The Independent LifeStyle Assistant™ (I.L.S.A.): Lessons Learned

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Abstract

The Independent LifeStyle Assistant™ (I.L.S.A.) is an agent-based monitoring and support system to help elderly people to live longer in their homes by reducing caregiver burden. I.L.S.A. is a multiagent system that incorporates a unified sensing model, situation assessments, response planning, real-time responses and machine learning. This paper describes the six-month study of the system we fielded in elders' homes and the major we lessons learned during development.

Key Words: elder care, passive monitoring, intent recognition, machine learning, ontology

Contents

1 Introduction

Historically, 43% of Americans over the age of 65 will enter a nursing home for at least one year. In spite of the financial and emotional strain placed on the family, a nursing home or other institutional setting is often the only care option available when we perceive that a loved one can no longer live safely alone.

We have been developing an automated monitoring and caregiving system called *Independent LifeStyle Assistant*™ (I.L.S.A.) [38, 43]. Researchers and manufacturers are developing a host of home automation devices that will be available in the near future. I.L.S.A.'s concept is to integrate these individual devices to detect and monitor activities and behaviour. The goal is to create an intelligent, coherent, useful assistant that helps people enjoy a prolonged, independent lifestyle.

From January to July 2003, we field tested I.L.S.A. in the homes of eleven elderly adults. The I.L.S.A. field test was designed to complete an end-to-end proof-of-concept. It included continuous data collection and transmission via security sensors installed in the home, data analysis, information synthesis, and information delivery to I.L.S.A. clients and their caregivers. The test concentrated on monitoring two of the most significant Activities of Daily Life (ADLs)[1]: medication and mobility. Our system issued alerts and information to family caregivers, who followed up to the events as necessary.

This paper describes the system we built, outlines the field study, and then describes the major lessons we learned in technology and usability.

1.1 Related Work

Research in systems that monitor activities through integrated sensor systems started approximately 15 years ago, and has accelerated dramatically in the last five years. Haigh & Yanco [40] present a more extensive literature survey.

Early systems developed methods to collect environmental data to infer the activity and physiological parameters of human subjects, e.g. [12, 34, 76, 84]. Inada *et al* [44] was perhaps the first system to incorporate the capability to raise alerts when there is a sudden change in the patient's condition. Numerous projects started approximately at the same time as I.L.S.A., for example the Georgia Tech Aware Home [1], MIT's House_*n* [58], and the Medical Automation Research Center (MARC) at the University of Virginia [55]. More recently, similar projects have mushroomed internationally, e.g. [45, 53, 68].

Several activity monitoring systems have been evaluated for usability by elders, e.g. [11, 50, 74], but very few have achieved commercial viability. Oatfield Estates, a residential care complex in Oregon, monitors and tracks medical data, weight via bed sensors, location via tags, and includes web displays for elders who can monitor their own health [7, 69]. Vigil has fielded over 2000 dementia-care systems in multiple assisted living facilities. Their system focuses primarily on incontinence and wandering [80]. Researchers at the MARC have conducted several successful field trials of similar technology in various care settings, e.g. [4].

In field testing a system for ADL monitoring with private clients in their own living environments, I.L.S.A. was a pioneer. Using a touch screen interface to communicate with elderly clients was similarly unique. The following sections discuss some of the questions and conclusions afforded by this research.

2 Human Factors Analysis

To understand the multi-faceted problem of elder care, we took a human-centered approach. A mix of usability specialists and geriatric health specialists were tasked with discovering and designing a *usable* and *relevant* technology solution to assist independent living. The specific goals included:

1. To identify those factors that threaten independent living,
2. To identify which of these could be alleviated with technological support,
3. To identify which services and functions from a caregivers viewpoint could be aided by technology,
4. To develop a realistic set of features based on financial and technological constraints, and
5. To generate a set of design guidelines that would result in a highly usable system.

[1] ADLs focus on assessing ability to perform basic self-care activities and include eating, dressing, bathing, toileting, transferring in and out of bed/chair and walking.

The process included a literature review of the issues, interviews with users, and interviews with domain experts to generate a list of prioritized features and design guidelines for I.L.S.A. This list was then pruned according technological plausibility.

2.1 Threats to Independent Living

We began the knowledge acquisition process with an extensive literature review examining factors that lead to formal institutionalization for seniors. We also examined the latest literature on seniors and computer usage to gain insight into whether the elderly would be open to the idea of having computerized caregiving.

We surveyed more than 160 articles in the areas of geriatric health and technology, e.g. [16, 23, 26], leading to an extensive list of physical, psychological, and social factors identified as threats to independent living. In addition, we identified several social, economic and cultural issues that influence the decision. It was clear that no one factor determined the decision to move an older adult to a formal care facility, but rather a combination of several issues [8, 62, 73].

While the driver of the decision is the severity of the physical and mental condition of the elder, other considerations include the stress placed on caregivers [65], accessibility to alternative care resources [21], financial constraints [13], and cultural beliefs regarding elder care [6]. Therefore, if the goal was to help older adults stay in the home longer, an ideal technological solution would need to address all of these issues.

Thus, I.L.S.A. had to support the physical, psychological, and social issues related to care, while addressing financial constraints and cultural influences. Because elder health was the central issue, we focused our efforts on supporting the basic activities of daily living (ADLs), such as eating, toileting, bathing, and dressing, and the instrumental activities of daily living (IADLs), such as mobility, medication management, and grocery shopping. We also focused on methods to ease caregiver burden, such as ways to automate some caregiver tasks and ways to coordinate multiple caregivers. We also wanted to encourage human interaction, thereby recognizing that human social interactions are critical to the health of the elder. Last, to meet financial constraints, we decided that expensive technologies would not be appropriate.

2.2 Matching Technology to Needs

Our next activity was to look for opportunities where technology solutions would meet the needs of the user groups. We identified four main user groups: senior clients, informal caregivers, home-care professionals (geriatricians, geriatric nurses, and pharmacists), and emergency personnel who respond to critical situations.

Some of the literature we reviewed suggested methods by which technology could support the needs identified above, e.g. [3, 14, 25, 28, 83]. Most of these articles focussed on technology solutions that would assist the elderly and informal caregivers. For example, Gallienne *et al* [28] examined the use of a computer network for caregivers of Alzheimer's patients; caregivers were able to share stories, ideas and, most beneficially, emotions with one another. The paper highlights how computers can be used to alleviate some of the emotional burden from caregiving.

We also conducted user interviews to brainstorm additional support methods and to discover what users would expect and want from a technological solution. We conducted interviews with each of these groups and accompanied caregivers on home care visits to collect field observations.

Several interesting requirements were revealed through talking to our users. For instance, one older participant reported not using a walker outside her home because for her, it was a sign of disability and made others aware of her frailty. More recently, Gallagher *et al* [27] has shown that feelings that assistive devices are stigmatizing are not uncommon. Thus, if possible, any device should not be conspicuous enough to suggest a handicap.

Emergency personnel told us that panic buttons result in many false alarms. For instance, an older client may wear a panic button to bed and trigger it while turning in bed. Research has shown that false alarms cause responders to discount the urgency of the alarm over time [9]. Therefore, any alerting device should be reliable and accurate, and minimize false alarms.

User interviews revealed that health care professionals were more interested in tools that would support their work, rather than directly supporting their older client. For instance, one nurse would scotch tape pills onto a blank piece of paper to help her clients identify which medications to take. In addition, nurses would often reorganize medication regimens to simplify them (sometimes in opposition to doctor and pharmacist prescriptions, but often necessary because patients would obtain prescriptions from multiple doctors). In our user interviews, four key areas were highlighted by the health care specialists:

1. Improvements in functional assessments,
2. Remote observation of elder locomotion,
3. Better coordination of medication information among patients, doctors and pharmacists, and
4. Better coordination and communication tools to help doctors manage care with remote facilities/nurses.

