Proposal: Odor Tracking with an Electronic Nose

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Table of Contents

I - Introduction -- 3

A. Problem background -- 3

B. Problem statement -- 4

C. Design objective -- 5

II - Method of Solution -- 8

A. Survey of literature, market, and existing solutions ------------------------ 8

B. Originality and creativity ------------------------12

C. Design constraints and feasibility study ------------------------14

D. Consideration of alternative solutions ------------------------16

E. Design validation ------------------------18

III - Other Consideration --20

A. Economic analysis --20

B. Societal, safety, and environmental analysis ------------------------20

C. Management, scheduling and team work ------------------------21

IV - Bibliography --25

I. Introduction

A. Problem Background

Odor tracking by electronic means has been a field of much research in recent years. Many advances have been made by trying to mimic the olfactory tracking abilities of animals such as dogs or moths. These behaviors have been reproduced in robots by using electronic noses, or “e-noses”. An e-nose is a collection of sensors connected to electronics used to detect changes in odor concentrations in an area. The e-nose takes in samples of the environment air, where the sensors translate the odor concentration into electrical signals that are then processed to identify the odor.

The idea of applying the sense of smell to robotics came about due to the need for an objective, quantifiable method to locate and identify odors in potentially hazardous areas. Since humans and animals have varying and subjective senses of smell that can fatigue over time, theoretically a robot could be used in situations where odors need to be located without such organic time constraints. The hardware for locating odors already exists and is manufactured by a number of companies. However, one problem with current technology is the response time of odor sensors. The metal-oxide sensors in the detectors take time to heat up and provide a useful signal to process odor concentration with. This slower response time by a robotic agent however, is still preferable to using humans or animals to locate potentially dangerous odor sources such as natural gas. Current research has already produced effective, accurate e-noses. Such devices are used as simple stationary sensors that monitor air quality in order to preemptively detect unwanted gases. Handheld devices have also been developed that are used extensively in agriculture and food production. Quality assurance personnel use these to monitor food quality and to ensure that food is still perishable by humans or livestock. E-nose devices are also found on the space shuttle mission to monitor air quality. Research on astronauts discovered that the change in blood pressure in space affects the astronauts' sense of smell, and they are not able to detect odors that they would be able to on earth. The newest area of odor localization and identification is applying such technology to mobile robotic agents.

B. Problem Statement

The goal of this project is to develop signal-processing procedures to reconstruct the changes in concentration of odor mixtures through the response of a gas sensor array. The main problem in this is how to instruct the robot how to react to the sensor response provided to it by the odor dilution system. These includes the development of an algorithm for odor location and tracking, and also signal processing algorithms for recovering the gas concentration profiles once the source is determined.

