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Designing Smart Health Care Technology into the Home of the Future

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Abstract

The United States health care industry is experiencing a substantial paradigm shift with regard to home care due to the convergence of several technology areas. Increasingly-capable telehealth systems and the internet are not only moving the point of care closer to the patient, but the patient can now assume a more active role in his or her own care. These technologies, coupled with (1) the migration of the health care industry to electronic patient records and (2) the emergence of a growing number of enabling health care technologies (e.g., novel biosensors, wearable devices, and intelligent software agents), demonstrate unprecedented potential for delivering highly automated, intelligent health care in the home.

This editorial paper presents a vision for the implementation of intelligent health care technology in the home of the future, focusing on areas of research that have the highest potential payoff given targeted government funding over the next ten years. Here, "intelligent health care technology" means smart devices and systems that are aware of their context and can therefore assimilate information to support care decisions. A systems perspective is used to describe a framework under which devices can interact with one another in a plug-and-play manner. Within this infrastructure, traditionally passive sensors and devices will have read/write access to appropriate portions of an individual's electronic medical record. Through intelligent software agents, plug-and-play mechanisms, messaging standards, and user authentication tools, these smart home-based medical devices will be aware of their own capabilities, their relationship to the other devices in the home system, and the identity of the individual(s) from whom they acquire data. Information surety technology will be essential to maintain the confidentiality of patient-identifiable medical information and to protect the integrity of geographically dispersed electronic medical records with which each home-based system will interact.

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Introduction

The United States health care industry is experiencing a dramatic paradigm shift with regard to home care due to the convergence of several technology areas. Increasingly-capable telehealth systems and the internet are not only moving the point of care closer to the patient, but the patient can now assume a more active role in his or her own care. These technologies, coupled with (1) the migration of the health care industry to electronic patient records and (2) the emergence of a growing number of enabling health care technologies (e.g., novel biosensors, wearable devices, and intelligent software agents [1]), demonstrate unprecedented potential for delivering highly automated, intelligent health care in the home while at the same time reducing the cost of care [2].

The concept of embedding automation and artificial intelligence into the home environment is not new [3,4,5,6]. While home automation products provide home networks potentially useful for health care device interconnectivity, they primarily address needs such as physical security, entertainment, communications, lighting, heating/cooling efficiency, and voice-activated environmental control [7] (e.g., for persons with disabilities [8]). Smart health care delivery in the home requires a more robust set of features, including collective intelligence algorithms, secure interactions with electronic patient records, advanced processing algorithms for physiological trend data, and a host of other capabilities referenced later in this paper. Intelligent hybrid systems that incorporate knowledge synthesis algorithms and artificial intelligence have been researched for some time [9,10]. While these technologies have migrated into application areas such as smart transportation systems [11], they have yet to embed themselves into home environments that utilize distributed sensors. A limited number of smart, *stand-alone* devices experience success in the home care market . For example, a company in Japan designs smart toilets that perform chemical analyses on urine specimens [12]. These devices demonstrate further potential for detecting iron deficiencies caused by colon cancer [13].

Current desktop telemedicine platforms [14,15] are a natural starting point for the continued integration of smart devices and automated care delivery in the home. These systems utilize video conferencing, medical peripherals, store-and-forward capabilities, electronic patient record management software, and/or a host of other emerging technologies (see Figure 1). While these leading-edge systems are bellwethers for highly advanced home telehealth, they do not provide a proper framework for fully-distributed, intelligent health care devices in the home. In this immature market, most commercial home telehealth systems are custom-designed, "stovepipe" systems that do not interoperate with other commercial offerings. Users are limited to a set of functionality that a single vendor provides and must often pay high prices to obtain this functionality, since vendors in this marketplace must deliver entire systems to compete. Besides increasing corporate research and development costs, this inhibits the ability of the user to make intelligent purchasing decisions regarding best-of-breed technologies. In their current instantiation, these systems do not provide the flexibility to integrate distributed sensors, intelligent agents, and knowledge assimilation mechanisms required for smart home-based health care.

Realization of automated, intelligent health care delivery in the home requires smart devices that are aware of their context and are therefore able to assimilate information to support care decisions. Sensors distributed throughout the home will help to provide this context, since each sensor will acquire information regarding a patient's physiology as well as environmental factors that influence their state of health. Through initiatives targeting home-based networks and distributed computing [16,17,18,19], communication infrastructures that accommodate these needs may soon be in place. Internet appliances are already taking advantage of some of these capabilities in other settings [20,21,22]. However, the integration of medical devices into home-based networks is hampered by a lack of technology in several areas, including (1) secure, component-based messaging standards that allow exchange of pertinent, patient-identifiable medical information both inside and outside the home (e.g., with the health information network available to a patient's primary care physician) and (2) information architectures and plug-and-play medical devices that allow consumers to assemble low-cost, home-based systems comprised of best-of-breed, commodity technologies, allowing patients to match system capabilities to their individual care needs. If these issues can be resolved, the payoff is that the technologies vital to intelligent home care also promote medical information exchange in other settings (see Figure 2).

