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Developing a Human Motion Detector using Bluetooth Beacons and its Applications

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Abstract

A human motion detector is needed for the device-free localization. Mainly infrared light and ultrasonic waves are considered as human motion detectors, but they have problems. These devices have positioning restriction due to their power supplies and its may irritate monitored people. We developed a motion detector based on the attenuation of Bluetooth signals within the 2.4 GHz band, by focusing on water. Our motion detector solves the key problems by the characteristic of Bluetooth beacons, which have long life without exchange their batteries and Bluetooth signals through any obstacles. We experimented with the attenuation of the Bluetooth signals and applied the motion detector to a remote elder care support system. Then we concluded that Bluetooth can be used for motion detectors. We also discuss our motion detector in comparison with others.

Keywords: Bluetooth, Device-free Localization, Motion Detector, Remote Elder Care, RSSI

1 Introduction

It is difficult to keep a track of elderly people because they forget and hate to carry positioning devices. So a human motion detector (hereinafter referred to as motion detector) is needed for device-free localization (DFL). Infrared light and ultrasonic waves are normally used as motion detectors, but they have problems with the positioning restriction due to requiring power supply and the loathsomeness of holding nude sensors. As will be described in detail below, our motion detector uses the attenuation of Bluetooth signals. Since a human body is about 60% water, it absorbs signals in the 2.4 GHz band. A Bluetooth beacon is a new positioning device that uses Bluetooth 4.0 (also called Bluetooth Low Energy). If received signal strength indication (RSSI) dips below a certain threshold, the system detects that a subject is near the devices.

We developed a DFL motion detector using Bluetooth beacons [1, 2]. We performed additional experiments and evaluations. We discuss the developed motion detector in comparison with other sensor devices. We developed the motion detector on mobile devices that is based on DFL using Bluetooth to better monitor people. Our motion detector includes two advantages. First, the motion detector can be installed flexibly to be covered from

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people. It is possible to locate Bluetooth beacons by utilizing a characteristic of Bluetooth signals that pass some obstacles. This feature supports to reduce a burden of elderly people and protects their privacy because they may hate being watched. Second, Bluetooth beacons work by small batteries because its transmit small data packets including only some IDs. It is easy to maintain a system with the motion detector because Bluetooth beacons drive for several years without exchange batteries. We applied its to a remote elder care support.

This paper is organized as follows. Section 2 describes the proposed method using Bluetooth beacons. We applied the motion detector to a remote elder care support system that is discussed in Section 3. We experimented with the accuracy of the motion detector to find a medium smooth for a given time window in Section 4. Section 5 provides the related works concerning DFL and remote elder care. Section 6 discusses our motion detector in comparison with others. Finally, we conclude this paper in Section 7.

2 Human Motion Detector based on Bluetooth Beacons

In this section, we first describe the human motion detection approach using Bluetooth beacons. Second, we show the results of a preliminary experiment, which improved the dispersion of the RSSI value.

2.1 Human Motion Detection using Bluetooth Beacons

Water, glass, and other methods can absorb Bluetooth signals, although these signals do penetrate through plastic and other materials. An ordinary system requires the removal of water and glass as they may prevent wireless connections. The human body is about 60% water and they obstruct Bluetooth signals. When a person is standing between a Bluetooth transmitter and receiver, the RSSI decreases. Consequently, we can use Bluetooth beacons to determine the attenuation of RSSI and achieve localization without carrying devices.

If Bluetooth devices are set within 1 m, a receiving device measures about a $-50\ dB$ RSSI from the Bluetooth signal. When a person stands between the devices, the signal is not completely shielded, because Bluetooth signals are omnidirectional. However, the RSSI decreases and the dispersion of the RSSI distribution increases. As a result, the motion detector can discriminate that a person is between the Bluetooth devices.

There are several advantages of using this method. First, there is no need for people to carry Bluetooth devices. This is especially suitable for elderly people because they often forget to carry devices. No other sensor devices are required in the method. General smart devices can even be used as motion detectors. On the other hand, there is also a disadvantage. It is lower accuracy compared with ordinary motion detection based on Bluetooth. We tried to improve this problem.

