# U-Health Smart Home

Innovative solutions for the management of the elderly and chronic diseases.

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THE ELDERLY POPULATION worldwide has been increasing in a significant manner as a result of longer life expectancies, primarily enabled by the significant improvements in public health, nutrition, and medicine. In the United States, the population above the age of 65 is expected to double by 2040. At the same time, developed societies are facing a new phenomena, such as the increase in the number of people with chronic diseases, such as diabetes, chronic obstructive pulmonary disease, and arthritis. This is not only due to the increasing aging population but also the change of diet and lifestyle in our modern societies.

According to the World Health Organization, diabetes is projected to become one of the world's main disablers and killers within the next 25 years. Because of its chronic nature, the severity (and possible fatality) of its complications, and the means required to control them, diabetes is a costly disease not only for the affected individual and his/her family but also for health-care providers.

The management of people with chronic diseases and the elderly is steadily pushing health-care costs upward in a dramatic way that could jeopardize the survivability of any national health-care system. With these current trends, it will soon be impossible for most governments to fully support their national health-care system without negatively impacting their economies. However, it is possible to reduce this cost by seeking innovative solutions for the management of the elderly and people with chronic diseases using advances in information and communication technologies (ICTs) combined with the potential from emerging areas such as nanotechnology (NT) and biotechnology (BT).

It has been proven that effective prevention of diseases and early detection of health problems help to significantly reduce the cost of health care. It is then necessary to develop new types of devices and protocols to implement these measures as soon as possible. Hence, to reduce the high cost of hospitalization or management in costly specialized institutions, it is necessary to develop new systems that allow the elderly and those with chronic diseases to live safely in their own home. This future home aims to provide self-management-style health and safety services to its inhabitants, e.g., self-health monitoring and medical self-measurements. While the patients will be self-managed for most of the time, the smart home is always connected to a back-end medical institution (e.g., hospital) where doctors are continuously informed about the situation of the smart home inhabitant. Also, through technologies such as game consoles, the inhabitant can be encouraged to practice regular exercise, weight control, and a diet suitable for their chronic condition.

This concept of a ubiquitous health-care (U-Health) smart home for the elderly has been identified by governments and medical institutions as an important part of the economical, technological, and socially acceptable solution to maintain the health welfare system viable for future generations. Most elderly people are concerned with their health, and they need to spend much to maintain good health; this unfortunate trend has been steadily increasing over the years. Therefore, we are investigating one possible solution: a U-Health smart home system.

## U-HEALTH SMART HOME AT POSTECH

A new generation of a ubiquitous health smart home is being developed at Pohang University of Science and Technology (POSTECH) in Korea by integrating advances in ICT–BT–NT to support the elderly and/or people with chronic diseases in their own home. The goal of the U-Health smart home is to help the elderly to continue to live a more independent life as long as possible in their own home while being monitored and assisted (as much as possible) in an unobtrusive manner. Monitoring is done by a self-managed intelligent system capable of handling in an autonomic way situations that are usually handled by humans. The U-Health smart home is connected via broadband Internet access to back-end health-care providers (e.g., hospitals and specialized institutions) who are continuously informed about the status of the monitored inhabitant for handling emergency situations that necessitate their intervention.

The U-Health smart home will provide the inhabitants with a large range of health and safety services that can be upgraded from time to time. The POSTECH U-Health smart home (Figure 1) takes advantage of advances in low-power electronics and sensor technologies, which has led to small-sized medical body sensors and actuators that are capable of collecting physiological data from the body of the monitored inhabitant and possibly delivering some drugs. This is done through the deployment of a wireless body area network (WBAN). The solution also introduces a complete home communication network (HCN) and a U-Health autonomic decision-making system (ADMS) capable of collecting data from the various context providers in the home (medical body sensors and environment sensors as well as cameras) to build a snapshot of the monitored person's situation and infer the status in terms of health and safety to take appropriate decisions directly in the home, on the body of the monitored person, or by communicating with back-end health-care providers (e.g., hospitals). The ADMS should be able to make autonomic decisions for many situations and therefore reduce the cost of human intervention.

