# The *Alzimio* App for Dementia, Autism & Alzheimer's: Using Novel Activity Recognition Algorithms and Geofencing

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***Abstract*:** Dementia, Autism, and Alzheimer's disorders affect millions of people worldwide. Suffering from forgetfulness, affected patients tend to wander off and potentially get into dangerous situations. This work introduces a mobile app, Alzimio, to provide two main alarm functions to these patients; safe-zone geofencing and activity-recognition. Caregivers designate certain activities (or zones) as dangerous, triggering alert message (with activity information) when detected.

Several challenges must be overcome to achieve our goals. First, the activities and zones must be detected accurately in a timely fashion, and with high confidence. Second, the algorithms used should operate effectively on regular smartphones without special hardware. Such challenges are not unique to *Alzimio*, but are general to most Internet of Things (*IoT*) healthcare apps. In this study, we devise several novel activity-recognition algorithms to meet our goals of accuracy and efficiency. Our threshold-based algorithms intelligently filter and process the output of Android APIs for activity recognition and geofencing, at different time scales. The app was evaluated using extensive scenarios of usage for several months. We find that our *max-in-window* algorithm is able to achieve over 95% accuracy in less than 30 sec in most scenarios. The optimal threshold was found to be 65% confidence, to achieve best accuracy and delay. The *Alzimio* app runs efficiently on budget (low-end and medium) Android phones without noticeably affecting power consumption.

## I. INTRODUCTION

Autism, Alzheimer's, and Dementia negatively affect the lives of millions of patients, caregivers, and loved ones around the world, and cost many billions of dollars annually. Dealing with memory loss is time consuming and usually restricts the freedom of the patient. Although there have been multiple studies to help the people who forget, which are mainly focused on prevention and how to deal with these diseases, there is currently no product for the combined detection of unsafe activities and zones to assist in improving the lives of millions that suffer from lack of memory.

As shown in Table I, there is a need to assist millions here in America and around the world. Dementia, autism, and Alzheimer's all lead to memory loss that can be dangerous[11,12]. Alzheimer's and dementia affect a large population of millions of patients and seniors who usually need continuous monitoring and assisted living, and usually do not have much freedom. Moreover, this affected population is (in many cases) disadvantaged due to medical and mobility conditions, and cannot afford expensive solutions including costly wearables.

Table I. The need for *Alzimio* in numbers

| Disorder | Patients (USA / World) | Dementia |
|---|---|---|
| *Alzheimer's* | (*5M / 48M*), *1/60 people*[9,10] | *60%*[9,10] |
| *Autism* | (*1.1M / 22M*), *1/68 children*[1] | *50%*[1] |

Several challenges need to be overcome in order to provide an easy-to-use cost-effective solution to this problem. First, the sensing needed to run continuously without disrupting users' daily activities, on affordable devices used every day (i.e., smartphones), without affecting its normal use. Second, the algorithm for getting the activity from the Android API needed to be accurate and obtained in a timely fashion. Finally, the design should maximize detection while minimizing false alarms to keep app reliable and usable.

One of the main directions in which IoT can contribute to healthcare is through mobile health (or *mhealth*) using smartphones. This study presents *Alzimio*; the first mobile app designed to automatically detect safe zone exits and unsafe activities (in-car, on-foot, or on-bicycle). Its design achieves continuous, energy-efficient, detection of unsafe zones and activities to provide quick response in the case a patient wanders off or takes part in 'unsafe activity'. *Alzimio* uses smartphones only (without the need for extra hardware) to offer two main features; automatic detection of safe zone crossing and detection of preset unsafe activities. *Alzimio* also offers a host of useful features to assist in providing help for the unfortunate case of an emergency.