C. Design Objectives

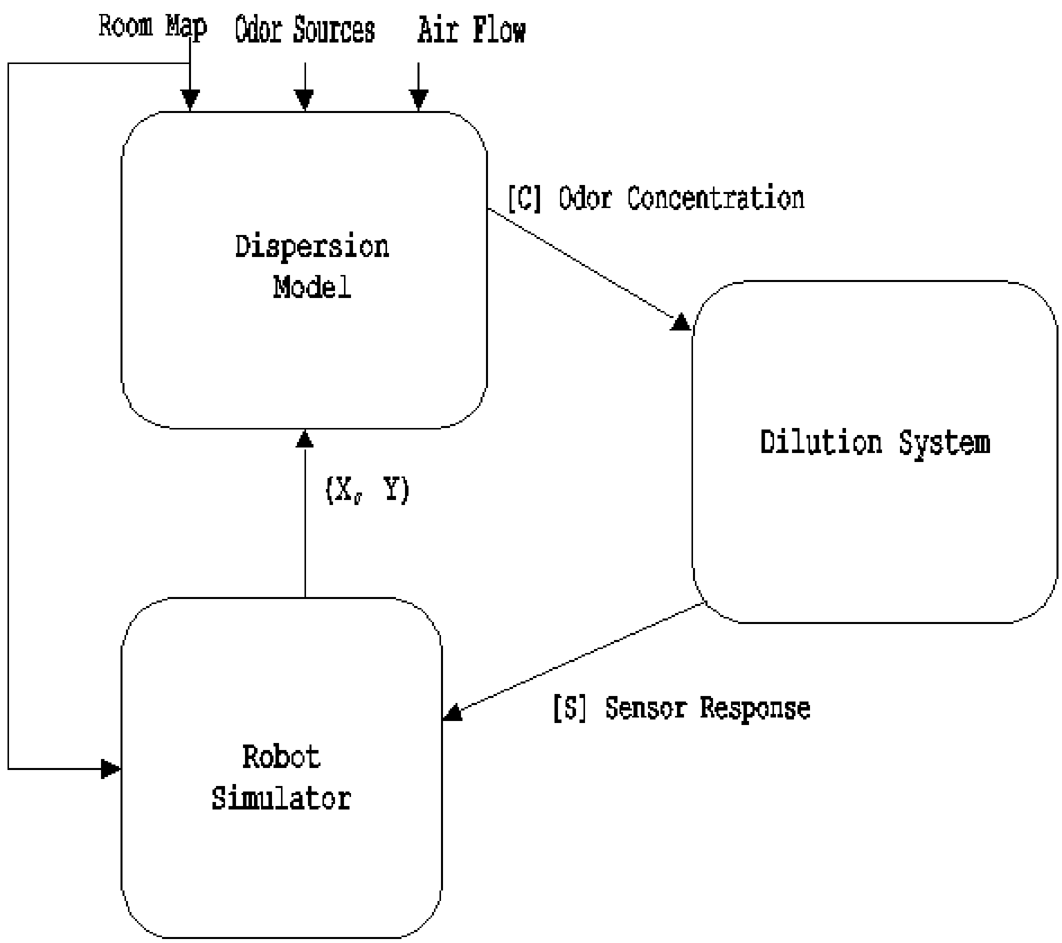


Fig. 1

The objectives for this project are to simulate the dispersion of an odor source in an area, and to simulate a robot's behavior in tracking the odor source. This model will be composed of three interrelated modules, as shown in Figure 1. The modules are the robot simulator, the dispersion model and the e-nose model. The robot simulator is given a map of the geometry of the room, so that it knows how to navigate around walls and other obstacles. The robot passes its' current coordinates to the dispersion model. This module receives a sensory response from the e-nose model and uses this to determine its next course of action. The dispersion model is given an arbitrary map of a room, one or more odor sources, and one or more airflow sources. This model simulates the dispersion of the odor sources based on the room geometry and the airflow currents. The dispersion model produces an odor concentration at the robot's current location, and passes this value to the e-nose model. The e-nose model takes the current odor concentration from the dispersion model and produces a sensory response, which the robot uses to determine where to move. This e-nose model will first be simulated in software as a simple equation, in order to easily test the other two modules interactions. After the dispersion model and robot simulation are confirmed as working properly, the e-nose model will be replaced by an actual dilution system. A team from a previous class has already designed and provided a dilution system, which we will use in our project. This dilution system is composed of three diluters, a sensor array, a pump and some circuitry to control the mixing levels. The system takes specified concentration levels and mixes the designated odors with air to produce the correct concentration. This concentration is passed through the sensor array, which produces the response for the robot simulator.

Our team will begin with simplified system inputs and gradually increase system complexity as time permits. We will start with simple room geometry, a single odor source and an airflow source. As time permits, we will consider the task of adding more complex room geometries, with multiple odor and airflow sources. We may also add new sensor heating profiles to the LabVIEW ™ interface. These profiles control the heat of the sensors, and provide for greater accuracy. By allowing more profiles, we will further increase the accuracy. Currently, only a sine wave is supported for the sensor heating profiles. We hope to add the step function, the ramp function, a stair step function, and perhaps a triangle function. However, these new profiles are not mission critical, and will be prioritized accordingly.