## LAYERED ARCHITECTURE

The functional architecture of the U-Health smart home is composed of four layers, as depicted in Figure 2. Innovation is expected in each layer of this architecture, which is the aim of the POSTECH project. The general requirements at each layer of this architecture are presented below.

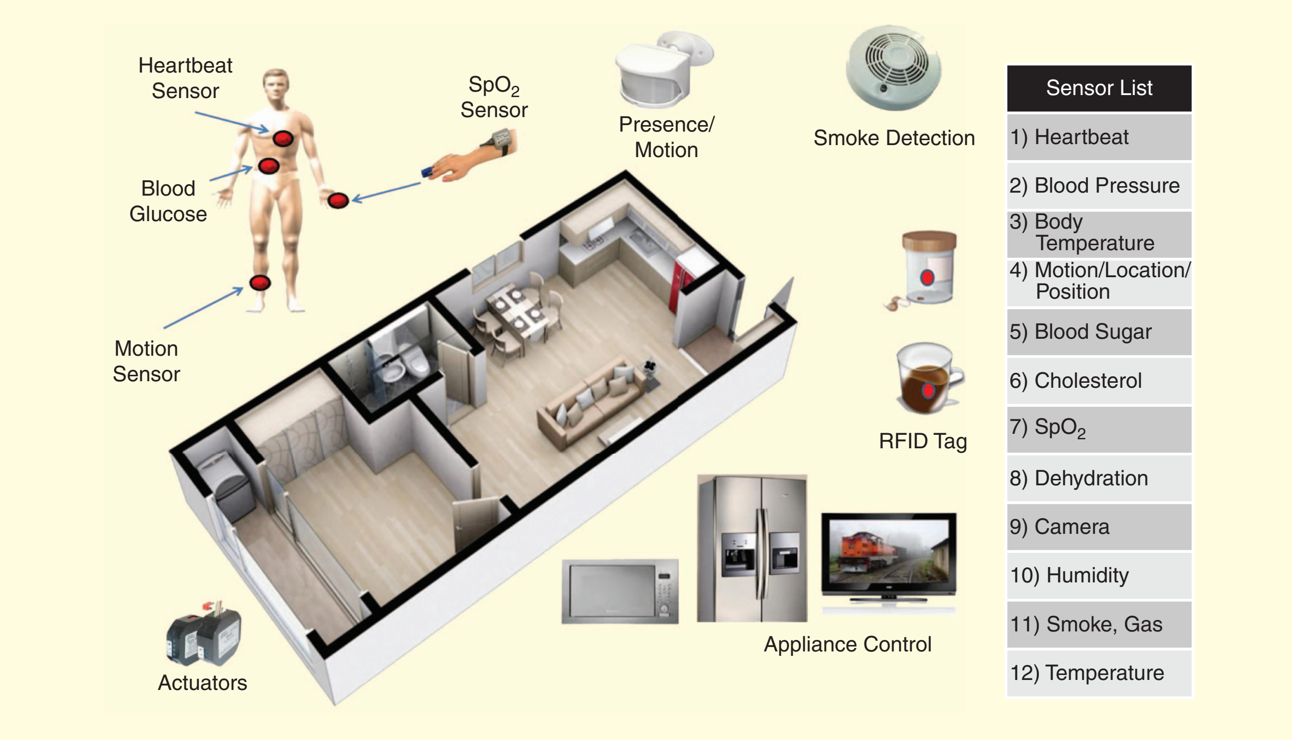


**FIGURE 1** Overview of the U-Health system.


**FIGURE 2** Autonomic U-Health smart home framework.

## *SENSORS AND ACTUATORS*

The lower layer consists of two main components: the sensors and actuators. The sensor components are physical devices that collect data about the environment (e.g., temperature, presence, sound, and gas/vapor) and about the health status of the monitored inhabitant (blood pressure, heart rate, and temperature). Actuators are physical devices that allow performing remote action on the environment (e.g., light control and appliance control) or on the monitored inhabitant's body (e.g., drug delivery such as insulin). There are a variety of sensors and devices available for monitoring a patient's health status: e.g., we can find a blood glucose sensor that is capable of continuously monitoring the blood glucose level, and an electrocardiography sensor can measure the activity of the heart. All these sensors can use wireless communication to send data directly or via the HCN to the U-Health smart home ADMS. Detection of health or safety problems is achieved by analyzing and correlating the physiological data collected from these sensors with some environmental information (e.g., localization, appliance status, etc.). Design requirements for these types of sensors and actuators are strict, especially for those addressing the medical needs. The acceptance of such devices by the inhabitants is only possible if they are easy to install or to wear and configure. Also, the devices should introduce as little inconvenience as possible to the patient.

### *HOME COMMUNICATION NETWORK*

The second layer of the framework is the HCN. Data generated by various sensors must be delivered to the ADMS for effective coordination of the actions in the smart home. Deployed sensors and actuators transmit their data either through wireless communication technologies using protocols such as ZigBee, Bluetooth, or Wi-Fi or wired communication technologies such as Ethernet or power line communications. The environmental sensors and actuators using wireless communication form a wireless sensor network (WSN) capable of transporting information from any sensor to