-home technology and related products. According to Dr. Passig's model2, it usually takes over 10 years before new technologies reach the marketplace for use in everyday life.

[1] Institute of Electrical and Electronics Engineers: http://standards.ieee.org/802_11
[2] http://www.passig.com/vault/Lec-fururetech/InnovationsCurve.pdf

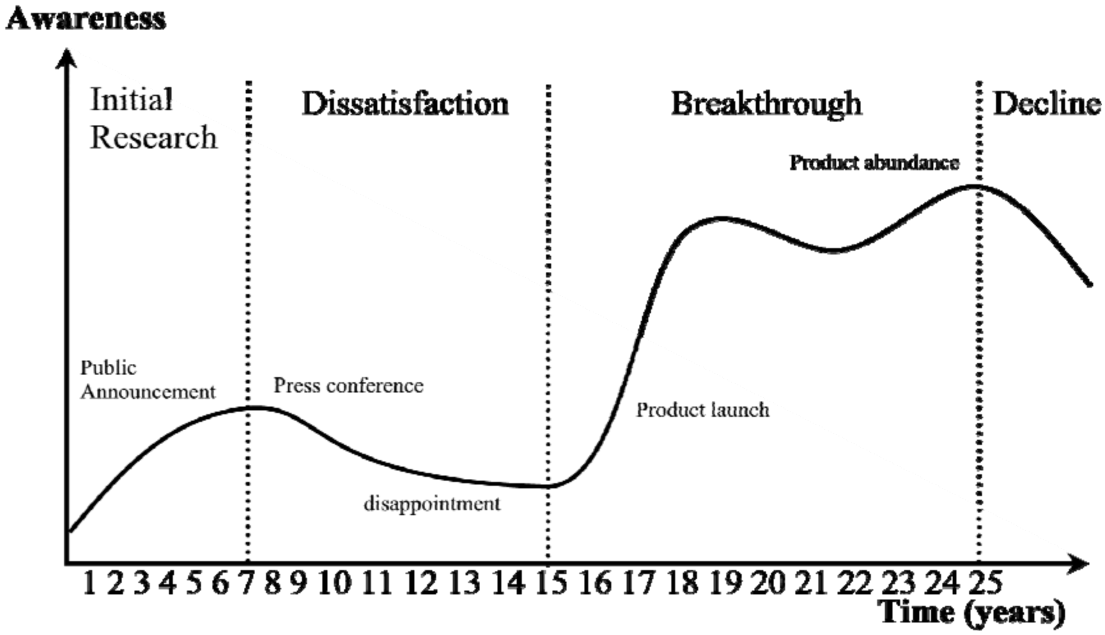

Figure 1. Passig's Technology Development Model

At present, smart-home development focuses on multimedia-related technologies: personal computers, Internet, mobile/cellular phones and cable/satellite TV. The charts below demonstrate the extensive penetration and usage rate of the presented technologies over the last two decades. The data, derived from The World Bank WDI Database3, includes the USA, European Community, Asia-Pacific, and OECD countries. At this point in time, the usage-rate of smart-home technologies is limited and specific, matching the "initial research" and "dissatisfaction" stages, as illustrated above. Following the Technology Development model, the world is about to cross the boundaries of the "breakthrough" stage in the near future.

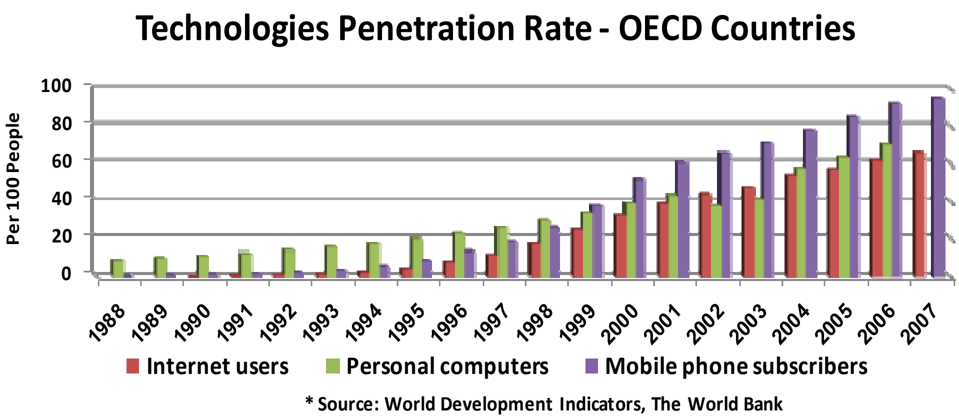

Figure 2. Technologies Penetration Rate – OECD Countries

[3] World Development Indicators (http://www.worldbank.org)

