Pseudoseeds: Investigating Long-Distance, Ocean Seed Dispersal with Wireless Sensors

Ryan N. Smith, Peter Prentis, Koen Langendoen and Peter Corke

***Abstract*— Recent theoretical research has shown that ocean currents and wind interact to disperse seeds over long distances among isolated landmasses. Dispersal of seeds among isolated oceanic islands, by birds, oceans and man, is a well-known phenomenon, and many widespread island plants have traits that facilitate this process. Crucially, however, there have been no mechanistic vector-based models of long-distance dispersal for seeds among isolated oceanic islands based on empirical data. Here, we propose a plan to develop seed analogues, or *pseudoseeds*, fitted with wireless sensor technology that will enable high-fidelity tracking as they disperse across the ocean. The pseudoseeds will be precisely designed to mimic actual seed buoyancy and morphology enabling realistic and accurate, vector-based dispersal models of ocean seed dispersal over vast geographic scales.**

I. INTRODUCTION

The seminal book *The Dispersal of Plants Throughout the World* was published by Ridley [14] over 80 years ago, yet we still know remarkably little about patterns of long-distance seed dispersal among isolated oceanic islands [12]. Dispersal of seeds among isolated oceanic islands, by birds, oceans and man, is a well-known phenomenon [11] and many widespread island plants have traits that facilitate this process. For example, ocean dispersal is responsible for over 78% of plant colonists arriving on the volcanic island of Surtsey [8], highlighting the importance of this vector for island colonization. Although we know that buoyant seeds of many coastal plants have dispersed long distances to colonize isolated islands, remarkably little is known about long-distance seed dispersal in oceanic environments [12].

Recent theoretical research has shown that ocean currents and wind interact to disperse seeds over long distances among isolated landmasses. Crucially, however, there have been no mechanistic vector-based models of long-distance dispersal (LDD) for seeds among isolated oceanic islands based on empirical data. Currently, it is only hypothesised that LDD in the ocean can be represented as a fat tailed dispersal kernel as shown in Fig. 1. Note that the a significant number ($> 80\%$) do not disperse a distance of more than 10 m, implying that only a small percentage of dropped seeds make it off the beach. Further, the ”fat tail” of the dispersal may only comprise 1% of the total dropped seeds, but

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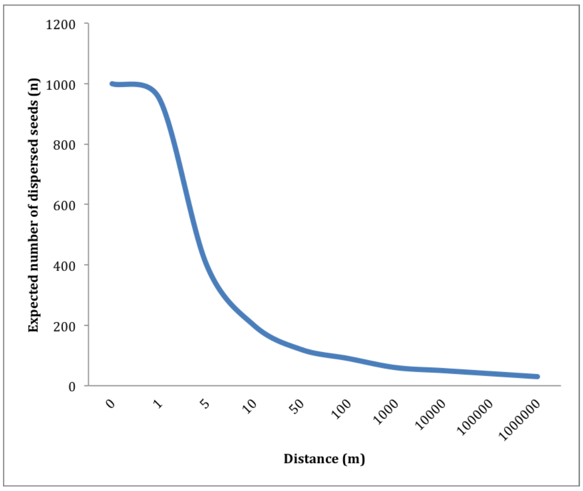

Fig. 1. A stylized representation of a fat tailed dispersal kernel for seeds of coastal plants that remain buoyant for long time periods immersed in seawater. The vectors that displace seeds in the ocean are surface currents and wind.

this percentage remains constant after a threshold distance. Such data is difficult to obtain because 1) LDD is rare and stochastic in nature [3], and 2) reconstructing past patterns of LDD is difficult in most organisms [6]. Drift bottles and drift cards have been used to study ocean currents as analogues for plant dispersal in oceanic environments, but suffer from a number of major limitations [7]. These limitations include a lack of information on which specific dispersal route a seed took, as only the points of release and stranding are known. A second limitation is that drift cards and bottles need to be found to provide data on where they strand, an unlikely situation if they wash up on isolated coastlines. The third major limitation is that drift bottles and cards are very different from seeds, both in terms of morphology and buoyancy as well as how they are released into the ocean. Here, we propose a way to circumvent these limitations and directly estimate a mechanistic vector-based model of seed dispersal in ocean waters.

