Energy Efficient LoRa GPS Tracker for Dementia Patients

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***Abstract*— Continuous GPS tracking devices always suffer short battery life when used by caregivers to reduce the risk of wandering to dangerous areas by dementia patients. Currently the best existing tracker for dementia patients on the market only supports less than 10 hours battery life with a gigantic battery. It not only requires daily battery charging from patients/caregivers, but also becomes a very restrictive device. In this paper we inspected individual energy consumption of the components in a GPS tracker and proposed a novel energy efficient, small wristband by integrating the latest LoRa communication and GPS duty cycling technologies. We verify our prototype's communication distance and energy efficiency through extensive experiments in the real world. Our model and data show the GPS wristband is able to support up to 40 hours continuous GPS tracking with a frequent 60 seconds location update rate. Its range also spans 3km, effectively monitoring patient locations.**

I. INTRODUCTION

Dementia is a group of mental disorders characterized by loss of memory and impairment to thinking and problem-solving capabilities, which has plagued all nations around the world and posed substantial challenges to health, aged care and social economics [1]. It is a leading cause of death and disability in persons aged over 65 [2]. By 2050 the amount of people with dementia will be tripled to 132 million, with societal economic costs accounting for 1% of global GDP [3].

Wandering is a common form of disruption for people with dementia for a number of reasons, such as memory problems, disorientation and boredom. According to the Alzheimer's association, 6 in 10 people with dementia will wander [4]. It can pose a great risk to the safety and well-being for the person and thus is a critical concern for caregivers. Although there is still no effective cure for dementia related wandering, precautions and efforts can be taken to reduce the risk of wandering to dangerous ares and to help release the burden and depression of caregivers. The Alzheimer society has thus suggested a list of off-the-shelf location technologies specifically designed for dementia patients to address wandering and to help keep them safe and secure [5]. In general, these devices utilize a GPS module to retrieve geolocation from satellites and a GSM module to transfer real time locations back to a central server. These locations are compared against a preset geofence or virtual boundary, i.e. safe zones, and will trigger timely interventions from caregivers when necessary.

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To maximize convenience, these GPS trackers are designed to be battery powered and in order to minimize obtrusiveness, these trackers are of a small size, light weight and are flexible so that they can be easily carried around. Unfortunately this small size also limits the size of the battery.

Figure 1 shows a comparison of battery life between some of the off-the-shelf devices during standby and live tracking modes. Standby mode refers to the status when a device is powered on without being used. The longest battery life of devices under this mode is no more than 3 days. If devices are working in a real time GPS tracking mode such as in geofence monitoring to ensure safety, the longest battery life drops to 10 hours.

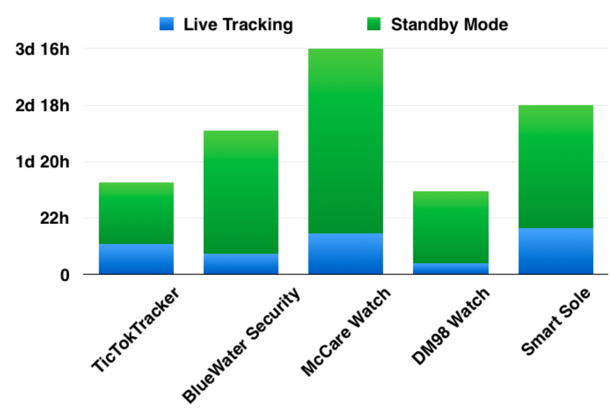

Fig. 1: Battery life comparison of existing solutions

For any generic GPS tracker with GSM communication module, we can get a rough estimation of the battery life by measuring the total power usages of its different modules against the device battery capacity. A typical GPS module will use 20mA of current during tracking and a GSM module will use 240mA. These are two significant energy consumption modules which overshadow the summation of the other components, which count for less than 5mA. Therefore, a tracker equipped with 250mAh battery can only last for 1 hour if GSM data and GPS connections are always kept alive, i.e. running at 100% duty cycle. Even if the users can tolerate a gigantic 2000mAh battery, which are normally used for large sized smart phones, the devices fail to last more than 8 hours. This poor battery life not only limits the GPS tracking duration, but adds extra burdens to patients/caregivers as they are required to charge the device daily. We believe this is the most critical issue that severely affects the acceptance rate of existing GPS trackers among dementia patients and carers.

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II. Architecture of the LoRa GPS tracker

The immediate approach of an energy efficient tracker will be reducing the consumptions of the two most energy hungry sections, the GSM and GPS. Furthermore, within our specific application of dementia patient location monitoring, there are two observations:

a) A GSM module is not a necessary requirement for real time tracking: It is true that GSM provides a wide coverage area, however for dementia patients, 75% in an urban environment are found between 1-3km from their home [6]. Therefore, for the majority of the time we only need to ensure that within a certain distance from their home the GPS information can be uploaded back to the server in real time. This motivates the use of LoRaWAN (Long Range Wide Area Network) communications protocol for transferring GPS data.