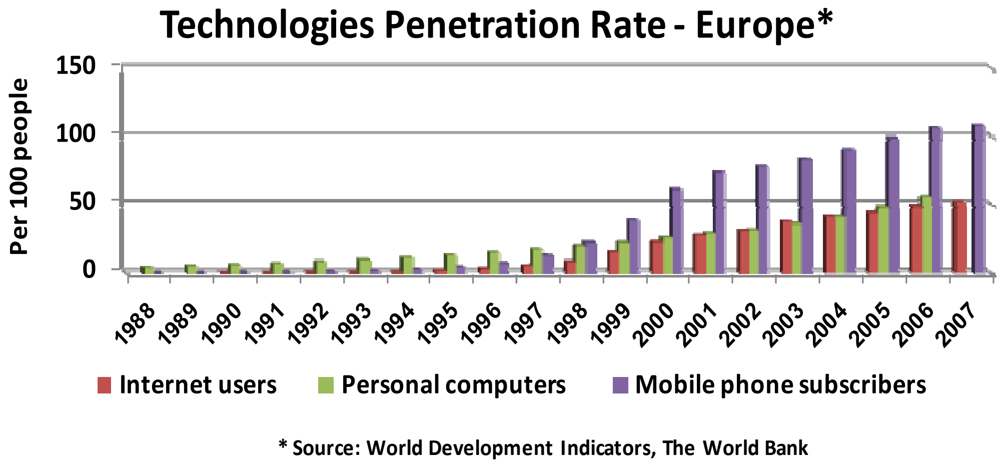

Figure 3. Technologies Penetration Rate – Europe

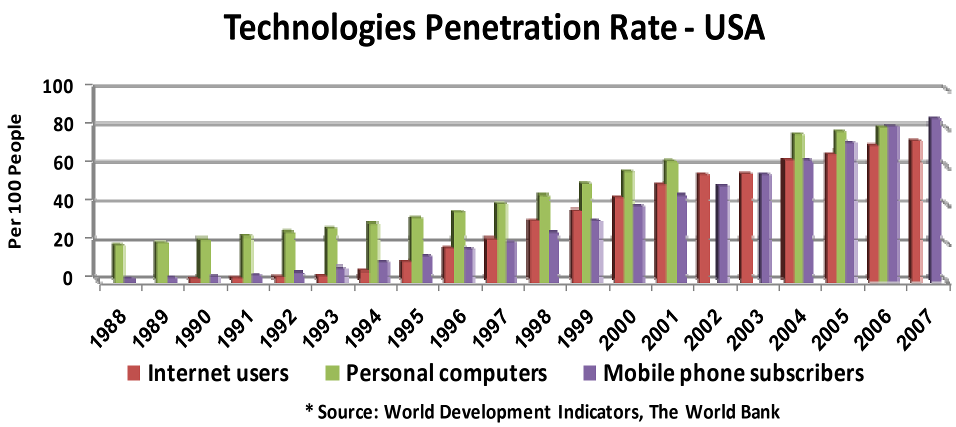

Figure 4. Technologies Penetration Rate – USA

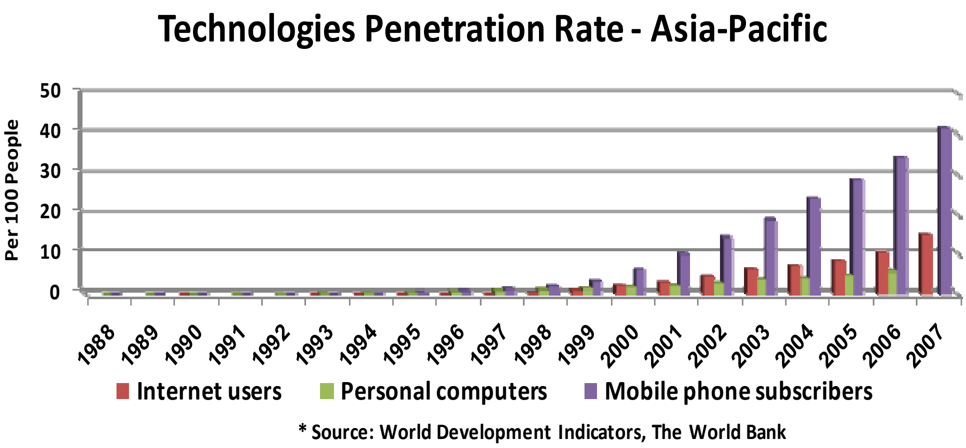

Figure 5. Technologies Penetration Rate – Asia-Pacific

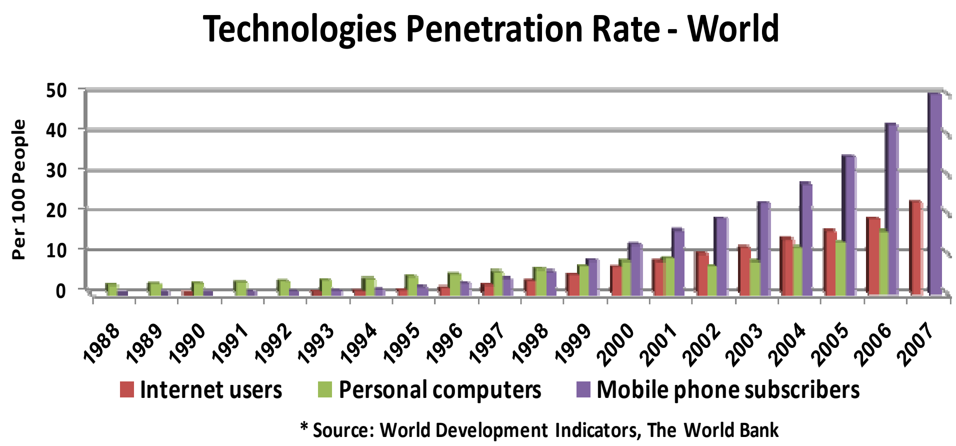

Figure 6. Technologies Penetration Rate – Entire World

1.3.2 What's missing? The growth of these technologies as building blocks indicates that smart-home architecture has all the essential elements for a fast growth track over the next decade. While current technologies provide an appropriate infrastructure for smart appliances and easy-to-use interfaces, certain elements, vital to growth, are still missing: central control mechanisms, event-management, and a set of standards for integrating components produced by different vendors [3], [4]. The central control unit, as further discussed below, is a fundamental part of the essential smart home, allowing the integration of different devices and applications into a synchronized environment. However, without using a proper event-management control mechanism, it is likely to be useless. Smart home-related activities should be regarded as a set of processes and behaviors - rather than a list of separated commands - and implemented as events.

2. The Proposed Universal Model

The proposed smart-home architecture comprises four modules:

- Central Management Units
- User Interface
- Home Equipment and Appliances Interface
- External Communication Interface

2.1. Central Management Unit (CMU)

The CMU is at the heart of smart-home architecture, and all devices are connected to it by either wireless or wired connection. The CMU controls devices and equipment, manages pre-programmed scenarios, and communicates with external resources. CMU monitors operate and control all smart-home components by checking status and sending commands.
The CMU - using application software-services, equipment, and built-in database (local DB) information - stores preferences and operation modes. With artificial Intelligence (AI) components, the CMU can manage smart scenarios and emergency situations. The CMU's independent operating system bridges between smart-home components and different

interfaces, thus allowing for constant device control, and immediate response in case of errors, alarms or pre-programmed activity.