We plan to develop seed analogues, or *pseudoseeds*, fitted with wireless sensor technology that will enable high-fidelity tracking as they disperse across the ocean. The pseudoseeds will be precisely designed to mimic actual seed buoyancy and morphology enabling realistic and accurate, vector-based dispersal models of ocean seed dispersal over vast geographic scales.

In the remainder of this paper, we will first outline the dispersal experiment in Section II. Then, we will discuss the WSN technology available for building pseudoseeds (Sec-

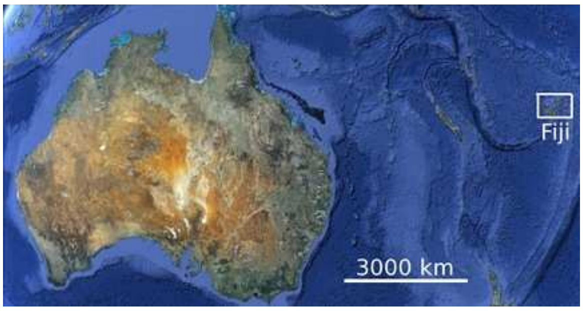

Fig. 2. The geographic location of Fiji relative to Australia, and the scale of the proposed seed tracking experiment. The primary landing location for the seeds is along the northeast coast of Australia.

tion III) and their use in monitoring the dispersal by ocean currents and wind (Section IV). We conclude in Section VI with a brief discussion of the feasibility of the WSN-based approach versus the use of standard satellite-based tracking devices.

II. Problem Formulation

Despite recent progress towards understanding patterns of long distance seed dispersal in terrestrial environments, relatively little headway has been made in estimating patterns of long distance seed dispersal in marine environments. Tracking seeds over vast spatial and temporal scales between their source and where they are finally deposited is the major logistical problem that has impaired progress toward developing realistic models of seed dispersal in oceanic environments. In order to overcome this challenge a multidisciplinary approach is required to develop ways to track seeds or biologically realistic pseudoseeds in seawater over long time periods (12 months) and large distances ($>$ 3000 km). The ability to track seeds from initiation to termination of dispersal will enable the estimation of a general mechanistic model of seed dispersal by ocean currents.

A. Geographic Location

This project will focus on seed dispersal in the southwest region of the Pacific Ocean. Primarily, we are interested in the transport of seeds between Fiji and Australia. Figure 2 shows the relative locations of Fiji and Australia, and provides the spatial scale of the proposed tracking experiment. The aim of this project is to release the pseudoseeds in Fiji during the appropriate time, and track them, hopefully along with other *real* seeds, across the southwest Pacific to the shores of Australia. This will be the first such demonstration of ocean seed dispersal tracking.

B. Seed Specifics

The coconut palm, Cocos nucifera, will be used as a model to develop pseudoseeds. The coconut is a range expanding species commonly found throughout the Pacific and Indian oceans. Seeds of the coconut palm remain positively buoyant and viable in seawater for extended time periods and commonly disperse to the Australian east coast, and Great Barrier Reef islands from the southwest Pacific. The coconut palm seed was also chosen as the pseudoseed model to allow for maximum size and payload capacity of a realistic seed to be tracked through the ocean. The details of an average coconut palm seed are presented in Table I. In particular, the large size provides adequate space for the electronics, and the weight allowance allows for a reasonable size battery to extend the deployment life for as long as possible. Depending on the exact route, currents, and wind speed, the pseudoseeds could take from four months to over a year to travel from Fiji to Australia.

TABLE I
Main ocean seed parameters.

weight	1.5 kg
size	
- length	30 cm
- max diameter	12.5 cm
dispersal speed	0.1 - 0.4 m/s

III. Pseudoseed Concept

The ongoing trend in miniaturization of digital circuitry has opened up the possibilities for in-situ sensing at high temporal and spatial resolution by means of deploying cheap, autonomous sensor nodes configured in a wireless ad-hoc network. Once a fantasy (Smart Dust [9]), now a reality with ever-more successful deployments of Wireless Sensor Networks (WSNs) [2], [5], [13]. We plan to capitalize on this development by utilizing pseudoseeds equipped with WSN technology, such that we can track their whereabouts for up to a year. In particular we will include the following components:

- **Battery** To keep the design of the pseudoseeds as simple as possible, they will be powered by means of a battery; the alternative of using solar power would include additional charging circuitry as well as battery, and introduce uncertainties as the energy harvesting may be compromised by befoulment.
- **GPS** A GPS unit will be used to record the actual location of the pseudoseed during its time out on the ocean. As GPS is a notorious consumer of energy, we will drive it to only take one reading per day.
- **Low-power radio** At some point the logged GPS data must be off loaded, and doing so wirelessly is convenient. It also allows for remote data collection, for example by a UAV, avoiding the need for physical recovery and offers the possibility for online tracking. As for the GPS, the radio must be duty cycled to avoid draining the batteries, a well researched topic with the WSN community [1], [10].
- **Accelerometer** Wireless communication goes best with a direct line of sight between sender and receiver. Since pseudoseeds travel on the ocean surface, it pays off to exchange messages when being on top of a wave, something which can easily be derived from accelerometer data.
- **Satellite modem** Although expensive, the Iridium satellite network provides true global coverage and is the

only option for pseudoseeds to report their trajectory while far out on the ocean. The form factor (20 cm^3) and power consumption (300 mA) make modern satellite modems a viable option, but raises the unit and operation costs considerably (cf. Section IV). Alternatively small low-power Argos tags could be used that are tracked by the Argos satellite network, and can additionally upload short messages. However the cost of these tags is high (cf 2000USD) as is the communications cost (cf 1500USD per year).

- **Processor** A simple microcontroller is required to orchestrate the periodic logging of GPS positions and communication with the outside world. As most time will be spent doing nothing, it is important that the processor can be put in a deep sleep consuming near-zero power.

These components will be fitted in a waterproof enclosure, roughly the shape and size of a coconut. The weight of a pseudoseed needs to be carefully set to get the right buoyancy, and basically determines the size of the battery pack that can be included. Following the parameters provided in Table I we can expect a pseudoseed to carry a payload of about 500 grams, of which about half (250 g) can be reserved for the battery. Using plain alkaline batteries that weight translates into a 30 Ah energy storage capacity, or roughly 80 mAh a day when targeting a lifetime of one year.

GPS units can take anywhere from a second to a minute to acquire a position, depending on the number of satellites in view and the movement of the device since the last reading. As pseudoseeds travel about 10 - 30 km a day, and we only take one reading a day it is highly likely that the GPS will go through a ‘cold start’ every day consuming about 1 mAh (= 60 s $\times$ 50 mA). Note that this cost is insignificant to the complete daily budget, that is, GPS consumes only about 1% of the total available energy budget, indicating that basically all energy can be spent on the communication part of the pseudoseeds, which is the key to successful operation as explained below.

IV. PROPOSED SOLUTION

As an alternative to the readily available satellite tag technologies we propose a solution to monitoring of ocean seed dispersal that uses both wireless sensor network (WSN) and robot technologies. A number of WSN-based pseudoseeds, set to log their position once a day, will be dropped off the coast of Fiji at the start of the experiment. Some of these will be deployed to the ocean, but the vast majority will quickly return to shore. These pseudoseeds must be located and collected as to provide empirical data about the bulk of the dispersal distribution, i.e. the left part of the curve in Figure 1. After physically recovering these short-lived pseudoseeds, they can be redeployed and the experiment repeated. This will provide rich statistical data about the probability of the seeds leaving the coast, based on a sample size that is some multiple of the actual number of pseudoseeds that are built. The devices that leave the coastal region and drift out to sea will eventually reach landfall at a time and position that must be determined.

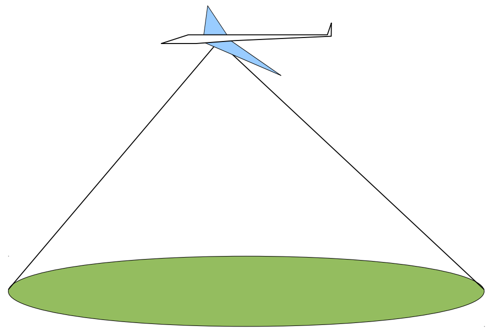

Fig. 3. Aerial locationing of pseudoseeds

A key part of the recovery strategy is that the pseudoseeds (or nodes in WSN speak) broadcast their GPS location, either periodically or in response to a challenge that is detected by a duty-cycled radio receiver. Modern, popular 802.15.4 transceivers such as the CC2430 have identical power consumption for receiving and transmitting (27 mA), so the simplest solution is to periodically broadcast location, rather than periodically enabling the receiver and broadcasting position in response to a challenge. Link level acknowledgement would be used to ensure that the node knows that its message has been received. A GPS measurement comprises 8 bytes of data (timestamp + position), so an 802.15.4 payload of 127 bytes can easily hold 14 GPS readings (from the most recent two weeks) plus device status information.