a sink connected to the wired home network and vice versa. The WBAN allows the medical sensors and actuators to communicate with a control on short range to receive or send data. A coordinator in the WBAN can directly communicate with some nodes in the WSN and then the wired home network. Using HCN, the ADMS can communicate with any environment and medical sensors to collect data about the context of the inhabitant and remotely perform appropriate actions when necessary.

### *AUTONOMIC DECISION-MAKING SYSTEM*

The third layer is the autonomic computing part, the U-Health smart home ADMS, which is a computing system installed in the home and connected to the Internet (Figure 3). It constitutes the heart of the system where all the decisions are made. Data generated by the environmental sensors and medical sensors are transmitted to the ADMS smart home gateway through the HCN. The ADMS collects, filters, and analyzes the data and then saves it in a local database.

The goal of ADMS is to build a model of the inhabitant's environment and maintain their medical profile. All the received data is transformed into knowledge to feed the embedded decision system. Based on the generated knowledge and as a set of predefined policy rules, ADMS may be able to understand the situation of the inhabitant and make appropriate decisions about his/her safety and health care in an autonomic manner. These decisions can be either new knowledge in the system, actions to enforce in the smart home components (e.g., switching on a light and opening a window), or actions on the medical sensors (e.g., delivering a drug and changing the sampling frequency). ADMS is also responsible for keeping the third-party medical and safety institutions (e.g., hospital and police) fully appraised of the situation of the inhabitant.

### *SERVICES*

The last layer is the service part of the architecture. This layer describes the set of health-care and safety services that will be delivered by the ADMS. These services can be either related to safety in the daily life of the inhabitant or to their health. The portfolio of services that could be provided can depend on the specific status of the inhabitant and the available devices in the home. Depending on the particular diseases affecting the inhabitant, specific customized health-care services can be deployed by taking advantage of the available medical sensors and actuators in the market. At the same time, daily life support service can be deployed to ensure the safety and well-being of the inhabitant.