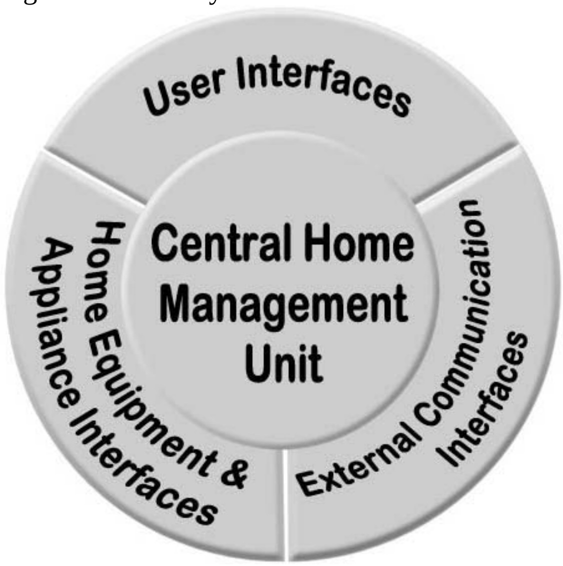

Figure 7. Smart Home Model Architecture's Diagram

2.2. User Interface (UI)

Smart-home UI provides the user with access to some or all of the integrated devices and appliances in the home. Once the user selects a device, its current status may be displayed, as well as the menu of available commands. Equipment may be associated with a particular group of activities, such as lighting, entertainment, security, etc., location or any combination of group and location. Access to a specific device is subject to authorization and the UI’s ability to control its functions.

User Interface devices can be of various levels of sophistication, e.g. playing music or using the home entertainment system may be controlled by simple UIs, such as mobile phones or by more advanced interfaces, such as PDA (Personal Digital Assistant or pocket PC), touch screens, High Definition Multimedia Interfaces, and others. Interfaces based on the mobile phone menu are useful for simple commands, requiring limited display. More advanced devices allow better use of graphics and software, and may present various screens.

Selective menus or options are based on UI device settings, stored in the CMU database. Software application programming interfaces (APIs) are used for operating external applications, such as online shopping, whenever a smart refrigerator senses a low supply of groceries. APIs are facilitated to operate devices using their built-in functions, based on standard commands and communication protocols.

Indicators

Besides operating equipment, UIs display current state, ongoing activities, warning messages and relevant information. Based on the device's UI capabilities and the nature of the information, some of the messages/indications are automatically displayed, while others appear only upon request.

Programming and statistical data

Different forms of UI may be used for accessing the CMU. Direct CMU access allows system programming, adding new devices, displaying reports, charts, and statistics, i.e. equipment usage, errors, alarms and warnings. Equipment manufacturers may contribute by configuring UIs to access further information, such as help screens for complicated tasks, scenario programming, and consumption related information.

UI device specification

The proposed universal model provides different devices for smart-home operation and control. Devices will differ according to size, mobility, supported communication protocols, displays and operation media, such as keyboard, touch screen, voice, and biometric sensors.
The universal model defines smart-home devices operation, using UIs compatible with mobile (or standard) phones, PDAs, personal computers, laptops, tablet-PCs, sensors, and biometric devices.

User Authorization

Most of the smart-home equipment may be used with no access restrictions. However, security systems or actions involved with potential risks - such us heating or cooking operations - require user login; thus, user privileges settings are essential. In order to maintain proper access control, the following guidelines should be implemented:

- Any UI related to access-controlled tasks must include user login options.
- Any commands or properties defined as ‘access-controlled’ will be hidden prior to login.
- An active log-off time-out mechanism must be included in order to prevent misuse by non-authorized persons.

2.3. Devices and Equipment interface

As smart-home equipment is currently being globally supplied by a wide range of producers and vendors, genuine integration of components and functions requires a set of standards and guidelines. At the same time, flexibility is necessary, in order to avoid malfunctions.

The following guidelines are important for enabling integrated smart-home architecture:

- A set of hierarchical commands, functions or accessible attributes for controlling and operating each integrated device. Each function or command may be independent, or a link in a chain. It should be predefined and recognized by the CMU.
- The equipment manufacturer determines the interface's "look and feel". Yet, the user's access to each one of the supported controls/functions has to comply with at least one of the UI standards (lists, icons, scrolling selection list, 3D widget), in order to assure a generic model and compatible appliances.
- Different forms of equipment embody diverse functionality and purpose. Thus, the suggested model refers to commands and properties only, regardless of the intended uses, main features or specifications.

- Any device must comply with at least one of the standard communication protocols.
- Some of the integrated devices, mostly those associated with multimedia and security, require a flow of information, either one-way or bidirectional. In order to utilize the common home infrastructure, streaming-dependent devices must support popular formats, such as MP3, MPEG-4, WMA/V, Flash-Video, QuickTime, etc.
- Programmable devices contain a built-in database for storage and data retrieval. In order to better utilize an integrated environment, it is strongly recommended to allow online CMU connectivity (at least read-only) in order to provide online, continuous data-exchange, and control of the local database.

2.4. Equipment functionality and control examples

Security/environment control: doors and windows.