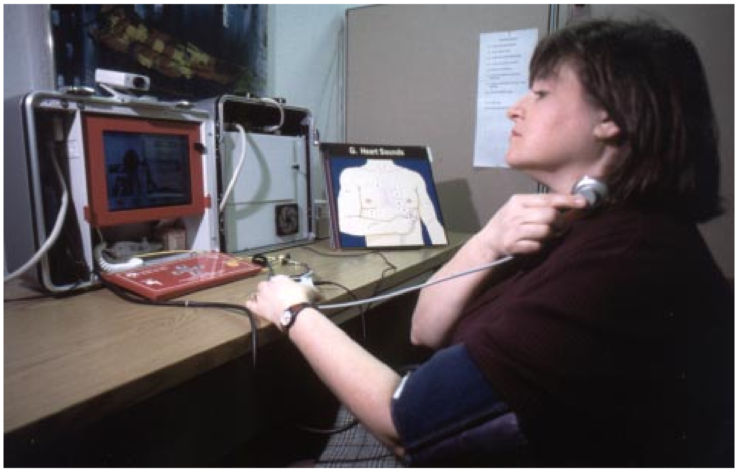

Figure 1. The patient end of a state-of-the-art, desktop telemedicine system. Photograph courtesy Richard N. Re, M.D. and Marie A. Krousel-Wood, M.D., Alton Ochsner Medical Foundation, New Orleans, LA.

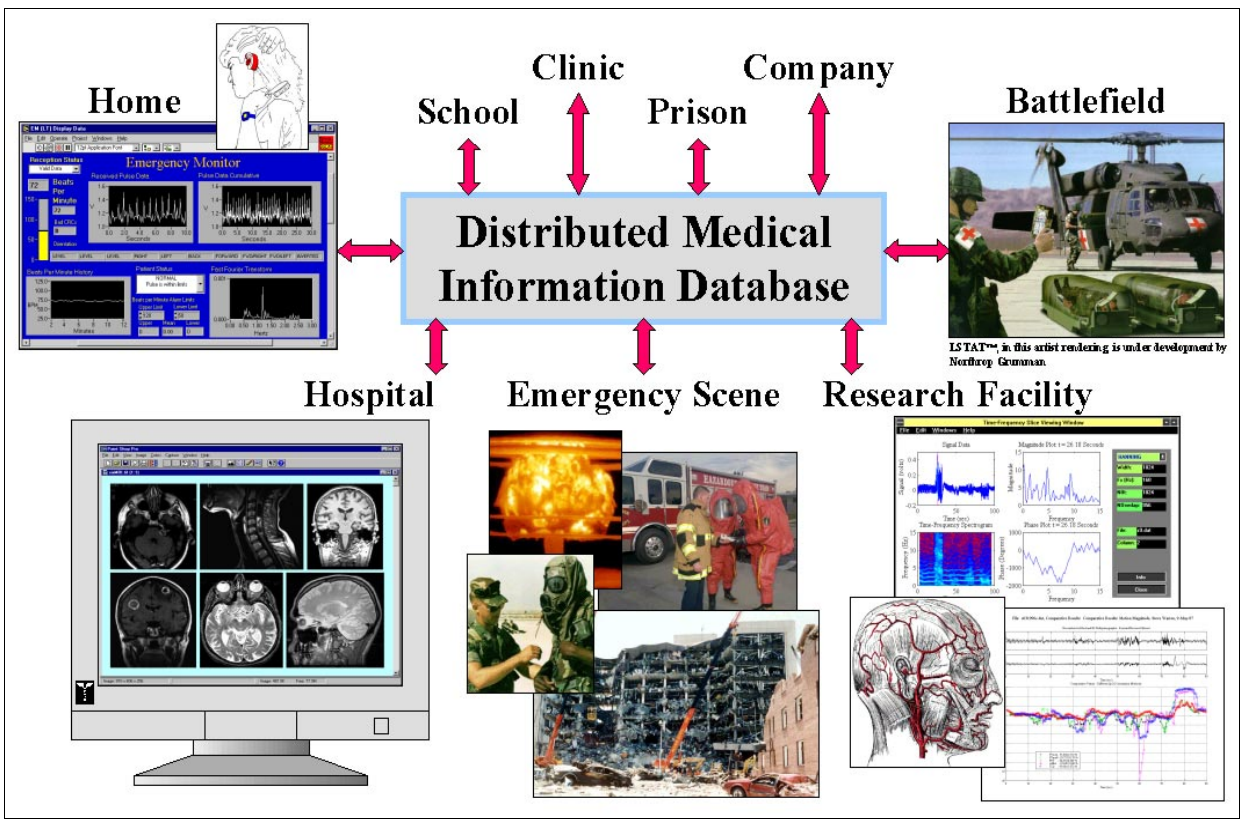

Figure 2. Secure, reliable exchange of medical information in multiple environments.

