Adaptable agents of exploration and discovery:

A swarm robotics platform to facilitate research

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Abstract

Swarm Intelligence is one of the newest emerging branches of robotics research and has many opportunities for teaching at a collegiate level. As with all research, progress is expedited when more people can engage with the research. In this paper, I will showcase a simple and cheap swarm-capable robot platform. These robots can be used to allow undergraduate students or DIY experts to experiment and explore swarm intelligence. Furthermore, I will showcase an application of these robots to simulate extraterrestrial planetary navigation; an area explored by Pat Langley that I found interesting.

Introduction

Swarm Intelligence (SI) is the study of the collective behavior of decentralized agents. From these agents, there is a form of self-organization (either natural or artificial) that can be utilized to complete some form of goal. Key aspects of SI swarms are their ability to dynamically grow and decay in population, self-autonomy (no central controlling agent), the ability for each agent within the swarm to sense its abilities and environment, and for the swarm to change goals dynamically (Wikimedia Foundation)

Following these conventions, swarm robots are generally made rather simply to allow mass production such as the Harvard Kilobots as seen in Figure 1. These robots while capable of swarm intelligence, are rather limited in their task completion capabilities. Instead, we created a low-cost robotic platform that is capable of being expanded upon over time to allow professors and students to adapt the robots to their current research goals. This modularity allows professors to utilize these robots within a classroom setting on a budget, create new course plans, or allow students to change the robots to their common goal.

Figure 1: Wyss Institute at Harvard University

The Robotic Platform

The robotic platform uses a modified 3D printable open source "Screwless/Screwed Modular Assemblable Robotic System" (SMARs) originally designed by Kevin Thomas and modified by Zwald Damien. Kevin Thomas's page details a plethora of helpful guides as well as his own outline of a teaching schedule for teaching a class with the SMARs robots visualized in Figure 2; however, this course is mainly aimed at high school level students or early undergraduate introductory courses. The SMARs platform is easily produced with a 3D printer and can be modified or expanded upon so long as the creator's original CC BY-NC-SA 4.0 license is upheld.

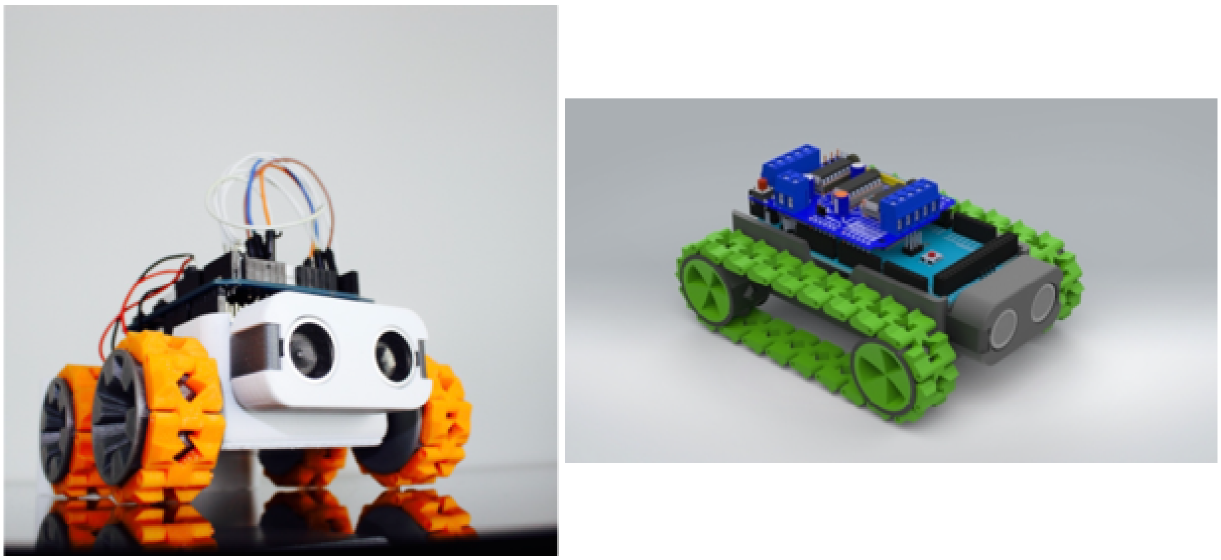

Figure 2: SMARS robotic platform by Kevin Thomas (left) and a remixed design by Zwald Damien (right)