From the results of this project, the next logical step would be to implement the odor localization algorithms in hardware and continue testing and refinement of the system. However, this task is beyond the scope of our project due to time constraints.

II. Method of Solutions

A. Survey of literature, market, and existing solutions

Many studies of how animals detect changes or gradients in the concentration of volatile compounds in order to locate the chemical plume sources have been going on. Adam Hayes, Alcherio Martinoli, and Rodney M.Goodman have published an article named “Distributed Odor Source Localization” on IEEE Sensors journal. This article presents an investigation of odor localization by groups of autonomous mobile robots. They describe a distributed algorithm by which groups of agents can solve the full odor localization task**.** It is called Spiral Surge Algorithm. The algorithm is shown as in the following figure:

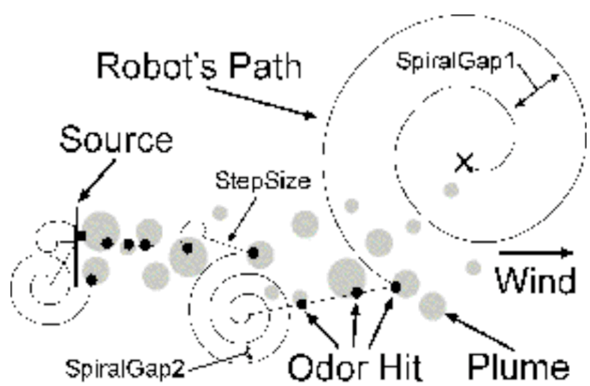


Fig. 2

It consists of different behaviors related to the three different subtasks. According to Haynes, Martinoli, and Goodman:

> Plume finding is performed by an initial outward spiral search pattern (SpiralGap1). This allows for thorough coverage of the local space if the total search area is large and initial information can be provided by the deployment point (an external 'best guess' as to source location). Alternatively, if no a priori knowledge is available, a spiral with a gap much greater than the arena size (producing essentially straight line search

paths) provides an effective, although not optimal, search procedure.
When an odor is encountered during spiraling, the robot samples the wind direction and moves upwind for a set distance (StepSize). If during the surge another odor packet is encountered, the robot resets the surge distance but does not resample the wind direction. After the surge distance has been reached, the robot begins a spiral casting behavior, looking for another plume hit. The casting spiral can be tighter than the plume finding spiral (SpiralGap2), as post surge the robot has information about packet density and a thorough local search is a good strategy. If the robot subsequently re-encounters the plume, it will repeat the surging behavior, but if there is no additional plume information for a set amount of time (CastTime), the robot will declare the plume lost and return to the plume finding behavior (with a wider, less local, spiral gap parameter).
Source declaration can be accomplished using the fact that a robot performing the plume traversal behavior at the head of a plume will tend to surge into an area where there is no plume information, and then spiral back to the origin of the surge before receiving another odor hit. If the robot keeps track internally of the post spiral inter-hit distances (using odometry, for example, which is sufficient because information must be accurate only locally), a series of small differences can indicate that the robot has ceased progress up the plume, and must therefore be at the source. However, because small inter-hit distances can occur in all parts of the plume, this method is not foolproof, and tuning the significance threshold, as well as the number of observed occurrences before source declaration, is required to obtain a particular performance within a given plume. (Hayes et al.)

Next, they establish that conducting polymer-based odor sensors possess the combination of speed sensitivity necessary to enable real world odor plume tracing and demonstrate that simple local position, odor, and flow information is sufficient to allow a robot to localize the source of an odor plume.

Finally, they show that elementary communication among a group of agents can increase the efficiency of the odor localization system performance.

