Demo Abstract: FreeBot, a Battery-Free Swarm Robotics Platform

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ABSTRACT

A growing range of networked embedded devices are moving away from batteries and towards super-capacitor charge storage. However, mobile robots remain largely dependent upon batteries with slow recharge cycles and limited lifetimes. In this demonstration paper, we introduce a novel battery-free platform for swarm robotics which features: 24 minutes of operation running at its top speed of 1.24 km/h, a carrying capacity of over 2.5kg, full recharge cycles of under 12 seconds and rapid peer-to-peer charge transfer or *trophallaxis* in the field. This is supported by an nRF52840 Cortex-M4F equipped with BLE/ANT/802.15.4 transceiver. Notably, while the autonomy of FreeBots is limited compared to battery-powered robots, their operational vs charging duty-cycle is significantly higher at over 99%.

KEYWORDS

IoT, Swarm Robotics, Battery Free, Energy Management

ACM Reference Format:
Mengyao Liu, Fan Yang, Sam Michiels, Tom Van Eyck, Danny Hughes and Said Alvarado-Marin, Filip Maksimovic, Thomas Watteyne. 2023. Demo Abstract: FreeBot, a Battery-Free Swarm Robotics Platform. In *The 21st ACM Conference on Embedded Networked Sensor Systems (SenSys '23), November 12–17, 2023, Istanbul, Turkiye.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3625687.3628401

1 INTRODUCTION

Replacing batteries with super-capacitor charge storage brings a host of benefits to networked embedded systems such as wireless sensors [6, 8] and personal electronics [1, 3] . These benefits include: a long lifespan, reduced waste and rapid charging. In this paper, we introduce the FreeBot, the first platform to apply this technology to *swarm robotics*, wherein low-cost robots equipped with wireless networking collaborate to perform coordinated actions. In addition to enabling battery free swarm robotics, FreeBot offers high speed trophallaxis, i.e. charge transfer between robots in the field. A novel switched capacity array building upon Morphy [8] enables: (i.) charging a high priority robot from a more depleted peer and (ii.) charge isolation for critical robot tasks.

SenSys '23, November 12–17, 2023, Istanbul, Turkiye

ACM ISBN 979-8-4007-0414-7/23/11…$15.00
https://doi.org/10.1145/3625687.3628401

Figure 1: Current Version of the FreeBot with Mecanum Wheels and Front/Rear charging ports (152x133x48mm)

As shown in Figure 1, we have created a prototype of the FreeBot with a 60F capacitor array, four drive motors, peer-to-peer charging connector and mecanum wheels for omni-directional movement. The FreeBot is controlled by an nRF52840 Cortex-M4F equipped with a BLE/ANT/802.15.4 transceiver. Evaluation of the FreeBot shows: 24 minutes of operation running at a top speed of 1.24 kmph, 2.5kg carrying capacity, 100% recharge in under 12s from a mains charger and similar charge times via trophallaxis. All hardware and software materials are released under an open source license: https://github.com/HippoYao95/FreeBot. Notably for swarm testbeds, the operational vs charging duty-cycle of FreeBots is significantly higher than battery-based platforms, at over 99%.

The rest of this paper is structured as follows. Sec. 2 describes prior work. Sec. 3 sketches the design of FreeBot. Sec. 4 evaluates the platform. Sec. 5 describes the planned demonstration. Finally, Sec. 6 concludes and discusses directions for future work.

2 RELATED WORK

This section reviews related work on battery-free systems followed by popular swarm robotics platforms.

Battery-free wireless sensors are well-established, with researchers demonstrating long-term deployments [2] and novel charge storage platforms [6, 8], which provide valuable inspiration. Specifically, FreeBot uses physical charge isolation as introduced by Flicker [6] and Morphy [8] to enhance trophallaxis.

Battery-free personal devices are also appearing, which must handle significantly higher power draws than embedded sensors. Examples include a Battery-free Gameboy [3] and smartphone [1]. The latter specifically demonstrates the trade-offs between fast charge and lifetime for super-capacitor based systems.

