Self-organised Feedback in Human Swarm Interaction

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***Abstract*— Human-swarm interaction (HSI) consists of bidirectional interaction between a human operator and swarms of autonomous robots. In HSI, a human operator directs robots to carry out tasks. However, in order to direct a swarm of robots, the operator must receive appropriate feedback about what is going on in the swarm.**

In this paper, we argue that self-organised mechanisms should be responsible for providing feedback in HSI systems, and argue against the current approach that involves an extra 'intepretation layer' layer dependent on additional infrastructure and modelling. We present a recent study that we conducted in the field of HSI, in which a human operator had to guide groups of robots to designated task completion zones. Based on this study, we propose some initial steps towards our vision of self-organised feedback.

I. Introduction

Swarm robotics systems consist of large groups of relatively simple and cheap robots, interacting and cooperating with each other to carry out (hopefully) complex tasks. Swarm robotics is inspired by the observation of social insect behaviours, like ants, bees and fish, all of which display robust, scalable and flexible behaviours [1]. Much recent research attention has been devoted to swarm robotics — prevalent examples including the multimillion euro Swarm-bots[1] and Swarmanoid[2] projects. While good progress is being made in increasing swarm autonomy, little attention has been paid to how such swarms can interact with human beings, to receive instructions and give feedback. The subject of human-swarm interaction (HSI) has been to a large extent ignored, partly, we believe because it is so difficult. While human beings have tamed, taught and used various higher mammals (sheep-dogs, elephants), no human being has even considered trying to make use of a swarm. The human in Fig. 1 is trying and failing to give the simplest of all instructions to a swarm of locusts — 'go away'.

The key problem when trying to interact with a swarm is the huge difference in perspective between the human operator and the swarm. Individuals in a swarm system perceive only local stimuli. By contrast, the human operator is not aware of these local stimuli and sees only the global self-organised behaviours that emerge through many self organised interactions between these locally aware individuals. It is, therefore, very difficult for the human operator to understand the low level dynamics that are driving the system.

To control or manipulate any system, one need to at least partially understand it. Before issuing a command to a swarm robotics system that will change its state, one must at least grasp what state the system is currently in. One of the key jobs in designing an HSI system is, therefore, to provide feedback to the human operator that helps him understand the state of the robots. Several technical challenges manifest themselves when we try to get the robots to send back state information to the operator. The first is due to the relative simplicity and small size of robotic hardware in swarm robotics systems. Individual robots may not be equipped with the dedicated hardware required to provide meaningful feedback to the human operator in the form of gestures, speech or visual displays. The second challenge is a consequence of the large number of robots. Even if individual robots could communicate meaningfully with a human operator, it would not make sense for each robot to do so — the human operator would get swamped by data overload, as each robot reported on its own local worldview. Hence, composite information, representing the state of the swarm, or at least of significant sub-groups in the swarm, must be provided to the operator.

Some existing studies have addressed the swarm robotics feedback problem. McLurkin [4] developed a graphical interface which allows a single user to control a swarm. The author based his work on the idea of real-time strategy video games in which the players can manipulate an army of more than 100 units. In McLurkin's work each robot provided individual feedback, and a lot of effort went into ensuring that these individual data points were displayed in a coherent fashion. Daily *et al.* [2] propose to send each robot direction feedback through an augmented reality head-mounted device. Baizid *et al.* [3] also provide a virtual environment to the user. They optimize this environment by removing useless

Fig. 1. How can a human being communicate with a swarm? Photo ©hellio-vaningen

[1] http://www.swarm-bots.org
[2] http://www.swarmanoid.org

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information. In [7], the authors use virtual reality in order to have feedback from the swarm that assist firefighters in their mission.

The fundamental drawback of all existing methods is that they involve an extra layer between the swarm and the human operator. We believe that this ‘interpretation layer’ approach is flawed as it involves additional overheads of infrastructure, communication and modelling. The extra hardware and infrastructure requirements may not always be satisfiable, especially as swarm robotics systems are often considered most appropriate for deployment in a priori unknown environments, in which it may not be feasible to deploy other monitoring infrastructure. Furthermore, any ‘interpretation layer’ requires an extra modelling step — to provide meaningful feedback about the state of the swarm (rather than just the state of individual robots), the extra layer must be able to take low level information about the state of individual robots and present this information in some form of coherent display. This modelling step implies significant communication overheads — information from all of the robots must be gathered at a central point. Furthermore the modelling itself may present a significant computational overhead in and of itself. The problem may even be intractable — the extremely difficult task of decoding low level swarm dynamics must now be solved programmatically.

