Collision avoidance for robot swarms focused on maneuvering and data collection rate from a RTOS approach

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***Abstract*—The ability to convey critical information promptly and efficiently between robots swarms is critical in collision avoidance scenarios. Different approaches to data collection are important considerations that must be taken in Real Time Systems where different units must effectively coordinate spatial movement to prevent collisions. Through the use of the computer networking concepts usch as the multicast protocol, our team has devised a new method for data collection in order to meet the timing constraints of a dynamic system such as this. The multicast concept allows for information management and establishment of policies related to a set of subscribers to a particular multicast group, which receives messages from a spatial element who manages and coordinates information and policies between the subscribed elements. The dynamics of different multicast groups (of which a single subscriber can be a part of many) creates localized information hubs and information that need not be distributed across entire networks. The resulting hubs are flexible, sometimes redundant, localized environments that have better adaptability to the immediate surroundings. Future studies and application of this networking concept can provide legitimization of the algorithms presented here; for example, use of robots swarms in an environment which is not homogeneous and where subscribers will obtain only relevant information to a specific area of this environment.**

***Index Terms*—MCAST, collision avoidance, RTOS, data collection, manuevering.**

I. Introduction

ADvances in technology have allowed automatons to gradually replace humans in many tasks involving control. Automated spacecrafts and UAVs (Unmanned Aerial Vehicle) are being heavily deployed in todays military operations and the scientific community uses unmanned spacecrafts in space explorations. Although these automatons are usually expensive and sophisticated, more economic solutions are now being used in civilian applications [YS1].

Well established engineering technologies have been made for these mobile UAVs to move around as a single unit and most of the time you will see a military drone fly alone to strike its target and then escape without being traced. Or a single spacecraft wandering over the surface of Mars and other planets. And rarely if not never will you see more than one Google vehicle cruising through the streets and roads to map every block of the city. Will the era of large fleet of planes like those of World War I and II one day return? Back in those times, large formations of planes consisting of many light fighters would often accompany a few large bomber in its bombing mission. Should a hostile plane come into the area to take the bomber down, the fighters will break formation, attack the intruder and return to guard the bomber. Such behaviour can be described as a swarm behaviour as it is similar to the movement of a swarm of bees or a flock of birds. Popular culture[YS2] in television and science fiction forsee the return of these swarm-like formations, often depicted in the form warplanes and spacecrafts using it's advantage in numbers to spam and overwhelm the opponent. Returning to the present real world, imagine a large fleet of unmanned spacecraft moving in a formations across Mars; if one or few vehicles stumbles upon a large obstacle such as a lake or a crater, it can quickly inform the other spacecrafts behind him to detour and find another route. And if one of the spacecrafts breaks down or gets stuck in a mud-like terrain, other spacecrafts close to it can assist him in getting out. Dispersion and redundancy are it's main strengths.

If the "robots" in this case scenario were to be exemplified as computers each with an operating system inside, it would require an RTOS (Real Time Operating System) to manage all its tasks as it exhibits all the characteristics that calls for an real-time solution. According to Stankovic [YS3], that system must be:

- Fast.
- Predictable.
- Reliable.
- Adaptive.

For this paper, we will delimit the use of real time system in the context of the robot's manuevering and data collection system to allow the robot to move freely without human intervention while preventing collision with obstacles including other units of the same type. It will focus solely on conceptual aspects and ignore all implementation considerations.

Additionally, there are some assumptions that are taken:

1) The spatial location is determined using 3-dimentional coordinates.
2) The units have a defined radius of communication.
3) All tasks are dynamic and aperiodic.
4) The arrival of the tasks are sporadic in nature.

In this paper, we will start off by discussing various concepts pertaining RTOS and how it applies to our model. We will also describe the use of Multicast protocol to improve the performance of the real time solution. The first part of this paper covers various concepts and definitions related to this subject. The second part describes the test we did to simulate such model. Finally, we will summarize our findings in the conclusions and discuss the advantages and disadvantages of such implementation.

This paper makes the following contributions:

1) it presents a problem that requires real-time solution.
2) it presents a novel solution to reduce the amount of information to handle.
3) argues the importance of reducing information to process to meet the timing constraints.
4) it presents a simple experiment to prove these ideas.