Through its new, refined and uniquely integrated algorithmic design, thoughtful app implementation with optimal trade-offs, and extensive data-driven evaluation,

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*Alzimio* is able to meet its design goals of detection, reliability, power efficiency and user-friendliness. Furthermore, *Alzimio* compares favorably to existing solutions for Autism and Alzheimer's as discussed in Sec II. Overall, we provide the following contributions:

1- Architect, implement and test the first mobile solution for integrating detection of unsafe zones and activities in an efficient, affordable, user-friendly app, *Alzimio*, to help dementia patients during emergencies.

2- Perform experiments to collect and analyze evaluation data. Such evaluation was performed in a systematic and repeatable fashion, using an extensive set of testing scenarios.

3- Devise innovative mobile algorithms for accurate real-time activity recognition using continuous sensing. Three algorithms; direct Android API output, *threshold-based*, and *max-in-window*; are introduced and analyzed. The *accuracy-delay* trade-off was introduced and captured through a utility function. Optimal setting achieves 95% accuracy in less than 30 seconds in our tested scenarios.

4- Refine the implementation to be user-friendly and power-efficient, using sensor data push and on-demand wake-up. *Alzimio* adds only 7.5% consumption with geofencing and ~16% with activity recognition, per day.

We hope to bring *Alzimio* to millions of patients, due to its scalability, utility and affordability. We also hope for this work to provide the base for a host of practical mobile health apps in the future Internet of Things (*IoT*).

The rest of this paper is outlined as follows. Section III provides comparison with related work. Section IIII presents design goals, architectural overview and approach. Section IV discusses algorithm evaluation and app testing, then presents the results. Section V concludes and discusses the planned future work.

## II. Related Work

There is a great need for tools to improve disease/disorder self-management, reduce response time for emergencies, and enhance freedom for forgetful patients, the elderly, and their families and caregivers. Two of the main functions often needed are safe activity and zone violation detection. Although there are some studies on geofencing [4, 6, 14], but for activity recognition detection [e.g., Fitbit], there are fewer products. Most of these products require extra hardware, and most of all incur high cost. None of the existing solutions (products or studies) integrate accurate activity recognition, geofencing and alarm/notifications in an affordable system. We shall discuss the existing related work in the areas of safe zone detection and dangerous activity detection. In addition we will quickly review existing products for Alzheimer's and autism.

For zone detection, existing approaches (products, research), mainly focus on the use of customized devices (e.g., smart watches [4, 6], small pocket-size boxes [7], and sticks that attach to bikes) that have limited reach, little scaling, and are usually expensive. In[14] the study uses quadtrees structure for locations/regions to reduce power consumption for geofencing. Does not use Android API (which consumes ~7.5% battery power daily as per our experiments) and does not have alarm system for patients.

On the other hand, the use of smartphones has great potential for scaling, potentially providing patients with an affordable alternative. Yet the majority of available autism apps are games to help patients' social skills.

*Alzimio* fills this gap with a new and unique approach, integrating various detection capabilities with the latest adopted technologies using sensing, computation, communication and user-interface capabilities of smartphones. *Alzimio* is unique in providing patients with tools for emergency detection and alert notification. *Alzimio* is the only product (of which we are aware) that can accurately and continuously combine both activity-based alarms and geofencing. The main detection algorithm uses Android API readings, which are then analyzed by algorithms optimized and driven by the collected data. *Alzimio* continuously monitors location and activity even when the phone is locked, to check for patients wandering out of preset safe zone. Furthermore, it includes a user-friendly modern design for the easy setup and usage of the app.

For activity recognition, much of earlier work focuses on off-line data processing using previously recorded data to draw algorithms that are not only accurate, but also are efficient. In [13] the study uses accelerometer data for accurate detection, but does not use Android API which uses considerably less battery power. Also, it does not trigger alarms/notifications and is not geared towards dementia patients (no geofencing). Many fitness wearables provide a log for activities, using extra hardware, but not activity-based alarms. *Alzimio* utilizes sensing, computation, and storage capabilities of smartphones to analyze API data in real time to give accurate and near-immediate detection of activities. This leads to lower emergency response times and reduced caregiver tress, while keeping the battery consumption low for day-long usage.