Our position is that the same type of self-organised mechanisms that govern swarm behaviour should also be used to generate swarm level feedback. Brooks changed the face of AI by arguing that the world is its own best model [8]. In a similar vein, we now argue that the best-placed entity to know and communicate what is going on inside the swarm is the swarm itself.

II. A Study in Human Swarm Interaction

Our position in this paper is based on a recent study we conducted in human swarm interaction. In the study, we considered the problem of a human operator moving groups of robots around an environment.

A. Task and Environment

We designed an abstract task, in which a human operator is aware of various tasks that a swarm of robots needs to solve, where the tasks are, and a rough sense of the robotic resources required for each task. The environment we used can be seen in Fig. 2. Note that we do not have any real tasks in our abstract environment. The robots are required to spend a certain amount of time in designated “task zones” (the green areas of Fig. 2). We simulate the execution of a task by freezing a group of robots for a pre-designated amount of time once they enter a task zone.

The job of the human operator is to direct the robots to carry out three tasks. To do so, the human operator must create three separate groups of robots by splitting the initial group, then direct each groups to one of the different task sites, and finally re-merge all of the robots back into a single group.

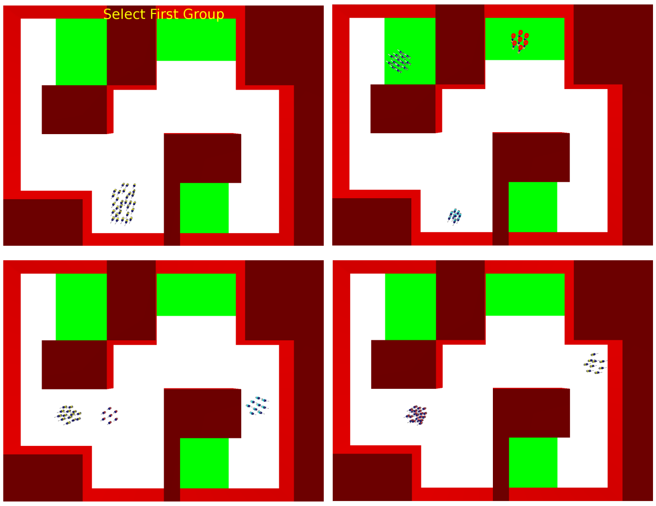

Fig. 2. Task and Environment. Top Left: Each experiment starts with the robots organised in a single group. The human operator must split the group into three sub-groups, and then direct each of these groups to one of the green ‘task zones’. Top right: Two of the three groups have already been directed into task zones. Bottom left: While the third group is going to its task zone, the two other groups are merging. Bottom right: The third group has finished its task and is heading back to merge with the other robots. Once all of the robots have been merged back into a single group, the experiment ends.

B. Control and Feedback

We decided on a *natural user interface* to try and reduce the expertise required by the human operator. We based our interface around the Kinect system from Microsoft, using the OpenNI library[3]. The major challenge running through all of our development work was to determine an appropriate equilibrium between the human’s level of control and the robots’ autonomy. A swarm of robots with too little autonomy puts an impossible overhead on a human operator. Too much autonomy however, reduces the level of control of the operator.

The initial set of commands we developed were designed to allow the human operator to select particular groups of robots, and to create groups of appropriate sizes by splitting and merging existing groups. As an essential part of this process, we developed feedback mechanisms that would give the user the feeling of communicating with a single group entity. Colour rules were used to distinguish the different groups of robots. One colour is assigned to a group and the robots all turn their LEDs on in that assigned colour. In order to show the user that he has selected a particular group, that group is ‘highlighted’ using the colour yellow (the robots illuminate their yellow LEDs). See Figure 3 for an example of colour feedback helping a human operator to manipulate groups of robots. Here the autonomy equilibrium was achieved by letting the user select which groups should merge and split. The human user is furthermore responsible for determining when the split operations is successfully concluded. The movement control required for the split and

