# VALMA: VOICE, ACTIVITY, AND LOCATION MONITORING FOR ALZHEIMER’S DISEASE AND RELATED DEMENTIAS

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## INTRODUCTION

Not only are work, social, and daily living affected for individuals with Alzheimer’s disease (AD) and related dementias, but caring for these individuals is a long-term progressive burden. In Canada, while the projected number of dementia cases is expected to increase 2.3 times to 1.1 million people by 2038, the projected associated economic burden attributed to dementia is expected to increase by 10 times to $153.6 billion dollars annually [1].

Few treatments are available to slow or stop the deterioration of brain cells in neurodegenerative disorders such as Alzheimer’s disease. The accepted view today is that reducing modifiable risk factors is the most effective way of reducing the chances of developing or slowing progression of disease [1], [2]. Specifically, promoting a healthy diet, aerobic exercise, an active social life, and intellectual stimulation are the recommended strategies for reducing the onset risk and progression of AD and related dementias [1], [2].

Lifestyle risk factors are assessed primarily through self-reporting, which are subjective and depend on good recall. Considering memory impairment is the hallmark of AD, self-report assessments of everyday activities may be misleading. The purpose of this project is to develop an ambulatory sensor system to provide accurate and sensitive assessments of everyday activity related to risk factors for AD and related dementias.

## VOICE, ACTIVITY, AND LOCATION MONITORING FOR ALZHEIMER’S DISEASE (VALMA)

Drawn from epidemiological studies [1-3], lifestyle factors related to AD and related dementias can be categorized into nutritional, physical, social, intellectual, and sleep activity domains. A candidate list of wearable sensors capable of capturing these activity domains in an ambulatory manner was first compiled, and screened using the system design criteria.

The overall system design criteria were based on applicability to elderly population at greatest risk for AD and related dementias. The system needed to be: i) unobtrusive (i.e., maintain regular appearance), ii) sensitive (i.e., high resolution), iii) simple to use and control, and iv) considerate of private data.

Sensors to capture limb motion, GPS


Figure 1: VALMA system components. Google Nexus One smartphone, headset, accelerometers and ankle straps.

location, and audio fit the design criteria and the data needs to profile physical, social, and sleep activities. Based on these sensors, the Voice, Activity, & Location Monitoring for Alzheimer's disease (VALMA) system was developed.

## System Description

The VALMA system (Fig. 1) comprises of 2 main components: 1) a smartphone, and 2) accelerometers placed on each ankle.

The core of the system is an application running on a smartphone (Nexus One, Google, Inc.), which itself runs Google's Android mobile operating system. The phone contains a GPS receiver which the application uses to record location data. A wired headset is connected to the phone and audio data is recorded through the headset's microphone. Both GPS and audio data are stored on the phone's SD card. The user interface includes the ability to stop, and later resume, the audio recording for privacy. In addition, the user may listen to any of the audio that was recorded and delete the files as they wish. For this purpose, the audio is recorded in five minute segments.

A pair of self-logging 3D linear accelerometers (X6-2 Mini, Gulf Coast Data Concepts, Inc.) are placed bilaterally on the ankles using custom-built velcro straps. These accelerometers operate independently of the phone and record data to their own internal memory, which is later retrieved via a USB connection.

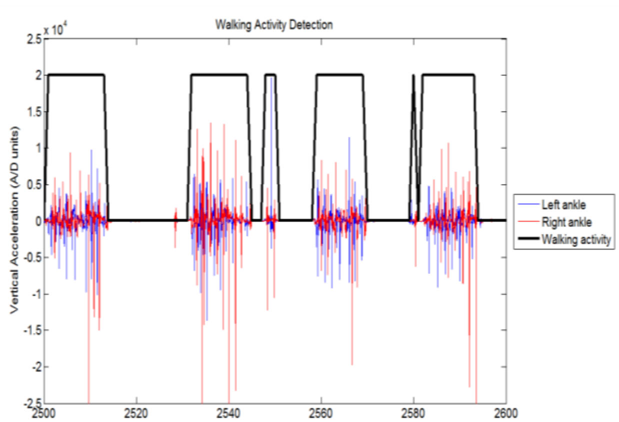


Figure 2: Sample ankle accelerometer record with identified walking activity. Walking activity is defined as reciprocal ankle motion with 3 or more steps.

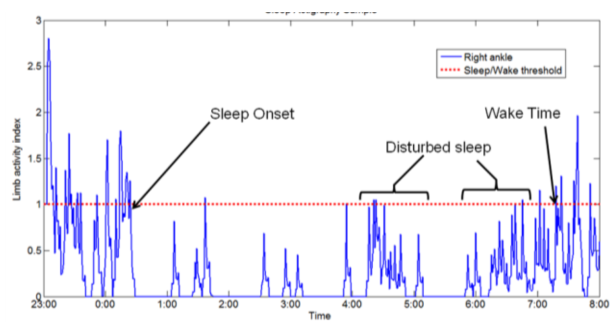


Figure 3: Sample accelerometer record of the right limb with identified sleeping periods.

## Physical Activity Measures

Regular exercise, even low-intensity activity, has been associated with reduced risk of dementia and cognitive decline [4]. The VALMA system extracts the most common type of physical activity, walking, from the ankle accelerometers. To extract walking activity, ankle acceleration data was high-pass filtered to remove gravity, followed by identification of bilateral limb activity using a cross-spectral approach. Time segments with bilateral leg activity were then inspected visually to confirm walking (≥3 steps). Figure 2 plots example acceleration records for the left and right ankles and identified walking segments.