## ROLE OF NANOTECHNOLOGY

Of the four layers mentioned earlier, autonomics, communications, networking,

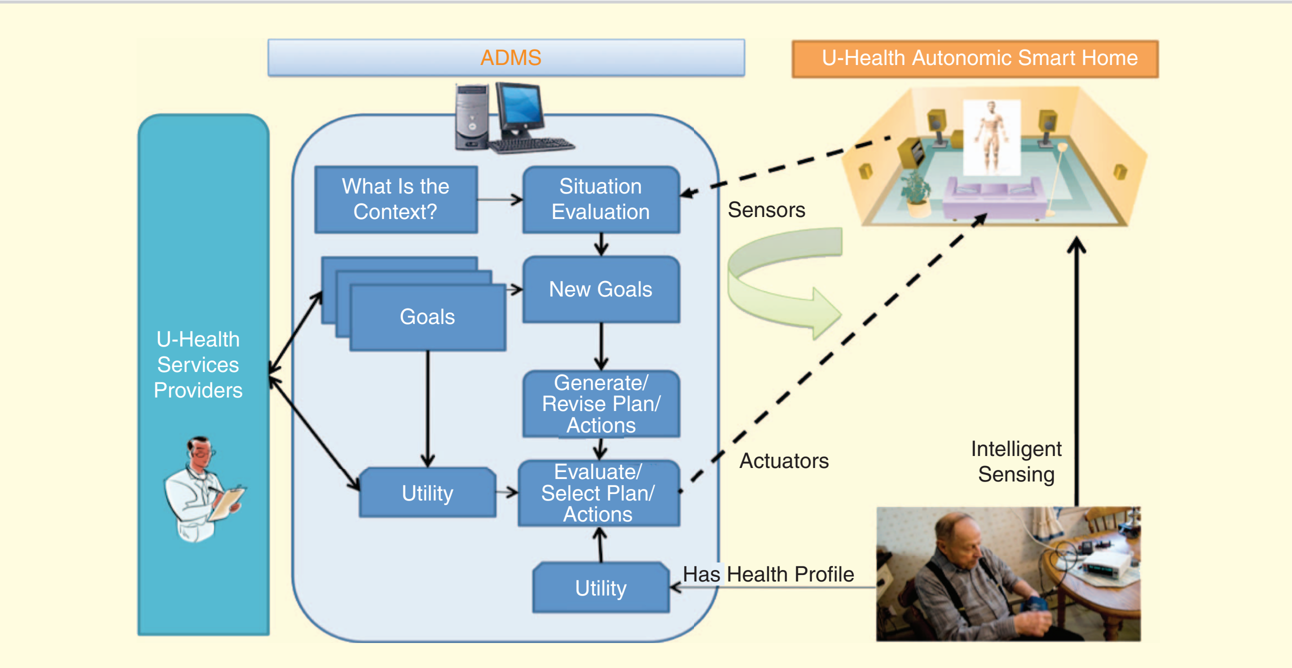


**FIGURE 3** Autonomic decision-making system.

and related information technologies have been relatively well advanced in comparison with the sensors and actuators. In general, sensors to monitor the smart home environment are adequate, e.g., temperature, humidity, carbon monoxide, motion detection, and ambient lighting. Actuators to control switching devices on and off, opening/closing window shades, and similar functions are also readily available. In the case of health monitoring, only a few devices are available, including blood pressure, pulse, heartbeat, and blood glucose. The anticipated sensor needs in a future smart home can be summarized as follows: 1) sensors or a lab-on-a-chip to monitor vital functions, including pH, cholesterol, complete blood count, white blood cell count, urine analysis, troponin-I (heart attack), bilirubin, and metabolic panel (Na, K, and Ca); 2) sensors for chronic diseases such as diabetes and asthma; 3) sensors for contagious diseases, e.g., flu, other viral diseases, and bacterial infections; and 4) sensors for specific diseases as demanded by the specific inhabitants of the smart home.

What is expected from a well-designed sensor system in any of the above cases? Small size and mass, low power consumption, minimal chemical resources, minimal human intervention or processing, reasonably rapid analysis, negligible false alarms, multiplexing capability for detecting multiple targets (i.e., performing multiple lab functions or detecting multiple viruses), reliability and robustness, and finally, a technology that is amenable to mass production to keep the cost low.