[3]http://www.openni.org

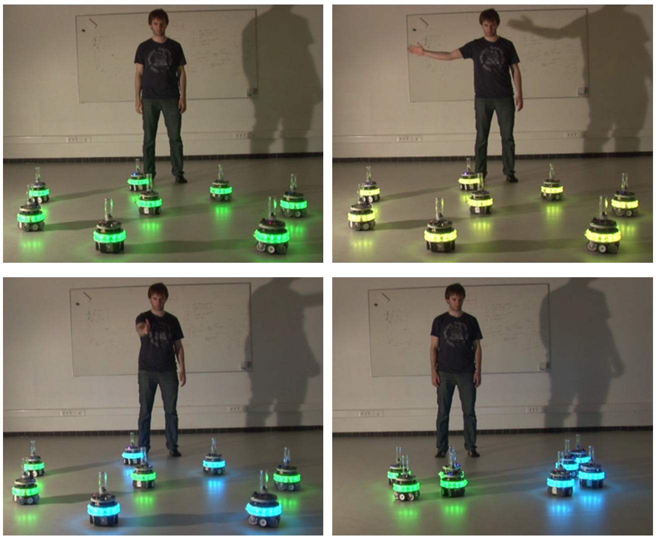

Fig. 3. Colour feedback allowing the human operator to read evolving robot grouping. Initially, the only group is represented by the green colour [top left]. After the user selects this group, it becomes yellow in order to inform the user that each command he will send will be executed by this particular group [top right]. Then, the user splits this group in two sub-groups, displayed by two different colours (green and blue). [bottom]

merge operations is, however, autonomous.

Once the group selection mechanism was developed, we still needed a way of guiding the groups of robots around the arena. We developed a dedicated Kinect gesture, replicating a virtual steering wheel, which caused the robots to turn in the environment according to the angle at which the human operator held the "steering wheel" (see Fig. 4). Using this mechanism, users could send the groups to the various task sites. The precision was sufficient to let the user avoid the obstacles and follow the arenas corridors to the desired task execution location and back. Here, the autonomy equilibrium was achieved through a flocking mechanism, that maintained group cohesion while the direction of the group was given by human command.

C. Results

We conducted 18 simulation based experiments in the simulated environment shown in Fig. 2. We used the ARGoS simulator [5] for our experiments.

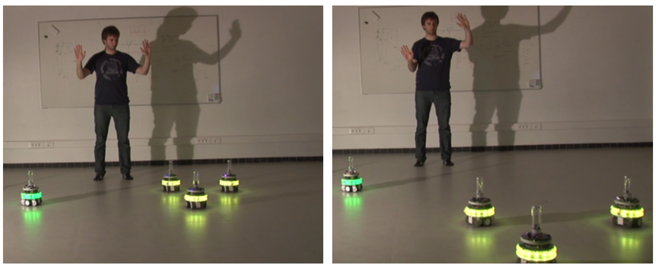

Fig. 4. Steering wheel mechanism: by turning his two hands, the selected (yellow) group of robots turn according to the angle of the user's hands.

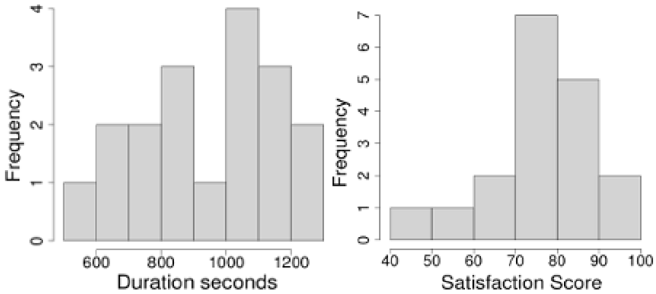

Fig. 5. On the left, the overall experiment time frequency. On the right, the satisfaction results of the SUS questionnaire. 14 people out of the 18 people tested have a score greater than 70.

We measured experimental results in two ways. Firstly, we measured time based statistics of how long various stages of the task took (e.g., how long to complete the first task, how long to complete an experiment). Secondly, we measured user satisfaction using the System Usability Scale (SUS) [6]. This is a 10 statements questionnaire with a scale of five options ranging from *strongly disagree* to *strongly agree*. The result score is a number that varies from 0 to 100 and it gives an overall idea of the user satisfaction. Both time and satisfaction results of our experiments are shown in Fig. 5.

Our experiments showed that the system was feasible, i.e. that human operators could manipulate and guide groups of robots around an arena.

III. Towards Self-Organised Feedback

In our study, the majority of users' complaints concerned the inadequacies of the feedback mechanisms. One complaint, for example, in our early trials was the lack of feedback about whether a command had been correctly received or not by the system. To address this problem we added some text based information that was displayed by our simulation environment. When a selected group received a command to perform, the name of this command appeared as floating text above the environment. Another common complaint was that there was no directional feedback about which direction a group was moving in when using the virtual steering wheel gesture. This lack of feedback rendered it difficult to know which direction to turn the steering wheel in. Our simulation based feedback fix for this problem can be seen in Fig. 6(left). Here, the direction of the swarm is indicated by arrows painted over each robot.