Communicating the location of the pseudoseed facilitates recovering those that return to shore and also in tracking those that drift out to sea. The shore recovery problem is easiest since it involves searching a bounded strip of coastline either side of the release point. Nodes would detect that they have been beached through the absence of motion detected by their accelerometers, and include this status in their broadcast messages. Beached nodes may increase their broadcast interval since energy considerations do not apply – they could have new batteries fitted before redeployment. A spectrum of beach recovery options are possible. The simplest is to drive along the beach, listening for messages from stranded nodes and using a GPS navigation system to drive toward the node. Alternatively an aircraft (manned or UAV) could fly along the beach and collect location data [16] from beached nodes, and this would be used to plan an efficient and targeted ground recovery mission.

Determining the eventual landfall for the pseudoseeds that drift to sea is a very difficult problem since the potential search area is massive. However they need to be found quickly after landfall since they will slowly become buried and unable to communicate. The most feasible way to solve this problem is to track the pseudoseeds while they drift in the ocean away from the release point. Continuous tracking will provide additional rich information about the paths taken by seeds, rather than just their start and end point. Predictive models of ocean currents do exist, but they are not perfect, and the seeds are also heavily influenced by wind and waves. Over time the uncertainty of the pseudoseeds will grow, so we need to periodically localize the devices and update the drift models. The actual position can be determined by aerial survey using manned aircraft or UAV (see Figure 3). For the purposes of this exercise we consider a UAV in a class similar to the Insitu Scan Eagle, which has a cruise speed of 75 knots (40 m/s) and an endurance of 20 hours, which would allow it to cover a total distance of 2800 km in a single mission. A UAV flying at 2000 m should be able to communicate with nodes lying in a circular region of radius 4500 m and an area of 64 sq.km. If the aircraft spent half its mission time flying to and from the search zone, that zone could be 700 km from shore and the searched area would be 12,600 sq.km. If the nodes emitted their GPS data once per minute the aircraft would hear a minimum of two broadcasts while the node was in the reception footprint. The UAV has a much greater power budget than the pseudoseed and would be able to carry a more sensitive receiver (higher weight and power consumption) than a normal node. The radio environment over the ocean is also electromagnetically quieter than on land. Since the accuracy of the drift models in predicting seed movement is currently unknown it would be appropriate to initially track the devices fairly frequently and this is while they are still relatively close to the release point. As the efficacy of the model is determined, a tradeoff can be made between the search interval and the area to be searched subject to the operational constraints of the aircraft.

V. Additional Outcomes

A. Ocean Current Modelling

In recent years, many large-scale, regional ocean models have been developed to help deepen our understanding of the complex and dynamic ocean. Model outputs are currently used to study and predict physical and biological phenomena [4], and to guide autonomous underwater vehicles for increased navigation and tracking features of interest [15]. Here, we plan to utilise ocean model predictions for preliminary simulations of the release of the pseudoseeds, and for a general knowledge of the regional currents to assist in tracking the pseudoseeds after they have been released.

A concern with any model is the accuracy of its predictions. Specifically, we are concerned with the spatial structure of the predicted *surface* current velocities. Existing ocean models assimilate surface velocities from and compare predictions to high-frequency radar data measurements. However, these data are generally only available near urbanized coastal regions; not in isolated island chains or the open ocean. To assist in improving the performance, quality and utility of ocean models forecasts, we plan to compare our pseudoseed trajectories with trajectories predicted by an ocean model. This will provide a fine-scale analysis of the surface currents in regions where measurements are difficult to obtain and groundtruth.

VI. Conclusions

We have proposed a solution to the problem of monitoring ocean dispersed seeds that uses both wireless sensor network (WSN) and robot technologies. We propose the use of low-cost WSN technology, and by using well known duty-cycling techniques we can easily achieve daily GPS fixes and frequent position broadcast, which facilitates recovery and tracking at sea. The overall cost advantage of this approach over the traditional satellite approach depends critically on the number of nodes and the cost of the aerial monitoring. The cost of the satellite uplink approach is linear in the number of nodes being tracked, while the proposed WSN-approach has an almost constant search cost. The cost of aerial monitoring however has two factors. The first is the operating cost per hour, and while UAVs have theoretically lower operational cost than manned aircraft reliable $/hour figures are very difficult to obtain. The second factor is the number of hours that need to be flown, and this depends on the rate of growth of uncertainty. If this rate is low then flights can be less frequent, but at this stage this is a significant unknown.