Similar to Zigbee[7], LoRaWAN is a LPWAN (Low Power Wide Area Network) protocol. Built on the Semtech LoRa modules, LoRaWAN is especially good at satisfying applications with long distance, low energy requirements at reduced data rate ($0.3k$ to $50k$ bps). Typically LoraWAN supports up to 5km communication range in urban areas and 20km in rural areas, with extremely low energy consumption rate, usually an order of magnitude lower than the GSM protocol as compared in Table I. Note that for reasons of simplicity, we use mA to represent the energy consumption rate, i.e. power, as all components use the same voltage. It is therefore not surprising to see that LoRaWAN is quickly being integrated into cities around Australia with the ultimate goal of full coverage [8], [9].

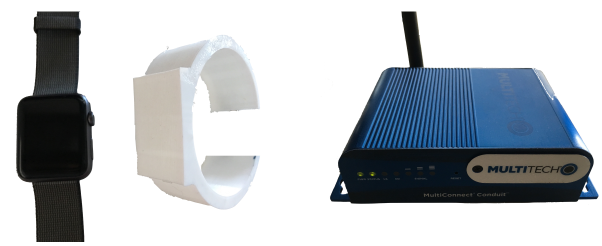
TABLE I: Comparison of power consumption

	Transmit (mA)	Receive (mA)
LoRa	40	10
2G Mobile	240	77
3G Mobile	153	78
4G Mobile	184	93

b) A frequent GPS location updates are not needed to ensure safety of dementia patients: Since we only start worrying about dementia patients when they are approaching the boundary and showing symptoms of wandering away from the safety zone, we can thus choose to turn off GPS whenever we are comfortable with the current location of the dementia patients while still keeping vigilant to trigger the device to work on full throttle when necessary. This dynamic duty cycling strategy helps keep the GPS module working in sleep mode longer and consequently less time in active mode. However, on the other hand, we can not keep the GPS module in sleep mode too long, because this will affect the duration required, i.e. GPS lock time (t_l), to get a geolocation from satellites when switched to active mode. This is because in order for the GPS Module to calculate its current location, it needs to know both the location of satellites (Loc_s) and the last location of itself (Loc_l). Specifically, the value of t_l is affected by the knowledge of Loc_s and Loc_l and can be categorized into three types:

- **Hot start**: With a short period in sleep mode, both Loc_s and Loc_l are still valid and will lead to a smallest t_l.
- **Warm start**: A longer period in sleep mode, usually forcing updates of Loc_l, thus results in a larger t_l.
- **Cold start**: The long time in sleep mode make both Loc_s and Loc_l invalid. The GPS module needs to download all necessary information from satellites with an extremely small data rate (50 bps) [10], therefore t_l will be the largest.

Motivated by the aforementioned two observations, we propose a novel LoRa GPS tracker that communicates GPS location data to a LoRaWAN server in real time. The tracker is designed in a compact and lightweight form to reduce obtrusiveness to dementia patients. Figure 2 (a) compares the size of our tracker against the Apple Watch®, with Figure 2 (b) shows the LoRaWAN base station used in our application.



(a) Compare the size of our tracker against Apple watch

(b) LoRaWAN Base Station

Fig. 2: The LoRa GPS tracker and LoRaWAN base station

To achieve maximum battery life of the tracker, we compare and choose modules with possible lowest power consumption in active and sleep modes, as listed in Table II. Although the LoRa communication module still consumes most energy, it is on average only $1/6$ of a GSM module.

TABLE II: Power consumption of electrical modules

Part	Active Current (mA)	Sleep Current (mA)
Microcontroller	3	0.051
GPS	25	0.01
LoRa	40	0
Accelerometer	0.024	0.001
Magnometer	0.06	0.001

Figure 3 (a) illustrates the final design of the board. We selected a micro-controller (MCU) from Silcon Labs® which is small enough to fit in the wristband and also has low power consumption. Our GPS is an all-in-one module with an internal Antenna and embedded amplifiers. This allows the antenna to be situated within the wristband tracker rather than relying on an external one. The LoRa module is from HopeRF®, which can easily fit in the wristband. However in order to work with the LoRaWAN base station, the LoRaWAN protocol had to be implemented for the MCU. Note that at the time of our system design, we could not afford to use any LoRaWAN module due to its large size, however we noticed that there will be some much smaller LoRaWAN modules available soon, such as the one from

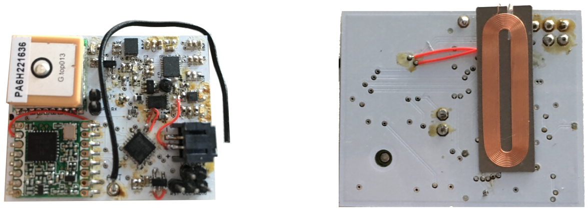


Fig. 3: LoRa GPS development platform

Murata® [11]. This can be considered a replacement in the next version of our tracker.

