Fast, Low-Cost Swarm Robots

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Spring 2018 - ECE 445: Project Proposal
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Introduction:

Objective:

Getting numerous robots to work together allows for various novel applications. The multiple robots can be used in parallel to complete multiple tasks at the same time. Or they can come together to complete a large task that would be too daunting for only one. In addition, there is something inherently satisfying about seeing physical objects move in sync. Unfortunately, while a robot tends to be very good at knowing its own state, it often lacks the environmental awareness required to coordinate its movements with others. Current methods of introducing this environmental awareness have been to add more sensors to the robot, but in doing so the price per robot increases.

Our goal is to design and build a robot that is low-cost by reducing the number of sensors required to identify the position of the robot. In addition, we want to allow high precision and but also high responsiveness of the robot. Our method for doing this is to create a base-station that utilizes advances in machine vision to report the position of the swarm robots. In doing so we can thoroughly simplify the swarm robots.

Background:

The most promising swarm robot interface currently is the Zooid project at Stanford[1]. This project is intended to use the swarm robots as a sort of physical display, where the robots act as physical pixels. The software is very impressive and provides a good demonstration of the uses of swarm robots. However, the price per robot and the base-station price is very high. Each robot costs $50 when not mass produced, and the setup requires a high-speed projector that costs roughly $600, plus the price of the computer and radio station. Our goal would be to create a system that dramatically reduces the price of the setup and of the individual setup.

High Level Requirements:

1) The price per robots should be under $30. The price for the base station should be under $150
2) The robots should be able to move independently and concurrently
3) The robots should be able to respond quickly and have good positional accuracy
4) The robots should have a footprint smaller than 35cm^2

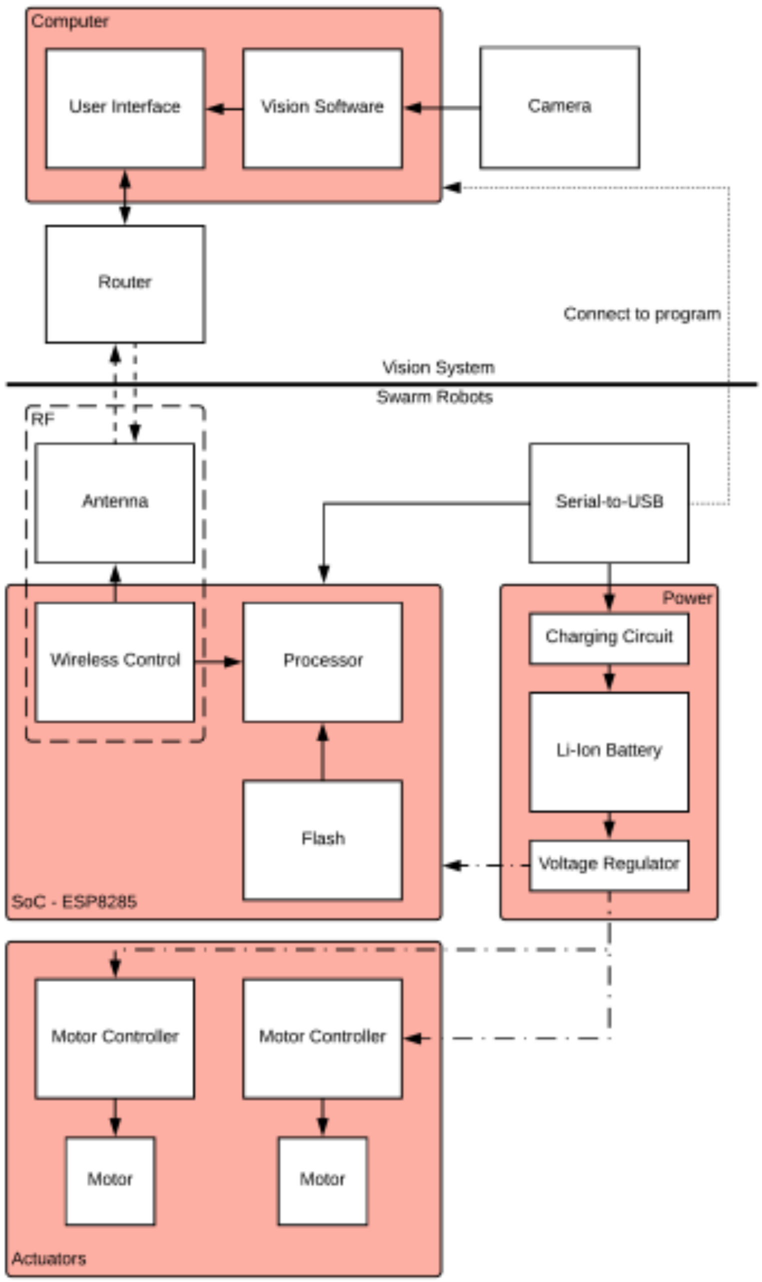
Design:

Overview and System Block Diagram:

The design will consist of two main functional parts: a vision system, and the swarm robots.

