An Exploration of Real-Time Environmental Interventions for Care of Dementia Patients in Assistive Living

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ABSTRACT
Patients in the early stages of dementia are often subject to a variety of dangerous symptoms and behaviors including depression, wandering, and aggression. These conditions severely influence both quality of life and the degree of caretaker intervention that is necessary. Non-pharmacological interventions can alleviate these symptoms in some cases and are preferred as an alternative to medication when possible. This paper explores alternatives to the traditional definition of intervention, wherein the involvement of a caregiver is assumed, using a new modality wherein interventions are automatically instigated in response to conditions detected by physiological and behavioral measures. The environment is automatically manipulated in these methods in response to detected symptoms, intervening without the immediate assistance of a caregiver.

Categories and Subject Descriptors
J.3 [Life and Medical Sciences]: Health.

General Terms
Human Factors.

Keywords
Behavioral interventions, psychophysiology, assistive living.

1. INTRODUCTION
Dementia is the long-term chronic decline of cognitive function due to disease or damage to the brain. 6–10% of Americans age 65 years and older experience dementia. Alzheimer’s disease is the major cause of dementia, accounting for two thirds of that total [1]. Patients with dementia often exhibit a wide range of dangerous behaviors including wandering, physical aggression, and disruptive vocalization. These behaviors typically require placing patients in situations that provide full time care where a wide range of pharmacological and behavioral interventions is applied to control or alleviate the problems. If the interventions could be elements of assisted living facilities and be automatically triggered in response to detected symptoms, it might be possible to control behavioral disruptions to some degree, allowing patients to retain self-sufficiency and independence for a longer periods of time and decreasing the cost of care significantly.

Many methods for the non-pharmacological treatment of dementia have been proposed. Some methods attempt to provide stimulation as a means of slowing the general progression of the disease. These methods include light therapy, music therapy, pet therapy, and activity therapy [2]. Cognitive stimulation therapy attempts to manage dementia by providing a regular presentation of reality orientation information to patients with Alzheimer’s disease, and it has been shown to increase cognition and quality of life [3]. Other methods are designed to immediately deal with the onset of disruptive behavior through calming influences such music or videos of family [4,5]. However, these methods require the presence of a caregiver to administrate them during times of duress. Other options include sensory stimuli, which have been studied as a general method to reduce agitation in dementia patients and may involve any of the senses. Sensory stimuli could be instigated through software and hardware implementation without the need for a caregiver’s presence. The stimuli could be invoked during times of ill behavior, which often occur with the emotions of anger, fear, or confusion [4,5,6].

Delaying the transition from assisted living to nursing care requires the management of disruptive and dangerous behaviors in ways that do not require the immediate intervention of a caregiver. This problem has two parts: a) the detection of the onset of inappropriate behavior and b) interventions that help to alleviate these behaviors. We approach the detection of these inappropriate behaviors through a combination of physical observation and physiological monitoring. The physical observations include the use of cameras to detect atypical behaviors and microphones to detect vocalizations. The physiological monitors include electrocardiograms, electromyography, and galvanic skin resistance using wireless sensors. Patterns in these media are analyzed to determine the onset of symptoms as well as the alleviation of symptoms due to interventions. The interventions include a range of environmental changes accomplished through the use of computer displays,
speak, lighting management, heating and air conditioning control, and olfactory stimulation.

This paper addresses the questions of detection of onset of inappropriate behavior and intervention methodologies through the examination of a wide range of literature on detection and mitigation of symptoms in dementia patients. It is meant to serve as a preliminary study of the potential efficacy of these methods. The questions addressed include how to apply existing methods for detection of symptoms to full-time monitoring, what interventions have been demonstrated to hold promise for the alleviation of symptoms, how the system must adapt over time as disease progresses, and how acclimation to the interventions can be avoided.

2. DETERMINATION OF ONSET

For any intervention to be effective, we first must determine the onset of inappropriate behavior in an objective manner. In any method we select, the retention of independence is important and should be accomplished without the continuous presence of another individual. We suggest microphones and emotional monitoring for this purpose. Microphones can monitor audio levels without imposing movement restrictions on an individual. In addition, since loud vocal disruptions are common, monitoring the decibel levels in a room may be sufficient to detect such behavior without crouching on privacy. Emotions are a probable determination measure, but they would require individuals in all stages of dementia to have a similar emotional response to stimuli as an unaffected individual. Fortunately, while different levels of adverse emotions are observed during the various stages of dementia, a degree of normal responses to external stimuli does remain. Magai et al. studied the emotions present during family visits [7]. They found that 35% of patients displayed sadness exclusively at the end of a visit and 12% during the visit and at the end. Even in patients with severe dementia, 29% still showed sadness exclusively at the end of a visit, which suggests that patients are still sufficiently aware to recognize when a relatives were preparing to depart and were saddened by the pending departure. They also found that the frequency of occurrence of most emotions does not change except for a degree of deteriorating joy and interest as dementia intensifies. Despite this, agitation and outward inappropriate behavior are more prevalent in later stages of dementia. While families rate less anger in patients than aides, it is likely due to the context of the interaction and does not skew the results.

These results indicate a moderate degree of normal emotional response exists at all stages and indicates that the detection of emotion may be useful for determination of inappropriate behavior through all stages of dementia. To detect these emotions we suggest the use of physiological signals for determining the present emotion is possible since they can objectively detect behavior through all stages of dementia. To detect these emotions patients than aides, it is likely due to the context of the interaction.

2.1 Device Selection

Unobtrusive monitoring devices are necessary for long-term monitoring of physiological states. While small microphones can be placed in living environment discretely, physiological sensors must still be attached to the person. Conventional characteristics considered when selecting effective physiological sensors include size, comfort, range of motion permitted, maintenance level, and resilience. More recent technology improvements have made dry sensors available for improved comfort and wireless capabilities allow greater range of motion permitting physiological sensors to become a viable option. Unfortunately, patients with dementia will frequently tamper with sensors if they are noticeable. To limit interference, the weight for the wearable sensory devices should be under 60 grams and less than four cubic centimeters [9]. In addition, proper positioning is required to limit tampering. Suggested positions include discreet locations such as the medial and lateral ankle positions [9]. A waterproof sensor may also be a necessity as shower baths are an event that is related to aggressive behavior and therefore should be monitored [6].

2.2 Emotion Selection

We can utilize physiological monitoring to detect emotional states or stress levels that are predictors of the onset of inappropriate behavior. However, we must select which emotions are the most informative and accurate. We do not want to select more emotion categories than necessary. As the number of emotions we attempt to detect increases, the error rate also increases [8,10]. Caregivers have suggested that the two emotional states that occur most frequently prior to or during ill behavior are fear and a state of confusion or frustration [6,4,5,11]. Evidence that the presence of ill behavior is more common with severe dementia when the cognitive function required to understand their situation has diminished supports this observation [6]. Anger is also a primary indicator, particularly in patients with aggressive behavior. Statistics that correlate patients with “disagreeable” personalities before the onset of dementia and aggression issues during dementia support this connection [6]. Thus, fear, confusion, and anger appear to be the most influential emotional states to consider when analyzing physiological signals.

2.3 Algorithms for Categorization

Several studies have examined the choice of physiological signals and algorithms for emotion detection. An earlier study by Picard, Vyzas, and Healey used Sequential Floating Forward Search (SFFS), using a k-nearest neighbor classifier for benchmarking. Fisher Projection (FP) with Maximum a Posteriori (MAP), and a hybrid of the two [8]. A later study by Lisetti and Nasoz built upon these results and used a pure k-nearest neighbor (KNN) algorithm, discriminant function analysis (DFA), and neural networks (NN) [10,12]. We shall give an overview of the algorithms and variable selection from Picard, and a more detailed overview of the algorithms used from Lisetti and Nasoz. Table 1 is an illustration of the algorithms’ selection accuracy of reported emotional states for our critical emotions. Fear and confusion were not tested with SFFS.

<table>
<thead>
<tr>
<th>Emotion</th>
<th>SFFS</th>
<th>KNN</th>
<th>DFA</th>
<th>NN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fear</td>
<td>NA</td>
<td>80.9%</td>
<td>90%</td>
<td>85.6%</td>
</tr>
<tr>
<td>Confusion/ Frustration</td>
<td>NA</td>
<td>78.3%</td>
<td>50.0%</td>
<td>77.3%</td>
</tr>
<tr>
<td>Anger</td>
<td>83%</td>
<td>70.8%</td>
<td>78.58%</td>
<td>91.7%</td>
</tr>
</tbody>
</table>

2.3.1 Sequential Floating Forward Search and Fisher Projection

In Picard’s study emotion detection and classification was performed on eight states: neutral, anger, hate, grief, platonic love, romantic love, joy, and reverence [8]. The physiological signals used were an electromyogram placed on the jaw, blood volume pressure, skin conductivity based on Galvanic Skin Response...
(GSR), and respiration [8]. Six statistics were computed for each of the four sensor channels, creating a 24-dimensional feature vector [8]. The statistics chosen were:

1. Mean of the raw signals
2. Standard deviation of the raw signals
3. Mean of the absolute values of immediate differences \((X_{i+1} - X_i)\) of the raw signals
4. Mean of the absolute values of immediate differences \((X_{i+1} - X_i)\) of the normalized signals
5. Mean of the absolute values of the second differences \((X_{i+2} - X_i)\) of the raw signals
6. Mean of the absolute values of the second differences \((X_{i+2} - X_i)\) of the normalized signals

The normalized signal is calculated as:

\[
\bar{x}_n = \frac{x_n - \mu}{\sigma_x}
\]  

In this equation, \(\mu\) and \(\sigma\) are the mean and standard deviation of the signal \(X\) and \(X_n\) is the \(n\)th value [8]. Heart rate, heart rate change from the blood pressure volume, and multiple respiration frequencies were all concatenated onto the feature vector to create a 40-dimensional space. SFFS was used to select the best features for determining an emotion category. SFFS takes the \(m\) input variables (in this instance 40) and then tests the set by including each new variable and searching for an old variable that can be excluded so as to determine the best \(n\) variables to maximize a certain criterion, i.e. to separate the emotion classes as accurately as possible according to the physiological signals. KNN applied to the resulting feature space determined the emotion category.

The FP algorithm reduces the number of variables by creating a linear projection, or linear combination, of the signal variables to a dimensional space one less than the number of emotion classes and then MAP to choose the emotion class from the transformed data. MAP is a posterior probability method used in statistics. The hybrid algorithm explored used SFFS to lower the number of variables that FP needed to consider [8]. The best results were with the hybrid method when determining among anger, reverence, and joy at 83%. When all eight emotions were considered, the accuracy was only 46% [8]. When the day the signals were captured was taken into consideration, the accuracy of determining among all eight emotions was much higher at 81% [8]. This is likely due to the method used to create the emotion signals. The researcher had requested a single actor to visualize the emotions, and the clustering is thought to be from the general mood of the day [8]. This is useful since these results imply that overriding emotion of a day are still present and cannot be fully masked by deliberate effort and that physiological signals may permit greater accuracy than a human’s perception.

2.3.1 K Nearest Neighbor

In the emotion detection studies from Lisetti and Nasoz the set of six emotions considered were sadness, anger, surprise, fear, frustration, and amusement based on galvanic skin response, heart rate, and temperature as their physiological signals [10,12]. Among the three classification algorithms utilized, KNN was the simplest. In these studies, movies clips were used that possessed general agreement on the emotions produced, which likely resulted in emotions that are more genuine for the sample data. For each signal recorded, they normalized the data by calculating the difference between a relaxed state and an emotional state [10][12]. This resulted in normalization of the form:

\[
\text{normalized}_{\text{data}} = \frac{\text{raw}_{\text{data}} - \text{raw}_{\text{relaxed}}}{\text{raw}_{\text{relaxed}}} \tag{2}
\]

This normalization aids in minimizing individual differences, allowing the training on data from a larger number of people [12].

The KNN algorithm requires two data sets, a training data set, and a test data set. For emotion detection, the training and test data consisted of the physiological signals with the a corresponding emotion class for the training data [12]. KNN calculates the distance from each of the training data points to the test data points and then reports the closest \(k\) training points, which are used to determine the emotion class. The distance formula utilized is an \(L_2\) norm of the form:

\[
d(x_i, x_j) = \sqrt{\sum_{r=1}^{m} (a_r(x_i) - a_r(x_j))^2} \tag{3}
\]

Where \(a_r(x)\) is the \(r\)th data point of physiological signal \(X\) and \(x_i\) and \(x_j\) are individual instances of the signal [10]. The KNN accuracy was sadness at 70.4%, anger at 70.8%, surprise at 73.9%, fear at 80.9%, frustration at 78.3%, and amusement at 69.6% [10].

2.3.3 Discriminant Function Analysis

Lisetti and Nasoz also applied discriminant function analysis (DFA), a method to categorize signals by using linear discriminant functions [10]. DFA is related to FP and its basis of creating a set of linear functions, or linear combinations, that cluster the results of related data but separate unrelated data to the greatest possible degree. The linear functions they used are of a form similar to:

\[
f_l(x_{\text{gsr}}, x_{\text{temp}}, x_{\text{hr}}) = u_0 + u_1 x_{\text{gsr}} + u_2 x_{\text{temp}} + u_3 x_{\text{hr}} \tag{4}
\]

In this equation, \(u_i\) is a linear coefficient. KNN is then used with resulting emotion clusters to map the test data to an emotion category [10]. DFA is shown in the paper to have an accuracy of 90% for fear, 88% for sadness, 79% for anger, 56% for amusement, 53% for surprise, and 50% for frustration [12].

2.3.4 Neural Networks

Lisetti and Nasoz also tested the use of a neural network as a classifier. The network used Marquardt back propagation for training [10]. The accuracy the neural network method showed an overall improvement over KNN and DFA methods with the accuracies of 89% for sadness, 92% for anger, 74% for surprise, 86% for fear, 77% for frustration, and 87% for amusement [10].

2.4 Comparison of Algorithms

In both studies, it was difficult to determine all eight emotions simultaneously, with smaller sets showing improvements. Specifically, selecting between emotions that dissimilar such as anger and peacefulness, high arousal and low arousal, or positive valence or negative valence had the greatest accuracy. When determining between anger and peacefulness the accuracy is remarkable: anger at 100% and peacefulness at 98% [10]. However, the results from Picard’s study are difficult to discern since it was only after considering individual day information that the best results were achieved [8]. Lisetti and Nasoz results were better overall. This is likely due to better data [10,12]. However, we can still observe trends in the results for each algorithm and their advantages and disadvantages. KNN performed better for
surprise than DFA and NN, while DFA performed better than KNN for sadness, frustration, and amusement [10]. The NN approach had the best results overall (84% compared to 72% for KNN and 75% for DFA) but performed less accurately for surprise and frustration than KNN and DFA [10].