2.3 Usability Guidelines

Arguably, one of the greatest challenges for systems in this domain is to provide an interface for potentially technophobic users with varying capabilities and constraints. A popular belief is that older adults do not want to use computers, that they have no interest in them, and that they cannot learn how to use them. Studies show that older adults do have more anxiety using computers [49] and require more time and training to use programs efficiently, although they can learn to use many programs [15, 61, 70]. Training is also a key factor for elders [54], but the type of training is critical as well—online training is the least effective method for older adults [17]. Interfaces that are poorly designed cause devices to be abandoned [2, 18, 33].

However, recent studies also suggest that older users want to use technology and are interested in computers [14], indicating an opportunity for us to leverage. Given that the number of older computer users is growing, we wanted to design a technological support system that would *engage* elders rather than *alienate* them.

Relying on this emerging literature about elders and computer use, along with earlier Honeywell work on design guidelines for elders [19], we realized that any new technology should capitalize on familiar computer metaphors and methods of navigation. If new forms of interaction are introduced, they must be reliable and easy to learn; otherwise, the technology will be rejected.

The ideal goal of interactions would be a system that mimics human-to-human interactions, such that no learning (by the elder) would be necessary. Multimodal interfaces seem to be effective [79, 52], however, existing technology does not yet support richly multimodal interfaces.

Given that constraint, we focused on common communication devices to interact with elderly users. Several options were considered, but in the end, we chose a telephone as the primary method of interacting with seniors because of its ubiquity and its familiarity. Our field test revealed that while users were comfortable using a phone, the method in which a message is delivered and the voice at the other end of the phone also had to be considered carefully (see Section 9). Despite the problems users encountered with our phone messages, we believe that familiar interactions offer a better option than introducing seniors to unfamiliar interactions.

As a secondary interaction device, we decided to design a web-based interface for a touch-screen, wireless computer. The goal of this device would be to provide real-time feedback to the elders, keeping them engaged and involved.

2.4 Selecting Features

The combined data gathered from literature reviews and interviews revealed many features and requirements to support the client and the caregivers. However, for practical reasons, we could not develop all of the features. We conducted an analysis to narrow the achievable list of features. We created a decision matrix to determine the importance of each opportunity; factors included contribution to institutionalization, impact on caregiving resources, ease of development, and prevalence of (other) technological solutions (for more details, see Haigh *et al* [37]). In particular, we decided to avoid research in areas being studied extensively elsewhere, notably personal emergency response services [20, 42, 51, 66] and medical monitoring at home [71].

Our list of high-priority, desirable system capabilities is provided below in no particular order.

- Medication management: verify medications taken; provide reminders to take medications
- Toileting: monitor toileting activity
- Mobility: measure activity level, detecting home occupancy, providing path lighting, detecting falls
- Security: monitor home environment, panic button, intrusion detection

- Caregiver Assistance: to-do lists, provide reminders, provide remote access to information, coordination tool for multiple caregivers
- Alerting: provide alarms, alerts, and notifications if safety is compromised; provide reports of alarms via phone and Web.

To meet the usability goals, we decided on the following specific features. First, passwords would not be used because they are difficult to remember and provide an extra step in learning a task. Second, system interaction would primarily be driven through wizards that query the user for simple answers. Third, controls would have to be simple, such as providing binary states (e.g., ON/OFF).

In sum, our list of desirable features is the product of our literature review which pointed to many different threats to independent living, our interviews with different user groups with varying needs and who wanted to see specific features, and our assessment of the impact and feasibility of developing such tools.

Five years have passed since this initial set of requirements, and we still believe it is an accurate depiction of appropriate features and design requirements. Our field test is among the few studies to test a number of elders using the system for an extensive period of time; it indicates that our choices were appropriate. While specific implementation details may change in future systems, the underlying requirements will remain almost identical.

3 System Description

The main goal of the field test was to evaluate whether technology of this nature holds any promise towards our goal of longer independent lifestyles for elders. We specifically wanted to demonstrate the complete cycle of I.L.S.A. interactions: from sensors to data transmission to reasoning to alerts and home control.

Given the initial list of desirable system capabilities described in Section 2.4, the system we field tested had the following specific implementation:

- Passive monitoring: basic activity, medication compliance, sleeping patterns.
- Cognitive support: reminders, date/time of day.
- Alerts and notifications: automated alerting to caregivers (by telephone).
- Reports: summary reports of client behaviour.
- Remote access to information via the Internet or telephone (allowing users to monitor or interact with the system).
- Control: modes (on/off), intended to also signify occupancy.

Other capabilities and features were tested in the lab.

In the sections below we describe the system architecture, functionality, and the user interface.

3.1 Architecture

Figure 1 shows a high-level sketch of I.L.S.A. as deployed in our field test. Data was retrieved in near real-time via broadband from client locations and processed centrally by the agent-based software architecture. Results of the processing were then recorded in a database and disseminated via push (e.g., telephone) and pull (web) channels. The hardware we employed consisted of off-the-shelf home automation and control products. A Honeywell Ademco home security system provided the means to configure and access signals from the devices. The Honeywell Home Controller served as the gateway for communicating sensor events out of the home to the Honeywell Global Home Server™.

We selected an agent-based architecture as our software infrastructure [38]. We expected that it would better support a modular, open architecture that would be easy to configure, customize and update, hence supporting changing elders and evolving technology. Figure 2 shows an example domain agent and its interactions with other agents in the system; more details can be found in Section 7.

3.2 User Interface

A few simple precepts guided our interaction designs, including the devices and modes we selected for client and caregiver interactions.

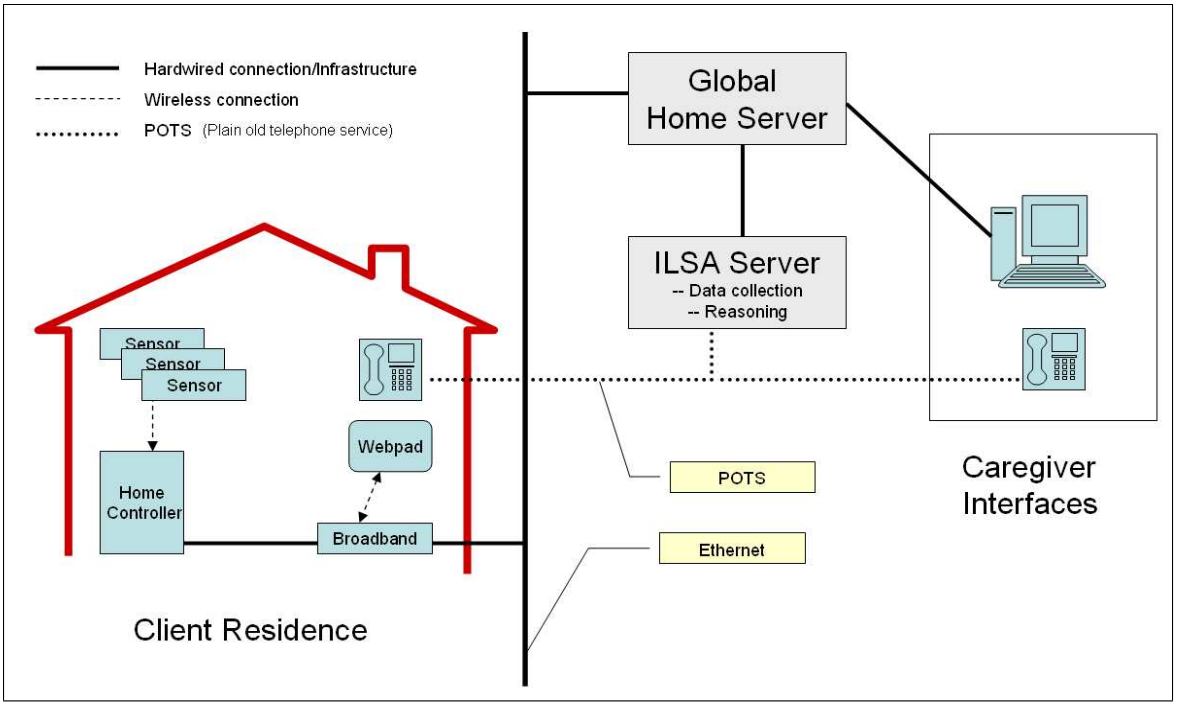

Figure 1: High-level view of I.L.S.A. hardware architecture.