The dispersion of RSSI increases when a person is present. Therefore, there is a possibility for errors due to RSSI variation, and this may cause the motion detector to determine that a person is present when that is not the case. Thus, we used the averaged value from some samples taken at the last minute. The system measures the RSSI at intervals of a second: it is $RSSI(t)$ at time t. We defined $AVG(t,T)$ as the average samples for T seconds from time t using the following equation. We observed a change in the RSSI when a person came between the Bluetooth devices. We compared the obtained RSSI when a person was present and when a person did not have a threshold value θ. If $AVG(t,T) < \theta$, we determined that a person was present.

$$AVG(t,T) = \frac{1}{T}\sum_{\Delta t=0}^{T-1} RSSI(t-\Delta t) \tag{1}$$

2.2 Preliminary Experiment

We performed a preliminary experiment to measure the attenuation of the RSSI by a human. In particular, we examined the change in RSSI caused by the presence of a human body. The experimental environment is classified in Table 1. The experiment was conducted in a meeting room (6 m $\times$ 10 m). We used a Bluetooth beacon as the transmitter and a note PC as the receiver. The Bluetooth beacon was a MyBeacon MB004 manufactured by Aplix, and the note PC was a MacBook Pro Retina 13 manufactured by Apple. The distance between the devices was 1 m, and there were no obstructions between them. Each device was set at a height of 1 m from the floor, and the subject was a male in his 20s and was 170cm tall.

We decided on the value of θ to identify the person's state as either existing or non-existing for the calibration of the RSSI. First, we measured the value of the RSSI when no subject was present between the devices (R_N). Next, we measured it when the subject was present between them (R_E). Figure 1 shows the distribution of R_E and R_N, which is the subject's distribution smoothed by a time window of three. The horizontal axis of the graph shows the RSSI; the vertical axis shows the frequency probability by the RSSI. We averaged the RSSI values and set θ to $-57.7\,dB$ to divide these cases.

However, there is a miss detection like this, and to prevent it, we smoothed the RSSI by using equation 1. Figure 2 (a) shows a graph of the measured RSSI that was smoothed by $T = 1$ and $T = 5$. The graph shows a fluctuation in the RSSI when the subject does not exist within the experimental place. The horizontal axis indicates the measured time; the vertical axis indicates the RSSI values. Figure 2 (b) shows the change in the variance of the RSSI with an increase in T. The horizontal axis indicates the Time window and the vertical axis indicates the variance in RSSI. The variance decreases with an increase in the time window.

Table 1: Experimental environment.

Experimental Factors	Information
Size of experimental room	6 m $\times$ 10 m
Transmitter	Aplix, MyBeacon MB004
Receiver	Apple, MacBook Pro Retina 13
Programming Language	JavaScript

3 Application: Remote Elder Care Support System

We applied the motion detector to a remote elder care support system. First, we describe the outline of the system. Second, we explain the system architecture and implementation. We call elderly people care receivers and their children caregivers in this paper.

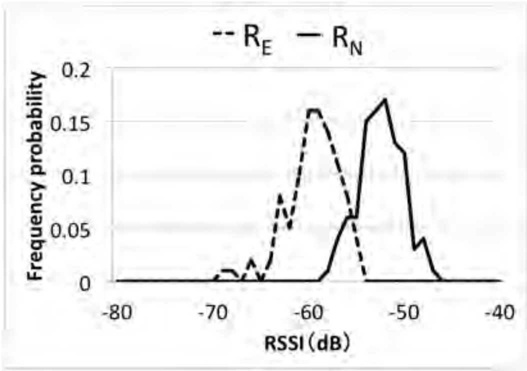
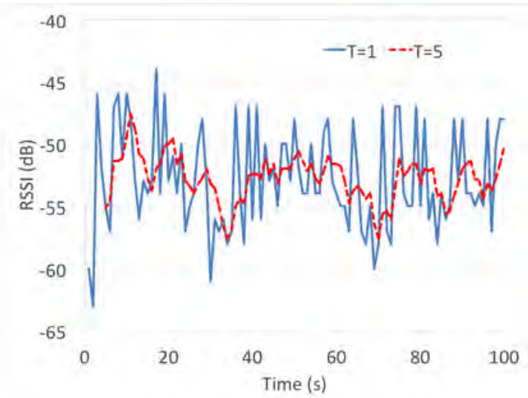
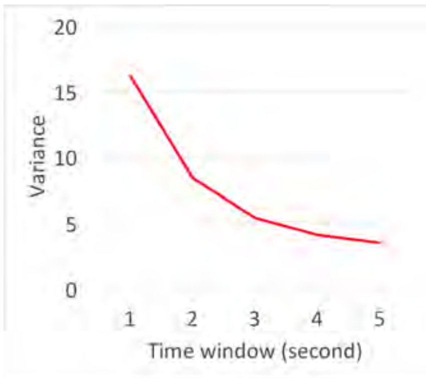


Figure 1: Frequency of RSSI.