*Alzimio*'s mobile algorithm's optimized parameters provide for a balanced trade-off between accuracy and delay, to enable the use of standard smartphones for such detection, providing scalability and affordability not possible with other competing solutions.

As shown in Table II, earlier studies on location sharing and geofencing have been done. Wireless carriers offer services share location, but this does not offer any sort of notification. The price of this service is \$10/month, or \$240/2 years. Other products that incorporate geofencing are mostly smart watches such as Nut [5] and Outdoor anti GPS watch [6], these solutions cost \$8-42, and do not provide activity recognition.

Other non-hardware solutions include apps such as Ihelp-play [7] and Autism touch and speak [8]. These solutions teach the patient how to deal with certain situations, and companionship to those that suffer from autism. These do not offer activity or location tracking.

Solutions for Alzheimer's patients are Tweri [2] and Prevent Alzheimer's with a maze [3]. Tweri is a geofence app but lacks activity-based alarms. Its reviewers complain that the user interface is hard to use and confusing. Prevent Alzheimer's with a maze provides brain training for those developing Alzheimer's, to stop the disease from developing.

Table II. *Alzimio* vs. existing leading Dementia products

| Solution | Cost | Function |
|---|---|---|
| Wireless Carriers | \$10/mnth | Location sharing |
| Autism Apps [7,8] | ~\$0-10 | Brain training & games |
| Alzheimer's Apps [2,3] | ~\$0-3 | Information |
| Devices, watches [4,5] | ~\$8-42 | GPS tracking |
| ***Alzimio*** | \$0 | Geofencing & Activity |

## III. DESIGN GOALS & APPROACH

*Alzimio* was specifically designed to provide several functionalities to the people suffering from dementia, whether it is Autistic patients, people with Alzheimer's, elderly, veterans, or children/adolescents. The main functions for *Alzimio* are the ability to establish safe activities and zones, and to automatically detect when they are violated (e.g., when safe zone is crossed/exited or a dangerous activity is detected). The design was carefully crafted to provide these functions with the best performance: I. qualitatively, in terms of ease-of-use and simplicity of design and II. quantitatively, in terms of 1. Detection accuracy, 2. Reliability in background detection, and 3. Affordable and efficient operation.

More specifically, *Alzimio's* design goals include:

1- *Detection Accuracy*: To provide patients, caregivers, and loved ones a peace of mind *Alzimio* has a goal to achieve excellent detection of emergency scenarios, to maximize sensitivity (i.e., the ability to detect an emergency) and minimize delay and false alarms). The goal is to provide at least 95% detection accuracy and delay below 30 sec.

2- *Reliability*: To capture emergency scenarios throughout the day, *Alzimio* should run in the background, even when the phone screen is turned off, and be able to process sensory and GPS data for reliable detection. The use of a combination of APIs, interruption receivers and wake-locks allows such reliable operation, while not sacrificing battery consumption (next).

3- *Affordability and Efficiency of Operation*: The continuous operation of the mobile sensing device is a challenge faced by any IoT device for healthcare monitoring, especially for emergencies that can occur at any time. *Alzimio* was designed with the goal of operating on any Android device, and having minimal effect on the phone battery lifetime. Effectively, the goal is to have the smartphone with *Alzimio* run through the day, just like it would without it.

In addition, other design goals include affordability, where many of these patients (due to their condition) may not be able to afford high-end devices or wearables. *Alzimio* can be run on low-end Android devices and does not require any additional hardware or wearables. Other goals include, maximum notification (SMS, email, phone), and easy to use interface.