II. Research

A. RTOS

A control unit responsible for the movement of any unmanned vehicle is constantly handling inputs from sensors to get information like the current speed, acceleration, the direction it is heading. It must be able to detect near term obstacles and perform various tasks like computing the shortest path, the amount of energy it needs to inject to keep the current velocity, etc. As such, it requiere a time sharing notion from a operating system's standpoint. Apart from being time sharing, the tasks have different priorities among them. There are critical tasks where the very existance of the robot is threatened should it miss its deadline and then there are tasks that can be done in its idle time. These characteristics makes it a suitable candidate for using a real-time multitasking operating system.

Real time operating systems can be divided into four clases depending of their characteristics; they can be Static or Dynamic, periodic or aperiodic. In this case, we can assume in the worst case that the task is dynamic and aperiodic meaning that the tasks are constructed in runtime and the arrival times of the tasks are not constant, in fact, they can be sporadic. An example of a sporadic task would be the obstacles encountered by the vehicle along it's path.

Multicast constrained by QoS routing its by itself NP problem usually resolved by Heuristic approaches [HH1] which its optimum performance is assumed out of the scope of the paper but the approach to intercommunication between individuals of the swarm is by multicast relying on the network infrastructure to take care of the the communication paths leaving to the individuals the task of just establishing the connections although Jin Lul et all.[HH2] propose ad hoc networks accross the individuals of the swarm having them as retrasmission stations and having needs for processing of information in real time.

The focus of this work is on using multicast as a source outside of the swarm like a control tower works for a airport or the cellular towers work for internet access to information like real time traffic reports[HH3]

B. Collision Avoidance

Collision avoidance is a reactive action based on information sensed from the environment without which a collision would be determined to happen.

C. Data Collection

D. Manuevering

Maneuvering should be understand as a proactive action planned based on information received by other individuals or by simply knowing a priori that a certain maneuver has to be done at a certain point in the route like taking an exit in a highway for a vehicle.

Individuals could be in various states depending on their relationship with a swarm, SingleSearch, SwarmSearch and Declaration according to Tang Ying [HH4] as is likely that individuals would like to join a swarm if they are alone, so a comprehensive research on the search of swarms by an individual could be found there.

Other assumption is that individuals have particle properties, meaning they could have infinite acceleration, no inertia nor speed limits[HH4], although in the experiment the speed was assumed to have discreet values, in particular a single positive speed and 0 or static.

There could be distinct types of maneuvering, for example thinking in the context of vehicles in a highway they could have a particular destination, they might want to be part of the swarm or a gorup of vehicles for optimizing energy consumption as they packet could be more fuel efficient, in such scenario vehicles join and leave the pack as their paths collide or diverge with the swarm, there is critical information that is needed to be shared for other individuals to take actions, like yield when a new individual is incorporating to the pack and same when it is leaving so that those transicions are smooth and doesnt require a quick and dangerous action as long as the affected individuals which are close to the one differing with the swarm movement are notified of the maneuver ahead of time so that they could take smooth action proactively

E. What problem did we set out to resolve?

F. What precisely was your contribution?

G. Why should the reader care?

H. What Larger question does this address?

An underlying realization product of the problem we set out to answer is that cross-applications of other fields can have interesting and unknown results. In our case multicast has no similar applications in the industry or research areas. First, there are possible applications of our use of multicast in other real time systems related to swarms, and for different types of swarms. Second there are many possible applications of networking concepts in many other areas, and it is possible that they may be applied in other types of swarms as well. This let us to think that our research and experimentation definitely support further research in this area, and a basis for an expansion of the current research to yield more conclusive results.