(a) Measured RSSI.



(b) Change of variance.

Figure 2: Smoothing of RSSI.

3.1 Outline of the Application

In this case, we assume that care receivers living separate from their caregivers take medicines at a particular location. The system intends to identify when a care receiver has missed a dose and send a notification to a caregiver. We used two iPads for a care receiver and a caregiver. The system estimates that a care receiver missed a dose if the system could not detect them. If this occurs, the system notifies a caregiver. Table 2 shows the implementation environment of the system. Although we used iPads in this study, iPhones or other devices may be used in the future; this system is independent of specific devices.

Many people on medication use a special calendar that manages their dose schedule (called a medicine calendar) to help them remember the dosage time or amount. However, the medicine calendar only works if a person remembers to check it. In this study, we support the dose to monitor whether a care receiver exists near the medicine calendar. The system supports the right dose to make sure that medicated people take the correct dose because they may forget their dose.

Our proposed system addresses three important needs. First, it addresses the difficulty of making care receivers always carry positioning devices. It is difficult for dementia patients to develop new habits such as carrying devices. Second, it addresses the need for the system to be easy. For example, the system needs to be installed by a non-specialist. Third, the system does not irritate care receivers, because it does not encroach on his or her life. As noted above, this is a real problem; when care receivers find that devices encroach on their lives, they may discard or avoid using these devices. The system uses Bluetooth beacons on devices that are already set within the care receivers' home. The only required installation and maintenance activities are to update the software. Bluetooth beacons are low-energy, inexpensive, and have long battery lives. Furthermore, Bluetooth beacons can be set up where the care receivers cannot find them.

Table 2: Implementation environment.

Experimental Factors	Information
Bluetooth Beacon	Aplix, MyBeacon MB004
Receiving Device	Apple, iPad Air
OS	iOS 8.1.3
CPU	Apple A7 (1.3 GHz)
Memory	1 GB
Programming Language	Objective-C

3.2 System Architecture and Operational Method

The iOS application detects if a care receiver is present in front of an iPad using the device's Bluetooth function. Figure 3 shows the system architecture. The Bluetooth beacon transmits a signal containing a unique ID, and the Bluetooth receiver measures the RSSI of the appropriate signal. As previously noted, the RSSI is constant if there are no obstructions between the devices. If someone is present between the devices, the RSSI will decrease. Therefore, when the measured RSSI falls below a set threshold value, the iPad transmits the unique ID to the server and the system executes the processing as per the received ID. For example, it sends a message to a care receiver and a caregiver device. A care receiver's device starts recording using its camera and transfers these data to the server. A caregiver can view the video data on his or her device in almost real time. The system also sends a message to both devices showing the last dose time to help prevent a care receiver from forgetting or repeating a dose.

A Bluetooth beacon is set on the medicine calendar and an iPad is set facing toward the medicine calendar. In this environment, the distance between the Bluetooth beacon and the iPad is about 1 m. The system does not detect a person when he or she only passes in front of the medicine calendar. It detects a person only if he or she remains there for a few seconds.

A client for a care receiver is sets at a care receiver's house and receives the Bluetooth signal from the Bluetooth beacon. When the system detects a care receiver using the detection structure, a client starts to record from the front camera on the iPad. If the data line at a care receiver's house is slow, a client converts the video data into image data and uploads them every second. Since care receivers do not need to operate the device, it contains only the above-mentioned function.

When a client for a care receiver detects his or her presence at the medicine calendar, a client sends an alert and notification through the server to a client for a caregiver. The caregivers can check the state of a care receiver on the video or images or they can set up the time when a care receiver usually doses. If a client for a care receiver does not detect a care receiver at the medicine calendar at that time, a client sends a notification to a caregiver's device.