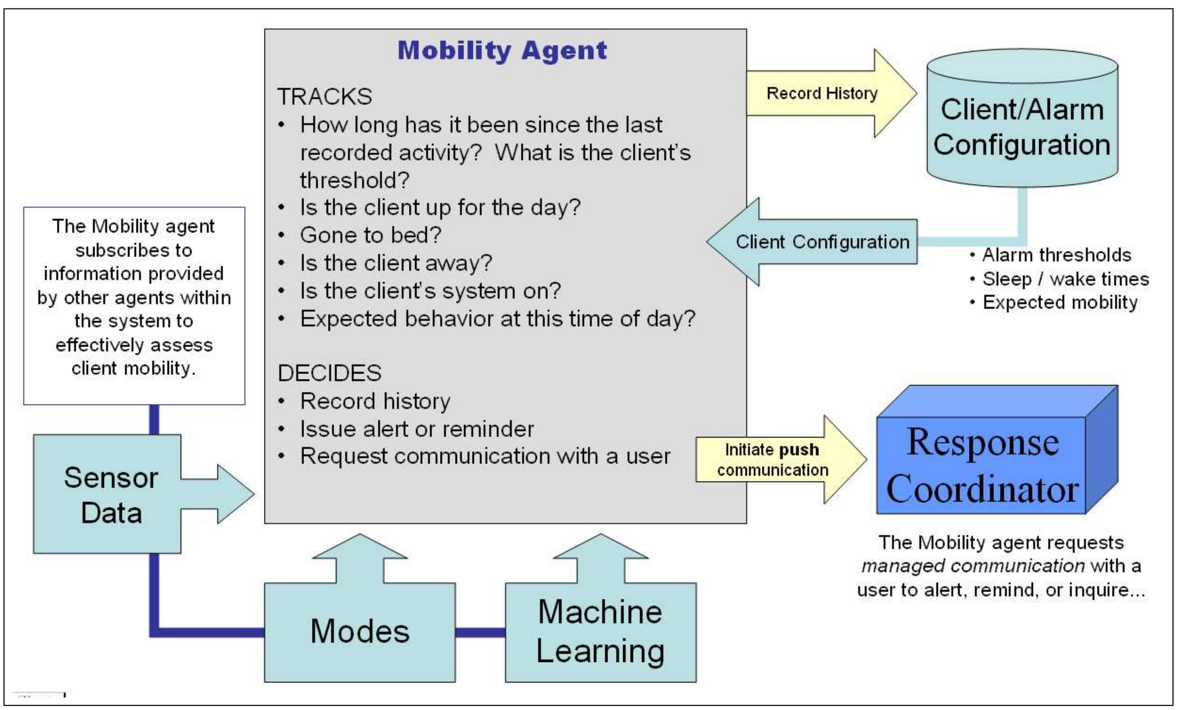

Figure 2: The Mobility agent tracks the client's activity.

- Make all sensing passive (no worn devices),
- Minimize intrusions on the users lives,
- Deliver accurate, unambiguous information, and

- Avoid client confusion.

We considered a range of interface options for delivering I.L.S.A. features to clients and caregivers, including the Web, telephone, pagers, PDAs, web-enabled cellular devices, speakers and microphones, electronic picture frames, and television remote controls. In Section 2.3 and refui we discuss the issues that led to use only telephone and Web interfaces.

Elderly clients were equipped with portable touch-screen Honeywell Web Pads™ with wireless access to the Internet over a broadband connection. Figures 3 and 4 show sample web pages for the elderly client. Through the Web interface, the elders could display:

- Reminders: Display of reminders issued for the day.
- Medication status: Medication schedule and status (taken/not taken).
- Mobility status: Mobility summary.
- Controls: Client control over alarm delivery (on/off).
- Caregiver information: List of people with access to their data, and messages issued recently.

Figure 3: Reminders presented to the elder.

Figure 4: Medication Schedule displayed for the elder.

Caregivers could access I.L.S.A. data about their client/family member with their normal ISP Web connection. The caregiver Web interface included these features:

- Notices: View and acknowledge alerts.
- Status: View general ADL status (including historical trends for medication and mobility.
- Profile: View and edit. prescription and medication schedule.
- Configure: Set up scheduled reminders and personalized activity alerts.

Alerts and reminders were also delivered by telephone to both clients and their caregivers. All of the telephone interactions were carefully designed to be friendly, both in tone, and in the simplicity of interactions. Since we expected that seniors might react negatively to a synthesized voice, and may have difficulty understanding it, great care was taken to pre-record personalized messages in a friendly and natural female voice.

Finally, a dial-in telephone interface allowed caregivers to get abbreviated status reports and record and schedule audio reminders for the elder.

4 Field Study Design

The field test was designed as a prospective cohort study of six months. I.L.S.A. was installed in client homes at the start of the field test, and monitored clients continuously for the six month period. The study protocols were approved to the Institutional Review Boards of the University of Minnesota and of the National Institutes of Health.

There was considerable risk in the selection of individuals for this test. On one hand, to collect data about system usefulness, we wanted to test the system with frail elders. On the other hand, frail enough elders may be at risk if they place too much trust in an early prototype; elders may be more susceptible to issues of misplaced trust [41].

To be eligible for the study, a resident was required to be living alone and competent in all activities of daily living (ADL). People could be dependent in one IADL (e.g., shopping, managing money). Each person also had to identify a family member (caregiver) with access to a computer who agreed to participate in the study. Because of the sensitivity of the motion sensors, eligible persons could have only small pets.

Our approach netted clients who were *interested* in participating in a test, but not necessarily those that were most in *need* of the technology. As a result, more than 60% reported that I.L.S.A. was not contributing much to their independence. Furthermore, their caregivers did not yet perceive a need for monitoring. None of the caregivers were uncomfortable about their parent's safety, even prior to installing I.L.S.A; caregivers that were uncomfortable with their parent's safety refused to further compromise safety by exposing their parent to a prototype system. Consequently, participation and feedback from caregivers in the study was very thin.

A longer discussion of how to design an elder care field study appears elsewhere [39].

Recruitment & Demographics: The field study had eleven elders, seven in Minnesota and four in Florida. In Minnesota, personnel at Presbyterian Homes invited residents to learning sessions about the I.L.S.A. study. Study investigators visited each facility and made presentations for all interested persons. At two facilities, we obtained a list of 23 potential clients. Dr. Krichbaum phoned interested residents and then visited each to explain the study and to obtain consent. Of the initial 23, 11 (47.8%) agreed to participate. By the time the study began, seven clients (30.4%) remained. Reasons for attrition included:

- time commitment
- some potential clients spent at least part of the year away from the state
- objections of family members

We did no statistical tests to determine if those who stayed in the study were significantly different from those who did not. The age range, however, was comparable.