***Architectural Overview*:** The main software architecture for *Alzimio* (in Fig. 1) comprises four main components: the sensing, detection, alert notification, and user interface subsystems:

1. The sensing subsystem; uses various sensors for geofencing and activity recognition, including tri-axial accelerometers, gyroscope, and location sensing subsystem (including GPS, WiFi access points, and cellular tower signal strength). Sensor fusion algorithms take input from the sensors to detect locations/activities of the user. Android offers APIs for both functions,

2. The detection subsystem; includes the detection algorithms for dangerous activities (as setup by the user), and geofence transitions, and the alert components that feed into the notification subsystem. The data flows from the sensing subsystem into the detection subsystem then into the alert subsystem. Novel algorithms for accurate activity detection are introduced; namely, I. the *threshold-based* algorithm, and the *max-in-window* algorithm,

3. The notification subsystem takes its input from the detection subsystem and notifies the user (using audio, visual and vibration effects, after waking up the phone screen) to allow for a *disarm* period (configurable, usually 5 sec) in case of false alarms. If the alarm is not disarmed by the user, then the messaging system is

invoked to notify the emergency contacts set by the user,

4. The user interface; to allow for configuration of geofence regions and transitions (entry, exit, or both), activity-alert triggers (e.g., dangerous activities, as considered by the user; walking/running, on-bicycle, and in-vehicle), timer (to allow for periods of detection and Alzimio *sleep* periods), and emergency contacts to notify in case of emergency detection or suspicion.

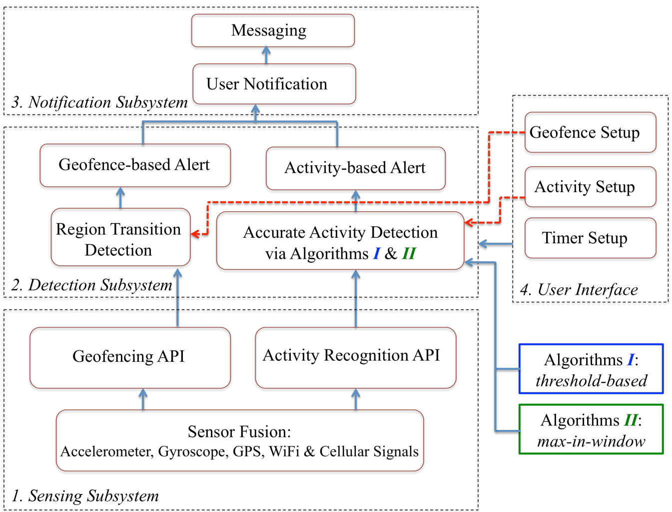



Fig. 1. Main architectural components of *Alzimio*: 1- Sensing subsystem, includes the sensor fusion (with accelerometer, gyroscope, GPS, WiFi, and cellular signal) to facilitate the geofencing and activity recognition functions, 2- Detection and alert subsystem, including algorithms for accurate activity detection, by processing data from the sensing subsystem and the user configuration/setup. The algorithms include the I. threshold-based and II. max-in-window algorithms, 3- Notification subsystem, for user notification and messaging, and 4- User interface subsystem to configure the geofence regions and activities to detect. The data flows upward in this diagram from the sensing to the user and to the care-giver (emergency contacts) during emergencies.

***Algorithmic Overview***: The two main functions of the presented *Alzimio* app; Geofencing and activity-based alarms, were achieved by using Android APIs for these functions. For Geofencing, the main effort was put to provide an easy-to-use interface for the users. The geofencing algorithms (provided by Android) are out-of-scope of this paper. On the other hand, the activity-recognition APIs for triggering alarms provided a challenge. Activity recognition was very unreliable giving out multiple readings at once, which was not user friendly in the case of an emergency. Using the Android API for activity-recognition provides a *set* of activities with confidence levels that cannot be used directly, and need further filtering and interpretation. A sample output of such API is given in Fig. 2, and can be quite confusing to the caregiver. It certainly cannot be used directly to trigger alarms either. *Alzimio* introduces two novel algorithms to filter the activity-recognition data at two time scales to provide accurate detection of dangerous scenarios. Note that the algorithms are kept intentionally simple, yet effective, to operate smoothly with least complexity even on low-end smartphones.