Biosensors meeting these needs for all the four sensing scenarios mentioned earlier are not currently available. Typically, a sensing system would consist of a sample delivery module, a sensing module, and a signal processing module. The sensor is likely to be affinity based, which means a probe is preselected for a given target and immobilized on the device platform. The probe may be DNA, an antibody, or an aptamer depending on individual targets. The sensor may use optical, electrical, or electrochemical transducers, i.e., the probe-target hybridization may be detected by a specific or unique optical or electrical signal. The device platform can then be an electrode, field-effect transistor (FET), light detector, imaging scanner, or any form of optical or electrical device capable of detecting respective signals accurately and sensitively.

Microfluidic technologies to deliver small samples of blood, urine, or other fluids have been well developed. The

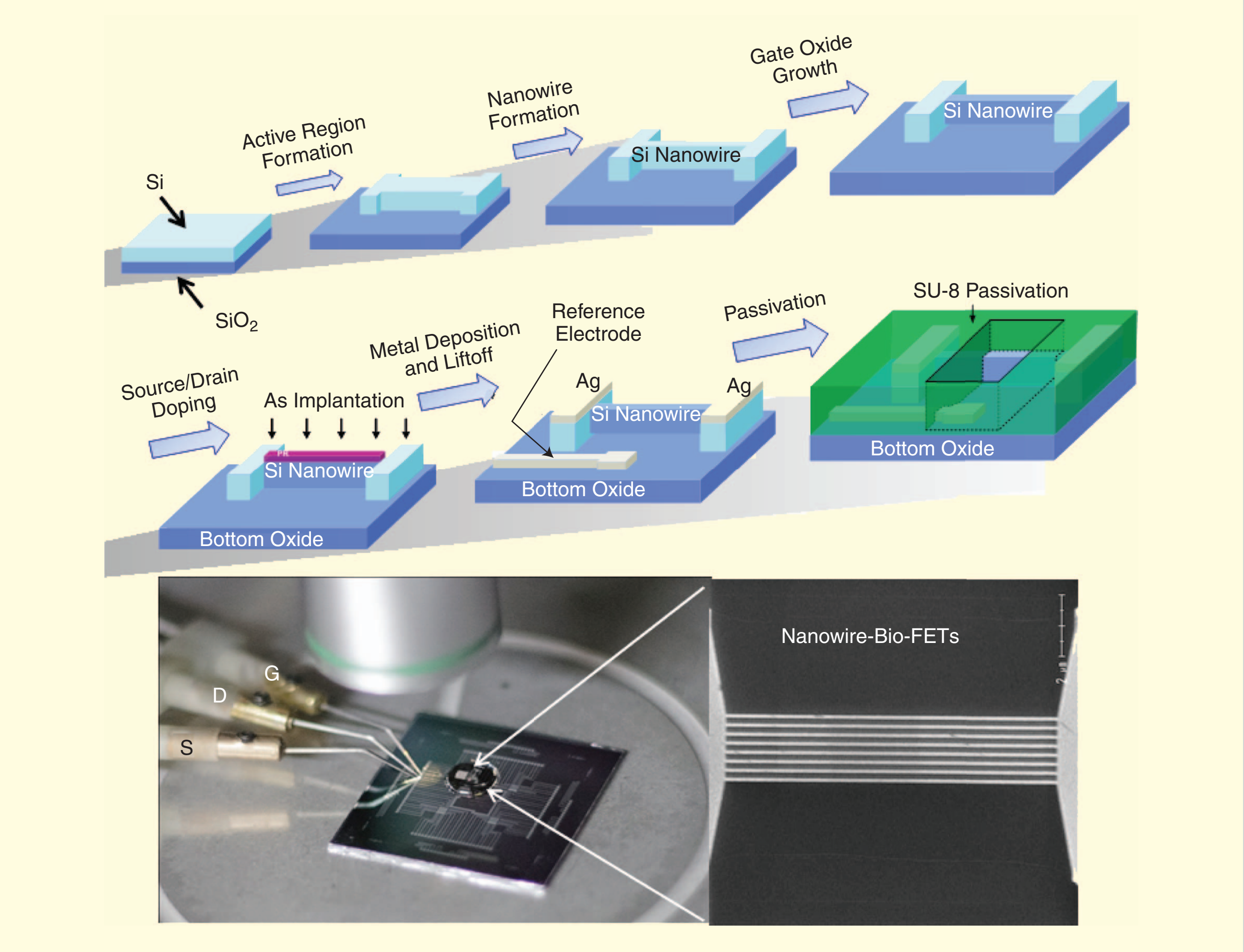


**FIGURE 4** Silicon nanowire-based bio-FET.

underlying substrate may be silicon, glass, or even plastic. The sensing component is where advances in nanomaterials and NT can be beneficial. Large surface-to-volume ratio and unique electronic and other interesting properties of various nanomaterials such as carbon nanotubes (CNTs), graphene, and inorganic nanowires are being exploited to construct biosensors of the future. These emerging devices certainly promise to be highly sensitive, selective, and fulfill the list of requirements provided earlier.

At POSTECH, we have chosen a silicon nanowire (Si-NW)-based bio-FET as our sensor platform (see Figure 4). A bio-FET is like a typical FET with the conventional gate replaced by an electrolyte solution (the sample and a reference electrode). The bio-FET has the ability to detect charges from biological molecules. At each stage of the process, the current–voltage characteristics of the bio-FET, including the so-called threshold voltage, differ: 1) bare device, 2) after attaching the probe, and 3) after the probe-target hybridization. The Si-NWs in the bio-FET are about a 50-nm diameter, and conventional top–down fabrication is used for patterning, electrode definitions, and isolation. The Ag/AgCl reference electrode is fabricated on the wafer along with the channel/reservoir for the sample. Currently, numerous devices are fabricated on a 6-in wafer with source–drain distances of several micrometers. Further, feature size reduction will allow an increase in the number of bio-FET devices per wafer. This fabrication also enables development of a biochip with multiple bio-FETs, each with a different probe for different purpose, thus allowing multiplexed operation.