The Minnesota sample included six women and one man, ranging in age from 76 to 96 years. The eldest client resided in an assisted living apartment while the others lived in independent apartments.

Our Florida clients had to meet the same conditions and were recruited by the University of Florida's Department of Occupational Therapy. That process yielded four clients. The Florida clients, who were all in their own homes, consisted of three women and one man, ranging in age from 55 to 76.

Measures: Client daily routines were assessed by questionnaire; we asked about medical history, medications that were prescribed, daily times for getting up, taking meds, performing routine activities, mealtimes and bedtimes. We also determined their level of comfort with technology.

Caregiver participation in the life of the client was assessed by questionnaire using the Montgomery Caregiver Burden Scale [59, 60]. We also assessed their level of comfort with technology.

Usability was assessed through weekly and monthly phone interviews of clients. Caregivers were asked to complete these questionnaires on the web or to mail them in. In addition, two focus group sessions were scheduled to gain insight about the clients' experiences with I.L.S.A.

Health of clients was measured by responses to questions on the Short Form (SF-36) [82] of the Medical Outcomes Study at baseline, midpoint and conclusion of the field test. Cognitive ability was measured by scores on the Mini Mental Status Exam (MMSE) [24]. At three months into the study and again at its conclusion, Dr. Krichbaum administered the SF-36 and the MMSE to clients. At these same data points, focus group sessions were held to which all clients and caregivers were invited.

5 Lessons: Configuration and Customization

Configuring, installing, and customizing I.L.S.A. for each client consists of installing devices in each home, and configuring the software system for each client. The important lessons are:

- Base configuration on objective data wherever possible.
- Re-configure on an ongoing basis when objective data is available.

Deploying I.L.S.A. in a home requires information about clients and caregivers, including contact information, capabilities, medications, and living habits. We asked caregivers to complete forms, and had a field worker (in our case, nurses) interview the client. When designing the forms, it is worthwhile to get input from geriatric experts, social scientists, and the software developers. The geriatric experts know what the elder can honestly answer, the social scientists know how to phrase the questions, and the software developers know what information the system needs and what it can do.

Subjective information was an extremely unreliable configuration tool. For example, asking "How active are you?" is a relative scale that can be interpreted differently by different users (even when told that '1' is sleeping and '7' is housework). For example, an elder might rate relative to their friends or to their own activity levels when they were younger. Some elders in our study used the scale differently depending on time of day; that is, a '5' can mean multiple different things. Using this data a baseline of "what to expect" for generating notifications or alerts caused I.L.S.A. to generate many false alarms (and hence complaints from both caregivers and clients). After the first few weeks of operation for each client we were able to adjust the configuration to more accurately represent their behavior, notably improving user satisfaction with I.L.S.A.

The form describing medication regime requested medication names, reason for using, schedules for taking, dosage type and size, and prescribing physician. This format worked well and translated easily to the data base and interface design and usage. It succeeded because the information was wholly objective. The client's habits in taking medication (time of day) was less objective. Variation in personal habits, even in the same person day-to-day, resulted in changes to handling medication reminders as the field study progressed.

Note that relying exclusively on collected information, even if entirely objective, does not guarantee a perfectly configured system. For example, clients and caregivers may simply be unable to provide objective configuration information [72]. Moreover, as clients age, their configuration needs may change [48].

We have shown that machine learning techniques can be successfully applied to address the challenge of inaccurate or changing configurations. While systems that use this approach will be far more reliable in the field, they will require a "getting to know you" probationary period during which special handling of notifications should be expected.

6 Lessons: Data Collection

A significant challenge of the I.L.S.A. program was determining what sensor data would prove useful for understanding clients' activities to determine their well being and need for support. Notable issues in this area concerned sensor selection and placement, as these directly impacted the usefulness, reliability and accuracy of the collected data.

Our focus was on finding sensors that would provide reliable information for the list of desirable features. As this project did not entail new sensor development, we employed off-the-shelf sensor solutions for the majority of problems. We tested many different sensors for appropriateness to this task (see [37] for more details), and determined that:

- Video identification is complex, expensive, and generally perceived as an invasion of privacy.
- Pressure pads present a trip hazard, are easily damaged and expensive to install.
- Motion sensors are inexpensive and easy to install, but difficult to place for reliable information about client location.
- Photoelectric beams are highly accurate but relatively expensive to acquire and install.
- Clients may forget or resist body-worn devices, including panic buttons, fall sensors and identity tags.

- Many existing approaches to medication dispensing and adherence monitoring are elaborate and not meant for clients to use independently (e.g. without having a nurse refill it) [10, 22, 56, 57]. Given the high importance of this feature, we designed and tested a more flexible medication caddy that was well-liked by the elders in our study [37].

In addition to these considerations for specific sensors and their relationship to specific ADLs or IADLs, designers of similar systems will need to carefully address general issues of *sensor accuracy* and *reporting accuracy*.

Sensor accuracy is dramatically affected by the quality of the sensor. Most commercial sensors are designed for security systems and give only discrete states of open/closed, or presence of motion or pressure—they give no real information about the signal source or signal quality, and therefore present challenges in establishing appropriate levels of confidence in the data they report. Moreover, few (if any) currently available commercial sensors are able to distinguish among multiple users of the system.

Sensor accuracy is not measured only by the quality of the sensor, but also the placement and calibration of the sensor (hence the skills of the installer). For example, an incorrectly-placed motion sensor could actually work against the intent of a "no-mobility" alert by picking up flailing arms or legs associated with a person in distress on the floor. This challenge notably increases the cost of deployment, as it requires more skilled installers. Recent similar lessons are reported by Beaudin *et al* [5].

The parallel to sensing accuracy is reporting accuracy. Simple sensor solutions usually implies that the system cannot monitor the true state of the elder or her environment. For example, knowing that medication caddy was opened and whether pills were removed from their containers, does *not* imply that the elder actually ingested the medication. Similarly, environmental sensors can usually only determine whether the elder is in bed, *not* whether the subject is actually sleeping. While true state can be determined through more complex sensing means, this solution may not meet usability, financial or installation goals.

In general, this kind of *related* information is enough for a caregiver, but there is a very real risk that a caregiver will draw inappropriate conclusions from the data [74]. The caregiver needs to be very clearly told the limitations of the system, and any user interfaces must use accurate and unambiguous language to describe that data.

7 Lessons: Agents

We selected an agent-based system to meet I.L.S.A. requirements such as modularity [38]. We describe the original agent design in Haigh *et al* [36]. The agents in the field-tested system included device controllers, domain agents, response planners, and system management. One of each of the following agents were created for each human client:

- **Medication**: monitor use of medication caddy, raise alerts and generate reminders.
- **Mobility**: calculate statistics about the elder's mobility, raise alerts. (See Figure 2 for a sketch of the Mobility agent's inputs, decisions, and outputs.)
- **Modes**: monitor client selection of on/off status.
- **Reminders**: schedule and initiate reminders as specified by caregivers.
- **ResponseCoordinator**: suppress and merge alerts and reminders as appropriate.
- **Machine Learning**: record alerts for unexpected activity based on profiles of normal behavior (users did not see these alerts).

Exactly one each of the following agents was created on the server (one server for all of the human clients):

- **PhoneAgent**: format messages for presenting and managing communication with appropriate contacts.
- **Platform**: provide general services, e.g. normalized time, for all agents in the system.
- **Database**: control access to client data and ensure data consistency.

We developed I.L.S.A.'s ontology in Protégé [32]. The Consolidated Home Ontology in Protégé (CHOP) was the common vocabulary for I.L.S.A.-related concepts and their relationships, becoming the agent communication interface between I.L.S.A.'s agent-based system components. Researchers interested in obtaining a copy of the ontology can send email to the authors of this paper.