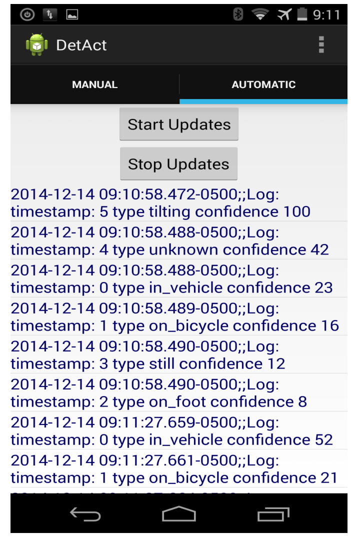



Fig 2. Example output of the Android API for activity recognition. The activities include 'still', 'on-foot', 'on-bicycle', 'in-vehicle', 'tilting', and 'uknown'. This is a screen shot of our compaion app 'DetAct' to facilitate the measurement and estimation of activity-detection accuracy

We present and analyze three (short time scale) algorithms for activity-recognition, and one long time scale algorithm. We start with the short time scale:

1. The first algorithm is straight forward, and is used for reference only, which simply takes the output of the Android API directly to identify the activity.

2. For the second algorithm, we introduce a *threshold-based* algorithm that rejects all activities below a confidence threshold ($th_{conf}$). The *optimal* $th_{conf}$ is determined via our data-driven analysis in the next section. This algorithm may incur some delay until $th_{conf}$ is crossed, providing an interesting trade-off.

3. The third short time scale algorithm processes multiple samples within a given window of time (1sec) and takes the maximum likelihood after applying the *threshold*. We refer to this as *max-in-window* algorithm.

The output of the short time scale algorithm of choice is sent with the alert message when the safe zone is crossed (i.e., in conjunction with geofencing).

To sum, the Android activity recognition API can be unreliable at times. We introduce our algorithms to clean up and process the data to distinguish the ground truth from noise, to tell apart an activity transition from low confidence levels, and to filter out abrupt false alarms.

## IV. ALGORITHM & APP EVALUATION

The *Alzimio* algorithms and app were developed using the Eclipse IDE with Android Development Tools (ADT), using Java and XML. Its components were developed over two years, and it was extensively tested in a test bed and in the field using systematic sets of scenarios. The algorithms were tested for accuracy for all activities (on-foot, in-vehicle, on-bicycle, and still) as well as the efficiency[1]. Two elaborate sets of tests are presented next.

***1. Activity-recognition Accuracy:***

The companion app we developed was to test the accuracy of activity-recognition. Initial tests, using our *DetAct* app, were conducted to obtain the ground truth (manually) while gathering the Android API readings. It also made clear the need to improve not only the accuracy of the API but also the user-friendliness.

After rejecting the 'tilting' and 'unknown' states from the data, three algorithms were developed to process the data obtained from Android activity-recognition API (as described in section III):

A. The first, for reference, uses the Android data as-is (this is a special case of the *threshold-based* algorithm, but with threshold=0; i.e., accept all the data),

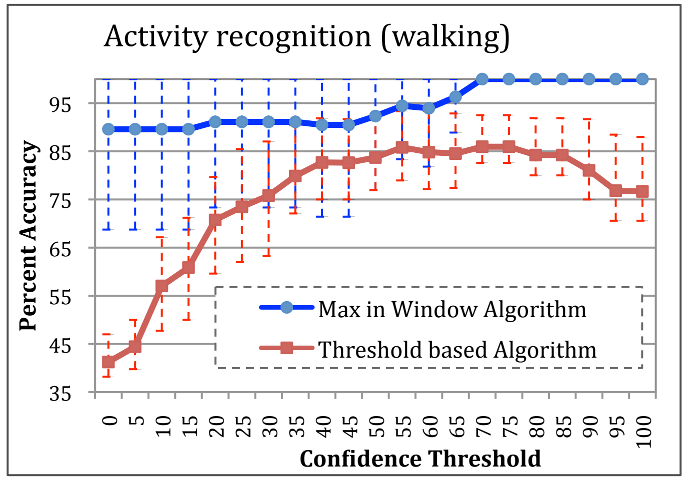
B. The second is the *threshold-based* algorithm, where the threshold was changed from 5 through 100 with increments of 5.

