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Author(s)	Taylor, K. Brian; Harvey, J. Andrew; Tourangeau, Luc et al.
Citation	The 9.5th International Symposium on Adaptive Motion of Animals and Machines (AMAM2021). 2021, p. 20
Version Type	VoR
URL	https://doi.org/10.18910/84861
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Bioinspired magnetic navigation using magnetic signatures and robots

Brian K. Taylor, Andrew J. Harvey, Luc Tourangeau, Delaney O’Connell, Catherine E. Kehl

The University of North Carolina at Chapel Hill, Chapel Hill, USA

brian.taylor@unc.edu, aj@unc.edu, lvt@email.unc.edu, delco@live.unc.edu, cekehl@email.unc.edu

1 Introduction

Earth’s magnetic field provides a navigational cue that can be leveraged by engineered [1] and biological systems [2] to travel over long distances (e.g., ocean basins). The magnetic field is a three-dimensional omnipresent vector signal that can be used to estimate both orientation, and absolute and/or relative position. In autonomous engineered systems, magnetic field information can be useful for guidance and localization [1], as satellite-based navigation degrades underwater and can be compromised [3, 4]. In biological systems, magnetic reception (i.e., magnetoreception) may help several species navigate across oceans and continents (e.g., [2]), and thus presents a potential a solution for satellite-free navigation that could be harnessed in engineered systems. The mechanisms for this are unknown, and animal migration is logistically challenging to study [5]. Mathematical modeling is therefore an attractive tool for studying magnetoreception and migration [6, 7, 8, 9].

There are several hypotheses to explain how animals navigate using the magnetic field (e.g., [2]). Based on experimental work with artificial magnetic fields [6, 10] and simulations of animal motion in the context of ocean currents and magnetic fields [6, 11], one possibility is that animals use magnetic signatures to navigate.

A previous study used both computer simulations and lab-based mobile robots to test the viability of magnetic signature-based navigation in highly idealized magnetic environments [12]. This work evolved into simulation studies that evaluated navigation performance for a variety of environmental and agent-specific parameters in both idealized environments [8, 9], and a simplified North Atlantic Ocean [13]. While insightful, the idealized environment studies do not represent a physical location on earth. The study that used a simplified North Atlantic Ocean was a pure simulation.

Building on [8, 9, 12] and [13], this study implements a magnetic signatures-based strategy in two different robotic systems. Each system must navigate a two-dimensional simplified magnetic environment that resembles the North Atlantic Ocean (Figure 1). In this environment, a signatures-based strategy might be challenged because lines of constant intensity and inclination are near parallel, potentially amplifying errors due to sensor noise or regional disturbances.

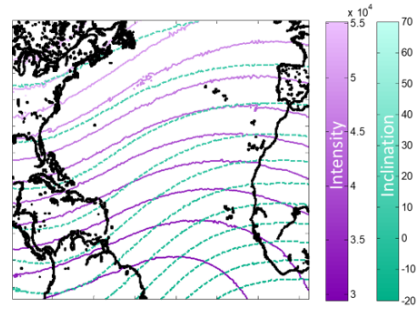


Figure 1: Magnetic field in the northern Atlantic Ocean. Purple lines are lines of constant magnetic intensity (i.e., strength), and green lines are lines of constant magnetic inclination (i.e., angle between the field and horizontal).

Each robotic platform navigates to a series of waypoints magnetically resembling locations on a loggerhead sea turtle’s migration route [10]. Each system only has an implicit understanding of trends in the magnetic environment, not an explicit detailed map. Additionally, each robotic platform must negotiate hard-to-simulate physical challenges that may include sensor lags, sensor noise, imperfect actuators, gravity, friction, and non-ideal substrates that can impede motion. Our results demonstrate the feasibility of magnetic signatures as a means of biological navigation and migration, and can help inform the design of new engineered navigation systems.

2 Materials and Methods

We leverage two different physical platforms to simultaneously study animal magnetoreception, and uncover principles useful in developing novel manmade navigation systems. The first system uses the iRobot Create® (an untethered robot), and 8 Vicon Vero motion capture cameras. The second system uses an Ideal Aerosmith 1291BL single axis rate table (a tethered robot) with a Sparten Attitude Heading Reference System (AHRS 8) inside of a custom artificial magnetic environment modified from [10]. The untethered system uses motion capture to identify the robot’s position, from which sensor values can be derived. In this way, the system uses simulated sensing, but faces the challenges associated with real-world motion and control (e.g. friction, gravity, imperfect floors). The tethered system uses

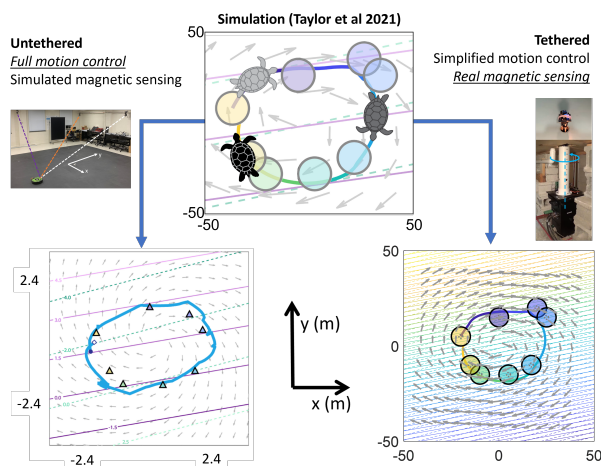


Figure 2: Simulation results from [13], and hardware results from this study. Results from the physical robotic devices match the results from the simulation, where a simulated agent is able to navigate to a series of waypoints around the Northern Atlantic Ocean.

a real magnetometer (AHRS-8) to sense real-world magnetic fields created by our magnetic environment. However, it can only rotate, so translation is introduced via software. In this way, the tethered system contains simplified motion, but must contend with real world sensor feedback including potential sensor noise, and delays between sensation and action.

3 Results

Our robotic systems are able to replicate closed-loop migration results in [8, 9, 13]. Figure 2 specifically replicates a trajectory from [13] in a simplified northern Atlantic Ocean, demonstrating the viability of our magnetic-signatures implementation. The strategy only has notional ideas of north/south and east/west motion, not a presurveyed map.

4 Discussion

Our work demonstrates that magnetic signatures can be used to navigate. Our implementations in different physical robotic systems demonstrate the strategy's viability as a biological navigation hypothesis. From an engineered system perspective, as discussed in previous works, this strategy appears to be able to navigate with only notional ideas of North/South and East/West motion. Neither the computer simulations nor the physical devices have an *a priori* magnetic map, suggesting a means of reducing the size, weight, power, cost, and computational burdens of engineered navigation systems.

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