These studies show only a relatively small subset of the signals is necessary for detecting emotions. For example, when SSFS is used, the means of heart rate, skin conductance, and respiration are never chosen [8]. Variables that are used for a majority of the instances are the mean absolute normalized immediate difference of the heart rate, the mean absolute immediate difference of the smoothed skin conductivity, and the higher frequency bands of a respiration signal [8]. This is an indication that further research is needed to determine the most appropriate signal modalities to use for emotion detection.

Beyond overall accuracy statistics, correlations exist between some physiological signals and certain emotions. There is a noticeable correlation between frustration and GSR, and a correlation of anger and fear with heart rate [10]. While happiness and surprise do not seem to correlate with heart rate, anger, fear, and sadness are generally accompanied by an increase in heart rate, while disgust decreases heart rate [12]. Anger also increases skin temperature more than happiness and sadness, while fear and disgust decrease skin temperature [12]. The acceleration of heart rate is more pronounced during disgust, joy, and anger than pleasantness [10]. These correlations are an important consideration when selecting physiological signals, particularly since emotions frequently occur simultaneously. Anger is often associated with other emotions such as disgust, while fear can be muddled with tension and interest [12]. Again, this supports the need to limit the number of emotions to be detected.

Overall, the categories for emotion selection that currently exhibit the best detection performance are anger, grief, joy, and reverence which interestingly are also the four quadrants of a valence-arousal plot or circumplex of affect (illustrated in Figure 1), a frequently taxonomy of emotions used by psychologists [8,13]. Anger is high arousal and negative valence. Reverence is low arousal and positive valence. Grief is low arousal and negative valence. Joy is high arousal and positive valence. For our purposes, it implies that we should select dispersed emotion if possible, as they are easier to detect properly.

### Figure 1: Unidimensional Scaled Valence-Arousal Plot with valence or pleasure-displeasure on the horizontal axis and arousal on the vertical axis with

#### 2.5 Further Concerns

Sensors are needed that can record the physiological data and still meet the requirements described in Section 2.1. The system used in the Lisetti and Nasoz studies to detect the signals was the BodyMedia SenseWear Armband (BodyMedia Inc., www.bodymedia.com) which is similar to what we require [10][12]. However, the sensor used a chest strap for heart rate monitoring which is likely too obtrusive, so an alternative means of heart rate monitoring would be required.

A concern in using physiological training data is that different cultural social structures may present varying physiological responses for the acceptable emotions, which will affect the detected physiological signals. A study comparing cardiovascular responses to anger and speech tone between Caucasians and Chinese displayed that the changes in biophysical responses were not significant, although there was a tendency for Chinese to self-rate anger increases somewhat lower[14]. Therefore, despite social constructs relating to anger, we can likely assume physiological signals do not appear to be skewed by what are considered socially acceptable emotions. However, another result from that study is the effects on physiological states from speech tone, which is liable to affect detection or intervention of ill behavior. When speaking loudly and rapidly, blood pressure and heart rate increased for both anger provoking and neutral material. This may be critical when detecting anger or choosing correct interventions as an angry speech tone for neutral material may yield similar blood pressure signals [14]. The probable reason for this effect is that loud, rapid speech is associated with anger and causes an increase in blood pressure by its association [14].

### 3. INTERVENTION

Intervention when disruptive behaviors are exhibited is a common event in assisted living that requires proper interaction with the patients to avoid exasperating the outbursts. Attempting to reason with a patient during disruptive behaviors is seldom successful and is not recommended [4]. Thus, to decrease the incidents of such behavior, intellectual stimulation and sensory stimulation have been applied as preventative measures. Intellectual activities consist of quizzes or interaction with pets and sensory stimulation may involve any of the senses. More recently, a merging of intellectual and sensory stimulation has become an option though simulated interaction, although all forms of stimulation have been found to reduce agitation to a similar degree [15]. In this paper, the stimulations that are of interest are those in which a caregiver is not required to be present, permitting independence to be retained for longer periods. Stimulation that meets these requirements may be categorized into sound, visual items, simulated interaction, and simulated environments.

In order to perform intervention, a wireless sensor network can be created which allows sensors placed on the various persons to communicate with a central system controlling preselected stimuli equipment [16]. The sensors periodically send data to the system. The system then calculates the various emotions engulfing the patient. Through these emotions, the central system can determine whether the person is currently at the onset of inappropriate behavior. If so, the system can perform the necessary intervention. Experiments that explore the potential for automatic intervention will need to be performed in a realistic assistive living situation. A sample environment for studying assistive living environments, the Heraclitus Human-Centered Computing Laboratory, is illustrated in Figure 2.
Sound as a stimulus is easy to create and present and is useful in both individualized and group settings. Music is the most common sound stimulus and has been shown to decrease agitation relatively quickly as an intervention measure. Favorite songs of an individual or music with softer melodies are among the more effective varieties while other music generally does not show significant improvement in agitation [15]. Music produced from speakers yields a method of stimulation that permits an environment requiring little supervision although singing, sing-alongs, and playing instruments also decrease agitation [2].

Lucero has several audio suggestions for minimizing agitation [4]. After gaining the attention of an individual, sing-a-long videos work as a more interaction version of sound stimulus by having the song’s words display across a screen. In addition to music, audio recordings of familiar written works are effective as an intellectual stimulation. Short stories such as from O. Henry or Aesop’s fables form a type of memory recall aid. Other written works such as poetry memorized when young yield a variety of reality orientation. Although sound can be used to lessen agitation as a general preventative measure, it may also be used as an intervention measure to reduce specific inappropriate behaviors. Behaviors such as wandering into forbidden areas or wandering at night can be reduced by playing an aversive sound during the event and can be used in conjunction with rewards for proper behavior to decrease further the number of incidents [5]. The aversive sound can be as simple as a single tone, or may be designed to be a reminder such as an audio-recorded “stop.”

Visual Stimulus

There is interest in visual stimuli to improve behavior and as automatic intervention measures that include light therapy, videos, and symbols. Unusual lighting effects such as bubble tubes, fiber optics, and light shows projected onto walls can be used to provide stimulation that decreases agitation [15]. Similar effects can be created using computer monitors or through the use of a small light producing device on a remote switch to permit their use without requiring direct supervision. Televisions are frequently already available which will lower equipment expenditures and will further provide the ability to play familiar videos. Videos such as old comedies or old World Series can be humorous and nostalgic for patients with dementia decreasing agitation in many cases [4]. Such videos may be designed to provide an intellectual element by using a question and answer format similar to spelling bees or quizzes of state capitols but leaving time for a patient answers. The selection of videos can be selected for a specific individual and played when deemed necessary. In addition to beneficial stimulus, visual intervention can include stationary symbols, which can provide unobtrusive reminders with requiring a caregiver to be present. Forgetfulness and confusion are frequent concerns in assisted living environment and signs provide immediate reality orientation [5]. Stop signs can be placed near exits as immediate reminders not to wander outside or may be triggered to appear on computer screens when movement is detected during the night.

It is important that visual cues not be limited to presentations on television monitors. While a television monitor is a highly flexible visual presentation device, it is also a physically limited device. It will only be effective if the patient is facing the screen. More general visual cues should work with the entire ambient environment using computer control of lighting. The effects of a more general ambient approach to visual intervention remain to be studied.

Simulated Interactions

While purely sensory stimulus provides a means of activity without another individual present, social interaction is an effective method to improve communication. Continual familial presence is not possible and thus simulated interactions are of interest. These can include videos of family members, pets, or related varieties of contact. Videos of family members can be created in which the filmed individual has a one-sided conversation with the dementia patient. The video can be triggered to play during certain selected events. These videos should be designed with the intent to comfort, to simulate conversation, or to persuade against a specific disruptive behavior with the results being an improvement of the problem behavior and communication level [4].

While these videos may be effective for more severely affected individuals, those that retain a higher level of cognitive function can recognize these as simply videos rather than true communication. To provide authentic interaction, pets can be requested to visit assisted living environments. While pets provide an effective stimulus that decreases agitation, there are inherent difficulties in pets in assisted living [2]. With diminished cognitive function, proper handling of the animals may be lost and the pets may react negatively to improper handling, which will cause detrimental simulation. As an alternative, a relatively new method has been proposed that utilizes robots to simulate pets and provide another form of structured stimulation. One such device is the entertainment robot dog, AIBO, which reacts to speech commands. Patients typically communicate with such robots and care for them, but the AIBO is still recognized as a robot. To remedy this difficulty, the robot was costumed, which aids patients to perceive the AIBO as either a dog or a baby, which results in an acceptable substitute for a real animal [17]. Another robot that has been used is a music robot that attempts to encourage and motivate interaction through a type button and song game. The robot requests that the users find the correct button for a song, then name the song, and then sing along. The robot is designed to have three difficulty levels wherein different
3.4 Simulated Environments
While individual stimuli can be used as intervention measure, there is some study into general continuous environment design for reducing agitation. The goal of these environments is to give the patients a sense of freedom while mitigate wandering behavior and the stresses of being in assisted living or in a nursing home. These environments are often designed to stimulate several senses at once and to be sufficiently pleasing to residents that they wish to spend time in the modified environments. Two such types of environments are the creation of an “interior redecorated” of a hallway and a wandering garden. In a study of redecorating hallways in a nursing home, two scenes were considered: a nature scene and a “home” scene [19]. The nature scene involved color murals of vistas, sound tracks of birds, forest scents, a bench, and fake plants. The “home” scene involved pictures of family scenes or earlier famous people such as Albert Einstein or President Kennedy, Jewish or classical music, citrus scents, an armchair, and a coffee table with nonsense papers and pamphlets. Patients spent more time in the simulated environments and exhibited a trend toward better behavior with less exit behavior although the results were not statistically significant [19]. Most caregivers approved of the environmental changes and reducing stress on the caregiver would likely yield more pleasant interaction with a patient indirectly lowering incidents of agitation [6,19].

A wandering garden is a physical garden space designed to create a safe escape-proof location while still providing the sensation of wandering freely and creating a high sensory environment from the materials or plants while minimizing disorientation [11]. The consideration of freedom of movement is particularly important for high elopement risk residents. The thought behind such a garden is that nature provides visual, sound, and tactile stimulation automatically through various shades of plants, wind, and texture of pathways or benches. A recent study showed such gardens decrease agitation and the need for medication, particularly for high usage residents [11]. However, the same study also revealed a surprising trend in ill-behavior incidents. Mild ill-behavior such as inappropriate language and severe ill behavior such as striking out and harming another person increased, while moderate to moderately severe ill behavior decreased such as inappropriate grabbing or striking out with no intended target. If the considered as a whole, the number of incident stayed the same, but due to this, we can only recommend with caution wandering gardens.

Simulated environments may be an indirect method of intervention, but the various discrete elements can be employed as options for direction intervention purposes. In addition, when there are several stimulus elements continuously applied in union, the intervention equipment used for direct stimulation can provide the means to create a calming background to limit the necessity for more direction intervention.

4. ADAPTATION AND ACCLIMATION
For any system that determines the onset of ill behavior and provide an automatic intervention to be used long-term, there must be a methods to adapt to an individual as dementia worsens. While physiological monitoring may be fairly accurate, the base line may change daily as Picard’s study with a single individual showed [8]. Moreover, a patient may become acclimated to stimuli that may have been effective earlier. Most individuals can relate to the concept that, after reading an advertising sign a few times, the same sign is, subsequently, no longer noticed. We become, in a sense, blind to it. This decrease in attention is due to a decrease in the corresponding neural activity and is referred to as adaptation mnemonic filtering, detrimental responses, neural priming, or the term we will be using, repetition suppression [20]. The effects of repetition suppression imply that careful consideration of stimuli choice and calibration measures are needed.

4.1 Repetition Suppression
There have been numerous studies involving repetition suppression, its cause, its time delay, and its level of effect. Repetition suppression is believed to be invoked when an identical or similar stimulus is repeated [20,21,22,23]. These stimuli may be entirely random stimuli or a single repeated stimuli with the key characteristic that the stimuli may be clearly grouped into a single set [20]. However, the time delay before a functional MRI records such a decrease in neuron activity is instantaneous for our purposes. A review of repetition studies by Grill-Spector et al. All considered the timing of repetition suppression [20]. Various studies suggested that the effects of repetition suppression are found to occur 200 ms after a repeated stimulus. This length of time decreases further to 160–190 ms if the stimulus is repeated with no intervening period. If there is a change in view of the object, the effect may be to increase the delay to about 400 ms. The difficulty of repetition suppression is that it persists despite intervening stimuli and that the neuron activity appears to decrease exponentially. Fortunately, studies have also shown that the effect may plateau after six to eight repetitions, which may allow stimuli that are still effective after eight repetitions to be viable for long-term use as intervention possibilities. There are also various stimuli that exhibit more or less severe characteristics in terms of repetition suppression. The effect is maximal when the stimuli are repeated without intervening stimuli and the most affected neurons are the visually excited neurons. The effect on auditory stimuli may be sufficiently different to make sound the preferred methods on intervention.

4.1.2 Visual Repetition Suppression
In general, visual stimuli can be placed in broader categories that include the same neurons as auditory stimuli. Studies have shown that repetition suppression does not only occur with identical images but also with close conceptually related images. For example, the repeated stimulus of umbrella images, where the images contain different umbrellas or when the umbrellas are viewed from a different viewpoint, still exhibits a degree of repetition suppression [20]. Although this may mean related imagery may not be viable to create new stimuli for intervention, there are still many options available. The primary difficulty with visual repetition suppress is the duration. A single experience with a visual stimulus may last days, and possibly far longer [23]. For our purposes, this may represent the inability to use an earlier visual intervention stimulus after a prolonged waiting period. Therefore, when selecting stimuli, care must be taken to use a visual stimulus only as needed to prolong its life as an intervention measure.
4.1.2 Auditory Repetition Suppression
Auditory stimuli may be more convenient for intervention due to the manner in which it affects the brain. In a study by Näätänen and Rinne, auditory repetition suppression was considered for both a string of erratic sound stimuli with a randomly placed repeated sequence, and a repeated sequence with random dissimilar tones [21,24]. In the instance where an erratic noise has an embedded repeated sequence, after the first unexpected repeated tone is played, each continuing repeated tone resulted in smaller deviation of brain waves which likely means that repetition strengthens the assumption of repetition. This also may suggest only sounds that are soon repeated are committed to lasting memory. Moreover, this response may be accentuated when the individual is actively listening compared to passively listening [21]. However, what may be more critical for our purposes is that as the number of repeated sounds increased between discrepant tones, the more repetition suppression behaves as it did during original response [21].

The possibility of the brain “resetting” is beneficial for our purposes. If a sound stimulus is only selected with long periods between its uses, the stimuli may be capable of being used for long-term intervention before repetition suppression becomes an issue. Another possibly is to create continuous soothing background noise and use the deviant sounds as intervention measures. There is a possibility that not all effects of repetition suppression completely fade in all portions of the brain. In the areas of the brain responsible for conceptual meaning rather than perceptual meaning, repetition suppression may not fully fade [22]. For example, repetition of normal environmental sounds does cause a reduced activation in auditory regions likely since individuals place a meaning on the sound. Thus, long-term auditory repetition suppression may still exist, so uninhibited use of sound stimuli for intervention is not advisable and should have careful consideration.

