Carnegie Mellon University

Robotics Capstone Project

Concept Evaluation

Friction Force Explorers:

Don Zheng
Neil Jassal
Yichu Jin
Rachel Holladay

supervised by
Dr. David Wettergreen

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Contents

List of Figures

1 System Description

RH: Brief discussion introducing project RH: Properly insert diagrams RH: Proofread

A description of the overall system diagram follows. Descriptions of individual subsystems can be found in Sec. 5.

The initial process begins offboard, where users will generate an input image and process it through a scanner. Image processing will then occur, where the input is processed into a format compatible by the planner and work distribution subsystem Sec. 5.6. Moving forward, the planner module will take in updates to current robot progress and use it to update commands it sends to robot agents.

Commands are sent to individual systems onboard robot agents. Communication protocols are able to send information both to and from the work planner to robot agents (Sec. 5.7). From here, onboard systems are separated into three subsystems: Localization (Sec. 5.3), Locomotion (Sec. 5.2), and Paint Distribution (Sec. 5.1). The paint distributor is involved with all commands regarding engaging and disengaging the writing implement to output paint onto the writing surface. Locomotion is the drive system, which engages wheels and motors used for movement. This subsystem also includes any motion-related safety mechanisms, such as quickly stopping. The Localization subsystem works to determine the position and orientation of an individual robot agent. This subsystem takes input from the sensor module (Sec. 5.9), which provides data about the surroundings for the localization system to process.

The sensor module gets data from external vision markers (Sec. 5.11) for processing by localization. It is important to note that the sensor module, along with the locomotion and paint distribution subsystems are all powered by an individual subsystem Sec. 5.10.

2 Concept Operation

RH: Properly insert user operation diagrams. RH: Proofread.

A description of the user operation figure above is as follows. For a further explanation of the user interface, see Sec. 5.8.

Initial setup contains two simultaneous operations: adding the image to be drawn to the system, and setup of the drawing surface. Adding the input image involves generating the image, and then scanning it into the system. This satisfies requirements for input the drawing plan (Requirements Specification 5.1, FR9), and a user interface (Requirements Specification 5.1, FR12). Setup of the system involves placing the drawing surface, placing and calibrating vision markers, and finally placing the robot agents within the bounds of the drawing surface. Once both steps are done, the user can enter any required settings for their use, and begin operation. Processing of the input image is done automatically by the system and is invisible to the user (Sec. 5.5).

Once the autonmous process begins, the user does nothing but observe until drawing completion. However, any errors will be reported to the user, who then has the option of fixing the issue to continue operation, or terminating the drawing process. The autonomous process satisfies functional requirement FR2 (Requirements Specification 5.1, FR2).

3 Use Cases

RH: Rubric: Use cases provide clear insight into the system and cover a wide range of possible interactions. Develop complete use case and detailed scenarios for the concept

RH: Question: how is this different from in the requirements?

4 Artistic Sketch of System

RH: Rubric: Sketch is very clear, providing significant insight about the design.

RH: Need to either make computer sketch and take a bunch of screen shots or draw a bunch of different views. RH: Explain how some physical aspects lead us to achieve our requirements.

5 Subsystem Descriptions

5.1 Writing Implement Actuator

Description: The writing implement actuator deposits writing material onto the working surface. It also manages reloading of the writing implement and ensures that the implement is properly secured. In the event of writing material depletion, its sensors will detect the occurence and alert the communication module (Sec. 5.7). This subsystem satisfies writing tool related requirements (Requirements Specification, 5.1, FR6, FR8).
Critical Components: Writing implement holder, actuation mechanism, writing material levels sensor, reloading mechanism.

5.2 Locomotion

Description: The robot's locomotion system propels each individual robot across the working surface. If the robots use a holonomic locomotion systems, they are able to move in any direction, ensuring their ability to execute intricate designs. They also provide enough clearance for the writing implement to work effectively. In the case of a tread-based locomotion system, individual robots can rotate in place to move in all directions. A driving system that allows for multidirectional movement satisfies motion-related requirements (Requirements Specification, 5.1, FR7).
Critical Components: Wheels or treads, motors.