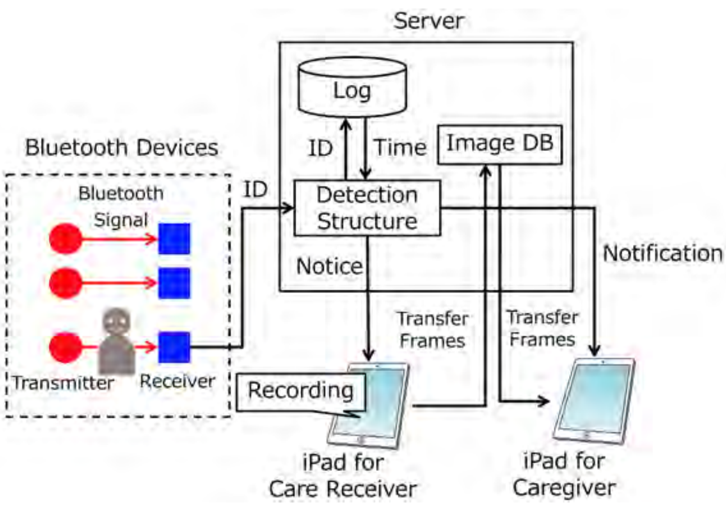


Figure 3: System architecture.

4 Evaluation

To apply our motion detector to a remote elder care support system, it is necessary to improve the precision of human detection. RSSI contains a fluctuation from surround environment, so we smooth RSSI to set a time window. We performed experiments to measure the accuracy of human detection by focusing on the window size and the distance between a transmitter and a receiver. The experimental result shows that our system can detect a person to the accuracy of 90% by calibrating for more than 3 s as the window size, and there is the accuracy of 80% when a distance between devices is less than 3 m. In this section, we explain the experimental environment and calibration method for detecting the attenuation of the Bluetooth signals by a human body. The experimental environment is the same as Table 1 in Section 2. The subjects were six males in their twenties, who are 170–180 cm in height. In this experiment, we measured the RSSI 100 times when there was the subject between the Bluetooth devices. Next, we calculate θ from the average of the RSSI when the subject does and does not exist. We confirmed a change in the detection rate with a time window using equation 1.

The detection rate is the percentage of the system's success in detecting subjects or lack of subjects (i.e., in the case of R_E, the detection rate is the percentage of correct detections when the subject is present, and in the case of R_N, the detection rate is the percentage of correct detections when the subject is not present).

Figure 4 shows the detection rate with a T of 1–5 s. The horizontal axis of the graph is time window T; the vertical axis is the detection rate. The results show that the detection rate rises with the window size. In particular, the detection rate is more than 90% when $T \geq 3$ for four of the subjects. We believe that body composition and worn metals influence the detection rate. Moreover, a T of more than 3 s can decrease the number of errors in the Bluetooth signal. Therefore, the motion detector discerns subjects with higher accuracy from a smoothed RSSI. In this experiment, the system can discern the subject by measuring for 3 s. When a care receiver takes their doses, he or she is likely to remain near the medicine calendar for more than 3 s. Therefore, we consider that an effective method for use with our motion detector.

In the experiment about the distance of devices, we set person A who is a man in his twenties as the subject and the time window was set 3 s. Figure 5 shows the detection rate with a distance between Bluetooth devices of 1–5 m. The horizontal axis of the graph is the distance of devices. the result shows that the detection rate decrease with increase of the distance. However, the detection rate keeps 80 % or more within 3 m. We consider that we can apply the system to a room which has suitable area. To expand the application area, we need to improve its detection rate by alternative method when a distance of devices is 4 m or more.

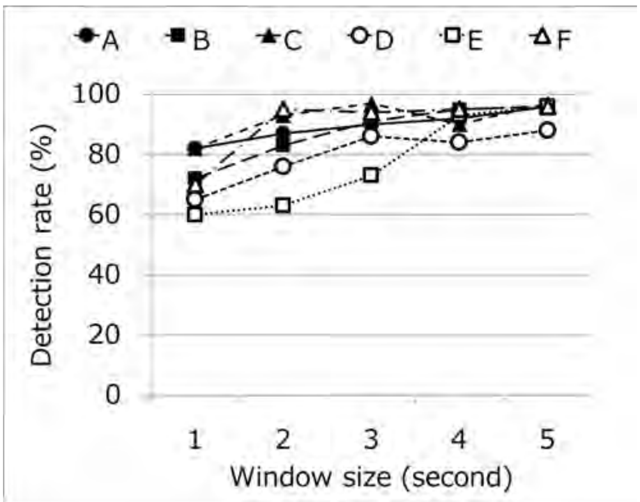


Figure 4: Evaluation result: time window and detection rate.