Swarm robotics platforms include devices such as the 3.3 cm diameter KiloBot [7] which moves by means of vibration at a maximum speed of 0.36 km/h and the e-Puck [5], a 10cm diameter robot equipped with two motor wheeled with a maximum speed of 0.9 km/h. Despite their divergent designs these robots both offer around 3 hours of battery life and a 3 hour recharge cycle for a duty cycle of 50%. One approach to extending battery life is *trophallaxis* [4], wherein robots recharge each other in the field. For example, evo-bots [4] take 160 minutes to charge a peer for 30 minutes of operation, achieving a 15.79% duty cycle.

3 DESIGN

The design of FreeBot has four major elements, each of which are sketched here at a high level due to space constraints.

Reconfigurable charge storage is provided by an array of four 15F 5.5V super-capacitors, each with an equivalent series resistance of 50mΩ and a peak current of 23A. The capacitors are connected in a switched array, which enables the FreeBot to (i.) draw working power from one capacitor at a time, (ii.) connect all capacitors in parallel for infrastructure charging and (iii.) connect any subset of the capacitors to the charging port in order to perform trophallaxis. As FreeBots can only charge peers where a positive differential exists, sequential use of capacitors maximizes opportunities for trophallaxis which is possible in all cases where the charging peer has over 25% available charge and the receiver has less than 100%.

Charge conditioning and monitoring: power to the motors and MCU is regulated to 3V by an efficient boost converter which can supply up to 3A and operates down to 0.5V. The charge level in all capacitors is monitored by the ADC of the controller MCU connected via a low power voltage divider.

Motor, driver and control: The FreeBot uses four 3V DC motors with a 1:100 gearing and rotary encoder to monitor rotation speed. An efficient motor driver regulates speed based upon input from a software controller. Omni-directional movement is supported via differential control of the mecanum wheels.

4 EVALUATION

We provide an initial evaluation of the FreeBot in terms of (i.) speed, (ii.) charge autonomy and (ii.) re-charge time.

Speed: The FreeBot has a maximum speed of 1.24km/h and minimum speed of 0.34km/h. This is in line with the speed of contemporary battery powered platforms [4, 5, 7].

Autonomy: The FreeBot has a maximum autonomy of 24 minutes running at top speed with no payload and can carry over 2.5kg, an order of magnitude more than prior swarm robotics platforms [4, 5, 7].

Charging: Using a dedicated 40A charger, FreeBot charges from 0-5V in 12s. The time required to perform trophallaxis is dependent upon the charge levels of the donor and recipient and is 50% efficient. To provide a worst-case example, using trophallaxis to charge an empty (0V) robot from a nearly full (5V) peer takes 6 seconds. Afterwards both robots have a charge autonomy of 6 minutes.

Reflection on the features of FreeBot, show that while charge autonomy is limited, the overall duty cycle of the robot is high at over *99%* for the dedicated charger and over *98%* when performing trophallaxis (excluding travel time). This is far higher than prior swarm robots such as the Kilobot [7] or e-Puck [5] at 50%, making FreeBot a good fit with always-on scenarios such as test-beds.

5 DEMONSTRATION

We will demonstrate the FreeBot using the following equipment:

(1) Three to five FreeBots operating on a table-top.
(2) A dedicated 40A desktop charging unit.
(3) A phone application to control the FreeBots.
(4) A live visualization of network-wide robot charge levels

The demonstration will show the FreeBots being interactively navigated by the authors in an omnidirectional fashion using the mecanum wheels. Robots will be recharged using the dedicated charger and trophallaxis. Attendees will be invited to take control of the robots and perform similar actions themselves. The live charge visualisation will show degrading charge levels and rapid re-charge as the robots perform various actions.

6 FUTURE WORK AND CONCLUSIONS

This paper introduced the FreeBot an open source platform for battery free swarm robotics that provides: (i.) fast charging, (ii.) reasonable autonomy and (iii.) rapid trophallaxis. Our future work will focus on building out platform support for experiments with large numbers of FreeBots. Key issues include: dense mobile networking, localization, sensing and distributed coordination of the swarm.

ACKNOWLEDGMENTS

This document is issued within the frame and for the purpose of the OpenSwarm project. This project has received funding from the European Union's Horizon Europe Framework under Grant 101093046. Views and opinions expressed are however those of the author(s) only and the European Commission is not responsible for any use that may be made of the information it contains.

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