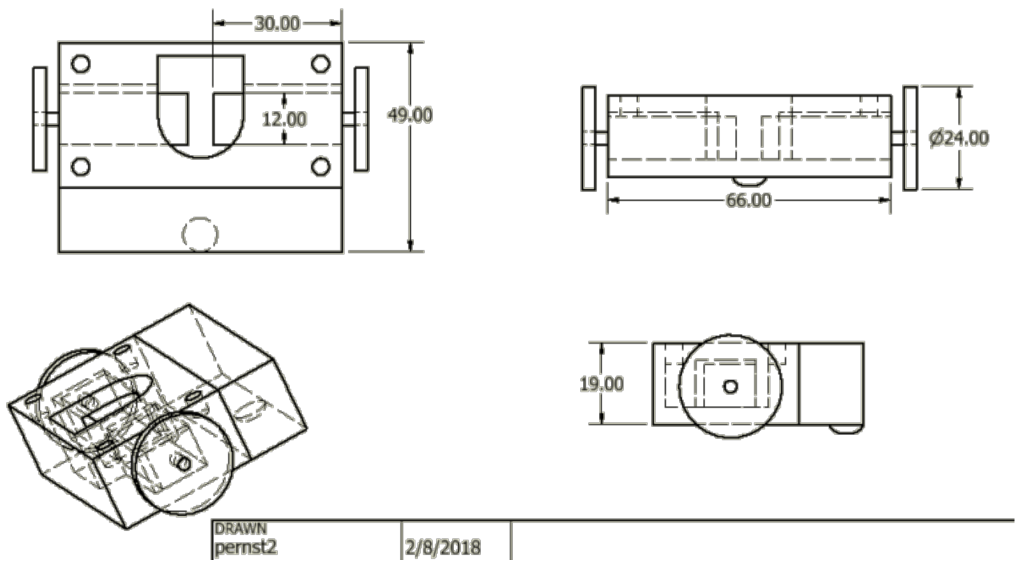
The vision system will consist of a webcam mounted overhead and will be connected to a computer for processing the image data. After computing the position and orientation of each robot, the computer will use an attached router to transmit that information, as well as the desired position and orientation, to the correct robot.

The swarm robots will consist of an SoC with an embedded Wi-Fi stack to handle the connection, and two motors capable of propelling the robot quickly around the table. A USB-to-Serial IC will allow us to program the SoC as well as allow for USB charging of the batteries which will supply power.



Physical Design:

The design of the robots will consist of a rectangular base with 2 wheels on the outside for motion. There will also be some variety of caster wheels to provide stability to the robots. The PCB and battery will ideally be located above the motors, and the top of the robot will have a vision target to assist with the machine vision.



Functional Overview:

Webcam:

The vision system will have a webcam mounted over a table. This will allow us to see the table with the robots on it and will connect to the computer via USB. This will be an off the shelf component that lies within our cost restrictions for the vision system.

Requirement: The webcam should be 1080p and provide at least 10fps

Requirement: The webcam should cost under $75

Computer:

This will be any sort of computer capable of doing image processing. The images received from the webcam will be analyzed and the position and orientation of each robot calculated. The computer will also handle determining the correct destination for each robot. The information for both will be sent to the router.

Requirement: The computer must be fast enough to analyze a frame in under 100ms

Requirement: The computer must have a USB port and an Ethernet port

Router:

This will be a Wi-Fi router capable of transmitting a 2.4GHz signal to the robots. This will also be an off the shelf component. The router will be communicating to the robots with a UDP connection to allow for quick and frequent connections.

Requirement: The router must be able to connect to 16+ devices and transmit 16 packets

SoC:

The most complicated block, the SoC will consist of an ESP8285, which contains a processor, embedded flash memory, a full Wi-Fi stack, and various GPIO interfaces. This will be the brain of the robot and will execute the control loop to move the robot to the destination position received from the vision system computer. It must be fast enough to handle the incoming position data as well as calculate the proper signals to send to the motors.