To fully understanding how animals find out the right path to the chemical plume source, professor Mark Willis from the Department of Biology at Case Western Reserve University has made the research on this matter. He used moths in his experiments. He found out that smell and vision were the main factors that directed the moths. He also studied how the moth's flight paths were influenced by smell and visual cues in the wind tunnel experiments and how the nervous system controlled flight maneuvers in the virtual-reality setting.

Dr. Danny Grunbaum, an assistant professor in School of Oceanography from the university of Washington, together with Dr.Jim Belanger of Dana Laboratory, Tufts University modeled approaches to understand odor-guided locomotion. They found out that many animals, "ranging from bacteria, through nematodes, to insects, fish and mammals, use air- or water-borne plumes of odor molecules to locate distant unseen resources. Remarkably, the movement tracks that many species produce when tracking odor plumes have a very similar side-to-side zigzag shape whether walking, swimming, or flying." (Grunbaum) They found the followings characteristics of in-flight tracking behavior of moths: first, the moth regularly alters his direction back and forth across the wind as he tracks the plume upwind. Second, most of the straight-legs in between the turns are oriented at about 50 degree with respect to the wind. Third, the moth's body is usually now oriented in the same direction that it is flying, because it is drifted off course by the wind it is flying into. And finally, as the moth gets closer to the odor source it narrows its flight track by slowing down and turning more frequently, effectively homing in on the source. They also constructed modeling approaches through the understanding of how moths control their behavior. They successfully simulated a moth as it tracks the odor plume through the simulating environment. Following is one of their examples of the computer's view screen after a successfully run.

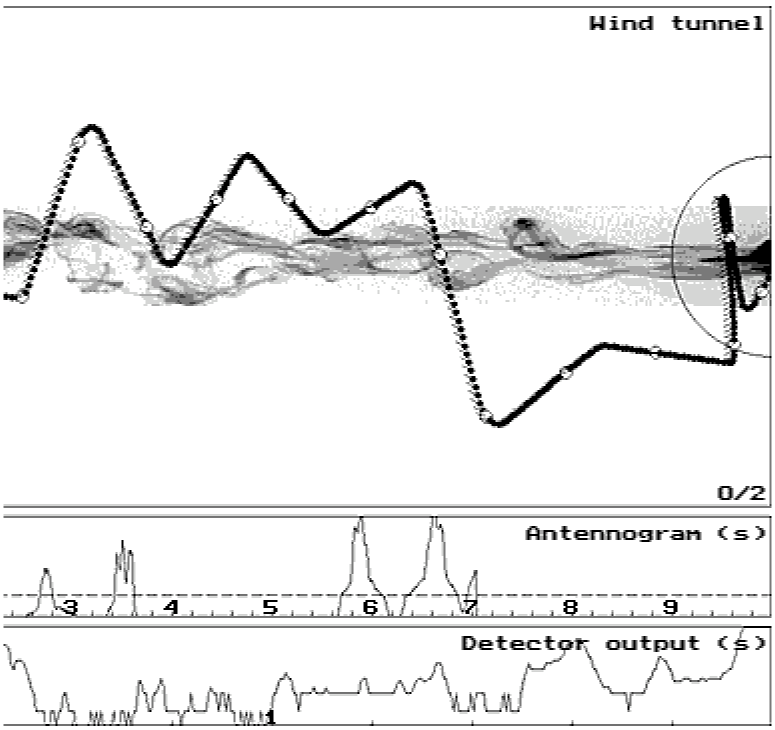


Fig. 3

B. Originality and creativity of the proposed work

In our research, we found that several algorithms have been developed for tracking an odor source. Some of these have even been implemented in software and hardware. However, our proposed project is creative in a number of ways. We will be implementing our modules entirely in LabVIEW ™ and integrating them together with the existing dilution system. LabVIEW ™ has not been used in other projects to model the odor dispersion, or to model the motion algorithm of the robot. Also, no programs have been made to interface with the specific dilution system we will be using. This dilution system is a proprietary device of Texas A&M University, and as such, our modules will be highly specialized and creatively designed.