5.3 Localization

Description: The localization system uses input from the sensor module to accurately determine an individual robot's position and orientation. It then communicates the information to the scheduling module (Sec. 5.6). This module directly satisfies local and global localization requirements, as well as indirectly allows for safe motion from the robots (Requirements Specification, 5.1, FR3, FR4). **Critical Components:** Localization algorithm, sensor module, vision markers

5.4 Input Image Scanner

Description: The image scanner takes a user-provided image or generates one, and transfers it to the image processing module (Sec. 5.5). The image scanner, being a module requiring user interaction, will also incorporate a front-end user interface (Sec. 5.8). This subsystem satisfies requirements for adding a drawing plan (Requirements Specification, 5.1, FR9).
Critical Components: User interface, image sensor.

5.5 Image Processor

Description: The image processor takes input from the image scanner (Sec. 5.4) and produces information that is recognizable by the planning module (Sec. 5.6). **Critical Components:** Image processing algorithm.

5.6 Work Scheduling, Distribution and Planning

Description: Given the output from the image processor (Sec. 5.5), and parameters such as the number of robots and the size of the workspace, the module determines the work that will be distributed to each robot. See software architecture (Sec. 7) for more information. Planning between robots allows for coordination and efficiency, satisfying requirements for both (Requirements Specification, 5.2, NFR2, NFR7).
Critical Components: Scheduling and distribution algorithm.

5.7 Communication

Description: The communication module is the link between the offboard system and the individual robots. To facilitate real-time changes in the working schedule, communication will be speedy and reliable. Potential communication protocols include WiFi and Bluetooth. Communication between the offboard system will allow individual robots to know their progress relative to the entire drawing (Requirements Specification, 5.1, FR10).
Critical Components: Antennae, wireless communication protocol.

5.8 User Interface

Description: The user interface provides a unified system for user input. This is the system with which the user specifies the input image and monitors the robots' progress. There will also be a system-wide kill switch in case of emergencies to satisfy requirement FR11 (Requirements Specification, 5.1, FR11).
Critical Components: Screen, input device.

5.9 Sensor Module

Description: The sensor module gathers data from environmental markers (Sec. 5.11). This data is used by the localization module (Sec. 5.3) to determine an individual robot's position and orientation in the workspace.
Critical Components: Vision markers, onboard sensors.

5.10 Power System

Description: The power system supplies power to the rest of the system. Each robot has an onboard battery that is small and light enough to satisfy the size and weight requirement, but also provides enough uptime to last a entire drawing session. The power system will satisfy battery life and contribute to portability requirements (Requirements Specification, 5.2, NFR1, NFR6).
Critical Components: Battery, voltage regulator modules.

5.11 Environmental Markers

Description: The environmental markers must be set up by the user before the system can begin drawing. They provide the data needed by the localization subsystem (Sec. 5.3) to determine the robot's position and orientation in the workspace. They will be mounted high enough as to be visible by every robot in the workspace at all times. **Critical Components:** Beacons/markers, elevated stands.

6 Trade Studies

RH: Neil and Rachel Trade on proofreading

In creating our multi-agent drawing robot, we face design trade-off and decisions for many of our major subsystems detailed in Sec. 5. We investigate four major decision points in the following brief trade studies. Our discussions led to a few technical solutions, when we feel we have enough data to make a reasonable decision. However, for some of our discussion points, further testing and prototyping is needed to evaluate our options fairly. For these points we lay out brief prototyping plans below.

6.1 Localization Method

Localization is an important factor for multi-agent planning that must be accurate in both position and orientation. Keeping in mind limitations in price and ease of use, there are two major methods for localization: vision-based, and marker based. They are described below.

Vision-based localization involves using cameras or other sensors to directly obtain information on the environment, and then localize the robots in the system based on found landmarks in that environment. One example of this is SLAM (Simultaneous Localization and Mapping), often used by autonomous vehicles to build a map and localize to it at the same time. In this system, robots could build a small map of their surroundings, then match their location to features they find in the environment. Benefits include being location agnostic, and requiring no additional parts or external setup. However, pure vision systems are difficult to calibrate and accuracy can depend heavily on static surroundings, which is not something this system can guarantee.