C. The third is the *max-in-window* algorithm, applying the threshold-based algorithm then taking the maximum confidence activity in a window of 1sec (with sample size of 2-5 samples).

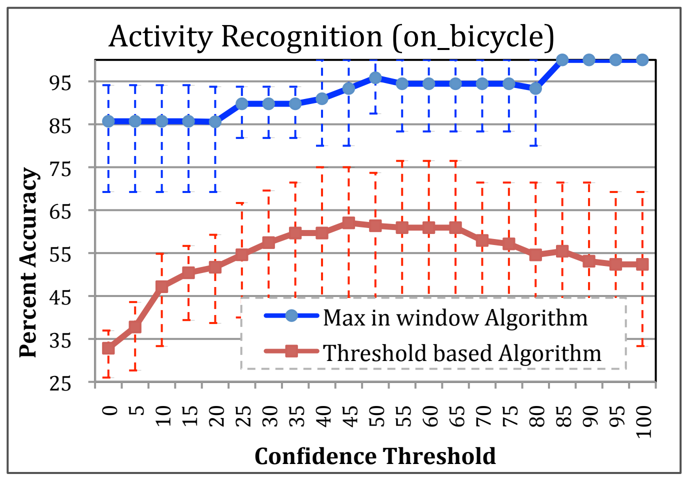
The algorithms were compared for the 'on-foot', 'on-bicycle' and 'in-vehicle' activities. The results are shown in Fig. 3, (a, b, and c). The main observations from our tests indicate that using the Android API directly would yield 32-42% accuracy (threshold-based with '0' threshold), while using a varying threshold yields up to 85% accuracy with 55-75 confidence threshold being optimal.

Note that higher thresholds yield less accuracy since most readings (those with confidence rate below the threshold) would not be accepted. On the other hand, the *max-in-window* algorithm, because it takes the maximum confidence in a window of 1sec, it can achieve much higher accuracy, between 85 (with low threshold) up to100% in many cases. Threshold above 80 give best results for accuracy.

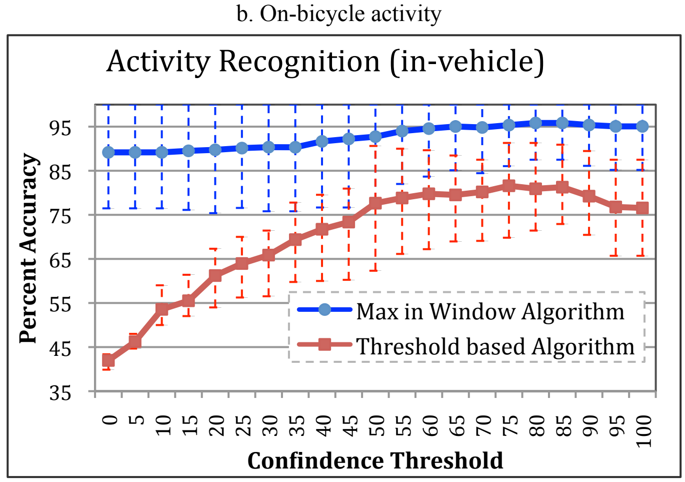
***2. Accuracy-Delay Trade-off*:** Because having a higher threshold means rejecting more sensor readings, this may lead to extended delays for the activity detection. On the other hand, minimum delay results from accepting every reading, which results in reduced accuracy. We want to maximize accuracy and confidence on one hand, and minimize delay (or maximize $\frac{1}{delay}$) on the other hand.




a. Walking (on-foot) activity




b. On-bicycle activity




c. In-vehicle activity

Fig. 3. Accuracy of activity-recognition using Android API (threshold-based with 0 threshold), threshold-based, and max-in-window, for various activities. Shown is the average of 3 trials for each activity. Superiority of *max-in-window* algorithm is clear.