4.2 Calibration
Physiological signals vary from person to person and even day-to-day for the same person, so training data will be required to be normalized for it to be applicable for the largest number of people. In Picard’s study, where there was an obvious relation to a person’s signals and the day in which they were taken, there is an indication that frequent recalibration may be needed even if this is simply due to the emotion only being “acted out” [8]. Individual physiological signals will change with time and drift in signals can occur within minutes. Therefore, the issue is not if recalibration will be needed, it is when and how. We wish to have an undemanding recalibration process and to lengthen the time between recalibrations. A method of automatic recalibration within the system would be preferable, but if an automatic recalibration is not possible, the recalibration process must be simplified so that individuals may perform it themselves for the greatest period. An example of this would be having a simple program with a “start recalibrating” function that begins a timed recalibration sequence in which an individual would be told to relax during recalibration. We can lengthen the time between recalibration through software and hardware improvement, but a large individualized training set would likely be the most beneficial. Repetition suppression may be considered a base line measure for intervention response, which should be included as parameters in the system [20]. Lastly, when considering calibration tuned to a specific patient, knowledge of physiology, such as men having greater cardiovascular responses than women, should be applied [14].

5. CONCLUSIONS
Alzheimer’s disease and other dementias are a long-term and costly health concern. The amount of care an individual requires due to early forgetfulness and progresses into ill behaviors severely influences the cost of dementia treatment. These ill behaviors may range from mild, but frustrating vocal disruption, to severe and dangerous behavior such as hitting or wandering. This paper examines automatic detection and intervention as means to alleviate these dangerous and disruptive measures. We discussed a physical environment that could be created that aids individuals by intervening without the need for a nurse or other caregiver to be present. As a result, it would allow an individual to retain a level of independence longer and lower the time and costs spent in a nursing home. Such an approach is ideal for an assistive living environment, since caregivers are still available, should the automatic interventions prove insufficient. We discuss the options that could be used to determine onset of ill behavior and the equipment required and indicate physiological signals that can be used to determine mood as an effective, unobtrusive, and accurate method for detection [8,10,12]. The equipment required for monitoring can be manufactured to be small, lightweight, discrete, and resilient [9]. The monitored signal may then be processed to determine the mood (anger, fear, and confusion/frustration) of the individual, which have been correlated with ill behavior [4,5,6,11].

The intervention techniques we discussed were sensory stimuli that can be initiated through automatic means. Sensory stimuli has been shown to reduce agitation in dementia patients and can be operated without a caregiver present allowing greater independence [2,4,5,6,9,11]. Sensory stimuli that are useful for our purposes are typically visual or auditory in nature, although there are interactive options such as robots [17,18]. A fourth option is the audiovisual simulated presence video in which a recording is a one-sided conversation with a patient [4].

For these methods to be used long term, we must consider adaptation and acclimation to the stimuli. Repetition suppression can cause previous effective stimuli becoming rapidly ineffective if used improperly. Due to the effects of repetition suppression, visual stimuli can suffer a decrease in effectiveness in 200 ms and the decrease may last for long periods [20,23]. Auditory stimuli suffer less from its effects, but caution is still urged against for using auditory stimuli too frequently or the same stimulus continuously [21,22,24].

Currently, the best choices for physiological signals are likely heart rate, blood pressure, skin conductance, and skin temperature due to the correlation with mood and prospect of unobtrusive devices [8,10,12]. A future study examining the possibility of other physiological signals could include the electrooculogram for eye movement. Patients with dementia show a decreased performance of saccadic movement compared to that of normal individuals [25]. Target prediction (where target lights are lit one at a time across the screen in a completely predictable fashion), spatial decision-making (where the subject was instructed to look at the light closer to the center of the screen out of two lights), and saccadic suppression are all impaired with saccadic suppression performance being the most pronounced [25]. The saccadic suppression is of particular interest since if there is a correlation a subject would have likely difficulty not continually looking to any
available stimulus. Electrooculograms may be possible through dry sensors set onto glasses, which fulfill the unobtrusive requirement, and could potentially be used for onset determination purposes.

Future work will examine how these systems can work together and begin to work toward a prototype that can be tested with willing test subjects, particularly those in the early stages of dementia and who are only showing moderate behavioral issues.

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7. REFERENCES
An Interactive User Interface System for Alzheimer’s Intervention

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ABSTRACT
Alzheimer's Disease (AD) is a neurological affliction that impacts primarily the aged due to brain tissue deterioration. It has been shown that this deterioration can be slowed down by engaging the person with daily interactive activities that include gaming, social interaction, memory exercises and physical activity. In this paper, we describe ZPLAY, a game-based user interface system which is designed to be web-based and to provide intervention therapy for AD. ZPLAY has two versions: the @lab version which is designed for diagnosis and used to measure different brain activation responses of AD and the @home version which is used to promote subject engagement and rehabilitation in a home environment in-between visits to the clinic.

Categories and Subject Descriptors
D.0 [Software]: GENERAL

General Terms

Keywords
Human computer interaction; Alzheimer’s, Dementia; rehabilitation; functional near infrared (fNIR) imaging; game design; machine learning; motion capture; data stream synchronization; physical therapy.

1. INTRODUCTION
Alzheimer’s Disease (AD) is a neurological affliction that impacts primarily the aged and brain tissue deterioration has been shown to be slowed down with interactive activities that include gaming, social interaction, memory exercises and physical activity [1][2][3][4]. By the time people meet criteria for AD they are in advanced “organ failure”, i.e. the organ being the brain. The key is preventing normal elders at risk from progressing to mild cognitive impairment (MCI) and maybe those with MCI from progressing to AD. The challenge is to identify and achieve prevention much earlier, even before MCI, with activities that are feasible and doable, such as game-like interfaces that also allow remote assessment, interaction and collaboration among clinical expertise, as needed.

In this paper we describe ZPLAY, a game-based interface system that has been developed to provide just such an intervention for AD. We focus on early – prodromal – stages of AD and include controlled features that allow personalization or customization of user preferences and capabilities. In addition, a more restricted version of ZPLAY is used to associate game performance data (metrics) with fNIR (functional near infrared) imaging classification in order to determine AD disease progression. Using noninvasive monitoring of functional brain activity, fNIR protocols for Alzheimer’s disease test the prefrontal cortex, by placing the INR probes on the forehead, to measure the hemodynamic response to higher order cognitive functions such as doing anagrams. fNIR and fMRI (functional Magnetic Resonance Imaging) [5]. It uses near-infrared light to measure changes in the concentration of oxygenated and deoxygenated hemoglobin in the cortex and is limited to the outer cortex. It is less invasive, portable, and more affordable than other neuroimaging methods, such as fMRI. It is also more robust to artifacts caused by movement and can be integrated with other technologies such as EEG[6].

2. Related Work
There are a lot video Games have been used for rehabilitative purposes for patients with CP, Stroke or other motor skill disability [7][8][9][10]. There are also some brain exercise games designed for early stage Alzheimer Rehabilitation [11][12][13]. The Alzheimer’s Association of Canada has launched a two-year campaign urging people to do regular memory exercises to ensure they keep the disease at bay [14]. Most of these games just games that have scores and where a specific challenge exists for each level. There are very few software game systems that have been developed to provide quantitative measures of AD progression and ability to make changes with controlled features that measure, for example, speed of response, stamina, scoring, complexity, level of interactivity, and other metrics.
3. System Overview

ZPLAY is based on a **front end**, a set of controllable and customizable computer games that provide controlled stimuli and extract a desired cognitive and motor response, and a **back-end**, a set of computational engines to enable data logging (from person playing the game), data fusion, machine learning, pattern analysis and decision support (Figure 1). There are **two versions**: The **@lab** version is constrained in order to avoid creating unnecessary brain activations that do not measure the desired response. This version is used to measure brain activation responses due to AD and can also be used with fMRI, if the game interface can be managed with a joystick. The **@home** version is used to promote subject engagement and participation in a home environment in a more natural setting, and in-between visits to the clinic. It does not require fNIR equipment, although our lab is testing new wireless and minimalistic “headband” fNIR that can be used at home. The **@home** system has remote wireless monitoring capabilities that can collect and combine different types of sensor data, ranging from facial expressions, eye tracking, EKG to other vital signs. The design of the system aims to encourage subject engagement, remote playing with others, and can make game adjustments for personalized treatment. It also allows for monitoring by healthcare givers, summarization of historical data, searching for similar patterns, and other behavioral pattern analysis by experts, family and caregivers. Different roles are assigned to different stakeholders and with different access permits.

### 3.1 Game Design

Our aim will be to design games that test specific AD-related functions. To measure specific mental skills we use a suite of computer games to assess the degree of deficiency. People with AD have varying degrees of mental capabilities, so the games we develop would need to be simple concepts that are easy to grasp, open source and easy to change and personalize. Given this, we will carefully select challenges to games we develop that also have a controlled way of which aspect of performance we are measuring. We differentiate game challenges from game measures. A game challenge is something that the patient is going to have a desire to achieve which is not simply a score. Thus, while there are performance measures collected from responses, there are different types and levels of game challenges for each game that can be upgraded or changed as needed. Since the mental capacity of our target group is over a large range, we will provide a range of challenges as well, which offers another classification category. Ideally, the game would learn the abilities of the patient with playing and would adapt to achieve the brain exercise purpose we need for our AD tests.

### 3.2 The fNIR System

#### 3.2.1 System Introduction

We assume the use of a portable fNIR brain imager (CW-5, TechEn, Inc; Milford, MA), that is fMRI compatible, in these studies. This system employs 16 laser diode sources (8 at 690 nm and 8 at 830 nm) and 16 avalanche photodiode detectors to detect fNIR reflectance signals at a sampling rate of 100 Hz, which is then typically down sampled to 10 Hz to reduce noise and data volume. Four sources per wavelength and 8 detectors are placed in a linear fiber optic array arrangement with a 3 cm source-detector fiber separation [15] on the each of the left and right sides of the dorsolateral prefrontal cortex each covering a 4 x 6 cm² area. Source and detector fibers will be held together by a custom made holder made by Velcro strips and the patient will be reclining into a comfortable chair in a dimly lit room. The fiber optics can be felt by the subject as mild pressure on his/her forehead skin, but there are no comfort issues with the fitting of the probe on the subject’s head. An advantage of the CW-5 system is its high temporal resolution because all laser sources are continuously ON and frequency-modulated, so the detectors can see different sources simultaneously without time-sharing during data acquisition. It can be used either by an individual or in a group setting. The system data is reconstructed using dedicated software to produce animations of brain activation that can he played back at a 10Hz rate.

#### 3.2.2 Method

We map the hemodynamic changes in the dorsolateral prefrontal cortex during a verbal fluency task. The cognitive task involves producing as many nouns as possible that start with a particular letter presented on a computer screen [16]. A block design will be used where the noun-finding epoch lasts 30 seconds followed by a 30 second resting period, for 10 consecutive periods of activation and rest over the course of a full experiment. The letters shown on the screen will only appear once per experiment. We will analyze the asymmetry in hemodynamic activation between the left and right prefrontal cortex sides and other spatio-temporal metrics as the time-to-peak and activation duration as possible indices of AD severity diagnosis. We will aim to recruit equal numbers of AD patients and age and gender matched controls. The recruited

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**Figure 1: ZPLAY System**

[@lab](#) [@home](#) Internet

- Assessment Game
- Data Log
- Data Fusion
- Exercise Game

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[@lab](#)

- Database
- Machine Learning Algorithm
- Server
- Assessment Tools
- Visualization

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@lab

- fNIR System

---

@home

- Database
- Machine Learning Algorithm
- Server
- Assessment Tools
- Visualization
patients will have been diagnosed as having probable mild to moderate dementia according to the ICD-10 criteria [17]. The study of the mild cases is expected to test the fNIR method’s sensitivity in detecting abnormal hemodynamic patterns with respect to healthy controls. Interestingly, patients with only mild age-associated memory impairments (AKA “senior moments”) as well as non-AD affected patients with major depression, at least among the limited number measured so far, are not different from the healthy elderly controls [18]. All recruited subjects will be free of any medication that could alter mental function and their detailed medical history and current medications will be recorded and taken into account during interpretation of the fNIR imaging results.

3.3 Assessment Function

The ZPLAY system provides for different levels of AD assessment, starting with a baseline assessment (initial visit and diagnostic evaluation) digitally simulating commonly administered manual tests (e.g., the Mini-Mental State Examination (MMSE)[19][20], the Physical Self-Maintenance Scale (PSMS) and the Neuropsychological Test Performance) to establish baseline cognition and functional ability. Recent work has been investigating the question of whether MMSE indices designed to measure “temporal and physical orientation, declarative memory, language, working memory and motor/constructional function can differentiate patients with different dementia diagnoses in AD. Significant correlation indices were found between the orientation indices and the neuropsychological tests of naming and memory and between the working memory and the motor/constructional indices and tests of executive control. These types of analysis [20] can be incorporated into the ZPLAY system in order to formulate interactive game functions that can assist in refining the cognitive assessment and in tracking the course of AD. The Mini-Mental State Examination (MMSE)[20] is the most common cognitive screening measure for the identification of dementia. Usually, a score below 23 is where cognitive impairment might occur [21][19].

The system includes mechanisms to (1) incorporate best behavioral/psychological intervention practices for AD into controlled game versions of ZPLAY; (2) establish a methodology for AD classification refinement based on game-related metrics that measure subject cognitive response, participation, and stamina; and (3) employ advanced data management methods, data stream synchronization for multiple types of sensory devices, and machine learning to define behavioral classifiers based on different metrics. Thus, ZPLAY allows us to establish a quantifiable association between brain imaging (fNIR) metrics and game-playing related behavior or skills for AD. Its intelligent data management backend collects and analyzes behavioral data and generates guided recommendations for personalized treatment. ZPLAY has adaptive interfaces and access methods for different types of users (subject, therapists, researchers, clinicians & family members) with the ability to integrate user input into the overall analysis of rehabilitation progress.

3.4 Behavioral Monitoring

The system, using different functions, also indirectly aims to answer questions regarding behavioral symptoms, such as agitation, psychosis, anxiety and depression to assess the patient’s response to AD treatment. ZPLAY generates quantitative measures of disease progression by comparing future assessments based on interaction between the subject and ZPLAY, to the baseline to track cognition and behavioral changes. Since MMSE and PSMS are used in the clinic and completed by a physician/clinician, they can be subjective and may change with different personnel. ZPLAY adds an additional, automated, point of reference that is more objective. PSMS testing is often completed by the subject and given at each subsequent visit in order to compare current scores to previous ones. ZPLAY combines this with other sensor-collected data and offers interactive and entertaining features that make this test more engaging.

ZPLAY also supports ongoing evaluation of AD and physical/behavioral/cognitive intervention at home. Once AD has been diagnosed and a treatment plan prescribed, subjects are able to work on stabilizing their condition at home through group or single-game activities before returning for an @clinic evaluation in 2-6 month intervals, depending on the stage of the disease.