I. What knowledge have you contributed that the reader can use elsewhere?

Our research in the available publications and papers indicate that that few if any (none were found) groups or individuals have used a computer networking protocol such as multicast applied to a robot swarm problem to specifically manage behavior (and ultimately communication) between swarm robots. Most of the articles and papers found related to robot swarms contain information about using robots swarms, particles or swarm intelligence to improve and optimize the multicast protocol [1IG, 2IG, 3IG], but not for the inverse relationship, were a networking routing protocol is used to improve robot swarms interactions. Not only is this promising because it is a novel idea that can be applied to other fields, but because there are still many networking protocols that can be used for exploration and improvements in robot swarm behavior (or other behaviors and problems). This let us to think of the substantial value of cross-applications of systems, methods and practices used in a field, applied to another field. A clear example of such a cross-application is the biomimetics field, where biological systems are used as models for design of machines or engineering materials and principles. Other clear examples include neural networks, ant algorithms, genetic algorithms; all which are used in the computer science field successfully (and ironically can be used to improve the multicast protocol itself [1IG, 2IG, 3IG]). Computer networking protocols and routing algorithms can be cross-applied to other fields. Many of these algorithms and methods have been modeled to efficiently manage packet data across networks, of which multicast is only one of them. There are many other protocols that can be cross-applied in an interdisciplinary fashion. The computer networking area is a mature field that has evolved and is used today as the basis of many Internet networks. It is possible that many of the elements of such a system such as meshing, spanning tree, policy based forwarding, tunneling, congestion avoidance (to name a few) or other capabilities of networking be applied to robots swarms or any other fields that may warrant an intelligent reuse of these concepts. Our study and our application of the use of multicast can be a starting point to a) further use multicast with more parameters that define the application of multicast. Our experimental application of multicast only takes into consideration the value of proximity; based on proximity robots belong to a multicast group. Other parameters can be used, for example types of robots, types of environments, or any other qualities that will serve as a criterion from which to define subscriptions to a multicast group. The second interesting application derived from our research is b) further applications of networking concepts such as the already mentioned (spanning tree, meshing, etc.) to similar problems. These concepts of a networking system need only be explored and analyzed in a similar way biological systems are used and applied by biomimetics into other fields. Furthermore there are benefits of having such concepts that can be described as digital concepts. These are conceptually already modeled in the computing field, and as such are easier to implement as programming models. Another strength is that networking tools and systems to analyze networking data and behavior are already present and used to simulate networking behavior. These are known problems with a longstanding in the computer science and telecommunications field, such that there may be a use of tools [4IG] and suites that can be adapted or used to model the possible behavioral cross applications of these concepts.

J. *What is your new result?*

Through the use of a multicast algorithm applied to a robot swarms, the conclusion arrived is that multicast provides a possible reduction on robot swarm transmission of data and information within members of the swarm. Since our experiment and simulation is at this point a testbench with a very small and limited number of simulated robots, the results are not strongly conclusive, but work as an introductory work in the field. Regarding collision avoidance, an improvement in data reduction yields a direct improvement in collision avoidance for two distinct reasons.

1) Collision reaction time reduction: One, since multicast reduces the amount of data to be processed (significantly) by a single entity of the swarm, it has the potential to reduce the amount of reaction time to reduce a potential collision. This is an important contribution in real time systems, where any possible improvement regarding reaction time must be efficiently incorporated into new systems.

2) Collision Prevention: Second, the ability given by the behavior of a robot swarms under multicast groups, where robots are subscribed to other robots according to relevant data, provides an interesting way to prevent collisions. To further explain, in a networked robot swarms such as those described in [5IG], there may be obstacles that do not warrant an immediate action from the acting robot to avoid collision, but do warrant a preventive action to avoid collision or an undesired path in the robots way. In this way a robot may receive environment data that is relevant only in a short proximity, which will provide and improvement from receiving all the data from all the robots. It is important to note, that proximity is the only criterion used in this simulation to subscribe to multicast groups. In other environments, there may be different criteria that could be more useful other than proximity. For example, a land robot may not want to subscribe to the information provided by an aerial robot, even if they are in close proximity.

III. Experiment

3) Simulation description: As previously stated a testbench was created as a starting point for further testing of multicast applications. The testbench consisted of a simulated environment where a robot swarm had to cross a small 50x41 grid where several obstacles lay in a path of a robot swarm with the task of successfully arriving at the right side of the grid. The robots were simulated as part of a real-time environment. Each robot possessed a set of algorithms that provided information about the obstacles and ways to avoid them. The multicast protocol was used to create groups within the robots. Robots could subscribe and unsubscribe to different multicast transmissions (transmitted by each robot), which would equate to different information received about the obstacles in their path at different point in time. The main criterion for belonging to a multicast group was proximity. If a robot was close enough to a robot in its vicinity, it would subscribe in real time to the information presented by the other robot.