Our odor-tracking algorithm will not be exactly the same as past algorithms. Instead, we will use an amalgamation of tracking techniques to achieve an optimal algorithm. Our algorithm will begin its search using random sampling of the environment. When it has sampled a sufficient number of points, it will create a motion vector based upon these points, in the direction it believes the odor source to be. It will then move in this direction, testing and correcting its hypothesis as it samples. Upon finding that it has lost the scent completely, and its vector is completely wrong, it will return to the point of highest concentration and choose a new direction from there, based upon its past information.

The requirements of our client are another aspect that makes our project original. Our client requires two separate modules to accurately test his existing system, and to help him in designing the rest of the system in the future. Our first module must model the dispersion of odor from an odor source in a room with wind through the room. Our second module must be a robot that is able to track the odor plume to the odor source, and identify the odor source when it reaches it. Not much research has been done in identifying the odor source by sensor response alone, without physical detection. Our project will pioneer this field of research. Interfacing these two modules in LabVIEW ™ will also be a unique accomplishment of this project.

Our treatment of the sensors is an original aspect of this project. Instead of keeping out sensors at a constant temperature, we will vary the voltage across them according to a sine wave. This will result in more accurate and timely sensor responses. If time permits, we are going to construct some new sensor heating profiles, which will heat the sensor in different patterns. Some ideas for this are the step function, the ramp function, a stair-step function, and a triangle function. To the best of our knowledge, no other group has attempted such an extensive set of temperature profiles, and we hope that this will give our project greater accuracy and credibility.

Besides these modifications, our project will not be very original. Other projects have succeeded in creating hardware implementations of odor tracking robots. That is the final phase of this project, which we are only simulating. Hopefully, we will be able to borrow heavily from these projects to create an accurate simulation environment.

C. Design constraints and feasibility study

There are several design constraints we will be facing while completing this project. Our choice of programming languages and environments is limited by the interface of the existing dilution system. It is only possible to interface with the dilution system through the LabVIEW ™ program. Therefore, our choice of languages and environments is limited to those that can interface with LabVIEW ™.

The cost of the project will not be any great constraint. We will be well below the allotted budget of $1000, because our project will be implemented almost entirely in software, which is already provided. Also, a group from a previous class created the dilution system that we will be using, so that will not be a factor in our budget either. We may choose to use a robot simulator to graphically represent the motion of our robot with respect to the odor plume.

The timetable for the project is tight. We have approximately three and a half months to complete our research, implement our design decisions in our software modules, test each module, and interface them together with the existing dilution system. This will be our most pressing constraint.

Another constraint on this project is our collective ignorance. None of the members of our group are familiar with the odor-detection/ odor-tracking field of study.

Also, none of us have ever used LabVIEW ™. Luckily, we are all intelligent people, and our learning curve is fairly steep for most subjects. However, extensive research time will be needed at the outset, before we can even begin to design, let alone implement our solution, and this will put pressure on our timetable.

The sensor response time will affect the accuracy of our robot's motion algorithm. The sensors have a delayed response time, which may cause our robot to travel in the wrong direction. This inaccuracy will definitely have to be taken into account when designing our motion algorithm.

The feasibility of this project can be analyzed from several different perspectives. The most positive aspect of this project is that several projects similar to this one have been completed and are available for public viewing on the Internet. While these projects are not similar enough to ours to make our project trivial, they do provide useful algorithms for odor dispersion, detection, recognition, and tracking. This wealth of information online should aid in completing the project within the time constraint.

On the other hand, the complexity of the project poses a risk to its ultimate completion. Advance differential equations and matrix manipulations are necessary to accurately model an odor source in a room with airflow. This mathematical challenge, coupled with our general ignorance of LabVIEW ™, poses a serious threat to the timely completion of this project.