We also include low power Inertial Measurement Units in our wristband tracker, an Accelerometer and Magnometer that are to be used for location estimation and to assist with the dynamic GPS duty cycling strategy for longer battery life. These units consume only 30uA when sampling at 100Hz, the required rate for accurate location estimation. Finally to simplify battery charging, we added a wireless charging module to the back of the board, as shown in Figure 3 (b). In following sections, we evaluate the effective communication distance and the energy efficiency of our wristband tracker.

III. Range of communication of LoRa

To evaluate effective communication range of our tracker in a real world scenario, we set the tracker to report to the LoRaWAN base station every 5 seconds. Then we walk with the tracker to different directions to find out maximum communication distances around the base station, i.e. where the base station can not receive report signals from the tracker.

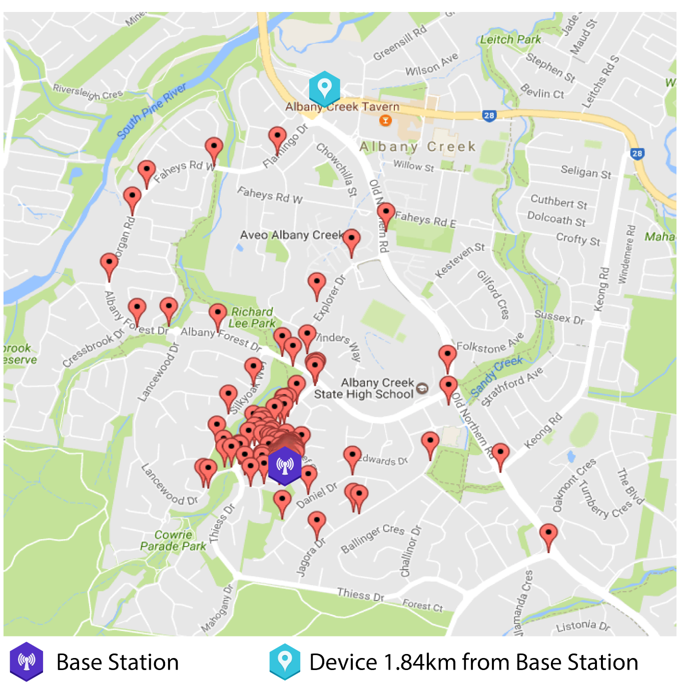


Fig. 4: LoRaWAN range test results

Figure 4 shows our experimental results on a map, with red markers representing locations that can successfully communicate with the base station. To the north of the base station, we can reach as far as 1.84 kilometers communication range. However to the southwest, the communication range is much shorter due to a big mountain blocks LoRa signals. Note in this test, we only use the default indoor antenna. In a more communication friendly suburban environment and with a reasonably good outdoor antenna, the LoRa signal transmission has a high possibility of reaching around 3km [12]. We believe this communication range should be enough to support our dementia patients tracking application.

IV. Energy consumption with GPS duty cycling

We use GPS duty cycling strategy to achieve energy saving in the tracker. Let P represent the total power consumption of the wristband. Let t_s and P_s be the GPS off time and corresponding total power consumption. Let t_l and P_l be the GPS lock time and corresponding total power consumption. And finally we define E_{LoRa} as the system's total energy consumption when the LoRa module sending location information back to the server. We can then model the total power consumption of the wristband in Equation 1:

$$P = \frac{P_s \times t_s + P_l \times t_l + E_{LoRa}}{t_s + t_l} \tag{1}$$

As discussed that values of t_s can affect t_l, we conduct experiments by setting t_s randomly between 1 to 600 seconds. Then we switch the GPS module to active mode and record the different lock time t_l. Figure 5 illustrates the results of $\{t_s, t_l\}$ pairs and shows a strong linear correlation between t_s and t_l. In our test, we have

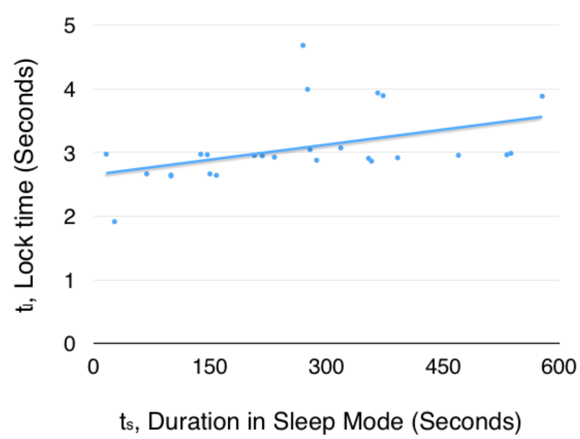


Fig. 5: Time to lock experiment results

$$t_l = 0.0016 * t_s + 2.6519, \tag{2}$$

with *p-value*< 0.02. Note that similar linear relation between the sleep time and lock time in other GPS modules was also observed in [13].