The @home ZPLAY version can fill different goals. One goal might be to test the impact of a particular medication on the person’s ability to play a game or respond to the interface task, as compared to previous sessions. Another goal is to assess improvement in cognitive functions or detect stabilization or worsening of cognitive/behavioral conditions while providing multi-functional intervention in the process. Since dementia cognitive and behavioral symptoms change with time or daily life conditions, ZPLAY can adjust to a person’s user model as collected over daily use and detect and battle symptoms of distress, discomfort, delirium, hallucinations, depression, agitation, and even pain, that may arise due to various medications. Recorded and analyzed feedback based on game-involvement with ZPLAY is important to doctors and medication treatment. However, longitudinal monitoring is currently possible only through subjective or manually recorded means that do not include patient direct interaction with a system. Thus ZPLAY performs that task of a daily stimulus to collect behavioral markers or features, and correlate these with brain imaging features. ZPLAY also can combine this information with other types of clinical data such as blood pressure, EKG, urinary condition, and pain. It also enables the subject to interact on a fun level with different caregivers who can use the system to record relevant information and assessment about the patient’s interest in playing, daily schedule, any unusual events involving accidents, moving to a new location, changes in physical condition or willingness to cooperate in medication intake, whether it is a “bad day,” over a long period of time. Such detailed daily history is important in determining medication or treatment efficacy as well as in adjusting the game interface or type and generating a more refined profile of disease progression. Since improvement may be minimal due to current AD treatment practices, ZPLAY provides a more sensitive and technology-supported way to record the cognitive status. It can particularly help in the early stages of the disease, with more rapid degeneration accompanying the later stages.

3.5 System Evaluation

We will evaluate the response, engagement and the participation. Engagement measures how long they use the system from week to week. Participation measures the frequency of use of the system. Our system is capable to inherently collect this information and present a summary analysis at the end of each week with graph showing the correlations among these three measures and, based on other knowledge, regarding the daily
schedule of activities, one can conclude on a pattern that shows, for example, that the best time for the therapy. We will also evaluate the result by getting input from therapy expert.

To make the evaluation system work, we will also involve human subjects to feed in the evaluation part. The study population will consist 8-10 human subjects. These human subjects will be assigned randomly to one of two groups: a study group that will receive the ZPLAY computer game exercise program and a reference group that will receive the traditional treatment program. Measurements will be performed to all people by applying selected test that have proved prior validity and reliability.

4. Conclusions and Future work

The ZPLAY system could play an important role for caregivers and family members of persons with AD or MCI. It can also play a role in helping general practitioners (GPs) in detecting persons with symptoms of dementia (e.g., memory changes in cognitive processes - http://www.biomedcentral.com/1471-2296/9/29). However, many of such neuropsychological tests for recognizing the onset of cognitive impairment require a great deal of training due to their complexity and thus are of limited use to GPs[22][23][24]. ZPLAY is currently under development and a prototype version is being evaluated by Alzheimer’s experts. (1) The ZPLAY system aims to bridge cognitive and physical behavioral data with digital game-based performance analysis and brain imaging using fNIR, a less invasive, cheaper and mobile brain scanning method. It thus provides new directions to AD behavioral analysis. (2) It impacts remote healthcare practices for AD and personalization. (3) It promises fNIR diagnosis improvements to make it the preferable brain imaging method. (4) It provides training and treatment decision-support to current subjective evaluations recorded on paper records and not directly connected to brain imaging outcomes. Since no existing treatment can reverse or stop the progression of Alzheimer’s disease, ZPLAY helps collect and record valuable information, engage the subject in a fun activity and provide a level of independence that improves his/her quality of life.

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5. REFERENCES

[12] “Brain Games For Alzheimer's | LIVESTRONG.COM.”
[19] Eugenio Magni, Giuliano Binetti, Alessandro Padovani, Stefano F. Cappa, Angelo Bianchetti, and Marco Trabucchi, “The Mini-Mental State Examination in
Alzheimer’s Disease and Multi-Infarct Dementia,” *International Psychogeriatrics*, vol. 8, 1996.


A Survey of Technology for the Elderly

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ABSTRACT
This paper surveys emerging assistive technologies in terms of the impact they have upon several key aspects of the elderly individual within society, including in the home, at work, and in the community. While advocates of the benefits of technological change typically see emerging technologies as offering hope for the betterment of the human condition, critics of the risks of technological change are quick to warn us of the dangers they pose. Thus, we also include a short discussion of the challenges and risks related to the adoption of these emerging technologies in regards to societal inclusion of the elderly.

Categories and Subject Descriptors

General Terms
Human Factors

Keywords
assistive technology, elderly, ethical issues, robotics, artificial intelligence, biotechnology, biometrics, nanotechnology, RFID, GPS, social networking

1. INTRODUCTION
Information highway. Internet revolution. Digital age. Information society. These familiar phrases are all used to describe the surging leaps in technology experienced over the past two decades. The late 20th and early 21st centuries have seen a driving force of technological change that continues to advance solutions for challenges facing society, as well as open up the collective imagination of what is possible. According to Raymond Kurzweil’s Law of Accelerating Returns, the overall rate of technical progress is currently doubling approximately every decade. As a result, the 21st century will see almost a thousand times greater technological change than the 20th century. At a point Kurzweil refers to as “The Singularity,” technological change will be so rapid and profound, it will represent a rupture in the fabric of human history. [1] He and other futurists predict that the exponential improvement in technological advances will eventually lead to a point at which progress in technology occurs almost instantly.

The acceleration in technological advancement provides extraordinary benefits to society, accompanied by extraordinary challenges. The pace of technological change has sometimes been at odds with the available supportive infrastructure, or the ability of the legal system to provide effective regulation and protection. Technological change can also highlight differences between the haves and have-nots in society, as financial, cultural, social, gender, disability or age-based issues may act as a determinant in access or adoption of new technologies. In many cases, such as technologies geared towards entertainment applications, these lower adoption rates may not be highly consequential, but as governments and civil society organisations rely upon advances in technology to provide key services to citizens, ensuring access to such technologies is critical to provide for an inclusive society.

1.1 The Impact of Assistive Technology
As the world’s population ages at an unprecedented rate, societies find themselves in a predicament where the communicative power of technology strides ahead, leaving behind an underserved population segment that stands to gain immeasurably from its full and proper adoption. The term “digital divide” refers to that gap between those people with effective access to digital and information technology and those without access, and reveals just how critical it is to include a growing elderly population in every technological advance made. Europe’s i2010 policy framework [2] is one strategy amongst many implemented to foster inclusion and better public services and quality of life for all through the use of information and communication technologies (ICTs).

“Assistive technology” (AT) is a broad term used to describe all assistive, adaptive and rehabilitative devices for older people and for those people with disabilities. While this broad definition encompasses both high- and low-tech devices, this paper does not include a discussion of the assistive technologies in common use (e.g., wheelchairs, walkers and hearing aids), but focuses rather on those new and emerging assistive technologies that enable older adults to more independently perform activities of daily living and give them an opportunity to participate in society longer and more fully, thereby addressing the problems of the digital divide and fostering e-inclusion.

This paper examines emerging AT as it impacts the elderly, though many of technologies mentioned herein also have an impact on other marginalised populations who confront similar challenges (e.g., financial, physical impairments, etc.), and
discusses technologies in terms of the impact it has upon several key aspects of the elderly individual within society:

- **In the home.** Emerging technologies are extending the ability of elders to live independently for longer periods of time, reducing the need to live in assisted living facilities or care homes, and reducing reliance upon family or paid caregivers to provide support. Technologies for the home range from those that aid in activities of daily living, that monitor and generate alerts based upon usual (and unusual) behavioural patterns, that improve physical safety, to those that bring essential health care services directly into the home. In addition to efforts by industrial actors under private R&D schemes, governments are investing heavily in programmes to encourage technological breakthroughs to enhance independent living. One of the primary embodiements of policy in this area can be observed in the level of financial investment that is being made in development projects by governments. The European Commission continues to encourage development through Framework Programme funding, along with significant private and national level investments through the AAL Joint Programme. Through NIH (National Institute of Health) grants, the US government funds development in the area of assistive technologies.

- **At work.** AT may provide the support for workers to stay in the work force longer for personal satisfaction or for financial reasons. As use of technology has become a critical requirement in many workplace settings, new technologies and adaptations are being developed to ensure that technologies are accessible for older workers, both in terms of addressing physical impairments commonly associated with ageing (such as hearing or vision losses, impairment of dexterity) and in terms of providing access to training on emerging technologies. Remote connections to workplace systems from home, enabled by broadband access, provide alternatives to overcoming mobility barriers.

- **In the community.** As technology has changed, so has the notion of community, augmented by the virtual, global reach of the Internet. Social connections with family and friends who live at a distance, with strangers who have similar interests and hobbies, with learning communities, are all enhanced through technologies. Access to these communities as well as to the services available to citizens from public authorities relies heavily upon ensuring access to the Internet for all citizens. In an address to the Internet Governance Forum [3], Viviane Reding, former European Commissioner for Information Society and Media, stated the need to provide an inclusive Internet:

> An open Internet is also an inclusive Internet. There are billions of people still without internet access. They must not be forgotten, nor must we make decisions now that they will regret in the years to come. We must act now to make sure that the global community can participate fully and equally in the important processes that underlie the development and future of the internet.

2. **A SURVEY OF TECHNOLOGIES**

2.1 **Assistive Technology and Emerging Applications**

Every technological advance presents a challenge to ensure that all segments of society are included in the revolution and that these technologies support the goals of independence and inclusion.

When technologies improve human capabilities, they have the potential to satisfy the needs of the elderly and to promote their inclusion in society. These solutions also offer otherwise elderly “disabled” bodies the same access to information, technology and services as younger “abled” bodies and extend the time in which the elderly can remain active.

The technologies surveyed below all support independence and e-inclusion, and offer a glimpse into the future needs of society at large. Many of the technologies serve as building blocks for broad applications, which are redefining how the elderly can remain fully engaged in society and the workplace, and independent in their homes. The survey also provides some examples of specific research projects that have been undertaken to advance the technologies or their applications in practical settings.

2.1.1 **Robotics**

The goals of robotic technologies are focused upon improving and supporting a user’s capabilities, rather than replacing the need for human assistance entirely. Assistive robots, defined as devices that cooperate with a user through physical activity in the user’s environment [4], can help the elderly in a number of ways.

Lack of mobility is a key issue amongst the elderly population, whether sudden and short-term (e.g., injury due to a fall), or a slow diminishing of capabilities over time; mobility limitations impact an individual in terms of their ability to perform activities of daily living (ADLs), causing them to lose independence in physical terms, as well as losing opportunities to remain socially engaged within their community and continue as active participants in the workforce.

Robotic technology is being employed to address the needs of the elderly, through intelligent walkers, mobile robotic guides and assistive robotic agents. Intelligent walkers are based on intelligent multi-agent systems technology and are similar to traditional walkers, but also have the ability to communicate with the user and react to their surroundings. They adapt to the specific needs of the individual and can recognise voice commands given by the user. For example, the i-Walker [5] is used in rehabilitation to modify the amount of support given to the user. The effort made in walking, distance travelled, calories burned, etc. is documented by the i-Walker and subsequently adjusted by a medical professional depending on progress made.

Other devices in which robotics have been implemented to improve daily life for the elderly include:

- aids for lifting and transfer
- home adaptation and intelligent user interfaces
- special controls for driving
- limb prostheses
- aids for self-care
- aids for games, exercise, sports, entertainment
• aids for memory
• diagnostic monitoring.

Additionally, when artificial intelligence (as discussed below) is integrated with robotic devices, the robots can be used to look after and monitor elderly patients and even provide some level of perceived nurture. These types of robots have been implemented to assist elderly people suffering from cognitive disorders and physical disabilities. Some specific examples include:

• The Nursebot project incorporated intelligent reminding for those with mild cognitive issues. A robot was programmed with information about the user’s daily routines and observed the user, offering reminders when necessary. The robot also learned which activities must be monitored daily and which only needed periodic monitoring. [6]
• Robot care bears were introduced in a retirement home in Japan. These bears watched over patients and monitored specific interests of doctors, such as response times and lengths of time spent on specific tasks. These robots also had a friendly exterior which enabled them to act as a companion for many elderly residents. [7]
• The LIREC (Living with Robots and IntEractive Companions) project [8] embraced a multi-faceted theory involving artificial long-term companions that can perform numerous functions, including rehabilitation, fetch and carry, security, dispensing medicine, and cognitive prosthetic tasks.

2.1.2 Artificial Intelligence

Popular culture has long been fascinated with the intelligent machine, able to replicate the best of man’s rational and logical thought and decision-making processes, and improve upon them through the elimination of emotional burdens. Today’s artificial intelligent (AI) systems are oriented towards adapting to unpredictable situations, often made unpredictable because of the presence of humans in the environment.

AI is commonly one technological component amongst many in an assistive product solution. For example, consider the robotic solutions discussed above that enhance mobility. A number of other applications built upon or integrating AI are emerging and being used in medical diagnosis and to produce new instruments to support medical research and training. Programs such as medical decision-support system and patient-centred health information systems can help medical professionals make care decisions. The system analyses medical history, symptoms, etc., providing diagnoses for the patient’s conditions and recommending appropriate treatment alternatives. These systems may also monitor and manage the patient’s conditions. [9]

AI is also one of the key technologies that contributes to intelligent telemonitoring, biometrics, and smart home development used to enable the elderly to live more independent, healthy and engaged lives in their own homes. These solutions are discussed later in this paper.

2.1.3 Sensing and Surveillance Technologies

Sensing technology has been around for decades; however, more recent technological advances have led to a dramatic increase in human-machine intimacy. Sensors are also becoming smaller and cheaper to produce, enabling them to detect and respond to a broad range of signals or stimuli, including movement, light, proximity, temperature of an object or of the ambient environment, force, humidity, acceleration and magnetism.

The development of smaller sensors and wireless sensing networks that enable their effective use for more applications has been significant. Smaller sensors provide the opportunity for technology to be used in increasingly novel ways, enabling the objects and environments into which they are placed to become “smart.” For example:

• Sensors are increasingly being embedded into textiles, enabling clothing to measure an individual’s physical condition, whether for medical applications, entertainment or for monitoring sports-performance.
• Sensors are being used within housing materials (carpets, walls, floors), embedded in canes or in the insole of shoes to measure and recognise an individual’s gait to detect impending falls.
• Sensors are also being used in biometric devices to monitor the wearer’s physical state and automatically contact a relative or carer in emergency situations.