For the brain of our robot, we used the FeatherS2 by Unexpected Maker Figure(3). The ESP32-S2 microcontroller was chosen for its ability to be programmed in Arduino code, Circuit Python, or Micro Python and its built-in Wi-Fi communication. This specific ESP32-S2-based board utilizes the Adafruit Feather layout, which allows it to be compatible with Adafruit's Wing addons. Interchanging Wing modules or stacking them allows new sensors to be added to the robot with ease via a UART connection.

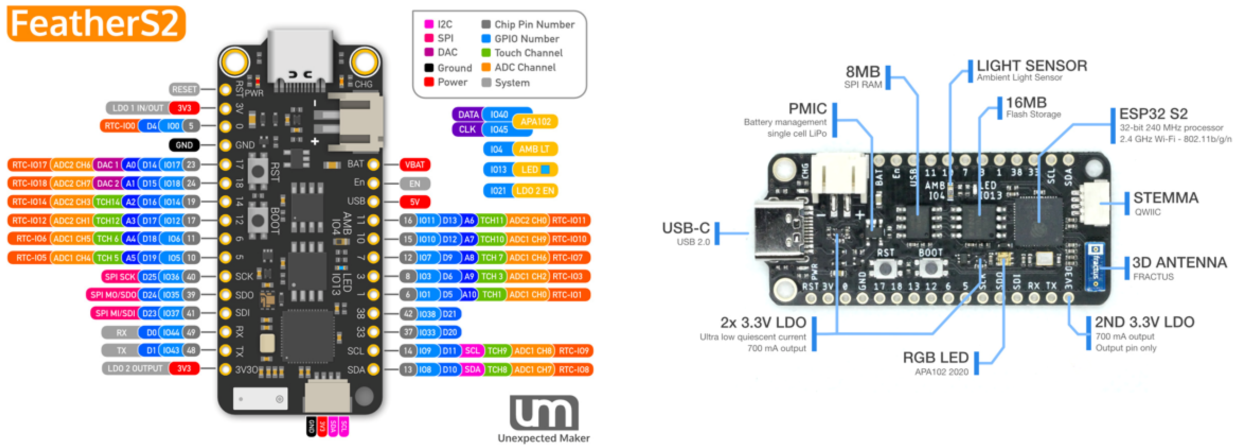

Figure 3: FeatherS2 features and pinout diagrams by Unexpected Maker

In addition, the board has a built-in STEMMA QT connector that allows additional sensors to be connected to the board via I2C connection protocol so long as their I2C addresses are unique. For power, a JST PH LiPo connector allows the use of a 3.7V one-cell LiPo battery which is capable of powering the robot for 6+ hours. Mobility is provided by a mini dual-channel L298N motor driver, controlling two N20 mini-DC motors with built-in gearboxes. These low-cost motors come in many gear reduction combinations that can allow for faster acceleration or more torque depending on what the buyer is desiring.

Pat Langley's Agents of Exploration and Discovery

Pat Langley from the Institute for Defense Analyses authored an amazing paper on the use of artificial intelligence-powered robots or "agents of exploration and discovery" to perform as modern-day pioneers that can explore new novel environments and construct maps, perform scientific experiments, and prepare for future exploration by humankind. Langley goes on further to state that these agents must be capable of autonomous behaviors, capable of variable locomotion, and able to have a variety of sensors attached to them. While the scope of our paper does not allow for professional-level robotics akin to a swarm of NASA's JPL rovers, we can utilize the robotic platform we have made to further research

Langley suggests for these robots to be able to explore they should be able to perform Localization, Target Selection, Navigation, and Mapping. Our current system detailed above could perform a rudimentary form of Simultaneous Localization and Mapping (SLAM) via sensor fusion of the IMU, GPS, and LiDAR data. Once SLAM is performed, obstacle avoidance using LiDAR in conjunction with the map created would allow the robot to successfully navigate to areas of interest. Finally, target selection can be performed as part of the swarm's algorithm, for example searching for a point of lowest elevation on an extraterrestrial planet as it may have extant evidence of life or exploring the highest peaks as they may contain frozen water.