Doors and windows may be either opened, closed (unlocked) or locked. ***Open, Close, Lock*** and ***Unlock*** commands allow users to operate doors and windows, while ***Closed*** and ***Locked*** properties allow users to monitor current status. Each connected window or door may be accessed by either choosing a specific room or by its description (i.e. 'garage door').
Houses equipped with more advanced windows bring in new attributes, such as ***Shading_Level***, and ***Landscape_Change***, which may be monitored or modified.

Light control

Bulbs and light fixtures may be switched on and off. Additional properties, such as light color and intensity, may be controlled or monitored. In such cases, a command, such as ***Change_Color***, may require selection of one color/color scheme out of a given list. ***Light intensity***, on the other hand, may be changed by using commands, such as ***Increase_Light***, ***Decrease_Light***, ***Set_Light_Amount*** or ***Max_Light*** to a specific level.

Streaming devices

Multimedia devices or security cameras may be used as either a source or target for streaming data [5]. These devices require a complex set of commands and properties. Some basic functions include: channel selection, format and compression, streaming direction (input, output or both), as well as movement and zooming options (***zoom_in, zoom_out, rotate_right, rotate_left, tilt_up, tilt_down***). In addition to the listed commands, a device's status is checked using attributes, such as: ***ready_to_transmit/receive, current_format, auto_focus_enabled.***

Smart appliances

Scenario-management allows users to define a set of behavior rules. For example, a smart refrigerator tracks inventory levels, and the expiry-date of stored groceries, thus assisting home residents with shopping and planning whether they are at home or away.

Voice, light and motion detection

Voice recognition applications and motion detectors may assist elderly people and persons with special needs. Motion detection equipment saves energy and essential resources by automatically adjusting climate control systems and lighting, based on current owner location, or estimated time of arrival to the house. Light sensors switch on outdoor and indoor lights at sunset, or control garden watering systems, according to the current weather conditions, sun radiation level, and humidity rate.

2.5. Interfaces for external environments and communication protocols

In order to allow maximum flexibility and optimal utilization of existing home communication infrastructures, the proposed smart-home CMU is able to support various network standards and protocols, including Ethernet, X10 (electric wire-based networking), home PNA (phone lines), ZigBee, Infrared, BlueTooth, WiFi, and others.
CMU's application services and database store an up-to-date list of all connected and integrated devices. Any new integrated device is synchronized upon connection, and becomes inactive or is removed when not in use. This is done automatically by sending any shared data (list of properties, commands, optional streaming, etc.) into the CMU upon initial connection, and on predefined periodic processes.

Communication protocols and interfaces should support three levels of connectivity:

1. <u>CMU control</u>

Upon command initiation, the CMU sends either an action or inquiry call to a specific piece of equipment. The CMU then initiates calls in accordance with pre-programmed tasks or scenarios. A status check or inquiry is conducted by sending a ***get*** command with the desired attribute to be checked. An action call involves ***set*** or any other supported command. Unlike the ***get*** command, ***set*** or ***action*** commands require passing parameters. For example, the CMU may send a security system the following command: ***Arm(night_mode).*** The CMU doesn't need to "understand" the nature of this command. Once the authorization level is satisfied, it sends the command and awaits a reply (if applicable). Such a command forces an action, rather than checks current status.

2. <u>Device/Remote (external device) initiated call</u>

Any built-in process or response may result in sending a call to the CMU. For example, integrated motion detection equipment will send a call to the CMU, following a particular type of behavior. When a motion sensor detects a movement in a particular zone, it sends the CMU a "message", resulting in a CMU response (dim lights, change climate setting, etc.). Some calls may be ignored, depending on CMU setup and scenario management rules. Users may initiate a call from remote locations with their mobile phones or other communication device. For example, users may initiate a ***fill_jacuzzi(95F)*** command to the CMU, which would in turn send a command to the hot tub, including the desired water temperature.

3. <u>Streaming</u>

Unlike single commands or inquiries, ‘streaming’ requires a continuous flow of data, for a defined period of time. The CMU stores extensive information about all streaming-enabled devices, including streaming direction, supported formats and compression.