This editorial paper presents a vision for the implementation of componentized health care technology in the home of the future, focusing on research areas that have the highest potential payoff given targeted government funding over the next ten years. First, a systems perspective is used to describe a framework under which these device components can interact with one another in a plug-and-play manner. Within this infrastructure, traditionally passive sensors and devices will have read/write access to appropriate portions of an individual's electronic medical record. Through intelligent software agents, plug-and-play mechanisms, messaging standards, and user authentication tools, these smart home-based medical devices will be aware of their own capabilities, their relationship to the other devices in the home system, and the identity of the individual(s) from whom they acquire data. Information surety technology (i.e., security, integrity, reliability, safety, and availability) will be essential to maintain the confidentiality of patient-identifiable medical information and to protect the integrity of geographically dispersed electronic medical records with which each home-based system will interact [23,24].

Vision

Smart Devices and Collective Intelligence

The word "smart" implies the ability to process information within context. Intelligence can exist on a stand-alone device given that the knowledge set required to make decisions is maintained in the memory of the device. However, more flexible implementations of intelligent devices should accommodate a modular design that allows access to geographically distributed knowledge (information) and the software capable of processing those data [25]. This on-demand contextual information will likely be patient-confidential, so functional implementations of smart health care devices for the home must utilize appropriate information surety technology before home-based telehealth systems will be given read/write access to electronic patient records [26].[1]

In the home of the future, some devices will contribute physiological information about the patient (e.g., heart rate, blood pressure), while other devices in and around the home will contribute information about the patient's environment (e.g., humidity, temperature, carbon monoxide level). These physiological and environmental data will be collated to assess the patient's state of health and to identify external factors that may influence that state. In some cases, groups of devices will have enough collective awareness to function autonomously based on sensor data (e.g., A carbon monoxide detector may note levels above a safety threshold, initiating a protocol to open the windows, sound an alarm, and activate vital signs sensors for individuals in the house. Each device in this sequence would know the context of its action and initiate the proper device procedures). In order to protect individuals in the home from unforeseen catastrophes, additional devices may be dispersed around the locality of the residence to detect air-born viruses, bacteria, and possibly chemical/biological agents. These collective devices would provide data for automated response procedures as well as demographic analyses yielding information about the scope and intensity of, for example, a disease outbreak or an attack with a biological agent. Collective intelligence technology will be essential to analyze data from these distributed sensors [27]. In a mass-networked, information-infused society, these sensors and systems become important components of the

[1] The requirement that home health systems have read/write access to electronic patient records stored in clinical databases is relatively new. Full integration of electronic patient records with *hospital information systems* has been underway for some time, supporting tools for workflow management and physician decision support. However, telemedicine systems have not been traditionally integrated with health information networks for various reasons, including the lack of standards for message passing, security concerns (i.e., patient confidentiality), questionable data integrity, and the simple fact that developers of legacy hospital information systems assumed an enclave model at system inception and therefore did not design mechanisms for remote access into those systems. As noted in Figure 2, secure exchange of patient-confidential information is key in multiple care delivery settings.

United States critical infrastructure because of their direct relationship to emergency response services [28,29].

Intelligent Health Care in the Home of the Future

The following editorial sections briefly describe how health care and smart technology will interrelate in the home of the future.

Optimized Care Delivery

- Basic vital sign sensors and interactive remote consultation equipment for the home will be inexpensive commodity items available at local department stores.
- More expensive equipment will be available through monthly lease packages via third-party suppliers (e.g., a lease package for home pregnancy monitoring).
- Individuals will have direct and immediate electronic access to information regarding their medical history, health maintenance, and procedures for dealing with emergency medical situations.
- Mechanistic duties traditionally provided by a care provider (e.g., vital sign acquisition) will be replaced by self-measurements and automated protocols.
- Care options will be tailored to each individual in the home.
- Monthly checkups will occur at home. Telehealth systems will acquire data, interpret those data, and make appropriate health care suggestions.
- Through the use of intelligent agents, smart health care devices will make routine decisions, allowing care professionals to spend more time on sophisticated tasks that require human intelligence.
- Care will be geographically decentralized (e.g., vital sign monitoring will occur at any location in the home). Physiological information will be obtained with a variety of wearable and non-contact sensors.
- Patients will interact with providers through everyday mechanisms such as television sets or palmtop computers.
- Home systems will have access to a life-long electronic medical record for every individual in the home.
- Trend data acquired with lightweight, continuously-operating sensors will become more important in the care delivery process, serving as a way to predict adverse events (e.g., a myocardial infarction): home health care will migrate to a more proactive, rather than reactive, delivery model.
- Home care networks will be aware of every individual's location and physiological status.
- Interactive care sessions will be fun for children and informative for adults.
- Health care systems in the home will exchange information with other systems in a manner similar to home automation technology available today.