4) Simulation results: Although the simulation proved rather simple at this stage and the initial test results are not conclusive enough, they work as a starting point for further research. A comparison was made between a) the maximum possible data a robot could process and b) the amount of data a robot could process with the multicast algorithm applied. This meant subscription only to information to robots in the close proximity that would essentially provide relevant data. It was assumed, that in a conventional system, all robots would need to process all the data from the surrounding robots (all the robots within range), as in this case there arent any criteria for selecting specific transmissions. The simulation was done for a single robot who worked in an environment with two sets of samples: a) first with three robots and then b) with eight robots. The proximity criterion was varied to show the effect of the proximity on different multicast groups. As the proximity units was reduced, as expected the data units processed lowered since there were less subscription the specific robot was subscribed to. The following results were obtained:

Proximity Criterion	Data Units Processed	
	3bots	8 bots
2	113	267
5	118	285
10	121	308
max	124	328

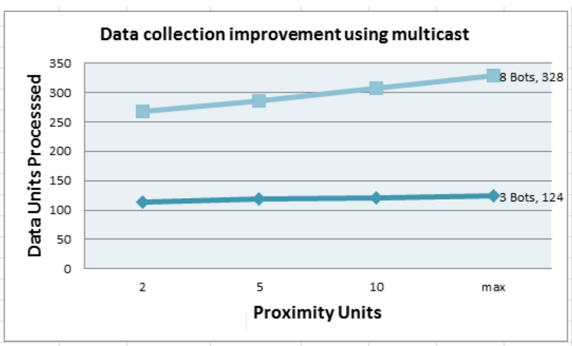

Figure 1. Data Units processed vs Proximity Units.

This same data can be since as percentages of the total data that would have been processed in a conventional system:

Proximity Criterion	Data Units Processed	
	3bots	8 bots
2	91.13%	81.40%
5	95.16%	86.89%
10	97.58%	93.0%
max	100%	100%

5) Simulation conclusions: The data is not enough to be conclusive, but the testbench provides a further starting point for analysis, as more robots are included in the simulation and eventually more obstacles and a bigger grid. Simulation improvements There are several improvements that can be explored in new simulation:

- The number of robots can be incremented to more significant sized swarms, were data collection inferences can be made with bigger sample sets of robots
- The grid size can be incremented and more obstacles included
- With a bigger grid and more robots, the probability of robot interactions can increment, such that the proximity criterion can be varied with other than minimal units
- More criterion can be included in the multicast selection algorithm (the algorithm that choses which multicast groups to subscribe to) other than proximity.
- The simulation environment can have more significant variables that approach real life characteristics of a robot swarm, such as visibility, robot types, wind, etc.
- Oportunity insert different robot types, to create a better swarm eco-system, to improve network behavior such as search, base and relay robots as introduce in [5IG].

IV. Conclusions

From the research collected in section I and the practical experiment demostrated in section II we can draw up the following conclusions:

1) The Mcast protocol can be used to reduce the amount of information being conveyed by the robots. Data collection rates are minimized by the subscription to an Mcast groups to obtain information of interest.
2) A real-time solution is needed to tackle the many critical aspects of the design. One of such aspects is the collision avoidance mechanism. Even if this is not the only activity a robot of this class can perform, the need to perform this task is, by itself, reason enough to use a real-time solution.
3) The nature of the arriving tasks are sporadic and unpredictable. The arrival of tasks depends of a number variables including
   - The distance and trayectory it is heading.
   - The speed with which it is moving.
   - The number of robots in it's vicinity.
   - The number and size of the obstacles.
4) The more channels of communication a robot ha access to, the more information it has to take better decisions but at the same time, the more information it has to process, risking missing the deadline for some tasks.
5) There is potencial demand in the future for such systems. As robot swarm technologies continues to evolve, the availability of these systems will increase and we will see more and more applications being made for it.
6) There is huge area for improvement in swarm robotics real-time paradigms. If we compare it to the personal computer industry, this is at it's infant stage.
7) Aspects of classic RTOS concepts and scheduling mechanisms can be applied. Future projects may include implementing a hybrid RM (Rate Monotonic) and a EDF (Earliest Deadline First) scheduler inside the kernel and test under what circumstances one is prefered over the other.

While the swarm robotics industry has yet to take off, it poses many challenges in making these systems robust and reliable. A relatively simple and practical experiment using simulated models can prove this point. For the RTOS community, this presents many rooms for improvements on the current scheduling paradigms and opens a door for new and exciting problems to solve. As we continue to thrive for more speed and intelligence in the robot design, the prospect of seeing a comeback of the machines swarms in a not so distant future is getting closer and closer with each passing day.

V. Acknowledgment

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