Replacing t_l with t_s in Equation 1, we can simplify it to:

$$P = \frac{f(t_s)}{g(t_s)} = \frac{f_1}{g_1} + \frac{f_0/g_1 - f_1 g_0/g_1^2}{t_s + g_0/g_1}, \tag{3}$$

where f and g are both linear functions of t_s:

$$f(t_s) = f_0 + f_1 * t_s$$
$$g(t_s) = g_0 + g_1 * t_s$$

From Equation 3, we conclude that

$$\lim_{t_s \to \infty} P = f_1/g_1,$$

which is the minimum power required for our wristband tracker. For our prototype, we measure that $f_1/g_1 = 1.7$. Consequently Equation 4 shows the final power consumption model as:

$$\frac{1}{P - 1.7} = a * t_s + b, \quad (4)$$

where a and b are coefficients.

In our experiments, we measure average system power consumption P with different t_s values, and then use the linear regression model to determine a and b in Equation 4. Specifically the wristband was programmed to run the GPS module in sleep mode for t_s, before switched to active mode and sent back the location information through LoRa. As soon as it finishes data transmission, it is switched to sleep mode again for another t_s. During this procedure, we can measure the corresponding average total power consumption P as shown in Figure 6. We also show estimated power consumption from our model, with a=0.004 and $b = 0.03$, and *p-value*$< 10^{-4}$.

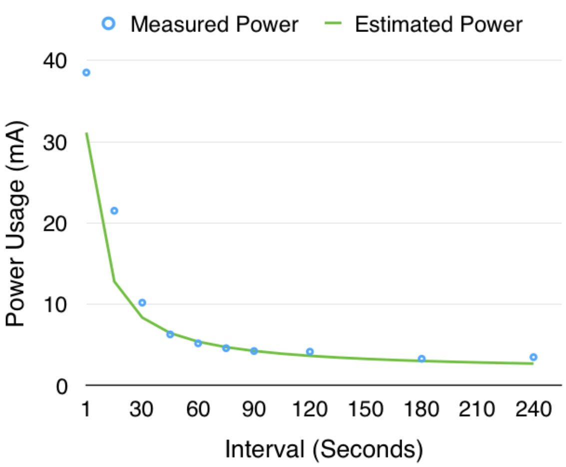


Fig. 6: Model and Measured power comparison

Let S be a GPS duty cycling strategy including a sequence value of sleep intervals s_n, i.e.

$$S = (s_n), n \in \mathbb{N}.$$

The total energy consumption of the wristband E can be finally computed as:

$$E = \sum h(s_n) * s_n$$

Considering the 220mAh battery used in our wristband tracker, if we assume a GPS duty cycling strategy with a fixed sleep interval s_n, then $s_n = 30sec$ leads to 30 hours battery life and $s_n = 240sec$ will push the battery life to 70 hours. Assuming a daily average of 4 hours outdoor activity of dementia patients, the wristband can thus support continuous GPS tracking up to 18 days. Alternatively we can also choose an adaptive GPS duty cycling strategy which only activates GPS module if the estimated future locations will be outside a preset safety zone. This will usually ensure even longer battery life of continuous GPS tracking [13].

V. Discussion and Future Works

In this paper, we discussed building an energy efficient LoRa GPS wristband tracker for dementia patients through leveraging the low energy consumption of the LoRa communication module and the GPS duty cycling strategy. LoRaWAN is becoming more prevalent due to its low power usages and long range data transmission. Moreover the range of LoRa communication will be extended greatly in the future with more base stations being constructed[14].This ensures greater flexibility and safety of dementia patients, which also gives peace of mind to the caregivers.

For future implementations, we will integrate the LoRaWAN module to replace the existing LoRa module to increase the stability of the system and also reduce the wristband's size. We will also investigate accurate location estimation technologies through on-board IMU units to further extend the battery life under continuous GPS tracking model.

Ethics Approval

The real-time LoRa GPS tracker data was obtained with ethics approval from CSIRO Health and Medical Human Research Ethics Committee - Proposal LR 2/2017.

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