While the current robots described above lack discovery capabilities, this can be expanded by adding more sensors to the system. The key points the robots should be able to perform are taxonomy formation, Descriptive law induction, and explanatory model construction. Taxonomy formation is the process of making scientific discoveries and mapping them into classes and subclasses via characteristics; therefore, providing an identification nomenclature to them. Descriptive law induction refers to taking the classes and subclasses formed within taxonomy and applying qualitative relationships or numerical equations to describe how classes and subclasses interact with each other. Once these relationships are constructed you can form the explanatory models for these discoveries. Models such as these would allow for hypotheses to be formulated, laws created, and observations documented. A picture relating all of these processes together can be seen below in Figure(2) provided by Langley.

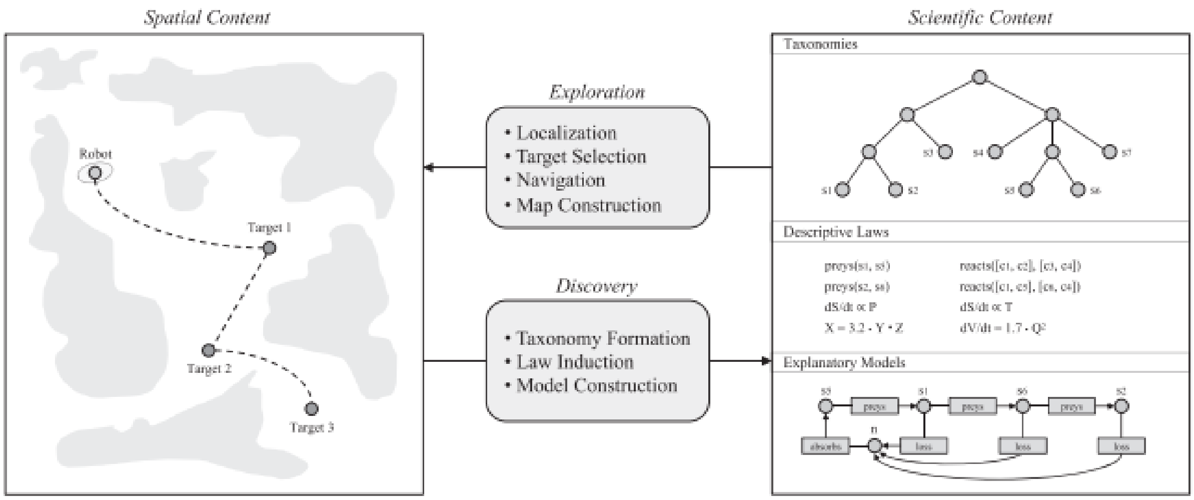

Figure 4: How exploration and discovery inform the complementary process of gathering spatial and scientific data

Wollowski and McKay's Agents of Exploration and Discovery

Using the above basis, Dr. Wollowski and I have proposed a novel example of how future research and approach agents of exploration and discovery, by harnessing the power of swarm intelligence and cheap but adaptable robotics. Our algorithm utilizes the ESP32S2's Mesh creation tool, as well as a particle swarm optimization (PSO) approach. Our goal is for the robots to explore a foreign terrain, searching for areas of interest, in our case areas of low elevation. The data from the robots is shared by the Mesh network to allow global variable cohesion between agents in the swarm. A separate observing ESP32S2 on the network acts as our "satellite" for the agents and allows us to view the data each robot is collecting while not interfering with or controlling any of the respective agents.