Several recent EU-funded projects related to developing sensor-based technology to monitor the elderly include:

• EMERGE: Emergency monitoring and prevention [10] – The aim of the EMERGE project was to support elderly people with emergency monitoring and prevention. The project aimed to detect deviations from typical behaviour patterns and acute disorders in their health in case of strokes, falls or similar emergencies. The project used ambient and unobtrusive sensors to monitor activity, location and vital data. Daily routine was tracked in order to detect abnormalities and to create early indicators for potential emergencies. In case an emergency cannot be handled by the senior citizen or friends or caregivers, an integrated emergency medical service (EMS) could be called and informed about the case.
• ENABLE: A wearable system supporting services for the elderly [11] – This project developed a personal system, with services for senior citizens in or out of the home, to mitigate the effects of any disability and to increase autonomy, mobility, communications, care and safety. The system used a mobile phone and wrist unit as an open platform by means of which third parties could add other services by “plugging” into defined interfaces. The project addressed problems of everyday living such as using the phone, raising an alarm to get help, monitoring for health conditions, taking medicines, ensuring appliances are turned on and off, etc.
• Netcarity: Networked multi-sensor system for elderly people [12] – Netcarity fosters the development of a “light” technological infrastructure, to be integrated in senior citizens’ homes, that provides basic support of everyday activities as well as detection of health emergencies, and encourages social and psychological engagement.

2.1.4 Biotechnology

Biotechnology is the science of using living organisms or systems to manufacture products to benefit the human race or other animal species. Biotechnology has long been used in the medical industry to discover the causes of many diseases, and to develop antibiotics and immunisations. It has also been used to enhance the production of food in the farming industry, and is now being used in bio-fuels research. The highly controversial stem cell research
falls under the umbrella of biotechnology. In everyday life, one encounters the application of biotechnology in many objects, including biodegradable plastics, detergents and fabrics, amongst others.

During the last decades, understanding of the human brain has increased, prompting the development and use of pharmacological and technological products and devices. Tapping into nerves allows the development of brain-computer interface (BCI) devices.

BCIs translate a brain’s electrical activity into a signal that controls an artificial component, and thus hold promise in the application of assistive technology to better the lives of the elderly. BCIs are being designed to restore lost motor and sensory functions and to overcome damages in the nervous pathway. Applications for the elderly include stimulation for chronic pain therapy, limb prostheses for anatomical compensation of damaged neural pathways, implantable neuro-stimulation devices, cochlear and retinal implants. [13]

The technology associated with brain computer interfacing is still in its infancy. Some applications being researched today include aiding long-term memory function by replacing parts of the hippocampus with a mechanical device, decision-making tools for the elderly, an aid to maintain brain plasticity to enable an enduring ability and capacity to learn, aids for well-being and virtual reality gaming to facilitate independent living, thought-controlled prosthetic devices, sensory replacement devices, and the ultimate in brain computing technology – an artificial brain.

One such publicly funded project related to BCI research is aptly named BRAIN (BCIs with Rapid Automated Interfaces for Nonexperts) [14]. This European Commission funded FP7 project aims at developing Brain-Computer Interfaces into assistive tools for a range of disabled users, enhancing the ability to interact with people, devices in their environment, and technologies.

### 2.1.5 Biometrics

Biometric technologies (which use scans of fingerprint, iris, face, palm print, vein, retina, voice, skin, hand geometry, ear shape, etc.) have featured especially in security applications over the past decade, and the advances associated with these technologies have generally served a security agenda. As the total cost of ownership for biometrics continues to drop, their prevalence in the market is becoming more mainstream and in some cases more obligatory (in relation to social service entitlements, immigration and international travel, physical or logical access at one’s job).

In the US, at the Massachusetts Institute of Technology (MIT) AgeLab, researchers are conducting studies on the application of telemedicine technologies to manage chronic conditions such as congestive heart failure (CHF), diabetes and obesity. AgeLab researchers hope to make a “check-up-a-day” not only possible, but a reality for everyone. The prevention demands of today’s older population and ageing boomers will drive health delivery from the clinic to the home. Working with the Philips Corporation, AgeLab researchers, MIT’s Department of Computer Science and Artificial Intelligence and the MIT Department of Mechanical Engineering are developing a system to provide early detection and warning for CHF patients and their families, using a home set of simple, non-invasive commercial medical instruments. [15]

One project funded by the European Union related to developing biometric-based technology to monitor the elderly is called HeartCycle: Compliance and effectiveness in heart failure and chronic heart disease closed-loop management. [16] The HeartCycle project is developing systems for monitoring people with a heart condition at home with the aim of improving disease management through telemonitoring. These systems will comprise unobtrusive sensors built into the patient’s clothing or bed sheets and home appliances such as weight scales and blood pressure monitors and report relevant medical data back to clinicians to monitor therapies and progress.

In-home monitoring via the implementation of biometric technologies has become increasingly important as an effective method for the elderly to maintain their independence. Two key applications in this area are:

- Telecare works through a series of discrete sensors positioned around one’s home. These sensors alert either a call centre or the user’s caregiver if a problem is detected.
- Telemonitoring, on the other hand, is focused on enabling individuals with severe illnesses or disabilities to live and function in their own homes for a longer period of time. Existing telemonitors detect abnormal physiological conditions and typically send an audio-visual alert to a doctor.

### 2.1.6 Nanotechnology

The concept of “nanotechnology” was introduced by Richard P. Feynman, physicist at the Los Alamos National Laboratory and later professor at the California Institute of Technology (Caltech), in a talk titled “There’s Plenty of Room at the Bottom” in 1959. [17] In that talk, Feynman introduced the concept of manipulating and controlling things on a staggeringly small scale. In nanotechnology, “small scale” means at or around the scale of a nanometer, where one nanometer is a billionth of a meter or about 1/80,000 the width of a human hair.

As of late 2009, the Project of Emerging Nanotechnologies reports over 1,000 nanotechnology-enabled consumer products, reflecting the increase use of tiny particles in everything from conventional products such as non-stick cookware and lighter, stronger tennis racquets to more unique items such as wearable sensors that monitor posture. [18]

Additionally, most smart devices used to aid the elderly in living independently have some type of embedded nanotechnology. In order for the technology to be ubiquitous and unobtrusive, the micro-processing component must be very small. In addition to sensor technology, robotics and biometrics, the smart home innovations discussed earlier in this paper incorporate the use of nanotechnology to enhance the autonomy and quality of life of the elderly and disabled people by simplifying their interactions with devices at home, improving their living space, enabling their mobility and monitoring their health.

### 2.1.7 RFID Technologies

Radio-frequency identification (RFID) is a technology applied to an item in an effort to identify or track the item using radio waves. RFID tags are most commonly used for supply chain applications to provide unique identification for objects. The recent main advances in RFID have been in the area of miniaturization of the tags, and the ability to produce such tags more economically.
With the advent of IPv6 and more easily deployed RFID technology, it is possible to have physical objects assigned unique identification, as part of what has been termed “the Internet of Things.”

In the assistive technology realm, RFID technology has been implemented in different products and solutions, including:

- RFID is commonly used in wander management applications in settings where there is a concern for those suffering from dementia. Wander management applications have also moved past the controlled environment of the senior citizens’ residence, and in some cases to law enforcement.
- Research is also being done in the use of RFID skin patches, which would allow for post-surgery monitoring by both physicians and patients. [19]
- With far less market uptake to date, VeriChip developed an FDA-approved RFID tag (about the size of a grain of rice) meant to be injected under the skin, and which is intended to act as identification should an individual be brought into a medical facility where they are unable to communicate effectively. [20]
- In response to new markets and the availability of research funding, many new applications using RFID are emerging from the global research community. For example, the SESAMONET (Secure and Safe Mobility Network) project, co-funded by the EC, prototyped a path for safe navigation for the visually impaired, through the combination of RFID tags embedded in the ground, along with a smart walking stick, phone and headset, providing recorded messages about location. Interestingly, while the costs of RFID tags are decreasing, this project kept costs at a minimum by using recycled chips which had previously been used for tracking cattle. [21]

### 2.1.8 GPS Technologies

Most location-based monitoring applications of GPS (the US-based Global Positioning System) are tied to personal safety and convenience, and provide benefits to the user who chooses to make use of them; however, for others, GPS technology may have different implications. There are several assistive products on the market now that make use of RFID tags, GPS and transponders to assist in navigation for disabled people and/or visually challenged seniors to navigate in an indoor or outdoor location. These same technologies are integral to providing alarms to carers or relatives if an elderly person moves beyond a designated area (with respect to wandering for cognitively impaired seniors).

Several projects funded by the European Union related to exploring location-tracking technology for the elderly include:

- **LOCOMOTION**: Location-based mobile phones for elderly citizens – The LOCOMOTION project developed a remote and nomadic location monitoring device for use in the telecare of people with dementia and learning difficulties. The aim of the project was to provide individuals with special needs, as well as their carers, with relevant information according to their geographical position via mobile phones equipped with position determination capabilities. These services were aimed at increasing mobility of users, along with enhancing independent living and social inclusion.
- **CAALYX** [22] is an extensible health monitoring platform that uses GPS to support health monitoring and emergency handling. It does not continuously track older people, rather location information is only sent in an emergency or when an alarm is raised. [23]
- **COGKNOW**: Helping people with mild dementia navigate their day [24] – The COGKNOW project was aimed at development of a service, including a PDA which users could carry in order to enable reminders and detailed information that could be sent to the carers who could decide if the patient was in danger.

### 2.2 Connectedness: Social Networking, Accessibility, and Communications Technologies

The physiological and psychological changes caused by ageing often prevent seniors from participating in the community to the extent they may wish. Visual and hearing impairment and decreased mobility are common among senior citizens, and have the tendency to affect seniors’ socialisation. Assistive communication technologies have the potential to allow senior citizens to continue their engagement in specific social settings or communities by providing necessary support and assistance. At the same time, these technologies may create access to new communities, thus either changing or increasing the individual’s social network and possibilities of engaging actively in social relations.

#### 2.2.1 Social Networking

Social relations and social interaction are changing with the development of new technologies and systems. These technologies are also changing our notions of social interaction and relationships, as well as the notion of community. Online communities have become a reality and they may provide great (online) support for many people, e.g., with health problems or recreational/interest groups, and may allow the elderly to remain active or become active in new ways.

But while online social networking systems could provide assistive aid to the elderly, the elderly often do not participate in using the latest technologies. Studies in the US have shown that the share of adult Internet users who participate in an online social network site had more than quadrupled from 8% in 2005 to 35% by the end of 2008. Still, younger online adults are much more likely than their older counterparts to use social networks, with 75% of adults aged 18-24 using these networks, compared to just 7% of adults 65 and older. [25]

Social networking is in large part enabled by the development practices and principles associated with what is known as Web 2.0, which is intended to facilitate interactive information sharing, interoperability, collaboration and user-centric designs. Currently, there are a limited number of social networking websites catering explicitly to the elderly, but more are emerging as commercial interests focus on tapping into the significant market potential represented by this group.

#### 2.2.2 Accessibility

In addition to offering demographically appropriate information, entertainment and forums, websites for older adults also need to be designed to contend with age-related changes in vision and cognition. Various guidelines have been issued to aid site developers in this, including guidelines from the US National
Institute on Aging and the National Library of Medicine [26] which address the needs of the elderly. More broadly, Web Content Accessibility Guidelines (WCAG [27]) provide recommendations for making Web content more accessible to a wider range of people with disabilities, including blindness and low vision, deafness and hearing loss, learning disabilities, cognitive limitations, limited movement, speech disabilities, photosensitivity and combinations of these. The European Commission has indicated that all public websites should comply with WCAG. [28] Similarly, the US requires compliance with Section 508 to ensure all IT systems are accessible.

The exact benefits of the use of any ICT product vary considerably depending on the individual’s ability and attitude towards human computer interaction. The ability to understand the application, to access it and trust in the technology is a key condition for its successful adoption and subsequent e-inclusion benefits. But for senior citizens, just being given the opportunity to use the technology can have a positive effect on their quality of life, their independence and on their family and social life, as well as their ability to participate in a work environment.

Examples of projects funded by the European Commission related to developing Web-based interfaces and ICT to keep older workers in the labour force longer include the following:

• DIADERM: Adaptable browser for the disabled and elderly [29] – This project aimed to provide an adaptable Web browser interface to help individuals with reduced cognitive skills remain active and independent both at work and at home. The project developed an “Expert System”, which monitors the user, adapting and personalising the computer interface.

• ICT for ALL: Measuring interaction with ICT – The ICT for ALL project focused upon indicators of the use of ICT by immigrants (including internal migration), the disabled, unemployed and older citizens. Its aim was to establish a framework for measuring the interaction of these populations with ICT and, in particular, broadband Internet, 3G, digital TV and ambient intelligence, as compared to other members of society.

2.2.3 Communications Technologies

In addition to the GPS technology embedded into mobile phones which can aid in tracking location, cell phone manufacturers have designed new products to facilitate use by the elderly, and thereby foster communication and enable socialisation. Those cell phone design issues that promote use by the elderly include better font spacing and size, bigger screens, larger device sizes and easy-to-grip surfaces. Many of the devices include hearing aid capabilities for better voice quality and emergency response services. Examples of cell phone manufacturers and their products that cater to the elderly include:

• Jitterbug handset and mobile service provider
• ClarityLife C900
• LG LX150
• Doro HandlePlus 334gsm, PhoneEasy 410, and PhoneEasy 335
• Alcom E110S Elderly Friendly GSM Phone
• Motorola W259
• UTStarcom Coupe 8630

3. ASSISTIVE TECHNOLOGY MARKET CHALLENGES AND RISKS

Advocates of the benefits of technological change typically see emerging technologies as offering hope for the betterment of the human condition, while critics are quick to warn of the dangers they pose. As with all new technology, the emergence of new assistive products and services includes both benefits and risks. One of the key risks that bears some further examination here are those barriers that currently constrain development and market adoption of these technologies.

The AT market is diverse and fragmented [30], and faces a number of challenges, including:

• Low awareness by users. There has been a low level of knowledge among the elderly population about the assistive technology devices which have been commercialised and made available in the market. In a study conducted with Belgian seniors residing in community living [31], it was found that, though the seniors were aware of assistive devices relating to using the toilet, there was a low level of awareness of assistive devices related to mobility, communication and other self-care aspects. Efforts in this area are led by international and national organisations, including EASTIN (European Assistive Technology Information Network) which specifically focuses upon providing information about European products for daily living in terms understandable by end-users and their carers.

• Lack of effective response to social factors in technology development. Technology evangelists, in earlier commercialisation efforts, have always focused on developing a product which is accurate and precise, most of the time ignoring the “social and human factors” [32] involved in its usage. An example of this was seen in the first generation of assistive robots developed to assist elderly at home akin to the industrial robots. The acceptance rate was low since it was missing the “empathy” factor and was designed to serve narrowly defined health-care problems. While there is a significant effort to enhance design of public spaces and places, as well as objects and artifacts used in the range of human experience, in Europe, especially as driven by Design For All [33] initiatives, research has indicated that acceptance of assistive technology would be greater with better attention to user preferences than was previously assumed.