Advanced Sensors and Treatment Options

- Non-invasive, lightweight sensors will replace bulky traditional sensors (e.g., a light-based wrist watch may provide heart rate, blood pressure, and oxygen saturation measurements previously supplied by a blood pressure cuff in tandem with a pulse oximeter).
- Surrogate diagnostics (i.e., alternative indicators of state of health) will replace diagnostics from traditionally cumbersome or problematic vital signs sensors.
- Noninvasive sensors will replace more invasive procedures (e.g., blood gas and blood glucose measurements).
- Equipment will emerge to provide therapy or treatment in a non-sterile environment.
- Sensors will work with all ages and sizes of individuals.
- Non-invasive, lightweight sensors will increase patient comfort and pave the way for continuous acquisition of physiological data and the resulting trend analyses.

- Advanced devices will provide analysis capabilities (e.g., urine chemical analysis) currently available with only hospital-based systems.
- High-risk patients may wear multiple sensors that communicate with one another through a local area network that resides on the patient.

Interoperable Devices

- Flexible information networks will promote plug-and-play functionality throughout the home by utilizing standard connectors, message-passing protocols, data definitions, and security mechanisms.
- All home-based sensors and devices will interoperate seamlessly so that monitoring functionality can be tailored to the needs of individuals.
- These devices will be affordable commodity items, since original equipment manufacturers will compete by producing best-of-breed technologies consistent with their company strengths. Competition will occur at component, system, and service levels.
- Wireless, low-power devices will communicate via radio-frequency repeater stations scattered through the home.
- All devices will be aware of their capabilities and be able to express those capabilities to other devices.
- Certain classes of devices will incorporate knowledge assimilation modules that gather information from all other devices in the home in order to provide context for medical decisions.

Patient-Device Interaction

- Voice recognition technology will reside on components of distributed telehealth systems as well as individual, stand-alone devices (e.g., the patient will be able to interact, using natural English, with the wrist-worn unit that is monitoring and displaying his or her vital parameters).
- Devices will be owner-aware through biometric mechanisms and intelligent association technology.
- User interfaces will be simple.
- Patients will be able to communicate with devices via gestures or sign-language.

Dynamic Interaction with Electronic Patient Records

- Every individual will be able to view his or her own life-long electronic patient record (EPR).
- Home-based health care devices will have (in)direct read/write access to EPR's.
- Appropriate knowledge databases and copies of individuals' EPR's will be stored in a repository and accessed on-demand through the home's local area network.
- Data from home consultations and automated measurements will be stored directly to EPR's.
- Individuals will carry appropriate portions of their EPR's (e.g., on watches, smart cards).
- EPR storage devices will "plug into" standard ports (through wireless or direct connections), updating the information on the devices and/or the EPR repositories.

Intelligent Assistants

- Intelligent software agents will interpret vital sign data and note anomalies to address. If a patient needs immediate assistance, an agent will send a message to a device that will call for help.
- Software assistants will process large volumes of health information (e.g., continuous physiological measurements) in order to provide physicians with meaningful quantities of relevant data, avoiding information overload.
- Data mining tools will search global repositories for information relevant to a patient's state of health.

Information Surety

- Medical information exchange will be secured at an appropriate level through role-based access mechanisms.
- Surety standards will exist for maintaining the security, integrity, reliability, and availability of medical information acquired in the home.
- Predefined rules will balance patient confidentiality concerns against the need to access medical information in emergency situations.
- Biometric mechanisms and other technologies will authenticate patients and establish patient-device or patient-system associations.
- Independent algorithms will monitor data integrity and maintain information security at each step in the care delivery process.

Robust Communications

- High-bandwidth access to information will occur at any location in the home.
- Each home will support its own local area network, utilizing both wireless and direct connections.
- Terminology and message passing standards will promote information exchange between home care devices, hospital databases, and home-based information networks.

An Example Home Layout

Sensor and system layouts in the home of the future may appear as shown in Figure 3. In this scenario, the following items come into play:

- A local area network supports sensors distributed throughout the home and the immediate outside environment.
- Transmitter/receiver boxes scattered throughout the home allow wireless sensors [30] to utilize low-power infrared [31] and radio-frequency telemetry mechanisms [32].
- In the living room, a set-top box [33] serves as a central information hub for sending and receiving sensor data, consulting with a care provider via video-conference over the cable TV line, collating information relevant to patient state-of-health, and providing educational material on health maintenance and emergency procedures.
- The home incorporates flexible switching protocols for communicating with the outside world over multiple modalities (e.g., UHF, FM, cellular, satellite, phone/ISDN/T1 land line).
- Although a temporary knowledge database and EPR repository exists in the home, the home information system is capable of communicating securely with remote hospital information networks and EPR repositories in order to obtain new information relevant to patient care. Data mining capabilities allow the home network to search large repositories for context-specific information. This information is filtered to provide meaningful quantities of health information to both patients and physicians.