[1] Geofencing was tested using numerous trips and mock-locations app, with near-perfect success. Details omitted for lack of space.

To tackle this trade-off problem we introduce a utility function to maximize as follows:

$$U = f\left(\frac{del_{Tar}}{del}\right) + g\left(\frac{acc}{acc_{Tar}}\right) + h(conf)$$

where $del_{Tar}$ is the *target delay* for the design (in our case 30sec), and $acc_{Tar}$ is the *target accuracy* for the design (in our case 95%). We take $f(x)=g(x)=x^2$, and $h(x)=0.1x$.

We calculate $U$ for the various *max-in-window* thresholds and activities in our experiments. The result is shown in Fig. 4. As seen, it is clear that there are values that maximize $U$, namely a threshold of 65 is optimal for both on-bicycle and in-vehicle activities. Thresholds lower than 65 result in lower accuracy than the target, while higher thresholds result in extended delays beyond the target delay.

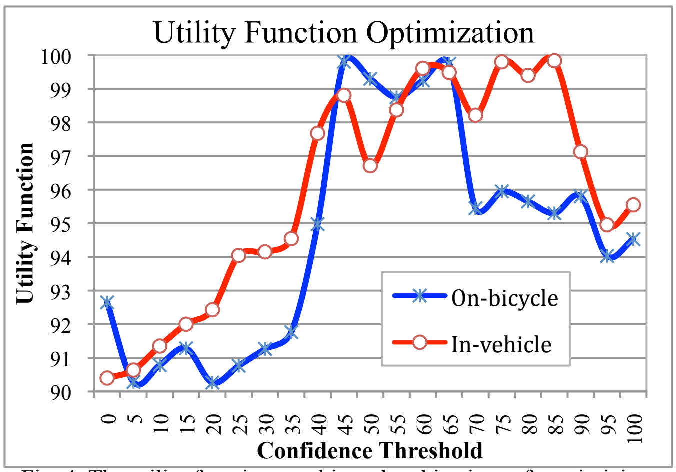


Fig. 4. The utility function combines the objectives of maximizing accuracy and confidence, while minimizing delays. A threshold of 65 is found optimal for both on-bicycle and in-vehicle activities.

It is evident that our algorithms can be fine-tuned to establish a near-perfect balance between the different goals of accuracy and delay, to maximize user experience.

## V. Conclusion and Future Work

In this work we introduced *Alzimio*; a mobile app providing geofencing and activity-based alarms to help users with dementia, autism and Alzheimer's. Through several threshold-based novel algorithms presented in this work (i.e., *max-in-window*), it was shown that *Alzimio* met its design goals of accurate detection of activities (above 95%) with low delay (less than 30sec), while running all day on a smartphone on a single charge. The optimal confidence threshold was found to be 65% confidence, to achieve the optimal balance/trade-off between accuracy and delay. Power consumption increased by 7.5% for geofencing and 16% for the activity-recognition function.

Our promising results encourage us to continue working on *Alzimio*. We plan to pursue our work in several directions: First, further test and detailed evaluation of power consumption shall be conducted. We also plan to add timed operation, where users specify time windows of background operation. Also, the function of activity-based alarms based on transitions will be integrated and evaluated.

Second, we plan to test our app with larger group of users/patients. We are talking to researchers brain institutes at certain universities, and we plan to donate our app for their use.

Third, we are developing the iOS version for the app for iPhones, and hope to release it (and the test data) to the community in the coming months.

Finally, the Alzimio app will be integrated with other health apps from HealthAppy to extend the activities detected such as seizures/falls (Seizario [15], and HeartEra [16]).

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