2.6. CMU components

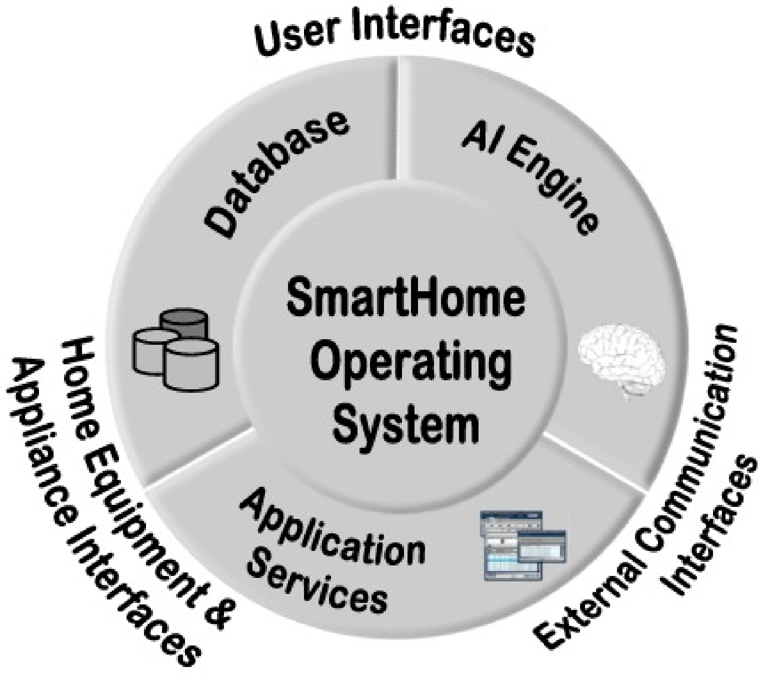

Figure 8. CMU Components

2.6.1. Operating System (SHOS - Smart Home Operating System): The CMU is responsible for continuous operation and control of all integrated smart-home devices. It constantly monitors devices' status, sending and receiving commands and calls, recording events in the database, and so on. The SHOS identifies any compatible device, complying with the suggested standard, and orchestrates the entire smart environment.

2.6.2. The Smart-Home Database: The database is the main storage point for all data in the smart-home environment. Any connected device is registered upon connection. This process results in creating new records, describing all supported commands, functions and controls, communication options and other information. Connected devices (equipment and UI devices) have a built-in local database (LDB) which is used for storing current status, streaming data, scheduled tasks and a list of commands in the queue.

The Smart-Home database is synchronized with the device's LDB, by sending and receiving commands and inquiry calls. The initial registration process loads all stored information into the CMU database from either a read-only chip or the LDB.

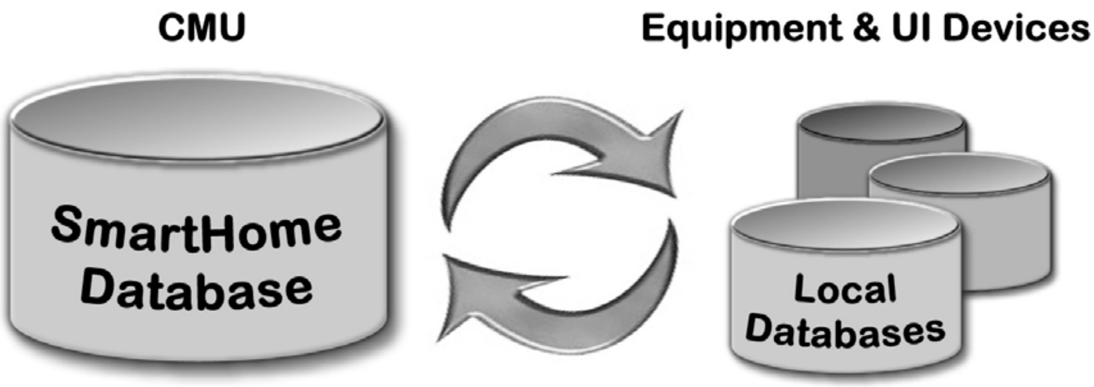

Figure 9. SmartHome Distributed Data-Synchronization

The following example [6] illustrates a relational Smart-Home-Database table scheme. Tables are either built-in or added upon installation of new devices.