Smart Spaces

For individuals requiring constant observation, future homes will have smart spaces that utilize numerous technologies to track behavior and state-of-health. These spaces may employ digital cameras, laser rangers, audio recognition mechanisms, and/or pressure-sensitive flooring that would identify occupants, track their locations, and "read" their facial expressions, gestures, and behavior [34,35]. While such data may not be sufficiently fine-grained to determine physiological state, these data could provide indicators for medical conditions characterized by deficiencies in motion control (e.g., individuals recovering from limb injuries, mobility-impaired individuals, or people with handicaps). In addition, the system may be able to recognize when an individual is in pain [36], experiencing an epileptic seizure, or having a heart attack. Digital cameras could use cueing and tracking techniques to follow an individual across their fields of view, developing a behavioral baseline for each person. Complimentary state-of-health data would be supplied by wearable sensors and/or remote monitors, such as micro-impulse radar devices [37] that measure and record heart rate.

The safety and alerting roles of such rooms are particularly important, especially for people with chronic conditions or individuals prone to falls. A smart room could monitor the walking behavior of an impaired person, determine if he or she is at risk of falling, and alert a domestic caregiver. In an emergency, the smart room could also alert local emergency medical services. This technology may be the only way that these individuals could live at home, although applications in geriatric wards would conceivably demonstrate a more cost-effective economy of scale.

Smart spaces may also include mechanisms for authenticating the identity of individuals in a room, thereby providing an independent measure of the integrity of data acquired from a person within that space. For example, smart floors ("smart carpets") being developed by Georgia Tech [38] can identify and track multiple people based on their footfall. Such floors incorporate thousands of pressure-sensitive piezoelectric sensors to measure an individual's weight, foot force profiles, length of stride, limb length, and joint angles. These biomechanical data, which are unique to an individual, can be correlated to sensor data acquired from that person, yielding an unobtrusive biometric indicator that corroborates the identity of the patient, thereby providing an additional means for maintaining the integrity of the electronic patient record to which these data are written.

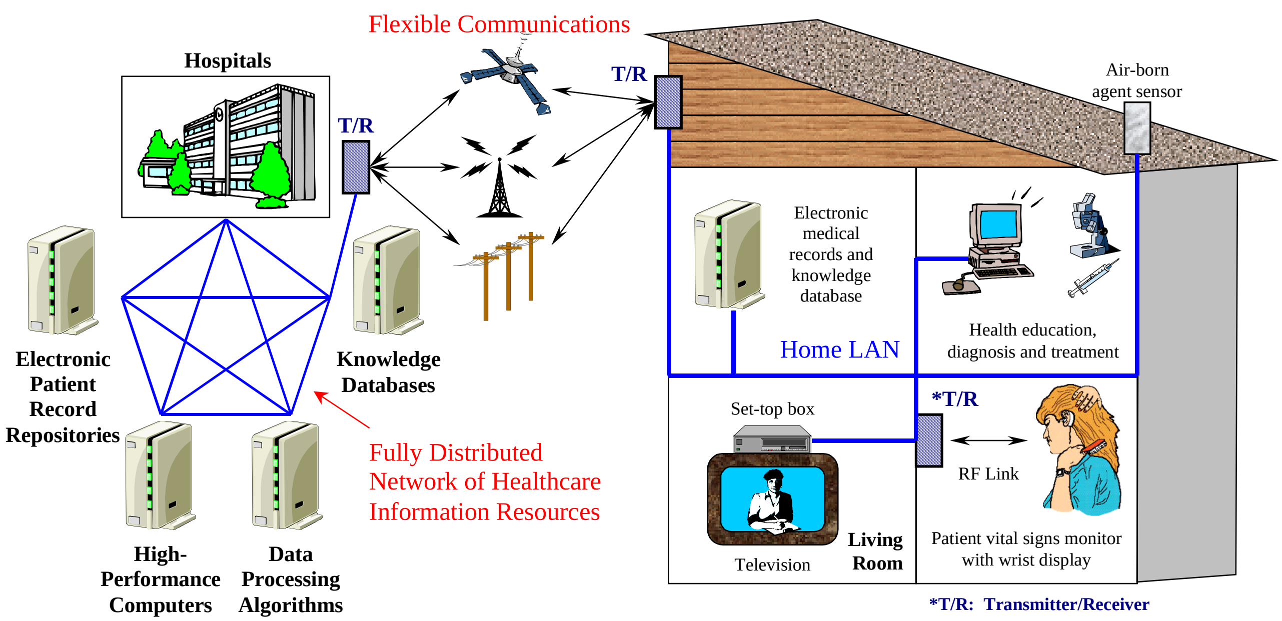

Figure 3. An example of smart device and resource connectivity in the home of the future.

Enabling Technologies

In order to realize smart health care technology in the home of the future, certain classes of technology must be refined or developed. This section describes those technologies within the context of a conceptual information framework.

