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From the lab into the wild: Design and deployment methods for multi-modal tracking platforms

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ABSTRACT

The high energy consumption of GPS modules has kept long-term outdoor localisation with battery-powered devices an unsolved challenge. While low-power sensors can trigger GPS sampling to reduce energy consumption, validating the long-term reliability of these sensors in unconstrained environments is challenging due to sensor drifts and the lack of ground truth data in the field. We describe the design of our feature-rich platform and our progressive approach for characterising and validating its multiple sensing modalities in long-term deployments. Using empirical data collected from both controlled experiments and wild flying foxes, we characterise the tracking accuracy, wireless connectivity, energy harvesting, and cross-validate sensing modalities against their GPS counterparts. The results show that accelerometer, magnetometer, and pressure sensor can estimate flying speed and altitude well with relatively small errors in the wild. We further study the utility of multi-modal activity recognition under real-world conditions and demonstrate the potential for significantly increased resolution in triggering GPS samples.

1. Introduction

The rapid rate of development of embedded systems technology has led to many new opportunities for monitoring and tracking mobile objects. The accuracy of tracking devices using GPS technology has increased while at the same time these devices have become smaller and consume less energy than the previous generations. Miniaturisation of sensor hardware has allowed to include sensors for multiple modalities in standard mobile phones, which would not have been feasible only a few years ago. Consequently, we have witnessed adoption of these technological advances to build tracking and monitoring platforms that are much smaller while providing increased data yield and more features to facilitate the work of domain scientists. However, for many mobile sensing applications, including tracking of smaller animals at continental scales and wearable sensors for human health services, the requirement for multiple sensing modalities and durable lightweight platforms still presents a major challenge.

The high energy consumption of GPS receivers requires careful duty-cycling of GPS location fixes in order to operate within the limited energy budget. Additional sensing modalities, such as inertial, acoustic, temperature and air pressure sensors, can provide behaviour and activity classification of the tracked object while consuming only a fraction of the

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energy of the GPS receiver. Consequently, we can use a combination of multiple low-power sensors and smart algorithms to maximise the utility of sparse GPS sampling in scenarios where the energy budget is restricted.

Using diverse sensor modalities as GPS sample triggers exposes the problem of uncertainty and imprecision of low-power sensor readings over time and in unconstrained environments. The uncontrolled mobility associated with tracking of humans, animals or objects can also have unpredictable effects on the performance of node components, particularly radio transceivers and sources for energy harvesting. All of the above challenges highlight the need for holistic design of feature-rich mobile sensing platforms with early prototyping to incorporate these subtle dependencies among system components. Careful evaluation of the system components, particularly the low-power sensors that trigger GPS samples, and algorithms for activity detection is necessary to make sure that the system will be able to perform its task when it is deployed and physical access is only limited or even infeasible.

This paper is motivated by the need to track *flying foxes*, also known as fruit bats, which are both essential seed dispersal agents and disease vectors in Australia, Asia and parts of Africa. Studying highly mobile species such as flying foxes requires platforms and algorithms that can deliver position and activity information over long time periods. We present our journey from designing the lightweight and feature-rich Camazotz[1] mobile sensing platform to its progressive validation in controlled experiments then in unconstrained environments. Camazotz combines a 16-bit microcontroller, a short-range wireless transceiver, and multiple sensing modalities such as low power GPS, inertial, acoustic, air pressure and temperature sensors. It is powered by a small and lightweight 300 mAh Lithium-ion battery and uses a tiny solar panel for energy harvesting. The total weight of the platform of around 20 g complies with animal ethics regulations required for tracking of smaller wildlife such as flying foxes.

We previously had described Camazotz and the concept of multi-modal activity detection in an earlier conference paper [1] based on preliminary results from a limited trial with captive animals. The current paper focuses on the process of taking the platform from the design stage in the lab to controlled experiments in semi-realistic environments and on to inaccessible long-term field deployments. We present the system architecture for the flying fox tracking application and the data storage and retrieval methods within that architecture. Most importantly, the current paper draws lessons from over 18 months of deployments of the platform on wild animals to cross-validate the performance of the sensors and propose methods for reliable long-term inertial sensing.

In summary, the contributions of this article are: (1) the presentation of the design and validation approach for a multimodal tracking and sensing platform from the lab to inaccessible long-term deployments and the evaluation of this approach through a case study of tracking flying foxes across the continent; (2) cross-validation of inertial and pressure sensor measurements in the field with GPS and proposal of methods for on-the-fly correction of these sensing modalities for reliable triggering of GPS; and (3) analysis of case-studies for single and multimodal sensor triggering of GPS to highlight energy and accuracy benefits.

2. Tracking of highly mobile and nomadic objects

This section provides an overview on long-term tracking of highly mobile objects. We first briefly highlight the generic design challenges in this area. We then discuss flying foxes as a real-world motivating application for this work, and we elaborate on the design challenges and the progressive design and validation approach in the context of this application. Finally, we present our system architecture for this class of tracking applications.

2.1. Design challenges

Objects that are highly mobile and nomadic in their movement (such as wild animals) are difficult to track over the long term. One challenge is the size and weight constraints of tracking nodes, which in turn constrain the energy supply at the node. In relation to energy efficiency, GPS duty cycling is critical, where GPS sampling times are best determined by low-power sensors. The long-term reliability of the low-power sensors as GPS sample triggers is therefore a key component for the sustainable operation of the system. This long-term sensor reliability requirement exposes the need for a suitable sensor validation process. We now present the problem of tracking flying foxes as a representative scenario for this large class of applications.

2.2. Motivating scenario: tracking and monitoring flying foxes

Flying foxes, also known as fruit bats, belong to the Megabats (Pteropodidae), a suborder of bats that forage from fruits and nectar. Flying foxes congregate in large numbers during the day in so called bat *colonies* or *roosting camps*. At night, they leave the camp and fly to foraging sites up to several kilometres away from the camp. Surprisingly little is known about flying foxes ecology behaviour due to difficulties associated with studying animals that are nocturnally active and which roost in large aggregations (often 40–50 000 animals at a single site [2]). Studies show that individual animals are highly mobile,

[1] Camazotz was a bat god in Mayan mythology.