During I.L.S.A.'s development we learned two major lessons about agent-based architectures. First, agent-based approaches to system development are still relatively new. Robust infrastructures for applying this technology to a real-world system are not commercially available; research prototypes are not yet fully reliable and are mostly unsupported.

Second, when designing the architecture, we believed that goals such as "detect falls" and "deliver medication reminders" were independent enough that they warranted independent agents. However, since I.L.S.A. was (primarily) interacting with and supporting a single human, during development it became clear that the agents were too tightly coupled, and that the agent paradigm was not suited for this level of granularity.

I.L.S.A. was one of the first agent-based systems seen by real end users outside the lab. As a result, we identified several risks and pitfalls in developing agent-based systems that had not been previously identified.

7.1 Agent Development Tools

We expected the agent-based approach to provide the following software development benefits:

- **Multi-person development**: Development of independent agents could be assigned to independent developers.
- **Scalability**: The distributed architecture would support a much more scalable system.
- **Robustness and reliability**: Distributed processing and control would mean that the system would not crash with a local single point of failure.
- **Testing and debugging**: Independent agents could be independently tested.

The lack of support tools, however, meant that these expected benefits did not materialize. The agent-based architecture caused many problems that would have been easier to solve in a simpler component-based system. Resolving these issues required a great deal of coordination among team members and added considerable overhead to development time.

Enforcement of System Policies. The first tool we very much would have appreciated is a mechanism for enforcing system policies. During the design phase, we formed several policies intended to govern system behavior.

For example, one policy was maintaining persistence over restarts. Many of I.L.S.A.'s domain agents needed a concept of recent history to make interaction decisions. If the system failed or was rebooted for some reason, agents had to reconstruct their history. Different agents reasoned over different windows of activity, hence only localized approaches to solving this problem were appropriate.

Another example policy was to combine multiple independent messages, such as reminders for different items that need to be issued at the same time. We therefore decomposed the message delivery task between the *ResponseCoordinator* and the device agents (see [81] for more), placing the policy to merge messages in the *ResponseCoordinator* while the device agents were only responsible for delivering the final message (allowing, e.g., the system to have multiple *Phone* agents and an *Email* agent). However, because a new reminder could be received by *ResponseCoordinator* right after it dispatched the previous reminder to the *Phone* agent, multiple messages were still delivered. To overcome this issue, we replicated the delivery protocol in the *Phone* agent, defeating the purpose of decoupling protocols. A *cancel* message would not have been an appropriate solution, because then it is possible that no message would ever be delivered.

Finding an effective scoping and decoupling of capabilities is extremely challenging and becomes more so as the system grows. The challenge is further complicated by the fact that that some solutions for global policies need to be locally designed (e.g. persistence over restarts), while others need to be globally designed (e.g. message delivery).

Currently, when any policy changes in any way, many agents may need to be modified. Our hope for "straightforward" scalability will not be possible until agent technology develops much stronger and more scalable mechanisms for enforcing these system policies. We need a mechanism that allows system policies to change while agents can remain relatively static.

Testing and Debugging Tools. A second tool that would have been extremely useful is much stronger support for testing and debugging. The requirement that every system needs to be thoroughly tested was noticeably more pronounced in the agent-based system than it would have been in a monolithic system.

In particular, the ability to communicate "freely" with other agents meant that every possible interaction needed to be tested and verified; in a monolithic system, however, interactions between components are much more controlled, and testing can be focused on the single point of change. Each time we changed communication protocols, changed policies about behavior, or added a new service (agent), we had to test the entire system thoroughly. As new agents are added, new functionalities and interfaces need to be added to existing agents: you cannot simply plug in a new agent.

Moreover, current agent technology does not provide adequate support to localize bugs: an error generated by an agent does not necessarily identify the root cause of the problem. Errors can propagate from agent to agent through communication channels, making it difficult to identify the agent at fault. We often found that we had to fix the same bug in multiple agents. This was very frustrating, increased development costs, and would make maintenance costs prohibitive. Note that stronger enforcement of policies would have mitigated—but not solved—this problem.

Specific tools that would have been useful include:

- Capturing connections between agents (e.g. each time an agent changes, report all "downstream" agents that may be affected);
- Capturing the data structures used by agents (e.g. each time a schema changes to support new information, report all of the agents that use that schema);
- Regression testing libraries (e.g. capturing and testing all prior trials, or better, monitoring which logical branches have not yet been tested).

A robust test-harness, rigorous unit testing, and as much automation as possible are valuable for any software development effort. These factors would be even more valuable in the development of an agent-based system.

The agent-based approach promised a highly open and flexible system. We learned that this approach still has many software development challenges yet to be addressed by the agent research community. Agent based systems will need to focus much more strongly on scalability, debugging, and reliability issues before they will emerge from the lab.

7.2 Appropriateness of Agents

One of the reasons we chose an agent-oriented approach was for modularity. We expected to use a small set of agents for the basic functionality of each installation of I.L.S.A. system. Each installation could then be customized by adding specialized agents. As client requirements or technology capabilities evolved, agents could be replaced with different versions.

We believed that goals such as "detect falls" and "generate medication reminders" were independent enough that they warranted independent agents. During implementation, however, it became clear that the agents were too tightly coupled.

First, their goals were not independent enough. For example, when a *Medication* domain agent generates a reminder to take a medication, it is processed by the *ResponseCoordinator*, which coordinates interactions over multiple domain agents. It is then delivered to the client by the *Phone* agent. The three goals (generate, merge, and deliver reminders) are not independent—they are subgoals of the single goal to deliver a medication reminder to elder.

Second, their underlying knowledge bases were not independent enough. For example, most of the monitoring agents need to have a common understanding of the elder's capabilities and the layout of the home. The degree of shared knowledge meant that developing new agents required *extensive* re-development of the existing agents. Moreover, to ensure database consistency, we implemented a single database agent that performed all data read and write operations, and thereby created a local bottleneck.

As a result, the promise of inherent robustness from distributed computation did not hold true for I.L.S.A. Notably, the system has several agents to provide services for other agents. Some of these service agents (e.g. *Database*, the *ResponseCoordinator*, or *Platform*) are more critical than others; if one of them fails, the whole system fails. Introducing redundancy in the system might remove the single point of failure, but will introduce other challenges, e.g. database consistency and multiple independent *Phone* agents trying to deliver exactly the same message.

Since I.L.S.A. was (primarily) interacting with and supporting a single human, it became clear that the agents were too tightly coupled and that the agent paradigm was not suited for this level of granularity. We believe that the development issues we faced will be shared by any system in which agents work cooperatively toward a common goal. The more centralized that capabilities need to be, the more likely that an agent-based approach is inappropriate.

8 Lessons: Automated Reasoning

At the outset of the program, a major focus was on using high-level reasoning to provide an intelligent monitoring system. We intended to build three main components: situation assessment and task tracking, response generation, and machine learning. Experiments in the engineers' homes validated our hypothesis that this domain is very complex and lends itself very well to advanced reasoning techniques.

8.1 Situation Assessment and Task Tracking

A significant requirement for a monitoring system like I.L.S.A. is accurate recognition of activity. Sensors are noisy, inaccurate and low quality. It is a significant challenge to assess the situation and recognize what activities are occurring.

We identified four kinds of reasoning that can be loosely termed "behavior recognition." These are: clustering, validating, assessing, and task tracking. A *report* is generated by a sensor when it trips. *Clustering* collects multiple reports about the same event to generate a *hypothesized event. Validating* is the process of inferring whether a hypothesized event is an actual event. *Situation assessment* infers the ramifications of events. *Task tracking*, also known as intent recognition, is the process of inferring the goals of an agent (in our case, the elder or caregiver).