Requirements: Must be fast enough to compute the control loop corrections within 100ms

RF Block:

This block overlaps the SoC block and contains an antenna for transmission and receiving of the Wi-Fi signals. The overlap occurs since the SoC contains the remainder of the Wi-Fi stack. Due to the short ranges we will be using, the antenna does not need to be extremely robust.

Requirements: Be able to receive packets with less than 10% loss from a source 6ft away

Power:

The power block provides power to the components on the robot. It will store the energy in a Lithium Ion battery. Charging will come from a micro-USB plug on the robot and will carefully controlled through the charging circuit to prevent over and undercharging. The power will then flow through a voltage regulator to the various components of the board.

Requirements: Be able to provide 350mA of peak steady state current

Requirements: Be able to store 350mAh of power.

Motors:

The motor blocks will each consist of a motor controller IC and a motor. The controller IC will control the current to the motors and receive control from the SoC.

Requirements: Be small enough to fit within the footprint of the device (<35cm^2)

Requirements: Be able to provide enough torque to move the robot and to push a 1lb box

Serial-to-USB:

The Serial-to-USB block will allow for the SoC to be programed from a computer's USB port. It will handle the conversion of the USB packets into serial data that will be flashed into memory. In addition this block will set a few pins so that the SoC will be in programmable mode.

Requirements: Be able to convert a USB signal to serial signals with a baud rate of 9600bps

Requirements: Have at least 2 USB-controllable GPIOs

Risk Analysis:

The most complicated block will be the SoC. While from a hardware perspective a lot of the pieces are integrated, making sure it is properly interfacing with the remainder of the board and properly programmed is very difficult. Hardware issues include soldering the device onto the board, verifying that all the pins are connected correctly, and verifying that any external pullups/pulldowns and other passives are correctly connected. We will be able to mitigate the last two with thorough design, schematic, and layout reviews, but the former will require well developed soldering skills. From a software perspective, we will need to be able to properly program the RTOS. It will require code with good performance to be able to receive data from the Wi-Fi stack, analyze the data, and send the signals to the motors in under 100ms. This will be difficult to mitigate and relies on our software skills.

Safety and Ethics

There are multiple safety considerations for our swarm robotics. The most important of which, is the lithium ion battery in each robot. Lithium Ion batteries have been known to, and can, fail. Their failure can cause injury in the event of an explosion when the batteries cell and discharge rate create a positive feedback loop leading to overheating.

To prevent this situation from occurring we plan to design a charge protection element. The protection element separates the battery from the circuit charging elements. It monitors the temperature of the power source insuring that there is no runaway heating. The other precaution is to prefabricated batteries from a trustable source. Each robots charging circuitry will be checked to insure that the proper voltage is drawn from each battery. We will not make any modifications to the prefabricated batteries to uphold our responsibilities to section 9 of the IEEE code of ethics – to prevent injuries to others. Our design will comply with the International Technical Commission standards for ion battery safety specifically 62133 for portable electronics.

A second concern is that in our project there is a web cam. Web cams are easily tampered with and provide the possibility for someone unwanted to spy on your property or person. We shall implement a method to automatically turn off the web cam when robots are no longer detected. As in section 1 of the IEEE code of ethics our design should concern the welfare of the safety of the public, specifically the users of our design. Privacy is a right that should be enjoyed.

Warnings will be provided for situations in which our electronics should not be used. For damaged components of our devices such as those caused by an element falling off the desk, we suggest discontinuing the specific robots use. The same is true of any parts of our project damaged by water. Other guidelines for proper usage will be established so that our project is enjoyed safely and ethically. Our robots are not designed at a size where children could consume them and provide a choking hazard. All parts of our project are not large enough to cause a threatening physical force to humans.

To properly adhere to minimizing conflicts of interest in our project as per Section 2 and 3 of the IEEE code of ethics, we will be specifically careful in our citations as to avoid plagiarism. Our project was inspired by the zooids project done at Stanford. All parts of our project will make sure to provide a citation when they are derived or closely related to their work. Special care will be made to clearly state what is our own design and work.

References:

[1] Mathieu Le Goc, Lawrence Kim, Ali Parsaei, Jean-Daniel Fekete, Pierre Dragicevic, et al.. Zooids: Building Blocks for Swarm User Interfaces. Proceedings of the Symposium on User Interface Software and Technology (UIST), Oct 2016, New York, NY, United States. pp.97 - 109, 2016, .