5 Related Works

We summarize our information concerning other motion detectors, Bluetooth beacons, and an existing remote elder care system.

Outdoor positioning is very popular because many contemporary smartphones have GPS functions [3]. However, GPS is not suitable for indoor positioning because buildings are obstacles. Wi-Fi, Bluetooth, infrared light, ultrasonic waves, and similar methods are used for contactless indoor positioning [4, 5]. Fingerprint methods use received radio field strengths from Wi-Fi, Bluetooth, and so on. They are based on a radio field strength maps that contain the RSSI at points within a room [6]. The RSSI of a target device is compared with the RSSIs of points within a radio field strength map. The DFL technique has garnered considerable attention as an emerging technique with promising applications. A significant

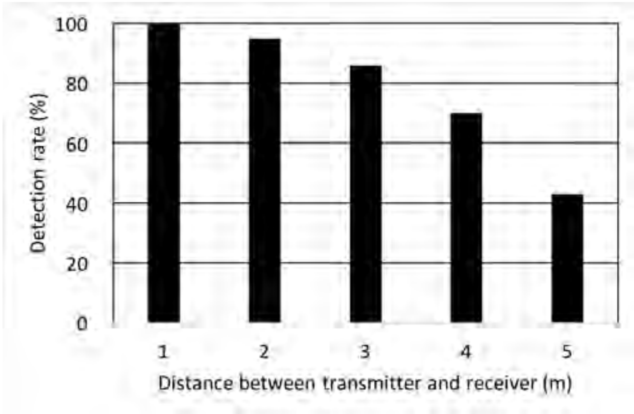


Figure 5: Evaluation result: distance between devices and detection rate.

point of interest is that it is able to achieve wireless localization without any need for a care receiver to hold or wear a device [7, 8]. The DFL technique detects shadowed links and achieves localization using the Wi-Fi RSSIs [9, 10]. This technique can be applied to aged care for people without smartphones or mobile phones if they have other devices using Wi-Fi or Bluetooth.

Bluetooth is installed on many portable devices and is the prevailing technology for radio communications. Its growing prevalence will make it possible to expand the range of applications with positioning by Bluetooth. Bluetooth Beacons are the prevailing positioning device using Bluetooth 4.0 [11]. Positioning with Bluetooth uses the RSSI between fixed and moving devices to estimate the distances between them. A Bluetooth device periodically transmits packets of data that contain information to detect devices. Bluetooth beacon devices have two advantages—low cost and long battery life. The price of Bluetooth beacons is normally 3–10USD. The battery life of a Bluetooth beacon is a few years. Therefore, it is possible to set up a system and install many beacon devices at a low cost. However, in general, positioning with Bluetooth beacons requires the subject to carry a beacon device. This is the problem with elder care, because people with dementia often forget to carry positioning devices. We propose using the attenuation of the RSSI by human bodies to achieve localization to resolve this problem.

In traditional remote elder care support systems, caregivers monitor care receivers using a RFID tag [12]. Some systems are developed using sensors like the fall detection system to detect any abnormalities with a care receiver [13]. Caregivers can monitor the behaviors of care receivers using indoor sensor data. However, this method requires care receivers to be equipped with positional devices. They may be inconvenienced or may forget to do so. The DFL technique overcomes these disadvantages. In remote elder care situations, caregivers and care receivers may have different demands. For example, caregivers may wish to improve the life quality of care receivers by monitoring and communicating with them. However, care receivers may be irritated by changes in their living environments. Thus, elder care support systems need to minimize the elements that can irritate care receivers.