Table	Description	Sample values
COMMAND	List of all devices' commands	
COMMAND_TYPE	Type of command	Check, assign, request-information, change-mode
COMMUNICATION_TYPE	Type of communication form	Input, output, BOTH, streaming
DEVICE	List of installed components	
DEVICE_COMMAND	Devices and commands relation	
DEVICE_TYPE	Device types	Security, climate control, entertainment, lighting
INTERFACE	List of available end-user interfaces	
INTERFACE_TYPE	Interface type	Character-based, GUI, keyboard, voice-activated
SCENARIO	List of programmed scenarios	
SCENARIO_COMMAND	Scenario commands list and schedules	
SCENARIO_TYPE	Scenario type	Home entrance, away, emergency, intra-home

Figure 10. SmartHome Database Data-Scheme

Major database entities include:

Device Any integrated component: lighting controller, door lock, appliance, sensor, etc.

Interface User interfaces: phone, keyboard, touch screen, voice-activated device, PDA or others.

Command Smart-home devices inter-communication is handled by sending and receiving commands. A command may be used in order to check status, set attributes, activate/shut down a device or send information to another device/User interface.

Scenario Set of pre-programmed, scheduled commands for devices operation, tasks initiation, or status checking.

Device Any integrated component: lighting controller, door lock, appliance, sensor, etc.

Interface User interfaces: phone, keyboard, touch screen, voice-activated device, PDA or others.

Command Smart-home devices inter-communication is handled by sending and receiving commands. A command may be used in order to check status, set attributes, activate/shut down a device or send information to another device/User interface.

Scenario Set of pre-programmed, scheduled commands for devices operation, tasks initiation, or status checking.

Table relationship is described in the following diagram:

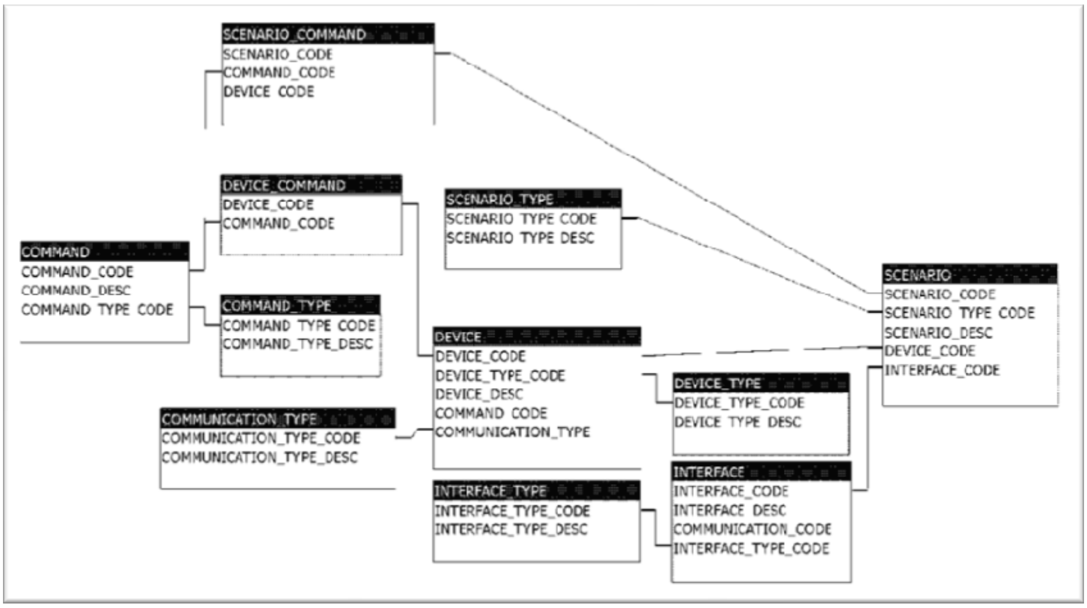

Figure 11. SmartHome Tables' Relationship Diagram

2.6.3. AI (Artificial Intelligence) Engine: An important added-value of an integrated environment, versus a group of sophisticated appliances and devices, is the intelligent behavior of the smart-home environment. The AI inference mechanism reacts according to changing conditions, reflecting suitable responses to different scenarios.

2.6.4. Application Services: The suggested smart-home flexible architecture allows adding software modules, in order to enhance devices operation and inter-device connectivity [3].

The Application Services module enhances the smart home by adding more flexibility in situations where commands or streaming data are insufficient for a materialization of a certain device. For example, programming a garden watering system may be much easier than using bundled software. The device manufacturer has to determine which of the supported UI devices is suitable to function as a medium for running the software, and develop compatible software accordingly.