The cost is not a very big concern in analyzing the feasibility of the project, assuming one is provided with the dilution system and a copy of LabVIEW ™. However, if LabVIEW ™ must be obtained, this will significantly increase the cost, as the base LabVIEW ™ package costs $995 (USD). Aside from this constraint, we anticipate little to no monetary expenditures on behalf of our project.

The feasibility of accurately modeling an odor source and plume in LabVIEW ™ is a major concern of ours that is still unknown. In researching LabVIEW ™ to determine the feasibility of using it to model an odor source, our main concern will be to determine if it supports calculus, and specifically, differential equations and direction field graphs. If it supports these mathematical constructs, it should be sufficient for our purposes. However, if it does not, this will drastically reduce the feasibility of this project. We will be forced to use some other mathematical package, such as MATLAB ™ or Maple ™, to model our odor source. Even if we are able to create our model using one of these software packages, we will have one more module to implement in our system, which will add to the overall complexity and difficulty, again lowering our feasibility.

D. Consideration of alternative solutions

Working on a new project, we think this is a "must" to come up with a back up, or an alternative solution. We have been carefully looking up the related information for the project including available resources and some of the constraints that we may encounter as described above. We are planning to code both model, dispersion model and robot simulator in LabVIEW ™ . However, in the worst case that we cannot continue coding in LabVIEW ™ , Webots is the alternative solution. Webot is a robot simulation language from Cyberbotics. It allows us to create custom robot and virtual worlds. We can control the simulated robot through coding using C or C++. Webots also "support programming environments include gcc/make on both Linux an Windows operating systems." We are also considering coding in Java or Visual Basic. Time is an important factor that we have to worry about. The question is that how can we know when will be the best time for us to switch the language? This question currently remains unanswered. However, we will closely work together to come up with appropriate solution.

We may add the wind sensor parameter in our model. The idea behind this is that depending on the input from the win sensor, robot can move left or right toward a chemical source. Adding a wind sensor will simplify our task in finding a suitable tracking algorithm for the robot.

As we have already stated, timing is a critical factor in finishing the project. In the case that we don't have enough time to work on the project, we will combine the two models into one. First, working on one model will simplify our programming interfaces. Second, we can eliminate the number of inputs. Instead of having the map input in both dispersion model and robot simulator, we just have one map input if we combine them together. This will also cut down on duplicate code that would be necessary between two modules.

E. Possible approach for design validation

The design validation for our project will involve testing each module for correctness, as well as compatibility with other modules. After testing each module, we will integrate them all and perform integration testing on the entire system. Finally, we will test the system as a whole for correctness and accuracy.

Module testing for the dispersion module will involve testing its ability to accurately represent a map as described in an external data file, its ability to accurately represent an odor source on that map, and its ability to represent the chemical plume from that odor source. Also, we will test its ability to produce an accurate chemical concentration for any and all given point on the map.

Module testing for the robot module will involve testing its ability to determine the next motion of the robot, given a sensor response and a response/location history database. The module must also be able to generate a motion vector from a random sampling of response/location points, so that it may determine which direction to travel in when it is first introduced to a new odor environment.

Our sensor module will eventually be replaced by the actual dilution system. However, while we are still using the sensor module to simulate the dilution system, we will test it to ensure that it produces an accurate sensor response, given a concentration as input. This can be done mathematically and programmatically.

The compatibility testing is inter-related for all of these modules. The dispersion module will be required to take a set of (X, Y) coordinates as input, and produce a chemical concentration [C] as output. This chemical concentration will be composed of at least three different concentrations, depending on the number of chemicals that will be mixed. The sensor module will be required to take the chemical concentration [C] as input in the same format as it is produced as output by the dispersion module. The sensor module will have to produce a sensor response (S) as output. The robot module will be required to take this sensor response (S) as input in the same format as the sensor module produces it. The robot module must produce a set of (X, Y) coordinates in the same format as the dispersion module is expecting them.