• Confusing array of options – AT is a large market in terms of the potential user group, and in terms of the number of services available for consideration. There are often both high and low cost and high and low tech versions of solutions to address specific disabilities, and as a result, providing users (or their proxies, including employers) with sufficient information about how to “best” address the needs of the user is taken on by industry associations, end-user advocacy groups, and in some cases government-sponsored agencies. There are a very large number of such organisations on a global basis, engaging at the local/provincial, national, and international levels.

• Cost of assistive technology devices. Assistive technology is quite costly, especially when devices or products must be purchased in a lump sum (often, as a proportion of the elder’s pension, such purchases are out of reach). Reimbursement policies differ around the globe and across Europe. In many
cases, adult children of the elder bear the cost of such purchases directly, and are thus involved in purchasing decisions. Difficulty in determining how to pay for AT can constrain users from making purchases, and likewise, constrain manufacturers from entering new markets, if only based upon a lack of knowledge of how best to price and market products in various regions.

- **Difficulty in achieving economies of scale.** For AT developers, being able to generate sufficient levels of uptake of new products, negatively impacts overall market growth, continuing to keep profit margins low and reducing further investment in R&D. Because of the lack of effective product distribution models, absence of strong service models to support deployment, diverse reimbursement schemes and lack of significant investment by large industrial players, AT manufacturers continue to struggle, and fail to build the market. The AAATE (Association for the Advancement of Assistive Technology in Europe) actively supports efforts to increase the uptake of AT within the European market, as do national level organisations.

4. **CONCLUSIONS**

In spite of the challenges noted above, it is clear that assistive technology has immense potential to address a wide variety of problems currently faced by seniors that have heretofore limited their ability to live healthy, socially robust, autonomous lives in their home and community. AT enables individuals with physical or cognitive limitations to perform activities that might otherwise be difficult or impossible to do, and in the case of the elderly, while there are applications and needs for AT in the workplace, most of the emphasis of AT development is on home life, enabling elderly to perform activities of daily living (ADLs).

The adaptation of new technologies always requires different business models and disciplines to converge and cooperate. All industrial concerns that play a role in the future technologies must be willing to make the required investments in order for the technologies to take root. Because ambient technology has the potential to be applied to products and systems that aid the elderly, there is a significant risk if industry and government policy cannot drive the new technology forward. Rather than ease the increasing burden on health and nursing care facilities, the failure of the technology to take root may result in even further demand upon these facilities and the potential neglect of needs of ageing individuals living independently.

As we move towards Kurzweil’s Singularity, it is critical that the inclusive society provide the opportunity for all to make use of new technologies as they are developed. These emerging assistive technologies have the opportunity to create significant changes in the life of individuals, and through their ability to promote independent living and foster the development of assistive products and services, they also provide an extraordinary opportunity to close the digital divide.

5. **ACKNOWLEDGMENTS**

This paper was adapted from the work Global Security Intelligence was involved in regarding the project Social, Ethical, and Privacy Needs in ICT for Older People: A Dialogue Roadmap (SENIOR). SENIOR is a 24-month project selected for funding by the European Commission under the 7th FWP (Seventh Framework Programme, agreement number 216820).

SENIOR was focused on establishing a policy and technology development roadmap as it relates to technology, ethics, and inclusion issues for the elderly. These studies, including a survey of socio-anthropological work in this area, indicated a clear preference by the elderly to live for as long as possible in their own homes, and a willingness to consider significant changes within that environment in order to accommodate that preference.

Global Security Intelligence was part of an 11-member consortium that examined how technological trends are responding to the goals of inclusion for the ageing and, using lessons learned from those trends, planned strategies for the future to closely link these issues to technology at the design level.

Specifically, this paper includes adaptation of some portions of deliverables from the SENIOR Project, including in particular:

D1.1: Environmental Scanning Report, D2.1: Ubiquitous Computing, D2.2: Ubiquitous Communication, D2.3: Intelligent User Interfaces, D2.4: AI & Adaptive Software, and D2.5: AT & Robotics.

6. **REFERENCES**


[2] i2010 is the EU policy framework that promotes the positive contribution that ICT can make to the economy, society and personal quality of life.


[8] [http://lirec.eu/](http://lirec.eu/)


[10] [http://www.emerge-project.eu/](http://www.emerge-project.eu/)


National Institute on Aging, February 2001 (last revised March 2009).

European Commission, European i2010 initiative on e-Inclusion: “To be part of the information society”, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2007) 694 final, Brussels, 8 Nov 2007, p. 4. The EC says that as of the end of 2006 a minority of surveyed public websites were fully compliant with these Guidelines. See also European Commission, “Commission wants a web that is better enabled for the disabled”, Press release, IP/08/1074, Brussels, 2 July 2008.


Meng and Lee.
Using Mobile Phones to improve Medication Compliance and Awareness for Cardiac Patients

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ABSTRACT
Improving cardiac patients’ medication compliance is a major factor in reducing mortality rate and reducing hospitalization rate. This paper describes a novel medication compliance management system. Its novelty lies in the combination of functionalities that helps the patient to comply with their medication regimen, together with a personal health monitoring system that monitors their health and collects vital signs data using a mobile phone and wireless bio sensors. The system is designed to collect and analyse medication compliance, side effects and symptom responses and transfers the collected data in real time to a web based system for remote monitoring by caregivers and health professionals. Health professionals can use the system to assess the effect of the medication regimen on their patients’ health and adapt it to reduce side effects and maximise the patient’s wellbeing.

Categories and Subject Descriptors
J.3 [Computer Applications]: Life and Medical sciences - Health

General Terms

Keywords
Medication compliance, Cardiac rehabilitation, Ambulatory monitoring, Tele-monitoring,

1. Introduction
According to the World health Organization, cardiovascular diseases are the world’s number one killer, claiming 17.1 million lives every year [2]. In Australia, cardiovascular diseases kill one person every ten minutes. It is the highest cause of death in Australia with more than 34% of deaths in 2006 due to cardiovascular disease [14]. Heart Failure and cardiovascular diseases are also the highest cause of mortality in the United States.

Medication compliance is a major factor in reducing the mortality and hospitalization rate [11]. To reduce the cost and burden on public health systems, it is important to bring down unnecessary hospital admissions due to poor medication compliance but also to increase health and medication awareness among people.

Medication compliance rates for patients with a heart failure condition vary widely from 7% to 90% for short to midterm treatment [9] [19]. A decline in medication compliance rate is observed for long term heart failure patients which is believed to be the leading cause for subsequent hospital admissions [2] [20] [21]. Some studies suggest that two thirds of rehospitalisation could be prevented by increasing medication compliance rates [22].

A study by Cline [15] found that only 45% of the patients could name what medication was prescribed to them. Only 50% of the patients were able to remember the prescribed doses. 36% were able to remember when the medication was to be taken. Research trials confirmed that noncompliance is common among elderly patients with heart failure condition [10][16].

Common reasons found for patients not complying with their medication regimens are [3][12][17][23]:
- Forgetfulness, the patient does not remember to take their medication.
- Deliberately choosing to disregard the physicians’ directives.
- The medication schedule changes.
- Confused by the instructions to take medications.
- Overwhelmed by the number of medications prescribed.
- The fear of side effects or actually experiencing side effects.
- Over/under use of medication or taking the medication at the wrong time.
- Feeling that symptoms disappeared and the medication is no longer necessary.
- Using another person’s medication or possibly using old or expired medication.

Age, education and social support are some of the major factors contributing to compliance. A research study in Sweden found that at least 24% out of 154 elderly cardiac patients needed to be reminded to take their medication. More than 65% of the patients did not know the benefits of the medication they were taken [13].

Many solutions exist on the market today to tackle medication compliance (see section 2). However, with the wide usage of mobile phones an interesting research question is to investigate whether mobile phones can be used to improve medication compliance for cardiac patients.
The aim of our research is to design and measure the effectiveness of mobile phones in collecting medication compliance responses from patients and providing health information to patients and health professionals.

This research is part of the Personal Health Monitor research project conducted at the University of Technology, Sydney [PHM]. The Personal Health Monitor is a personalised, intelligent, non-intrusive, real time health monitoring system using wireless sensors and a mobile phone. The wireless sensors can be either attached to the user’s body (for example ECG and Accelerometer) or can be external devices, such as a blood pressure monitor or a weight scale, that are used when required. The sensors are Bluetooth enabled or integrated into the mobile phone. On the phone, the Personal Health Monitor software analyses, in real-time, the data received from the sensors. The phone gives immediate feedback and personalised advice to the user based on the analysis of sensor data collected.

In this paper we focus on the integration of a medication compliance system with the use of bio sensors to monitor and provide personalized feedback to patients and health professionals. Section 2 presents an overview of existing medication compliance solutions. Section 3 compares the functionalities offered for each technology and outlines the potential of mobile phones for monitoring medication compliance. Section 4 outlines our novel approach and section 5 discusses the next steps to trial the system in a usability trial at a Sydney hospital.

2. Existing Medication Compliance Solutions

Many solutions are available to help improving medication compliance. These solutions can be categorized as pill holders, alarm based pill holders, pill monitoring devices and mobile phone based solutions.

**Pill Holders** are boxes or containers to carry medications. Usually they are divided into different compartments. The medication is loaded manually in the compartments. The compartments can be labelled for each dosage interval. The differences between pill holders are usually the shape, colour, number of compartments and size. These pill holders are passive i.e. they don’t remind patients of their medication, patients need to alert themselves to take their medication.

**Alarm Based Aids** are active solutions compared to pill holders. Some of these devices consist of compartments to carry medication attached to a timer. When the medication is due an alarm is triggered and the patient needs to open the correct container and take the medication (see Figure 1). All alarm based medication reminders need to be programmed manually with medication times and names.

**Pill Monitoring Devices** are home-based medication devices which are sealed (see figure 2). They dispense medication and some of them have voice and text alarms. They can be connected to the internet and alert the patient/caregiver via mobile phone if a dose is missed. They need to be pre-loaded manually with the correct medication.

**Figure 2: MedSmart® Automatic Medication Pill Dispenser**

With the advance of technology and telecommunications, new methods are developed to help collecting medication compliance data. The Med-eMonitor [9] system for example is a portable device with several compartments to store the medication (figure 3). It alerts the user when the medication is due and compliance information is transmitted daily via an internet connection to the medical center server for further follow-up by health professionals.

**Vitality Inc.** [8] is a wireless pill box that will initiate a call and SMS patients reminding them to take their medication. The system does not involve health professionals and no medication compliance information is transmitted to health professionals.

**Figure 3: The Med-eMonitor™ System**

**Philips** [12] offers a medication dispensing service, which is connected to the patient’s phone line. When the medication is missed the patient receives a message from the dispensing box.

These are some of the more advanced portable devices that help patients managing their medication regimen. However, these devices are solely designed to measure medication compliance and most of them are home-based devices.

**Mobile Phone based solutions** are very suitable to manage medication regimens independent of the patient’s current location. Two popular commercial solutions are pillPAL [6] and OnTimeRx [4]. These systems require patients to enter manually their medication into the mobile phone or PDA and set the dosage and reminders. These applications are useful for personal use. The
medication compliance data is not transmitted to health professionals to monitor patient’s compliance.

**Figure 4: OnTimeRx® medication reminder**

Pill Phone and PillBoxer [24] [25] are two solutions to manage medication reminders. The medication regimen is automatically downloaded from a medication pill database into the mobile phone. These solutions allow emailing the medication list and remind patients to take their medication. They are for personal use and there is no interaction with a health professional.

**MOBITEL** [5] measures vital signs data (blood pressure, pulse and body weight) and transmits it using wireless internet to health professionals on a daily basis. Cardiac patients enter manually the medication dosage on their mobile phone which is then transmitted to the health monitoring centre.

**M-PILL** [7] reminds patients of their medication and doctor appointments using SMS. The system does not yet support tele-monitoring of medication compliance. However, the health professional can send SMS messages to the patient to encourage them to take their medication. Medication compliance data is not transferred to the health professionals to help them in the follow-up.

**eMedonline** [25] and **MoviTap** [26] are two mobile medication management solutions using smart phones, RFID and web services to interact between health professionals and patients. These systems are innovative, but do not analyse the effect of medication on the patient’s health.

### 3. Technologies versus Functionalities

Table 1 summarises the various functionalities offered by the different solutions presented in the previous section. Using mobile phones for medication compliance seem to be a logical choice. However, mobile phone solutions do not support the pill holder functionality and it is impossible to actually check whether the medication has been taken on time. An ideal solution would be to combine a pill monitoring device with a mobile phone. For example, a Bluetooth enabled pill monitoring device communicates with a mobile phone application signalling whether the medication has been taken on time. The software on the phone checks the medication regimen and collects feedback from the patient regarding side effects and transmits the collected data to a web based system where health professionals can monitor the medication compliance of their patients. To enhance the system with more accurate feedback, bio sensors can be used to collect physiological data such as blood pressure, weight, blood glucose, oxygen level or even record an ECG to complement the more subjective feedback given by a patient on the use of their medication. For example, Warfarin (to prevent blood clots) can have side effects such as fatigue, joint or muscle aches and many patients would like to reduce/change the dose. If physiological data is collected while altering the dose, better insight is obtained about the effects of dosage change on the patient’s wellbeing.

<table>
<thead>
<tr>
<th>Functionalities</th>
<th>Technology</th>
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<tbody>
<tr>
<td><strong>Pill Holders</strong></td>
<td>Manual</td>
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<tr>
<td><strong>Alarm based Aids</strong></td>
<td>Manual</td>
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<tr>
<td><strong>Pill Monitoring Devices</strong></td>
<td>Manual</td>
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<tr>
<td><strong>Mobile Phone based Solutions</strong></td>
<td>Manual</td>
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<tr>
<td>Data collection (E.g. Side effects response)</td>
<td><strong>Limited</strong></td>
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<tr>
<td>Data Transfer to health centre</td>
<td><strong>Limited</strong></td>
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<tr>
<td>Remote monitoring from health centre</td>
<td>Manual</td>
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<tr>
<td>Record date and time of Pill Bottle opening</td>
<td>Manual</td>
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<tr>
<td>Medical appointment management</td>
<td>Manual</td>
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<tr>
<td>Education and awareness of patients about medication</td>
<td>Manual</td>
</tr>
<tr>
<td>Personalisation</td>
<td>Manual</td>
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<tr>
<td>Monitoring of vital health signs</td>
<td>Manual</td>
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### Table 1. Technologies vs. Functionalities

<table>
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<th>Functionalities</th>
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4. A Novel Medication Compliance system

This section discusses a novel medication system to help patients, caregivers, family, health professionals, pharmacies and health insurance organisations dealing with medication compliance.

The medication system is integrated in the existing Personal Health Monitor (PHM) system which offers a patient a personalised vital signs monitoring solution using a standard mobile phone (Figure 5).

The patient is monitored using a mobile phone and one or more wireless sensors. The phone reminds the patient when measurements or medication is due. Patients can keep track of their blood pressure, weight history and can monitor the progress of their rehabilitation program both on the mobile phone and web based interface on their home computer.