Health-care sensing does not always involve liquid samples; instead, one can use gas or vapor samples. Human breath consists of more than 400 organic compounds, and some chemicals happen to be in excess quantities in a sick person relative to the normal population. Therefore, a chemical or organic compound can serve as a biomarker for a disease. Apparently, Chinese village doctors, even a century ago, were able to diagnose the onset of diabetes if the breath of a person was sweet smelling. Modern biochemistry diagnosed acetone as the culprit of this sweet smell. Similarly, biomarkers for asthma, lung cancer, and several other diseases have been identified in human breath, and this list has been growing.

A gas or a vapor sensor can also take the form of an FET, although with a metal oxide (tin oxide, for example), instead of silicon as the conducting channel. Adsorption of a gas of vapor in the gate region will affect the current–voltage characteristics. Unfortunately, these sensors work only at or above 300 °C. Nanoenabled sensors using CNTs and graphene have been successfully demonstrated for some biomarkers such as acetone and NO at room temperature. In a smart home, a tiny chemsensor can be embedded in the bathroom mirror. Standing in front of the mirror while brushing your teeth or combing your hair will automatically analyze the breath and monitor the health situation.

## SUMMARY

The U-Health initiative is being pursued vigorously in several nations across the world with strong research and development programs in many universities with participation from hospitals and industry. The showstopper to realize the full potential of the initiative is the lack of availability of biomedical sensors that are small, reliable, sensitive, and inexpensive. This is a challenge that the NT community can take head-on since it has the materials, processes, tools, and the interdisciplinary knowledge to develop low-cost biosensors.

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## READ MORE ABOUT IT

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