Integration testing will primarily involve making sure that our two modules interface correctly and effectively with the given dilution system. This will include comparing the chemical concentration created by the dispersion module with the chemical concentration received by the dilution system, and comparing the sensor response generated by the dilution system with the sensor response received by the robot module. Once this is confirmed to be working correctly, we will test the system to see if it can correctly navigate a robot towards an odor source, given only the chemical concentration at any point in the room. This will be the final test of the complete system. If it is able to accomplish this, we will have addressed our design objective and satisfied our client.

III. Other Considerations

A. Economic Analysis

Since our project is implemented entirely in software, there is very little cost involved. One option we are considering is to purchase a robot simulator, which will simplify our development process if we only need to integrate the existing simulation with the rest of our design. This will cost approximately $220 if we use a robot simulation package from Cyberbotics. However Cyberbotics also offers a free version of its software with reduced features that we are also considering using. This would be our only potential cost, because our other development tools such as NI's LabVIEW software are already provided for us, as is the dilution system for odor production.

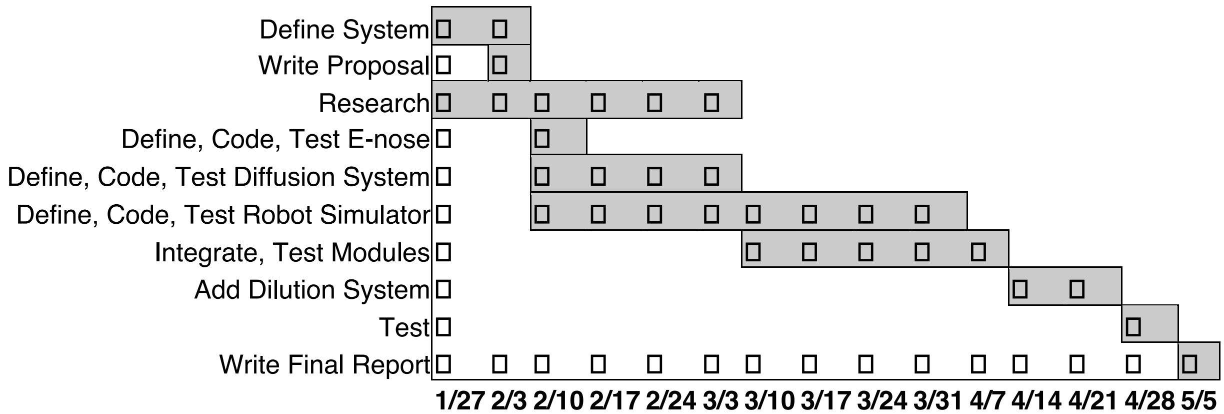
B. Societal, Environmental and Safety Analysis

A mobile robotic agent for odor localization could present a number of benefits to society and the environment. One of the main advantages of such a system is an increase in safety. This would include such applications as detecting harmful odors before they become a hazard to humans. An E-nose system could also be used to analyze food products in order to detect freshness and remove or alert personnel to spoiled food. As previously mentioned, a mobile robot would be extremely useful on the space shuttle and onboard the International Space Station. A robot could be used to detect harmful substances, or to find air or fuel leaks. Since a robotic agent is automated, this would free the astronauts from needing to check for such a leak on their own, allowing space missions to be more efficient. A robot could also be used in future space exploration of other planets. An odor-sensing robot could be placed on the planet ahead of astronauts and be used to detect air quality or find resources. To protect the environment, an odor-sensing robot could be used to analyze hazardous waste. A robot could also be used to monitor factory emissions or air quality to assure that it meets current standards. Another possible benefit of an odor-tracking robot is in finding missing persons. If a robot could be trained to follow an odor as well as dogs can, a robot could be used in the same task to locate people.