The health professional can remotely manage and check the information about their patients using the web based system. They can remotely personalise and adapt patient reminders and thresholds (e.g. max heart rate set to 120 bpm) and use the collected information to generate reports.

Changes made by the health professional and data collected on the mobile phone are synchronised periodically, giving both the patient and the health professional access to the latest and most accurate data.

Figure 5: Personal Health Monitor system

The integrated approach enables the collection of complementary information. That is, the vital sign measurements (e.g. blood pressure, heart rate, blood glucose) can complement the self-reported side effects. It also enables complex data mining on medication side effects and compliance.

The PHM system is a web-based system accessible by the different stakeholders. Figure 6 shows a high level view of the PHM medication compliance system showing several stakeholders that interact with the system.

Figure 6: PHM Medication Compliance System Stakeholders

Health professionals can monitor their patients' compliance with their medication intake. Higher compliance rate means that health professionals can make better informed decisions on the effects of the prescribed medication [10]. They can monitor the effect of the medication on their patients and can remotely adapt the medication regimen accordingly. Additionally, health professionals receive indications through the patient’s feedback about potential medication interactions that might occur when new medicines are prescribed to the patient.

Family members and caregivers may find it difficult to manage the patient’s medication regimen, especially when several medications are prescribed to be taken at different times and dosage [3][12][17]. Family members of an elderly patient may want to know that the medication is taken correctly and be able to personally remind the elderly person of their medication and medical appointments. With the patient’s permission, they can subscribe to a service to receive alerts on their mobile phone when medication is due, or have access to view the medication compliance history. If the patient is not compliant for a period of time, an email or SMS can notify caregivers of the problem.

Pharmacies can increase their sales and inform patients better if patients comply with their medication [18]. They receive a warning about potential interactions between different medications used when the patient or health professional updates the medication regimen.

Public and private health insurance companies can connect to the system and request anonymous medication compliance information. This information can help them in developing data mining techniques to assess the effect of increasing/decreasing medication compliance statistics on the number of claims made. Special programs can be introduced to target certain age groups in order to reduce hospitalisation or identify best practice treatments.

Patients are the main beneficiary of the system since it helps them overcome the reasons why they do not comply with their medications. In the introduction, we identified the main reasons...
why patients do not comply with their medication. They can be classified into 4 categories that reflect the need for common functionalities. We integrated these functionalities in the PHM application to help the user complying with their medication.

**Issue 1: ‘forgetfulness and complex medication regimen, wrong time usage of the medication’**. These issues can be solved using better planning aids and reminders. In the PHM application, audio and visual reminders are used to alert patients when it is time to take their medication to overcome forgetfulness (Figure 7, left). The system takes into account the changes made by the health professional and ensures that the medication schedule is always up to date. The application also reminds the patient about their next appointment with their health specialist or to collect new medication at the pharmacy when running low on medication (Figure 7, right).

![Figure 7: Medication reminders](image)

**Issue 2:** ‘complex instructions, overwhelming number of medications, overlapped use of medication or the use of another person’s medication’. These issues can be addressed by offering better guidance to the patient. When the patient gets a reminder, he gets a clear and simple description of the list of medication to take at that particular time. For each drug, it includes a photo, the dosage and simple instructions (i.e. take with food) (Figure 8). The patient takes the medication and taps next on the phone to receive the subsequent instructions for the next medication to be taken.

![Figure 8: Simple instructions](image)

Ideally, the PHM mobile application interacts wirelessly with a pill dispenser device to confirm that the patient has taken the right medicine. Unfortunately no such device exists yet on the market.

**Issue 3:** ‘experiencing side effects’. This issue suggests the need for ways to report, log and cross check (using sensors) the side effects. Knowing the side effects and medication compliance responses allows health professionals to alter medications accordingly to try decreasing side effects. The patient can provide feedback he experiences at any time or when he is taking the drug (Figure 9). The patient can report different side effects or pains he experiences by answering the simple questions asked by the PHM application. Examples of side effects caused by medication include fatigue, dizziness, rash, mouth swelling, chest pain, fever and shortness of breath.

![Figure 9: Feedback can be reported to health professionals](image)

**Issue 4:** ‘fear of side effects, disregarding the physician’s directives or feeling that it is no longer necessary’. These issues suggest a need for more education and information about the medication and health condition. The PHM application has an Info button (Figure 8 Info) directing the patient to an educative link or a common drug database specifying side effects and other information about the medication. It informs patients and caregivers and allows them to post questions to health professionals and receive feedback on their emails about different aspects of their medication.
collected and if necessary, sensors collect vital signs data such as blood pressure, weight and ECG recording.

The PHM web based system is extended with a medication compliance module. Additional information collected for each patient are:

- A list of medication and prescriptions (dose, frequency and history).
- A log of medication compliance data consisting of medications taken/ forgotten and side effect reported by the patient.
- A log of the interactions between the patient and health professional or Medical web sites.

The patient has also access to general information on medication and possible interactions and side effects.

5. CONCLUSION

We are in the process of setting up a clinical trial at the Sydney Royal North Shore hospital to test the potential of the Personal Health Monitor medication compliance system for both patients and health professionals. Other stakeholders such as pharmacies and health insurance companies or not involved in the first phase.

On the patient’s side, we intend to incrementally adapt the system to take into account the patient feedback to the medication compliance system. Based on feedback of a previously conducted trial with over 90 patients with the Personal Health Monitor system, we are confident that the user interface is useable by patients of any age. In this trial, however, we would like to understand the impact of reminders on taking medications, as well as, obtaining insight into medication compliance and adherence. We will have a control group not using the Personal Health Monitor medication compliance system to compare the results.

We also want to identify what is missing, or could be improved to motivate patients to comply with their medication. We hope to see health improvement and better patient awareness with respect to their medication.

From the health professional perspective, we would like to get feedback on the different methods used to motivate patients. Many methods have already been tried in measuring medication compliance and assisting both patients and health professionals. However, these methods prove to be expensive in the long term or not effective. The use of mobile phones to help improving medication compliance and monitoring side effects is still a research question and we want to investigate if mobile phones might achieve a better result than conventional methods.

Another goal is to find out what business model works best with our medication compliance system and obtain insight in the costs/benefits of using our system. For example do patients contact health professionals more often or less? If the workload increases is it manageable and cost effective? For example if interactions with health professionals increase but hospitalization rate is reduced, is that economically cost effective?

The main objective of improving medication compliance rate is to reduce mortality and morbidity rates and reduce the cost and burden on the health system, due to preventable hospitalizations. We hope that the integration of the medication compliance module into the Personal Health Monitor suite of health services allows for collecting valuable medication compliance data and side effects responses. We believe that our Personal Health Monitor medication compliance software is of particular interest to patients and health professionals in remote rural areas since it allows them to save travel time to do trivial medical checks like checking ECG rate and to manage complex medication prescriptions.

6. REFERENCES


Web Based Medicine Intake Tracking Application
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ABSTRACT
One of the issues in healthcare systems or medical information systems is the reduction of medical errors to ensure patient safety. Inside an assistive environment, we apply RFID tags to monitor drug taking pattern and its consequences are reported to the care giver. This paper talks about an application which tracks the medicine intake pattern for the elderly using RFID readers and tags, motion sensors, and a wireless sensor mote. With the adoption of this ambient assistive technology in healthcare systems, the concept of heterogeneous sensor data management becomes an issue. In this paper, using a Web Based Caregiver Module makes the process of monitoring medicine intake for health-related matters of the elderly living alone simpler and easier. We also propose to use an energy efficient technique by using multiple sensor devices which employ a sequence of in-network data fusion as needed.

Categories and Subject Descriptors
J.3 [Life and Medical Sciences] Medical information systems, H.3.5 [Online Information Services] Web-based services

General Terms
Algorithms, Management, Experimentation, Theory, Verification. Assistive Environments

Keywords
RFID, Hidden Markov Model, Data Fusion, Energy Efficiency

1 INTRODUCTION
Any assistive environment is an area where people live and work and are helped by the embedded technology within their space. Examples of these include systems to help the elderly, such as monitoring, tracking, smart furniture, and reminder systems[17][18][19][20]. One aspect of assistive environments is smart furniture and the software applications that support and analyze the collected data. Another important aspect is tracking the intake of medication.

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Monitoring medication intake for a person who needs assistance has become an important research area recently. Statistical report has shown that almost 55 percent of the elderly people in US fail to adhere to their daily medication routine [1]. Among these, 26 percent of the errors are severe. As patients forget to comply with their prescription, they need constant care from doctors, nurses or other caregiver. Therefore, at home pervasive and assistive monitoring systems with minimal intrusion into a person’s personal life can be very effective in this scenario.

Sensor motes nowadays have multi-functions such as data processing, seamless data transmission, data storage, as well as sensing the physical world. When these sensors interconnect so that they communicate with each other or relay sensed data to a base station, we call them Wireless Sensor Networks (WSNs) [25]. WSNs are generally used in areas where people cannot easily reach or where a long term monitoring task is required. Currently, traditional monitoring and reminder systems for patient’s drug taking deploy multiple sensors in order to achieve improved accuracy in their systems. The Smart Drawer is an application that helps patients in maintaining their medication intake as consistent as it is prescribed by a healthcare professional to them. Besides reminding a patient to take his or her pills on time, the system also logs all the activities of the patient for further analysis in case he or she fails to obey the prescription [2].

In our recent development, the Smart Drawer system has integrated additional sensors to detect the open or close state of the drawer. Moreover, the system has incorporated a precision balance to detect how many pills a patient has actually taken out of the drawer. Therefore, efficient data integration techniques are needed in order to combine information from all these sensors.

Data Fusion is a technique which integrates information from multiple sources in order to achieve better accuracy and higher precision when identifying patterns. In the context of a pervasive environment, the application of multi sensor data fusion will improve the inferring capability of the system more than it could using single sensor alone [3]. Perhaps, the most appropriate example for multi-sensor data fusion would be the one that is naturally performed by humans and animals. A human uses the combination of touch, smell, taste, vision and hearing capability so that they can access their surrounding environment better in order to improve their chances of survival.

In this paper, we present a web-based application of data fusion technique into a multi-sensor environment like Smart Drawer. Our system records the removal of each individual medicine bottle from the drawer as well as the time when the medicine is actually taken. We now define a way we can study the pattern of the medicine intake. By knowing the pattern of medicine intake we
can track the most common problems in patients and can help us treat them better according to their medical history. We try to track prior and subsequent activities of a person before they remove a pill from the drawer in order to derive useful information about the person’s behavior. A person may open or close the drawer several times but forgets to take the medicine from it. On the other hand, the person may remove the medicine out from the drawer but put back it again without consuming a pill. Therefore, our system identifies useful patterns from a person’s activities over the time.

This paper proceeds as follows. Section 2 covers the related work and similar projects. In section 3, we review the Smart Drawer and describe our approaches to the web application and data fusion. In addition, we describe the experimental layout and describe sensor usage. Section 4 details the working tool and finally in Section 5 we discuss our conclusions and future work.

2 RELATED WORK

This research area comprises of several related fields which we will review. These areas include the use of RFID technology, Data Fusion, the classification of human behavior, and similar medicine intake tracking systems. Traditional medication reminder systems use the phone in order to remind the patients or elders that a certain medication should be taken.

RFID is used in many aspects of the modern world, from logistics and inventory management to pervasive technology such as personal security and mobile healthcare. The basic components of an RFID system are the radio scanner unit, aka reader, and the remote transponders, aka tags. The tags consist of an antenna and a microchip transmitter with internal memory and their architecture can be read only, write once read many or rewritable. Passive tags are more common in use because of their lower cost, smaller size and greater lifespan, despite their small range. In addition the most commonly used tags in terms of frequency are the LF(125-134 KHz) and HF(13,56MHz) although UHF(860MHz) and microwave(2,4GHz and 5,8GHz) tags do exist but are not that common [15][14]. The use of RFID in health care becomes more and more frequent. In October 2004, FDA approved the use of RFID implants that hold a patient's medical record, under the skin. In Korea, WOnJu Christian Hospital uses RFID to match new born children to their mothers, It is estimated that there are 20,000 mother-child mismatches in the US each year. The tracking of medication packaging is already been done with the use of machine vision. In order to accomplish that a 2D data matrix code is implanted in the cap which is marked either by color or by ablating some of its material [12]. Pharmaceutical companies already use RFID to track their drugs and guarantee their genuity by keeping a database of all the packages sold through their certified network[15].

With so many inputs coming from RFID and other sources, it is necessary to combine the data into a usable and meaningful form. Data fusion is the procedure of combining data from multiple sensors and information from associated databases, in order to increase the accuracy in comparison to using one sensor alone. In the medical diagnosis area, data fusion is used in order to fuse data from advanced sensors such as nuclear magnetic resonance, acoustic imaging devices and medical tests and therefore provide a more accurate diagnosis and reduce the percentage of false diagnoses [3]. Our system incorporates high-level data fusion techniques in order to identify medicine-intake pattern or deviation from the normal one instead of generating reminder alone. Our work is closely related to the data fusion technique described by Yuan [5]. In this paper, they present a Multi-level synchronization protocol in which data related to an event are fused at the sink following round of aggregation. They identify the importance of combing as much sensor’s information as possible in each stage of aggregation, which eventually increases the credibility. At the same time, they present an aggregation tree topology to balance out the trade-off between credibility and latency incurred on each aggregation process.

With Data Fusion providing a combined data set, methods are needed for recognizing human behavior from that data set. There are several previous works that used classification techniques in the application of recognition of human being’s behavior for healthcare monitoring systems [8][7]. Tapia et al. built a system for experiment to recognize human being’s activities using low-cost state-change sensors in [8]. They developed simple state-change sensors instead of using multi-purpose sensor motes and cameras in order to minimize intrusion of privacy. Initially, they get pre-knowledge about what the residents are doing at particular moment by the context-aware experience sampling tool (ESM) so that the information can be used as a training set. Then the system calculates the temporal features (exists and before) to generate training examples. Bayesian network classifier is used to calculate the probability of the current activity. In our work, creating a training set will be replaced by a dictionary. Haghighi et el. proposed an architecture for context aware adaptive data stream mining in [7]. They used temperature, age, location, time, heart rate, and battery level for context attributes to monitor heart patients. They used K-nearest neighbor algorithm to classify unknown situations based on the present situations. Wireless sensor networks are convenient to sense data remotely and gather useful data from them seamlessly. However the data from wireless sensors are not reliable due to many sources of noises and inaccuracies. Elnahrawy et al. proposed a platform for cleaning and querying sensors in [6].

The combinations of these features are the components of medicine tracking systems, and several of these systems are available or are being developed. More specifically, GlowCap, is a wireless pill bottle that glows and plays a tune in order to remind the person that a pill has to be taken. In addition it can enumerate the number of pills taken by monitoring the number of times the lid has been opened. It then makes contact with a central database operated by the developer company, where the amount of medicine taken is tracked in a daily and even monthly period, and if any abnormality occurs, a notification is sent to anyone that could be interested [10].