3. Smart Home Situation Examples

The following examples illustrate handling common situations, following the proposed model's principles.

Home cinema (Streaming data)

Broadband Internet connection and high-definition-supported devices enable new and exciting entertainment capabilities [7]. Smart-home architecture makes it possible to watch streaming video on television screens, devices' monitors and projectors. Movies and other content, downloaded from the Internet or derived from Video-On-Demand (VOD) servers or any other resources, may be digitally recorded, thus assuring high quality viewing. For instance, a request to play a specific movie, on a certain monitor, at a desired time may be sent to the CMU. The CMU sends the appropriate request to the AI Engine, which in turn locates the best media source, either internal or external, and allows it to be stored temporarily or permanently, on any suitable content-storage device, such as hard-drives, optical disks, and flash memory chips. Local stored content may be transferred to other devices, such as handheld computers, portable media players, television sets, etc.

Security: Protecting property when away from home

Comprehensive security systems combine wireless sensors, motion and sound detectors, indoor and outdoor surveillance cameras, and external communication. Once none of the residents are at home, devices and application services may monitor in-house activity in real-time, and use external communication interfaces or the Internet, in order to broadcast video, send alerts in case of emergencies, or operate defense systems. Calls can also be automatically initiated to the fire department or the police/security call-center.
Smart-home flexibility and APIs (Application Program Interfaces) allow different uses for specific devices. For example, a security indoor camcorder could also be used in order to monitor infants, displaying the video at home or at a remote location.

Appliances automation

Besides turning house lights on and off in an intelligent manner [8], operating lights according to a pre-defined set of scenarios, such as TV viewing, reading, or going to sleep could conserve energy and reduce expenses. Devices may be operated remotely, using mobile phones or the Internet. Smart refrigerators can store a list of essential groceries, and track capacity. The refrigerator could also be connected to a central grocery ordering system, and form part of the ordering process. A smart refrigerator could also track expiry dates of dairy and other products.

Special needs

Various technologies can monitor the health of each family member. Today, these technologies are currently being used. For example, people who suffer from heart disease transmit their ECG results over the phone. A smart home could also use more sophisticated AI technologies, monitoring family members' health indicators, and generating an alert when an unusual pattern is detected. The system senses a heart failure in real-time, and contacts other family members or the physician directly. A smart toilet could perform routine diagnostic examinations, and save the results in a central database, accessible to the family physician. In the case of elderly family members, the system can learn to identify each person's typical behavior, and issue an alert whenever the common pattern of behavior is broken.

4. Conclusion

The smart-home environment is rapidly becoming a reality. However, the lack of a universal model results in vendors developing products, based on self-defined standards. Integration of devices and user interfaces produced by various manufacturers is almost impossible. In order to promote the emergence of a smart-home environment, a universal model is essential.

The proposed model emphasizes the following principles:

Standardization

By adopting universal standards, and introducing a variety of components that may be integrated easily, manufacturers may reduce production costs, and attain higher product quality. Third-party vendors may mass-produce components that may be used by other manufacturers.

Usage expansion

The suggested model allows for expanding the utilization of devices. For example, video equipment can be used for entertainment, security, medical monitoring and more. As long as devices and user interfaces share the same standards for built-in and acquired properties and commands, complex scenarios may be programmed; hence, smart-home utilization may be further improved.

Compliance with existing infrastructure and communication standards

The suggested model is based on existing communication standards and infrastructure, allowing for easy installation in any house. Another advantage of using the available infrastructure is intra-home connectivity: expanding usage of the smart-home environment by connecting houses, sharing information, and exploiting the potential of smart appliances and user interfaces, beyond the boundaries of the individual house.

The older population and physically-challenged persons would benefit from the model's implementation. According to US Census Bureau statistics, the older population will continue to grow significantly in the future. By 2030, there will be about 71.5 million elderly persons in the USA, more than twice their number in 2000. The 85+-year-old population is projected to increase to 9.6 million by 2030. As people become older, they need more assistance. However, assistance is commonly provided by nursing homes. One would like to stay at home for as long as possible, before moving to a home for the elderly. More than half of the older population reported having at least one disability of some type. Many disabilities require professional assistance to meet personal needs. According to the National Center on Health Statistics[4], over one-third of the older population reported at least one severe disability. Smart-home architecture can be implemented in order to assist people with special needs.

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