Our task tracking system was based on the Probabilistic Hostile Agent Task Tracker (PHATT) [30]. PHATT has a number of capabilities that are not available in other task tracking systems, making it uniquely suited to applying to this domain. Continuing our research on I.L.S.A., we reached the following list of requirements for task tracking systems in this kind of domain:

Abandoning plans: All people abandon plans at one time or another: they forget what they are doing, get distracted, or decide explicitly to abandon a goal. Recognizing abandoned goals could provide significant assistance in the case of dementia.

Hostile agents: Not all elders are willing to have their actions observed by an assistant system; they value their independence and will therefore try to hide their actions. This unobservable action stream is a significant challenge.

Failed actions: People will often try to achieve a goal but fail. This information could be extremely useful in this domain.

Partially ordered plans: People frequently work on multiple goals at the same time. The task tracker must be able to recognize interleaved plans.

Actions used for multiple effects: Often one action can achieve multiple effects; the task tracker must be able to handle this kind of *overloaded* action.

World state: Different factors in the environment can significantly affect the likelihood of the elder adopting different goals.

Multiple hypotheses: One set of actions might be contributing to more than one plan. The task tracker needs to provide a ranked list of different possibilities.

Geib [29] describes these requirements in more detail. Geib and Goldman [31] describe the specific extensions made to PHATT to incorporate reasoning about abandoned goals.

The PHATT-based intent recognition component was removed from the I.L.S.A. field study for two reasons. First, as experimental code, there were scalability and memory management issues that were not fully addressed; these have since been corrected.

Second, in an effort to reduce the deployment cost for the elders in the field study, I.L.S.A. chose to focus on a reduced set of low-cost sensors. To fully realize the potential of the task tracking system, a more dense set of sensor data is required. Recently emerging studies, notably Proact [67] and House_*n* [77], indicate similar results.

8.2 Response Generation

Response generation deals with 1) deciding *how* to respond to a given situation that exists with the elderly, and 2) *coordinating* all responses that may occur at any given moment.

Domain agents decide how to respond to a situation in a *context-free* manner. That is, they generate an appropriate response only within the context of their expertise; they do not take into account responses that other domain agents may be generating. Responses fall into four categories: reminders, notifications, alerts, and alarms. Each response category is defined by specific protocols and priorities that I.L.S.A. must follow.

Excessive and inaccurate alerts are a significant risk for this kind of monitoring system. In our field study, excessive no-motion alerts were a major cause of client and caregiver dissatisfaction. In a few cases early in our test, they created a small amount of panic when elders forgot to "turn I.L.S.A. off" when leaving the apartment. A secondary and very real risk is that the bad alerts will cause real alarms to be ignored ("never cry wolf") [9].

These context-free messages must be prioritized, coordinated, and timely. Messages cannot be lost in a flood, and elders (and their caregivers) must not be overwhelmed. Thus, we chose to coordinate responses centrally rather than allowing domain agents direct access to devices. The centralized approach supports a higher degree of *context-awareness* in message delivery:

- All responses from all domain agents must be presented on one set of devices, to one set of recipients. If we allowed domain agents to access devices directly, recipients could be overwhelmed. Imagine receiving a dozen phone calls for different reminders at 9:00am, or a caregiver who supports 10-20 different clients; it is essential to merge closely timed communications into a single call.
- I.L.S.A. must recognize message priorities. Allowing domain agents to have distributed access to devices could cause important messages to be lost or delivered too late. For example, if the elder were to fall, the emergency call to a caregiver might be delayed behind a reminder to eat lunch.

For more detailed discussion refer to Wagner *et al.* [81].

Another novel piece of I.L.S.A.'s response generation and execution technique is the partitioning of response protocols from delivery methods. This structure allowed us to decouple protocols for delivering different types of messages from the details of the message mediums.

8.3 Machine Learning

Success in this domain requires that I.L.S.A. capture the complex interactions among devices, the environment, and humans, and be particularly responsive to constant changes. Currently available commercial systems are typically inflexible, and their initial configuration is labor intensive. To adapt to changes in the client or in the environment (inevitable in this domain), we must reprogram the system. Reprogramming adds to the cost of system maintenance and presents an inconvenience to the client.

We explored three machine learning applications to assess their impact on I.L.S.A.'s actual operating environment:

Patterned behavior profiles [35]: build models of what sensor firings correspond to what activities, in what order, and at what time. For example: "In 60% of the days, the Kitchen-Motion sensor fires between 18h00 and 18h30, and then the Living-Room-Motion sensor fires between 18h20 and 20h00, and then the Bedroom-Motion sensor fires between 19h45 and 22h00."

Unexpected Activity : raise alerts when activity occurs when it is probabilistically unlikely.

Schedules [46]: learn schedule information for regular activities in the clients home (e.g. medication, wake/sleep, occupancy)

Our analysis results showed that machine learning is a useful enhancement to even the simplest system. At a minimum, machine learning techniques can learn schedules and provide long-term trends of activity. Given a rich sensor suite, machine learning techniques can learn complex models of the environment, the elder, other people, and even the effectiveness of its own devices. These models can then be used by the system to improve its assessments and responsiveness. Machine learning techniques will allow a fielded system to:

1. Tune itself to the operating environment, greatly reducing the amount of tuning and knowledge acquisition required at setup.
2. Respond to changes in the users and the environment, directly reducing maintenance costs.
3. Capture the user's preferences, enhancing system usability.

Two main barriers remain: evaluation and automatic incorporation of learned models into the system.

Gathering ground-truth for I.L.S.A. was not possible: users were not willing to note every activity, nor be constantly videotaped. Our evaluations were based on "eyeballing" results for plausibility and then observing whether changed system behavior was more or less acceptable to the elders and their caregivers. While short-term ground truth can be gathered, researchers will need to develop good techniques for long-term evaluation.

Currently, the elder-care industry will only accept a system with a human-in-the-loop; many other industries have regulations that explicitly prohibit automatic modifications. Our approach of presenting the results to a human before incorporating them into the system was well-accepted, but is unlikely to scale to a larger community of users in its current form.

9 Lessons: User Interface

While I.L.S.A. was in the field, we were able to derive important lessons by tracking user behavior with the system, responding to user issues, and listening to user input in focus groups and one-on-one interactions. The following lessons reflect common threads in the feedback.

- Elderly users tended to personify the system, even though the design did little to encourage this.
- Elderly clients were engaged by simple reports from the system and wanted more.
- Family caregivers did not like being the primary responder to automated reports and made little use of the additional data provided.
- System-generated telephone calls were perceived as rude and intrusive, no matter how pleasant the voice.
- Even simple, automated telephone interactions can be cognitively overwhelming for elderly clients.
- Speech recognition and generation technologies might never be appropriate for interactions with the elderly, even if they increase in sophistication.

9.1 User Engagement

Though we expected and planned for our clients to be engaged by the I.L.S.A. interface, clients wanted and could probably use *a more complex* interface than we expected. Conversely, caregivers wanted *less detail* than we anticipated. (For descriptions of what we delivered to each audience, refer to Section 3.2.)

Client Engagement. Most current monitoring systems for the elderly provide for little or no interaction with an elderly client. At the time I.L.S.A. was conceived, we were aware of no other systems attempting a high level of communication with an elderly client through a computer interface. Our experiments with I.L.S.A. show that this communication and additional interaction have the potential to be beneficial to clients, making them more active in the management of their own health, and providing additional cognitive stimuli.