Information Frameworks

Intelligent home care systems will require secure, component-based information frameworks that promote secure, 'plug-and-play' interaction between device and system components through standardized interfaces, communication protocols, messaging formats, and data definitions. A telemedicine device architecture has been proposed that defines functionality sets within which these technologies can be grouped [39]. The implementation of this framework would vary depending on the technologies that render the framework. However, the functionality sets are relatively constant (see Figure 4).

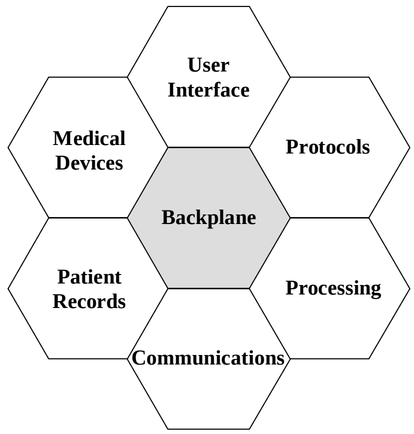

Figure 4. Service areas represented in the proposed telemedicine device architecture.

The following items describe these architectural services:

- The ***USER INTERFACE*** service area represents hardware and software with which the user interacts, including mechanisms that support telemedicine device control (e.g., buttons and lights on the front panel of an instrument) and person-to-person interactions.
- The ***MEDICAL DEVICES*** service area represents mechanisms for acquiring patient data, delivering therapy to a patient, or analyzing specimens collected from a patient.
- The ***PATIENT RECORDS*** service area represents a device's ability to store and retrieve information that the device has collected about a patient.
- The ***PROCESSING*** service area consists of specialized routines to manipulate data. Examples of this include statistical routines to analyze trends in data sets, filtering routines to manipulate waveforms and images, and "intelligent agents" that aid in diagnosis and care planning.
- The ***COMMUNICATIONS*** service area represents (1) mechanisms a telemedicine device uses to communicate with other devices and (2) the services that support these communications (e.g., address books that contain email addresses, or directories that indicate where to find specific services).
- The ***PROTOCOLS*** service area constitutes the brain of a telemedicine device. The "programs" or "scripts" in this service area accomplish specific medical objectives by utilizing resources acquired from the other services. A simple protocol might, for example, direct a medical instrument to take a reading, tell the patient record to store the reading, and tell the user interface to display the reading. Protocols can deliver sophisticated functionality through command nesting.
- Finally, the ***BACKPLANE*** service area represents mechanisms that tie the other six services together. It provides intra-device communications, as well as profile information needed for device "self-awareness." This self-awareness is essential to creating devices that work with one another in a plug-and-play fashion.

Given the partitioning shown in Figure 4, it is possible to include some portions and exclude others in order to produce what would appear from an external point of view to be fundamentally different devices (see Figure 5). This approach to construction of telehealth devices is cost-effective because it allows developers to specialize on system components/services while offering the user the ability to purchase only the system components that are necessary for their needs. Note that the partitioning arrangement in Figure 4 is fractal in nature: a collection of segments can represent (1) an individual sensor, (2) a collection of sensors, memory, hardware, and software that constitutes a device, (3) a stand-alone telemedicine system, or (4) a fully integrated home-based telehealth system.

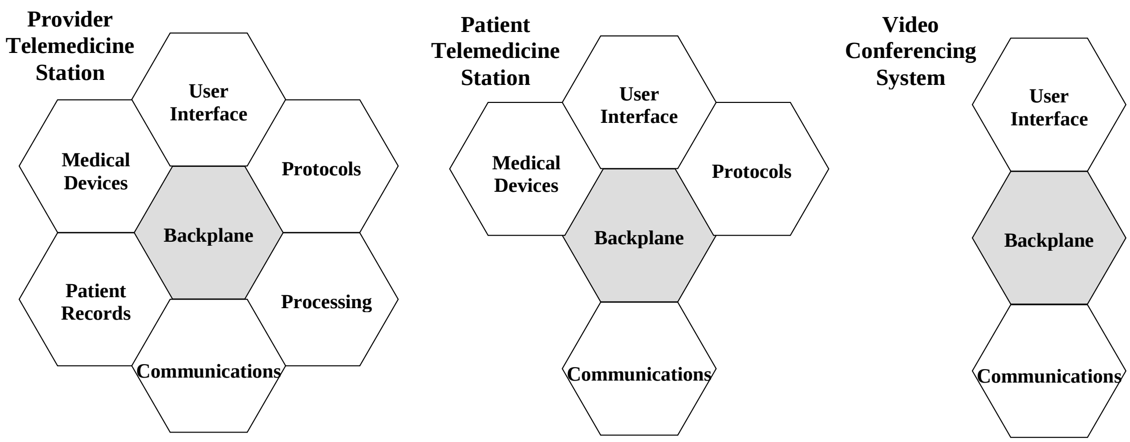

Figure 5. Creation of various telehealth devices and systems through different combinations of the fundamental architectural building blocks.