References

[1] A. Bachir, M. Dohler, T. Watteyne, and K. Leung. Mac essentials for wireless sensor networks. *Communications Surveys Tutorials, IEEE*, 12(2):222 –248, 2010.

[2] J. Beutel, S. Gruber, A. Hasler, R. Lim, A. Meier, C. Plessl, I. Talzi, L. Thiele, C. Tschudin, M. Woehrle, and M. Yuecel. PermaDAQ: A scientific instrument for precision sensing and data recovery in environmental extremes. In *8th ACM/IEEE Int. Conf. on Information Processing in Sensor Networks (ISPN09) - SPOTS track*, San Francisco, CA, Apr. 2009.

[3] M. L. Cain, B. G. Milligan, and A. E. Strand. Long-distance seed dispersal in plant populations. *American Journal of Botany*, 87(9):1217–1227, September 2000.

[4] Y. Chao, Z. Li, J. Farrara, M. Moline, O. M. E. Schofield, and S. J. Majumdar. Synergistic applications of autonomous underwater vehicles and regional ocean modeling system in coastal ocean forecasting. *Limnol. Oceanogr.*, 53(5, part 2):2251–2263, 2008.

[5] O. Chipara, C. Lu, T. C. Bailey, and G.-C. Roman. Reliable clinical monitoring using wireless sensor networks: experiences in a step-down hospital unit. In *8th ACM Conf. on Embedded Networked Sensor Systems (SenSys 2009)*, pages 155–168, Zurich, Switzerland, Nov. 2010.

[6] M. D. Crisp, S. A. Trewick, and L. G. Cook. Hypothesis testing in biogeography. *Trends In Ecology & Evolution*, 26(2):66–72, February 2011.

[7] P. Heyligers. The role of currents in the dispersal of introduced seashore plants around australia. *Cunninghamia*, 10:167–188, 2007.

[8] S. I. Higgins, R. Nathan, and M. L. Cain. Are long-distance dispersal events in plants usually caused by nonstandard means of dispersal? *Ecology*, 84(8):1945–1956, August 2003.

[9] J. Kahn, R. Katz, and K. Pister. Next Century Challenges: Mobile Networking for ''Smart Dust". In *5th ACM/IEEE Int. Conf. on Mobile Computing and Networks (MobiCom '99)*, pages 271–278, Seatle, WA, Aug. 1999.

[10] K. Langendoen. Medium access control in wireless sensor networks. In H. Wu and Y. Pan, editors, *Medium Access Control in Wireless Networks*, pages 535–560. Nova Science Publishers, Inc., May 2008.

[11] R. Nathan. Long-distance dispersal of plants. *Science*, 313(5788):786–788, August 2006.

[12] R. Nathan, F. M. Schurr, O. Spiegel, O. Steinitz, A. Trakhtenbrot, and A. Tsoar. Mechanisms of long-distance seed dispersal. *Trends In Ecology & Evolution*, 23(11):638–647, November 2008.

[13] S. N. Pakzad, G. L. Fenves, S. Kim, and D. E. Culler. Design and implementation of scalable wireless sensor network for structural monitoring. *Journal of Infrastructure Systems*, 14:89–101, 2008.

[14] H. Ridley. *The dispersal of plants throughout the world*. L. Reeve & Co., Ltd., Lloyds Bank Buildings, 1930.

[15] R. N. Smith, Y. Chao, P. P. Li, D. A. Caron, B. H. Jones, and G. S. Sukhatme. Planning and implementing trajectories for autonomous underwater vehicles to track evolving ocean processes based on predictions from a regional ocean model. *International Journal of Robotics Research*, 29(12):1475–1497, October 2010.

[16] S. Teh, L. Mejias, P. Corke, and W. Hu. Experiments in integrating autonomous uninhabited aerial vehicles (UAVs) and wireless sensor networks. In J. Kim and R. Mahony, editors, *Australasian Conference on Robotics and Automation*, Canberra, Australia, 2008.