The Code

Our code written in Arduino is available on GitHub. The code uses the Painless Mesh by author Coopdis, Scotty et al. as a basis. This Mesh network is the foundation that allows our swarm to be dynamic in nature while also allowing each agent to share information globally. The network allows for each agent in the swarm to function as its own master, providing the autonomy Langley desired. A visual example of a simple network can be seen in Figure(1). Localization for the robots is provided by the onboard GPS system, which can provide accurate location data within two meters by using a universal transverse Mercator conversion from a geographic coordinate system. Our target is pre-selected, and navigation is performed by using our GPS, and LiDAR to avoid obstacles. Maps of the environment are created from LiDAR, IMU, and GPS data.

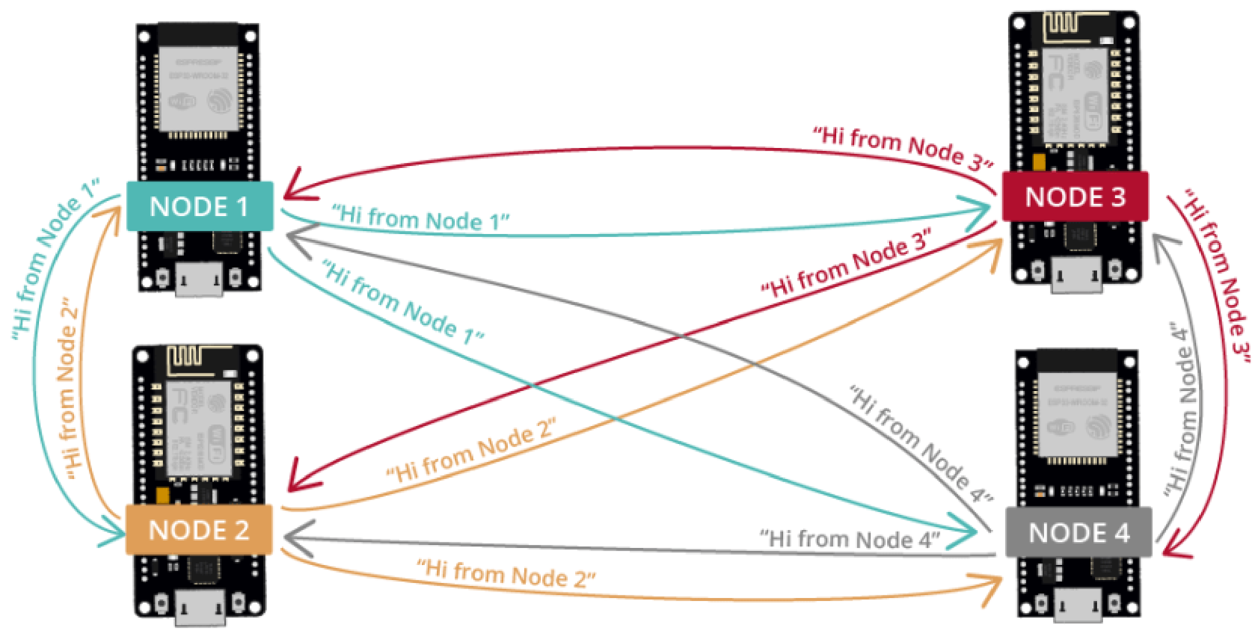

Figure 5: Visualization of a Mesh Network by randomnerdturotials.com

Task scheduler, an Arduino library created by Anatoli Arkhipenko is in our mesh to prevent any one agent from controlling the network or allowing the network to fall apart. The task scheduler also schedules our robots to autonomously run functions with preset time schedules.

The Code

The current rendition of the code is available for free at my GitHub repository, as well as plans for the robots and supporting material.

Conclusion and Future

The following approach is easily adaptable to a university-level course on swarm intelligence. The robotics platform while cheap is very modular and can be changed to suit a novel pursuit of agents of exploration and discovery. We have included in the appendix of this paper, a rough outline of topics a typical semester-based college course could follow to teach students about swarm intelligence. Furthermore, our code, schematics, and experimentation are outlined in detail and are open source. Our experiment using a particle swarm optimization algorithm on the robotic platform was a failure as with the current code we were unable to fully implement the algorithm. In hindsight, future researchers wishing to apply the same algorithm could work to improve upon this experiment by taking the robots and building them to accommodate their own goals and procedures.

References

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Appendix