Smart medication cabinets, which serve as medication reminder systems that notify a patient or an older person that a pill should be taken, do exist but their use is limited. The software of the same cabinet could be used to prevent potential interaction hazards between medications and even notify the person and the pharmacy in case a prescription should be refilled or a certain medication reaches its expiration date. In addition, pill bottle caps exist which change colors if a certain medication should be taken [9].

In addition to the commercial pill-tracking system, at home systems are also available for monitoring medicine-intake. Among these applications, the system that is most similar to our work is the ‘Magic Medicine Cabinet’[4]. Magic Medicine Cabinet system reminds a patient whenever it is time for him to take a pill.
The system integrates RFID based smart labels as well as face recognition units and voice synthesis mechanisms in order to remind a patient about his daily medication. The system aims to generate alerts to the patients in advance whenever an emergency arises. For example, if the pollen count of the area where a person lives exceeds certain threshold, the system alerts him/her to take an allergy pill.

Another system that is also similar to our work is a ubiquitous medication monitoring system presented by Kenneth P. Fishkin and Min Wang [1]. The system employed an RFID subsystem that contains both a reader with a custom made antenna and RFID tags attached to the medicine bottles so that it can detect when and which bottles are pulled off/ back. They used a high precision digital scale as we do in order to determine the individual dosage. The system incorporated all the components such as RFID subsystem, the scale, communication devices and a custom PCB board for unifying power supply to all other components into a off the shelf box, which is called as monitoring pad. It reminds a patient about how many pills he/she needs to take or the name of the other medicines he/she requires to take on this time along with post medical suggestions whenever the patient removes a bottle from the pad.

Remote medication dispensing systems that release the right pills for the patient at each time are already in use, and they are monitored remotely by a central pharmacy. In addition if the canister for a certain medication gets low, the pharmacy is notified. Although in the past, medication dispensers where used in long term care facilities and correctional institutions, prototypes have made their appearance as home devices. “Smart pill”, the winner of the Microsoft “Sparks will fly contest” is an example. “Smart pill” consists of a touch screen, a barcode scanner, a speaker, LEDs, and a Velleman K8055 I/O board all connected on a Via Artigo computer. When a new pill bottle is bought from the pharmacy, its barcode is scanned and entered in the smart pill’s database. Then, the device contacts the pharmacy database using an XML web-service and retrieves the drug’s prescription along with possible interactions with other medications. Then when a certain pill has to be taken, the device plays a sound and lights a led on the appropriate bin [11].

Another system that monitors vital parameters of a patient and dispenses medication accordingly is @HOME. According to its creator, sensors are connected to a PocketPC which then connects wirelessly with a desktop PC using Bluetooth. The desktop PC hosts the main application which contains critical thresholds about the measurements obtained by the sensors. In case of abnormal measurements, the PC communicates with the Clinic’s central server using the GSM network, in order to report the readings to a doctor. The clinic’s server maintains a database with health records of the patient and a user interface for the doctor. When a certain pill has to be taken, the device plays a sound and lights a led on the appropriate bin [11]. According to [16] smart homes will implement automatic pill dispensers that provide the right medication at the right time, especially for people with Alzheimer’s disease.

3 APPROACH

In this section we explain our approach by describing the system architecture, the layout of the experimental setup, a state diagram followed by a sequence diagram.

3.1 System Architecture of the Web Tool

The Smart Drawer project implements a web based tool for an RFID reader system and first we establish the connection by imposing some constraints on the hardware. This system is required to have a caregiver view, a maintenance view and a patient view. The caregiver view enables to view the details about the history of the patient’s drug taking pattern. The maintainer’s view will mainly involve the detection and analyzing the working of different sensor nodes at some defined time. The patient’s view includes an alert system that will include a prompt to the patient when they have forgotten to take their medication.

In an assistive living environment, a patient may be required to take different types of pills each day. Our approach involves detecting the sequence of the medicine intake by creating a pattern which may help the patients and the caregivers in reminding them to take the medicine on time. It also becomes necessary to take the right number of pills which will be notified by a precision balance which is integrated with the Smart Drawer system.

The caregiver/doctor is required to authenticate themselves as being legitimate users of this web based Smart Drawer tool. On successful logon into the system, they can get all the details of their patients and check if they have taken the right medication at the right time. They can also add a new patient and their details at this point. The medication details are compared with the backend database. The caregiver or the doctor can verify if the patient had taken the right medication.

The web tool architecture shown in Figure 1 can visually be divided into two parts for clarity and better understanding. The left portion of the figure deals with crucial web module design, the right portion is mainly the maintenance view. The Controller Module acquires the heterogeneous data from all the sensors operating in the Wireless Sensor Network Environment and determines the Pattern using an algorithm like Dynamic Time Wrapping algorithm [26]. The Controller Module also compares the pattern with the backend Database to recognize if the pattern
making an event is a normal or an abnormal. The database contains a dictionary of behaviors which are defined to be normal events. By dictionary of behavior, we mean a data set which is composed of valid events. All valid events result in a successful activity of medicine consumption pattern.

3.2 Architecture of Data Fusion Model

The top level of a Data Fusion model, which is shown in Figure 2 contains a Human computer interface module, a module containing all sensors, a source pre-processing module named Data Cleaning and Filtering module [3]. The bottom layer contains a Database Management System that consists of two components named as Support Database module and Fusion Database module.

The Sensor Module contains all the disparate sources of information connected to the Data Fusion system. For the purpose of Data Fusion, we are considering only the information from the RFID reader, SunSPOT [21] device and a precision balance as part of the Smart Drawer project. Here, the RFID reader generates a continuous stream of tuples identifying the presence of a medicine bottle inside the drawer. The SunSPOT device generates data to represent the drawer opening/closing status at a particular moment. Finally, the precision balance generates data representing the total of the weights of medicine bottles in the drawer at a specific time.

The Data Cleaning and Filtering module is a very important component in data fusion. Basically, sensors generate a large volume of data; most of which might be irrelevant to the current context. Moreover, data generated from sensors contain both redundancy and error. Therefore, appropriate filtering techniques must be adopted in order to remove this redundant information. Reliable data cleaning techniques should also be applied to the data in order to correct any errors.

The next part of the Data Fusion model is the Data Aggregation module, which combines all the preprocessed data from different sources according to the domain specific logic. In the context of Smart Drawer application, we will aggregate the data in the form of (drawer open time, drawer close time, RFID event start time, RFID event end time, RFID tag, weight changes).

Next, the Database Management System is a very important component for our Data Fusion model. It consists of a Support Database along with a Fusion Database. The Support Database contains information about doctor’s prescription for a patient, patient’s current medical condition as well as his or her personal information. It also contains medicine records, total number of bottles per medicine, total weight per bottle along with its associated RFID tag and expiry date as well. Our Fusion Database will contain all the aggregated information generated from the continuous interaction of patients with the sensors. The Database Management System will provide support functions to access the fused data as well as making queries of the data.

3.3 Physical Setup

The medicine intake tracking system has various real-world components that make up how the tool will have to be constructed. The furniture containing the Smart Drawer will be part of a simulated apartment. And for this drawer to operate, it will be necessary to identify when the drawer is open in addition to the previous problems of identifying the bottles.

3.3.1 Experimental Layout

The web tool and data fusion described in this paper are being used in conjunction with a sensor-equipped drawer, the Smart Drawer. The Smart Drawer system being used for this paper is part of the @Home assistive Living apartment. Figure 3 shows the floor plan of the bedroom from our experimental setup at the Heracleia Laboratory. The drawer to the right of the bed, which is encircled in red, contains the equipment used to measure the medication.
An RFID reader is placed inside that can read the values from the individual bottles. Next, a precision balance, which has a resolution of 0.001 g, has been placed in the drawer and has a serial connection to report a stream of the current weight of the contents. A SunSPOT sensor is mounted to the front of the drawer to detect the position of the drawer. In addition, a Motion Detection sensor, from Phidget, is mounted on the leg of the lounge chair to detect when a person has entered the bedroom. This combination of sensors and spaces define the workspace for the sensor input that will need to be combined into a functioning application.

### 3.3.2 Drawer Events

Several key sensors are part of the overall system being accessed by the web tool. One of the sensors mounted on the medicine drawer is a SunSPOT wireless sensor mote mounted with an accelerometer with three axes.

Empirical tests were done with a drawer, on which a SunSPOT sensor mote was mounted on the front. The drawer was then opened and closed while readings of the raw data were recorded for analysis. As a result, two methods were applied to determine when the drawer would be in use, to be open or to be shut. We call this detection of the drawer motion the drawer event to indicate the usage.

The first method of calculating the drawer event was a simple approach to finding a threshold that indicated that the drawer was in motion.

\[
\left( x_j - \frac{\sum_{i=1}^{n} x_i}{n} \right) > t_k
\]

Where \( x_j \) is the current reading, \( x_i \) are the past \( n \) readings, and \( t_k \) is the threshold in gravities for the acceleration of the drawer (0.064 g), an \( n \) is 30.

Given that when the motion of the drawer exceeds the threshold, the program on the SunSPOT reports that an event has occurred, and then sends a signal over the WSN.

The second approach is to take a look at the Multi-Gaussian HMM method for recognizing the behavior of a data stream. The same data used to create the threshold was imported into the Java Hidden Markov Model API that allows the data to be processed. By using the K-Means Learner, the status of the drawer can be modeled as seen in Figure 4.

In Figure 5, we use A1 through A9 to symbolize the action events. A9 are those set of action events which could be determined to be external noise, or don’t care cases for the given state. A1 through A8 describe the main transitions between the states themselves.

### 3.4 State Diagram and Sequence Diagram

In order to combine the various sensors and events in the medicine intake system, a design has to be considered for the fusing of the data.

#### 3.4.1 Sensor Combining State Diagram

The setup for the drawer describes the types of sensors put into the environment. These sensors by themselves, however, must work together in order to create a sequence to find meaning and to conserve energy.

Figure 5 shows a system consisting of 5 states that correspond to the different types of sensors involved in the tested. State 1 represents the start state, representing a system where no motion is detected within the room with the medicine drawer. When the motion detector is triggered by the presence of a user, the machine will transition to state 2. State 2 remains unchanged until it is triggered by a drawer event where it changes its state to 3. A set of values are used primarily to detect the state of the system and hence we have five different states which constitute the overall performance. State 4 indicates that the medication bottle has been removed from the drawer, and its absence should be noted by the system. When the medicine is replaced, then the balance should record the new weight.

In Figure 5, we use A1 through A9 to symbolize the action events. A9 are those set of action events which could be determined to be external noise, or don’t care cases for the given state. A1 through A8 describe the main transitions between the states themselves.

#### 3.4.2 Sequence Diagram

We can describe the whole process using a sequence diagram as shown in Figure 6. When a patient opens a drawer, the system starts scanning for the available RFID tags in the drawer. When a reader misses a tag in the drawer for a while, the system will create a corresponding RFID event from the raw RFID data. Next,
our system will measure the weight difference between the time intervals of a RFID event. If the weight changes within this time, system records the weight difference and logs the time, which is eventually displayed to the caregivers through the monitoring medicine intake interface. The system also keeps track of all the activities such as individual drawer event, RFID event in order to identify some useful information about the patient’s behavior. The system will summarize the entire drug taking activities for a patient whether it is close to normal or deviating from normal and will convey this information to the caregivers or doctors through the generating statistics interface.

Our system will measure the weight difference between the time intervals of a RFID event. If the weight changes within this time, system records the weight difference and logs the time, which is eventually displayed to the caregivers through the monitoring medicine intake interface. The system also keeps track of all the activities such as individual drawer event, RFID event in order to identify some useful information about the patient’s behavior. The system will summarize the entire drug taking activities for a patient whether it is close to normal or deviating from normal and will convey this information to the caregivers or doctors through the generating statistics interface.

4 RESULTS AND SNAPSHOTs

After describing all the necessary major components or modules for the execution of the experiment, some applications are under study for the project. Firstly, the caregiver or the doctor logs in to the system by means of a web based tool whose snapshot is shown in Figure 7. The caregivers who use this system have to authenticate themselves to the web based Smart Drawer module or a new caregiver can register and enter their details. On successful registration, the care giver can make use of all the services provided by this tool. By using a web based module, this tool exploits all the web based technologies.

On successful logon into the system, all the sensor devices are currently ready to listen to signals which will make to sensor mote to go to active state. If motion is detected in the bedroom area, the motion sensor detects motion and reports it to the backend system. This path event is recorded which makes a sequence to determine the presence of the person in the bedroom area.

On successful login , the caregiver can view the details of their patients which is shown in the Figure 8. The details that can be seen by the caregiver includes the time at which the patient has taken his medication ,the type of medication taken in quantity and also this system reminds the patients to take his medication at the prescribed time by sending an alert message .

On detecting the name of the medication taken by using different RFID tags for different medicine bottles , our web based medicine intake tool further determines the quantity of medication taken by the patient by having an analytic weight sensor attached to this environment. We place all the medicine bottles bearing the RFID tag on the analytic weight sensor balance and record the changes in weight when the bottle is placed back. The weight balance can detect changes in weight of the order of milligrams.

The screenshot in Figure 9 below shows the result from the weight sensor balance which displays the value in different consoles.

5 CONCLUSIONS AND FUTURE WORK

For now, the components of the system have been gathered and tested. The motion detectors, SunSPOTs attached to the drawer,
RFID on pill bottles and the analytical weight sensor send the values to the base station reader where all function as individual units. The raw data from different sensor units form a heterogeneous data set which leads to data fusion.

The main improvements in connection with our previous work and other related projects is the deployment of a complete medicine tracking system instead of a standalone device. From the technical point of view several improvements have been incorporated. A motion energy sensor has been integrated in order to reduce energy consumption. Furthermore, the sensors turn on sequentially in the order depicted in fig.5 making the system even more energy efficient. A precision scale has been used for the detection of actual pill consumption. In addition a data cleaning module refines the data acquired by the sensors and a database system logs the detected events, giving the opportunity for further processing.

One of the key results in this paper includes the development of the tracking tool using the web. Internet plays a crucial role from the caregiver logins being the primary authentication step till the determination of the quantity or the amount of medication consumed by the patient at the prescribed time. This makes the system to be accessible from a remote workplace while the medication is being tracked by the tool using the web interface. For this web based tool, the applications have been extended to creating the caregiver interface, patient view and a maintenance view using the web. Our future goal in developing the material side of the system is to combine these different sensors using the state and sequence diagrams to achieve data fusion to recognize what, when, and how much medicine would be taken by the patient.

For the data aspect of the project, the expansion of the collection of data to be fused must be compared to known prescriptions. The sequence of events for each medicine will need to be compared to the description from the prescription. Dynamic programming methods, such as Dynamic Time Warping, will be investigated as a means for making a match between the different sequences.

![Figure 9. Weight Sensor Balance output data values](image)

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7 REFERENCES


[22] “Phidgets Inc. - Unique and Easy to Use USB Interfaces.”

[23] “Lab Precision and Analytical Weighing - METTLER TOLEDO - United States.”