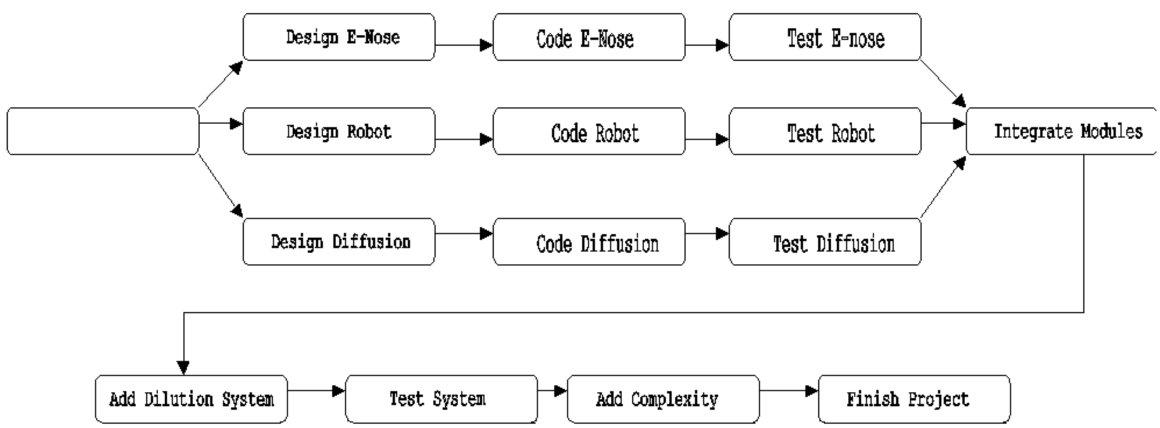
There are potential disadvantages to such a system however. If a robot were to have difficulty in tracking an odor quickly, it could be dangerous to society and the environment if the robot were intended to preemptively detect harmful substances. If an area were also relying on only one robot, rather than a distributed network of robots, it could be detrimental to the surrounding area if the robot were to malfunction and not be able to properly locate an odor source. At times, humans themselves produce offensive and even dangerous odors (provided they exist in high concentration), and robot detection and removal of these persons poses a serious, although humorous, social *faux pas*.

C. Management, Scheduling and Teamwork

In this project, the tasks have been divided into four job categories: Head Manager, Time Coordinator, Documentation Coordinator and Head Programmer. For this project, Simon Saugier will act as Head Manager. His tasks will include allocation of project tasks to other team members, module integration and supervision of project progress. Once the three separate modules are completed, he will initiate integration, and ensure that they all work together properly before the project proceeds. Ninh Dang will act as Time Coordinator for our project. His tasks include scheduling group meetings and meetings with our client, as well as maintaining the project schedule. He will communicate with our client and pass information along to the rest of the team. He will also keep track of our progress on the Gantt chart to ensure that we complete the project tasks in the allotted time. Greg Allbee will act as Documentation Coordinator in our team. His tasks include product documentation, recording meeting events, and producing the bi-weekly reports. The product documentation is necessary to turn in at the end of the project so that future users can understand and make full use of the system. He will record meeting events so the results can be compiled into the bi-weekly reports. Finally Jason Hamor will act as Head Programmer. His tasks include supervising the progress of project code, supervising the integration of project modules, and ensure module compatibility. If issues with coding parts of the project arise, Jason will be in charge of solving these problems.



Gantt Chart



Pert chart

As seen on the Gantt chart, all team members are involved in defining the system, writing the project proposal, and initial research. Once these initial tasks are completed, the team will split up to develop the three system modules. One team member will be assigned to each of the E-nose and the diffusion systems. The other team members will begin work on the robot simulator. Once the E-nose and diffusion modules are completed, those members can begin integrating their modules together in the system. As soon as the robot simulation is completed, all team members will work together to integrate all system modules together and test them. Upon completion of this task, the real dilution system will replace the E-nose model in the system. All team members will work on testing and refining the completed system, adding any complexity as project schedule permits. When the system is completed, all team members will work to complete the final project report.

IV. Bibliography

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