The other main choice of methodology is marker-based. Using markers placed around the drawing surface, robot agents can quickly locate these markers and their position relative to each one, and consequently triangulate their position and orientation. While requiring additional setup and more parts to calibrate than vision-based localization, existing technology makes it convenient and cheap to get marker-based localization working quickly. One example of a marker-based localization system is AprilTags [1], which can be described as 2D barcodes placed in a scene. Within marker localization, however, are two subcategories: passive and active. Passive markers do not output any information, and exist for the robot agent to observe and triangulate accordingly. AprilTags are an example of a passive marker system. On the other hand, active markers will l̈ook atr̈obot agents to determine where the agents are, rather than the robots searching for markers. While less common, active systems behave well in conditions when the markers may not always be easily visible to robot agents [2].

Given the convenience and ease of use of marker-based localization, it is clearly the better choice. However, it is more difficult to determine whether using active or passive systems will be more effective. A prototype for each system should be made for further evaluation.

6.2 Locomotion Method

One of our functional requirement with the highest priority (FR1) is to be able to move in specified directions with a high degree of accuracy. Additionally, a medium high priority functional requirement (FR 9) is a drive control system that enables this movement.

Therefore, it is clear from our requirements that locomotion is critical to our robot's performance. When considering locomotion options there are three large categories: flight, legged and wheeled.

Our drawing occurs on the two dimensional plane. Therefore, any flight based system would have to heavily constrain its third dimensional of position and two additional dimensions of orientation when drawing. Practically speaking, this seems to over-complicate the problem with little additional gain.

Therefore we are narrowed to a legged or wheeled system. We are inspired by the wide spread success of wheeled robotic systems and especially appreciate their stability, a critical concern when carefully drawing images. While a legged system would have the ability to traverse uneven terrain, this is not necessary in our project due to our assumption (A3) that the drawing surface is flat and homogenous.

Therefore, in our analysis we have concluded that our agent's drive system should be wheeled. In our next analysis we further detail the type of drive train.

6.3 Drive System

In continuing to prioritize our functional requirement (FR1) of being able to in specified directions, we investigate possible drive systems.

Three similar drive systems first come to mind: differential drive, ackerman steering and four-wheel steering. Differential drive on a robot typically consists of two independently driven wheels and a non-driven wheel. Moving up in complexity and taking after some cars is ackerman steering, where the back pair of wheels is fixed in orientation but the front pair can pivot. In more complex is four-wheel steering, which is similar to ackerman steering but allows the back wheels to also pivot. However, these systems suffer from the fundamental issue of being nonholonomic. Therefore, while they could achieve full mobility, this might complicate drawing and path planning.

Therefore instead we want an omnidirectional base that is holonomic. This can be achieved with omniwheels, perhaps more commonly, with mecanum wheels.

NJ: Treads **RH: Add cites?**

6.4 Drawing Tool

RH: No sure. Need to prototype.

7 Software Architecture

RH: Rubric: Describe the system software architecture and detail diagrammatically.
RH: Diagram of software flow. Need think thru.

8 Installation

RH: proofread Setup for the demo of this system requires a drawing surface and setup of the vision markers under specific conditions. Conditions for setup must be in line with the scope and assumptions made for successful operation of the system. Maintaining scope of the project, as described in the requirements specification (Requirements Specification, 2.3), the drawing surface must be placed indoors and in an obstacle-free area. For compliance with surface requirements (Requirements Specification, 2.4, A1), the surface chosen must be a flat and homogenous surface.

Once the drawing surface has been placed indoors on a flat surface, vision markers must be set up and calibrated. As per Sec. 6.1, localization markers must be placed around the edges of the drawing surface. These markers must then be calibrated by the user, who will input marker locations into the system. The localization markers serve as calibrated base points from which the robot agents will determine their position and orientation.

References

[1] E. Olson, "Apriltag: A robust and flexible visual fiducial system," in *Robotics and Automation (ICRA), 2011 IEEE International Conference on*, pp. 3400–3407, IEEE, 2011.

[2] R. Cassinis, F. Tampalini, and R. Fedrigotti, "Active markers for outdoor and indoor robot localization," *Proceedings of TAROS*, pp. 27–34, 2005.