It is important to note that information surety (i.e., security, integrity, reliability, safety, and availability), plays an extremely important role in this architecture, since it is distributed by nature. Stovepipe, point-to-point systems are relatively straightforward to secure given the small user population, the static network topologies, and the limited range of technologies from which these systems are composed. Future home-based telehealth implementations will incorporate mass-market communications, emphasize distributed computing over private networks, and support both legacy and leading-edge technologies. These health care information networks will be highly dynamic, and the range of technologies used to deliver medical services will be increasingly diverse. In this environment, security solutions will be more important than ever while at the same time more problematic [40].

Industry must continue to develop standards for the ways these devices interact at the component, subsystem, and system level in order for smart device technology to move forward. Standards are currently under development for security, messaging, communication, plug-and-play hardware, nomenclature, protocols, and diagnostic procedures [41]. Many of these (e.g., the Health Level 7 (HL7) standard for health data exchange [42]) are moving forward quickly and being adopted by industry, while others are either still in the definition phase (e.g., the CORBAmed Health Research Access Control (HRAC) standard for role-based access to medical information [43]) or have been in development for some time but have experiences limited industry support to date (e.g., the IEEE 1073 Medical Information Bus (MIB) standard for plug-and-play peripheral systems [44]). The bottom line is that standards promote interoperability and the determination of context: two key components for building smart devices and systems.

Smart Component Functionality

Concentrating on the architecture component areas described in the previous section is a good way to focus thoughts regarding smart devices and the technologies that must be developed in order to realize these devices. Using the architecture service areas as a starting point, this section lists the classes of technology that must be developed in order to realize smart, home-based health care capabilities that function within a mass-networked, fully distributed environment.

The **Backplane** service area stores functionality information about devices as well as their addresses/locations within the home system. From that standpoint, the Backplane provides context and allows devices to communicate with one another, which is the fundamental starting point for a smart home subsystem consisting of distributed sensing elements. Other information used for context is stored in the **Patient Records** service area, which allows access to distributed information databases that may contain vital information. Instruction sets for automated devices are stored in the **Protocols** service area, while the **Processing** service area implies functionality for intelligent agents, decision support systems, data interpretation algorithms, and signal extraction techniques. The **Medical Devices** service area supplies smart-device sensor functionality, while the **Communications** service area gives components "access to the outside world." Interestingly, the **User Interfaces** service area is the only area for which a broad mapping to smart devices is unclear, since intelligence is more highly aligned with the ability of devices to process information. Table 1 below lists a subset of technologies that populate the service areas of the framework discussed above. Although every class of technology may eventually contribute to smart devices and systems, some technologies have a much more immediate and telling effect on the availability of intelligent home-based systems. As a means for distinguishing key technologies from contributing technologies, Table 1 ranks each class of technology according to its perceived potential to influence smart system design. Technologies that simply supply data are ranked as contributing technologies, while technologies that enable integration of data and sensors are ranked as key technologies because of their ability to contribute to contextual decision making. In other words, the goal of the scoring in Table 1 is to differentiate between intelligent technology and capabilities that would simply "be nice to have" for other reasons.

Table 1. Classes of technology that contribute to smart medical devices and advanced systems. These technologies are assigned to the framework component that is the best match. In addition, they are scored relative to their perceived potential to contribute to contextual decision making: contributing element (*), enabling element (**), key technology (***).

User Interface			
**	Voice recognition	**	Sign language and gesture interpretation [34]
Medical Devices			
***	Wearable devices with integrated sensors, communications, and processing [45,46,47,48,49,50]	***	Noninvasive, light-weight sensors for continuous data acquisition (trend data)
***	Smart, self-aware sensors [25,51]	*	Micromachines for sensors, invasive therapy [52]
**	Remote, non-contact sensors [53]	*	Sensors for airborne agents, particulates [54,55]
**	Surrogate diagnostics	**	Emergency event detectors
*	Light-based sensors [45]	***	Battery technology [56]
***	Low-power sensors	*	Hand-held units with diagnostic capabilities
**	Small sensors	*	Low-cost, high-resolution cameras
***	Self-calibrating sensors [57]	**	Embedded ORB's [58] and Java applets [59]
Patient Records			
***	Distributed electronic patient record repositories	***	Wearable or portable devices for storing EPR information [60,61]
**	Terminology translators	*	Longitudinal EPR construction utilities [62]
***	EPR software in the home	**	Patient identification services [63]
***	Data mining and search engines	***	Better memory storage