6 Discussion

Our method does not require care receivers to be equipped with positioning devices. Hiding the Bluetooth beacon from care receivers is easy, because it is very small and can be set flexibly. Therefore, care receivers do not have to change their lifestyles. As shown in Figure 4, the method that uses samples within T seconds can accurately detect a care receiver. When a care receiver repeats a dose, there can be a health risk involved if this scene is not recorded and communicated to a caregiver. Thus, it is more important not to miss dose than to incur excess detection. With this method, we prevent the risk to a care receiver by setting up a time window.

Table 3 compares the cost, power source, penetration, and robustness of motion detectors. Bluetooth beacons are easily obtained and low in price. A device equipped with the Bluetooth function can receive Bluetooth signals from the Bluetooth beacons. Therefore, the system can be expanded to encompass more of a care receiver's house by using a number of Bluetooth beacons. In this case, the system determines care receiver's behavior from his or her positional information. The system can also detect if a care receiver is in a difficult situation (e.g., not moving) from this positional information. We selected Bluetooth beacons to expand the DFL method in the future.

Image recognition is also used to detect people. However, there are problems with human detection by image processing. As problems, image processing may rise temperature of its device and a camera may violate care receiver's privacy. Our motion detector does not have such problem because Bluetooth signals contain small data. In remote elder care, going down due to thermal runaway is undesirable. We tried to drive image processing using iPhone 4, a temperature of the device reached 40 °C in ten minutes. Bluetooth beacons transmit small data packets containing unique IDs, then receiving devices process only those received data. Processing those data is simpler than image processing; therefore, the possibility of a system failure is low. Also, Bluetooth beacons can be installed flexibly and can be hidden by elderly people, we consider that our motion detector does not irritate them.

Infrared sensors are popular as a motion detector. It is more accurate at detecting people than a Bluetooth beacon, but it does not pass through material objects, and they need to be seen by care receivers. Like image recognition, care receivers may feel monitored by sensor device. A system using infrared sensors needs to be installed by specialists, but the motion detector proposed in this paper can be easily set up. When a number of motion detectors are set up, Bluetooth beacons can be flexibly arranged.

Ultrasonic sensor is active sensor that transmits ultrasonic waves and receives reflected waves from obstacles. Ultrasonic sensors can measure the distance between itself and an obstacle, and the sensor has high resolution. However, it has the same disadvantages as infrared sensor; ultrasonic waves can not pass through obstacles. When part of the sensor becomes to dirty, the precision of detecting decreases.

Wi-Fi access points are used as DFL when using RSSI. In this study, we assume the installation of motion detectors in a care receiver's house. Multiple Wi-Fi devices are needed to use motion detector through Wi-Fi, but it is difficult to achieve this and flexibly install it. In motion detection using Wi-Fi, there is also a positional restriction because the access points need a power supply, and must connect to a LAN socket. There is also a real problem in that care receivers can find the devices and feel they encroach on their lives, so they may discard or avoid using these devices. Thus, we need to hide sensors from care receivers, and so, Bluetooth beacons are good because they are smaller than Wi-Fi devices.

Table 3: Characteristic of sensors.

Technoloby	Cost	Power Source	Ease of Operation
Bluetooth beacon	Low	Battery	Easy. Beacons run for several years without changing batteries.
Camera	High	Power supply	Laborious. There is possibility of thermal runaway using image processing.
Infrared light	Low	Power supply and battery	Moderate. Specialist is needed to install devices in care receiver's house.
Ultrasonic wave	Medium	Power supply and battery	Moderate. Surface of sensor is weak and become dirty, somebody must clean it.
Wi-Fi	High	Power supply	Moderate. There is restriction of installation due to power supply and LAN sockets.

7 Conclusion

We developed the novel device-free motion detector using Bluetooth beacons. The motion detector uses the RSSI attenuation by a human body to detect a person, and covers the problems with the other motion detectors. Bluetooth beacons have long lives and can be flexibly installed. Bluetooth beacons can be installed to cover themselves, so care receivers do not feel like he or she is being monitored in someone else. Instead of being carried by care receivers, the Bluetooth beacons are set near specific locations to detect care receivers. In this case, the motion detector decides the threshold value for detecting a person based on the RSSI averages. Although the RSSI widely varies based on the environment, we verified that the variations in RSSI can be decreased by setting a given time window. Our experiments showed a detection rate of more than 90% and the accuracy every distance between Bluetooth devices.

Acknowledgements

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