Client interactions with the website were entirely information-pull actions. They had no explicit requirement to use the web interface, but could view it as often as they wished, or not at all. This supported our design imperative to create a system that could be used effectively with an entirely passive client. Though

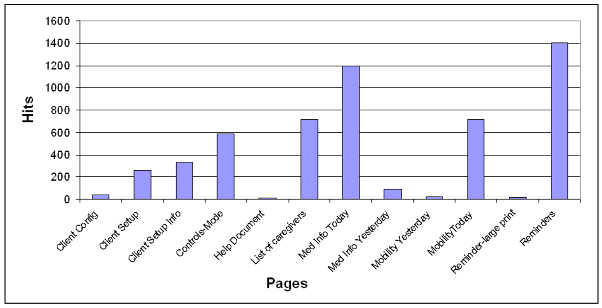

Figure 5: Web page usage on the Client User Interface.

we tracked navigation through the web pages, none of the pages included interactive elements requiring data input or acknowledgement.

Figure 5 shows client navigations (page changes). Subjective surveys indicated that 30% of the users did not use I.L.S.A. frequently, while 40% used I.L.S.A. several times a week, and 30% of users reported daily access. Figure 6 illustrates how page use declined for all users during the three months trended. There were three "unusual" clients. Client 1110, our most cognitively challenged user (lowest mini-mental score), was one of the more frequent users, being very engaged in the activity of tracking personal behavior and checking it against our reports. Client 5030 ("reminder dependent") expressed increasing dependence upon medication reminders, illustrated by the anomalous increase of usage in June by that client. Only one client avoided the interface consistently; she was our oldest client, and the only one living in an assisted living facility.

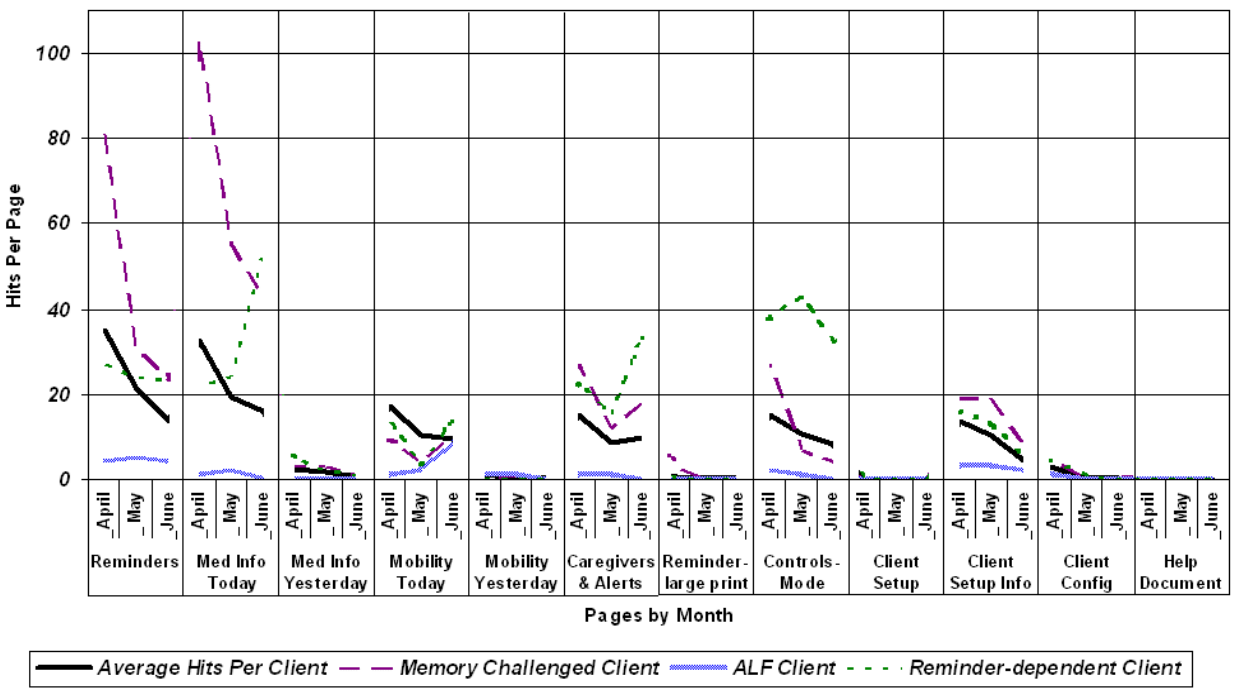

Figure 6: Client Web page usage trend.

Clients were marginally accepting of the interface. Of the 70% that reported frequent use, 65%-66% reported feeling "comfortable" and "in control" of the interface; scarcely more than 30% of the total group. It is difficult from our survey data to determine if non-users weren't comfortable, or whether they were just

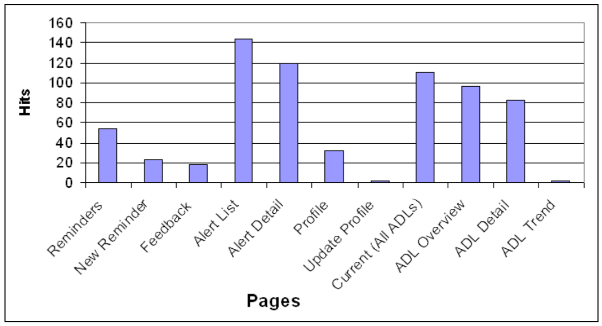

Figure 7: Web page usage on the Caregiver User Interface.

bored or uninterested.

Requests for more functionality generally came from those clients who were both frequent users and more comfortable with the interface. Specific requests included messaging capabilities and a chance to refute or corroborate I.L.S.A. reports.

Caregiver Engagement. As noted in Section 4, our approach to subject selection produced family caregivers who, generally, did not become deeply engaged with I.L.S.A. during the field test. To some degree, their lack of engagement provided its own lessons. Other important feedback was gleaned from one-on-one conversations and incidents that arose during the field test.

Figure 7 shows caregiver accesses to the website. Note that page names have been modified from the original. Caregivers viewed the Alert and Status (ADL) pages most frequently. They almost never looked for the trend graphs of ADL history (ADL Trend) and, to our surprise, showed a general disinterest in reminders. In particular, caregivers rarely set up reminders for clients and did not use them as designed, trying instead to deliver greetings rather than reminders. Similarly, caregivers did not use the profile feature to update prescription information. We believe several factors contributed to this lack of engagement within our test group:

- No immediate health crisis with our elderly clients.
- Caregivers too busy.

Response to I.L.S.A. surveys from family caregivers was sparse, therefore no statistically relevant information can be provided about their acceptance of the I.L.S.A. interface or specific features of the prototype. In anecdotes collected during personal conversations, family caregivers indicated that they desire succinct reports, including current status summary, charted history of important indicators, and links to further details.

In our early surveys, many caregivers requested and were excited about receiving reports on their client's wellbeing. While some caregivers did use I.L.S.A. to improve their peace-of-mind through these up-to-the-minute reports, we discovered that most family caregivers often do not know what to do with the type of information an I.L.S.A.-like system provides, and generally do not want to be responsible for receiving alerts from such a system. (This was a case of caregivers getting what they asked for.) Without a third party to interpret, filter and respond to the resulting reports, I.L.S.A. may only *add* to caregiver burden.

Most systems on the market today provide little or no reporting to family caregivers. There are many ways in which appropriate reporting to responsible family members would improve the long-term independence and overall health of elderly clients.

9.2 Telephone Interface

The I.L.S.A. telephone interfaces consisted of message delivery—reminders to clients; alerts about possible client problems to caregivers—and a dial-in enquiry system for caregivers. The dial-in telephone interface was the only alternative to the caregiver web site.