Communications			
***	Low-power telemetry technology [30,64,65]	*	High-bandwidth infrastructures
***	Home-based repeater networks [32]	*	Data/voice synchronization technology
*	Fast, effective compression / decompression algorithms and chips	**	Patient locator technology
*	Better teleconsultation technology	***	Body LANs that unite autonomous sensors and wearable devices [49]
Processing			
***	Intelligent software agents [1]	***	Trend data analysis tools
***	Automated diagnosis algorithms	**	Demographic analysis tools
***	Knowledge assimilation techniques for state-of-health determination	**	Advanced filtering (e.g., signal extraction) and waveform analysis tools [66]
***	Artificial intelligence algorithms for care decisions [67]	***	Information reduction and interpretation tools to avoid physician information overload [68]
***	Neural network [69,70] and fuzzy logic [71] technology for decision making	**	Techniques for collating non-health sensor data with physiological data for determining patient state of health
***	On-chip or on-device decision support tools		
Protocols			
***	Evaluation procedures	**	Mechanistic activities
Backplane			
***	Standard device descriptions	***	List of resources for establishing context
Information Surety			
***	New biometric algorithms [72]	*	High-speed, low-power encryption chips
***	Owner-aware sensors	**	Audit trails for the home
***	Health databases with role-based permissions	*	Procedural guidelines
***	Role-based access control standards	*	
Standards			
***	Information architectures [39,73]	***	Storage
***	Security [74]	***	Nomenclature [75,76]
***	Plug-and-play hardware [25,44,77,78]	***	Protocols
***	Communication [18]	***	Diagnostic procedures [79]
***	Messaging [42]	***	Device descriptions [80]

Conclusions

Health care is moving closer to the patient, and a host of technologies (including increasingly capable telehealth systems and the internet) allow patients to play a greater role in their own care. In order to maximize the health benefit to the patient, these home-based telehealth systems must be smarter than former generations of telemedicine systems because of the limited medical knowledge base of the typical patient and the inability of care providers to ascertain all health indicators at a distance. Conversely, the implementation of smart health care technology in the home opens up fields of care that have not been fully explored, such as proactive health models that rely on continuous vital sign monitoring and trend data analysis to predict health, rather than reacting to medical conditions as they occur.

Intelligent health care systems in the home will utilize a myriad of technologies in their implementation. However, while some of these technologies will simply contribute to smart systems, other classes of technology are key to the implementation of intelligent devices and systems: primarily those that allow devices to be aware of their context and those that assimilate information to support meaningful care decisions. Table 1 listed classes of technology that will contribute to future home care systems, scoring them according to their ability to enable smart systems. In general, key technologies noted in Table 1 are summarized by the following items.

- ***Distributed Computing***:
  - frameworks for interoperability and plug-and-play devices,
  - device component registries that provide a "lay of the land" with regard to the resources available on a home system,
  - standards for terminology and device interaction, and
  - home-based networks that allow distributed medical devices to function as virtual systems.
- ***Intelligent Processing***:
  - knowledge assimilation algorithms that collate data from separate devices into care decision matrices,
  - intelligent agents that facilitate data mining and automated care delivery,
  - data mining and search engines that gather missing EPR information or information relevant to a patient's medical history,
  - artificial intelligence, neural network, and fuzzy logic algorithms for making care decisions,
  - information reduction technology for avoiding physician and patient information overload, and
  - protocols and procedures that promote automation of common or mechanistic tasks.
- ***Information Surety***:
  - new biometric algorithms for authentication and access control,
  - owner-aware sensors,
  - role-based access control mechanisms for EPR databases, and
  - surety mechanisms for protecting data integrity and reliability at each point in the information exchange process.
- ***Novel Devices and Sensors***:
  - wearable devices that incorporate non-invasive, self-calibrating, and low-power sensors,
  - body LANs that use low-power telemetry to unite data from autonomous sensors worn on the body,
  - on-board processing algorithms that filter data prior to storage and transmission,
  - low-power telemetry chips, and
  - smaller, more powerful batteries.
- ***EPR and Data Repositories***:
  - distributed EPR repositories and knowledge databases that can be securely accessed through role-based security mechanisms,
  - temporary EPR's and knowledge databases that reside in the home, and
  - wearable or portable devices that store EPR's.
- ***Standards***:
  - information architectures,
  - security,
  - plug-and-play hardware,
  - communication,
  - messaging,
  - storage,
  - nomenclature,
  - diagnostic protocols and procedures, and
  - device descriptions.

Even with targeted government funding for intelligent home care technologies over the next ten years, research and development will not proceed in an optimal way without ***effective communication between the medical and scientific communities***. Communication can be difficult since physicians, scientists, and engineers approach problem solving in different ways because of the nature of their work, their experiences, and their education/training. Technical designers are often unaware of the medical applications for their technology because they rarely engage in active discourse with members of the medical community. An ***ongoing dialogue*** must be established so that health care providers can (1) help scientists and engineers understand care needs in the home, (2) learn about emerging technologies that may have implications for health care, and (3) specify operational requirements for home-based telehealth systems, focusing the work of scientists and engineers on cost-effective technology that meets practical needs while it improves the quality of home-based care.

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