Currently, the VALMA system measures total walking duration and the number of walking bouts. Placing sensors at the ankle bilaterally permits measurement of gait events, such as heel strike and toe-off, to provide more detailed indices of gait. For example, step variability has been used to indicate balance control during gait.

## Sleep Measures

Disordered sleeping patterns, such as increased number of awakenings and reduced (deep) slow-wave sleep duration, have received increasing attention as a risk factor for AD and related dementias [5]. Motor activity measured by limb accelerometry has been used as a proxy measure for the resource-intensive sleep laboratory techniques that have characterized sleep principally using neurophysiological measures such as electroencephalograpy (EEG) [6]. The VALMA system extracts sleep timing measures using automatic sleep/wake identification algorithms developed by Cole et al [6]. This algorithm uses the number of zero-crossings in 1-min epochs as activity counts, and computes a score based on the preceding 4, current, and following 2 epochs. The current minute was considered as sleep when the score < 1. Figure 3 plots an example night of activity count data, including sleep onset, restlessness, and wake times.

### Social Activity Measures

There is mounting evidence to support the hypothesis that having and participating in rich social networks are protective of AD and related dementias [7]. As a psychosocial factor, this domain is typically measured through questionnaire-based instruments. For example, marital status and number of organized social groups a person belongs to (e.g., church, bowling team) are indicative of social integration and network size [8]. We hypothesize that social activity may be reflected by mobility and verbal activity patterns to complement and extend traditional instruments. Specifically, the ability of GPS location and audio data streams to profile social activity will be examined.

From the GPS location data, a geographic mobility envelope that encloses all of the participant's activity can be determined. Potential measures to indicate social activity include the envelope area, perimeter, number of trips made outside of the home, and time spent away from home (Figure 4).

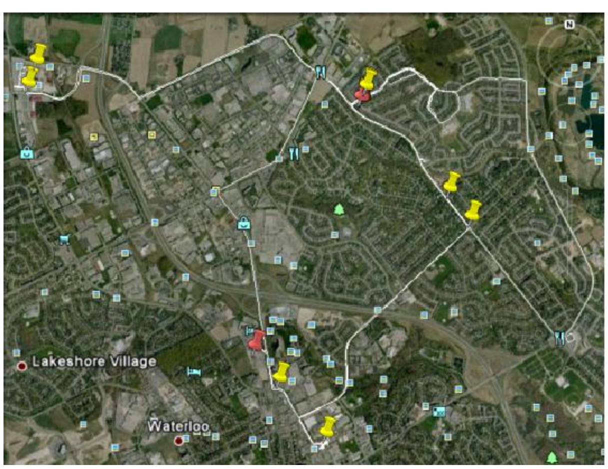


Figure 4: Sample mobility envelope based on GPS location data.

We hypothesize that a more socially active person would be more active verbally throughout the day. Early signs of Alzheimer's disease often manifest themselves in the speech of patients, such as a diminished lexical richness and increased repetitions [9]. However, it is unknown whether measures such as the quantity of speech and the duration distribution of utterances are affected by the disease. To that effect, the system includes a voice activity detector (VAD) that segments talking versus not talking from the audio recordings.

Initial evaluations of the VAD standard used by the telephony industry (G.729 [10]) demonstrated an overestimate of verbal activity (i.e., labels anything that might sound like a voice) and does not distinguish between the user's voice and background voices. To address these limitations, a VAD algorithm based on a conditional random field (CRF) [11] was developed. Briefly, the CRF technique is a discriminative classifier for temporal processes that uses rich voice features trained on 5 min of labeled data for each participant. Preliminary results are encouraging, showing a high consistency between its classifications and manually annotated audio tracks. The automated nature of the classifier allows extraction of statistics such as the amount of talking and the duration distribution of talking segments.

### Composite Measures

While physical activity, sleep, speech and mobility factors are worthwhile measures in isolation, combinations of measures may prove to be insightful. For example, there is interest in understanding the natural occurrence of dual-tasking behaviour, specifically simultaneously walking and talking. Decreased ability to perform dual-tasking in individuals with AD has been suggested to be a reason for a three-fold incidence of falling in this population compared to healthy older adults [12]. The VALMA system captures measures of both walking stability (i.e., step variability) and verbal activity to potentially provide an accurate assessment of everyday occurrence of dual-tasking activities.

## FEASIBILITY AND PROOF OF CONCEPT STUDIES

Initial studies will assess the feasibility, construct validity, and sensitivity of the VALMA system to profile everyday behaviour. In pilot studies, the feasibility of collecting everyday activity using the VALMA system for 4 days was assessed in 2 healthy older adults and 1 AD patient. Feedback and high compliance rates indicate that collection is feasible with a 15 minute training session, and a telephone support line.

A validation study has been designed to examine the construct validity and sensitivity of the everyday activity measures collected by the VALMA system. A sample of community-dwelling mild to moderate AD patients and a control group of healthy age-matched controls will undergo a battery of cognitive, language, and gait tests, followed by a 4 day everyday activity collection period. We expect that the VALMA system will provide objective measures of everyday activity, and the correlation to laboratory-based measures will be evaluated.

## CONCLUSION

VALMA represents a novel ambulatory sensor system designed to capture natural behaviours across multiple domains to profile lifestyle risk factors related to AD and related dementias. Lower limb accelerometry provides quantitative measures of physical activity (i.e., walking) and sleep duration. Audio and GPS location records provide verbal and mobility activity, respectively. Given appropriate training and support, everyday collection using the system is feasible. Accurate assessment of everyday activity will impact the design and prescription of exercise, sleep, and social interventions to prevent and slow disease progression.

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