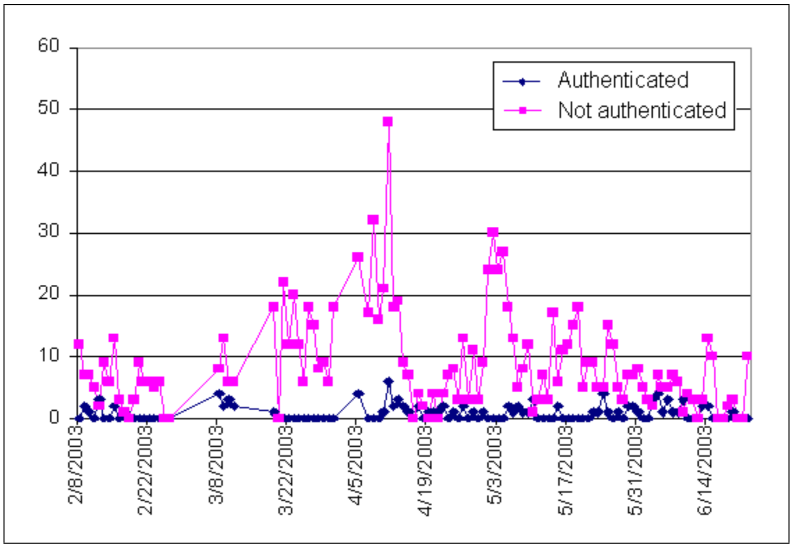

Figure 8: Unauthenticated phonecalls far outweighed authenticated ones.

I.L.S.A.'s telephone interface was, therefore, vitally important to the success of the application and was given considerable attention in design and implementation. All of the telephone interactions were carefully designed to be friendly, both in tone and in the simplicity of interactions.

Despite much literature indicating the effectiveness of telephone interfaces, e.g. [25, 64], I.L.S.A. test clients and their caregivers universally disliked the telephone message delivery. We found that messages were perceived as computer-generated and synthesized, even though a pleasant pre-recorded voice was used. Also, the calls were intrusive, sometimes waking clients if they were not following their typical schedule.

Figure 8 shows that most phone calls were not authenticated. To address the issue of client privacy, and delivery confirmation, we required authentication ("Press one if you are Lois"). For clients that had wireless phones in which the keypad was integrated with the receiver, this required a context switch (listening, to viewing, back to listening) to complete the action. We discovered that the cognitive and visual load required to complete this interaction would annoy and sometimes agitate a client. In this field test we did not have the flexibility to try an alternative, such as voice response. See Section 9.3 for further discussion of the issues related to natural language alternatives.

Several clients reported that they remembered to take their medication (or complied with medication schedules) only because they wanted *to avoid these telephone calls.* Unfortunately, call avoidance also resulted in attempts to fool I.L.S.A.; for example, one elder would open the medication caddy "on time" but not actually take the medication until later.

While the telephone is widely agreed to be a device that most people are comfortable using, that comfort does not extend to automated telephone interactions. The realization that a machine was controlling the dialog was annoying to all of our clients and caregivers and made them disinclined to respond as requested. Responding to the system was stressful for some of our clients and impossible for others. In our experience, some elders even found it difficult to talk with a real person they can't see, creating a challenge for even "normal" telephone use with familiar people. As many elderly also have hearing loss, all systems wishing to communicate with an elderly user will need to provide more than one mode of communication.

While caregivers were more capable of the cognitive challenge, calls initiated by a machine were not desirable, as indicated by caregivers choosing to ignore the request for authentication, caregivers ignoring the automated messages, and caregivers panicking as a result of receiving an alert.

No matter what the intent, or how friendly the message, incoming pre-recorded calls were perceived as rude and annoying.

System:	*Lois, it looks like you've fallen. Are you OK?*
Lois:	*Yes, I'm fine.*
System:	*But you haven't moved in 5 minutes.*
Lois:	*I'm OK. I'm just winded, that's all.*
System:	*Are you sure you don't want me to call for help?*
Lois:	*Yes, I'm sure.*
System:	*Maybe you'd like me to call your daughter.*
Lois:	*But I don't want to be a bother.*
System:	*I'm sure she wouldn't mind.*
Lois:	*OK, call her. But don't tell her I've fallen.*

Table 1: A sample conversation between an intelligent monitoring system and an elder.

9.3 Speech Recognition and Delivery

At the beginning of the program, we felt strongly that a speech interface was a mandatory component for this kind of system. After exploring the technology, performing some pilot studies, and understanding the problem domain in greater detail, we decided to remove the capability completely. This decision was based on three primary factors:

1. It is difficult to understand an elder's voice. Not only is it difficult to locate enough microphones to get a high quality signal, but elders also have less "rich" voice streams. An elder's voice or speech patterns can change dramatically with medical issues such as a stroke and even during the course of a day due to fatigue. Removal of dentures or simple distress will significantly reduce the ability to recognize speech during actual emergency situations.
2. Interactive speech interfaces can confuse an elder when they hear a "disembodied voice"; elders cannot cope when the system misunderstands; and elders cannot handle the delayed response time caused by (possibly remote) processing. Familiarity with the voice, or the message, does not necessarily mitigate this problem.
3. The technology is not yet ready to handle the complexity of interactions with elders. The system must not only generate dynamic syntactic structures so the elder doesn't hate the interface, but it must also understand the situation to a greater degree of accuracy than we can provide (including when to "coax" the elder). Take for example, the conversation scenario of Table 1. This conversation shows a deep understanding of the situation and its severity, in that it's not an immediate emergency, but a situation of concern. The system recognizes that Lois is reluctant to be a burden and needs to be coaxed to accept help.

Koester [47] provides additional evidence that speech interaction is unlikely to be effective in this domain. Among other issues, they point out that there is a significant "cognitive cost" to use speech recognition systems: the user must notice and correct recognition errors, learn how to speak to maximize recognition accuracy, and learn a (possibly large) set of commands to control the system. Moreover, more cognitive resources are required for speaking than for physical activity. Elders have more problems with speech [63, 75, 78], notably due to short term memory.

The elders most likely to benefit from an I.L.S.A.-like system are unlikely to be capable of meeting these challenges.

10 Conclusion

I.L.S.A., in its form as an agent-based system, has been retired. Using an agent-based system, contrary to our expectations, *significantly* added to the development effort. I.L.S.A. had many capabilities that needed to be centralized, and therefore it is clear to us that pursuing a simpler route would have saved us time, money, and frustration—a single-threaded, component-oriented architecture may have been a better approach.

We view the I.L.S.A. program as a success because of the following significant achievements:

- We successfully prototyped a passive monitoring system for elders in their own homes.

- We have a much better understanding of what constitutes an *acceptable* monitoring system for elders and, in particular, added to the growing literature disproving some of the assumptions made about "technophobic" elders. Through our knowledge acquisition effort, we learned what factors affect elders' independence and identified technology opportunities. We improved the understanding of factors that impede the delivery and acceptance of assistive technologies, and also improved our ability to overcome these factors.
- We validated the importance of artificial intelligence technologies to support a broad customer base in widely varied and unstructured environments. Notably, we have validated the importance of machine learning as a technique to mitigate expensive installations and ongoing adaptation (Section 8.3).

We are currently exploring ways to field activity recognition technology within Honeywell's HomMed medical monitoring product line. The largest technical barriers we perceive to incorporating activity recognition are:

- Further development, testing and verification of intelligent automation within this domain;
- Cost-effective, non-intrusive, user-friendly and reliable means of sensing relevant conditions, such as falls and medication management;
- Development of effective and comfortable methods of communication between the system and the elderly clients.

By providing intelligent, affordable, usable, and expandable integration of medical and activity sensing and interaction devices, technology of this nature will be able to effectively recognize and support daily activities. Technology will never replace hands-on human caregiving, but it will allow us to direct these scarce and expensive human resources more effectively.

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