It is part of our ongoing work to translate these feedback mechanisms from simulation to the real robots. The most obvious solution would be to provide the same type of visual feedback using some extra infrastructure, for example using virtual reality goggles. However, we quickly realised that in the absence of the omnipotence granted us by the simulation environment, such feedback does not only involve more hardware, but even more importantly requires extra modelling. In simulation we can retrieve any information about any robot that we require, including internal state

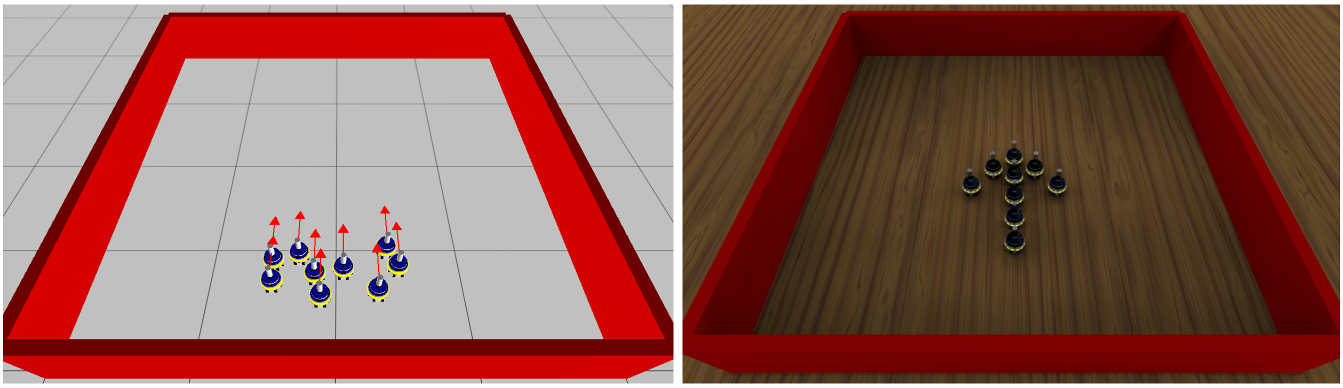

Fig. 6. Feedback with and without an extra layer. Left: Using the omniscience of the simulation environment, an arrow is drawn on the top of each robot. This approach would have high infrastructure, modelling and communication overheads in a real-world scenario. Furthermore it requires that the operator integrate a large number of different data-points. Right: Self-organised feedback (not yet implemented). The swarm forms an arrow indicating direction of motion. Internal swarm-knowledge guides the self-organised process. Only a single composite data-point needs to be processed by the operator.

information. In the real world, retrieving such knowledge would have a potentially prohibitive communication cost.

It is our proposal in this paper that the feedback mechanisms in swarm robotics systems should also be self-organised, perhaps leveraging the same self-organised mechanisms that create the functional behaviour. The light based feedback about robot groups that we have already implemented could be considered a version of this type of feedback. The colours chosen by robots reflect internal state used in the self-organising mechanism, and thus give the human operator an immediate global picture of what is going on.

A vision of a more complex, dedicated self-organised feedback mechanism can be seen in Fig. 6(right). Here, the robots form in an arrow facing the direction of motion, obviating the need for any extra hardware (goggles), communication (to extract internal state of the constituent robots) or modelling (to analyse internal state data and display it meaningfully).

IV. Conclusions

There is no value in an autonomous system that cannot be controlled. Human swarm interaction (HSI), a to date largely neglected area of research, is therefore vital if we continue to dedicate effort and money into swarm robotics research. Feedback, furthermore, is a vital component of any HSI system. Meaningful feedback is potentially both more important and harder to achieve in swarm robotics than in other robotic contexts. This discrepancy is due firstly to the radical difference of worldviews between operator and robots, and secondly due to the large number of different worldviews present as a result of the many different robots comprising a swarm system.

Based on our experience derived from a study in HSI, we argue that self-organised feedback is a good approach for swarm systems. The alternative — using extra layers of external hardware to provide feedback has potentially high overheads of infrastructure, communication, and modelling. Our current research is dedicated to proving this hypothesis, by developing practical swarm robotics feedback mechanisms.

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References

[1] S. Camazine, J.-L. Deneubourg, N. R. Franks, J. Sneyd, G. Theraulaz, E. Bonabeau, "Self-Organization in Biological Systems.", *Princeton Studies in Complexity.* Princeton University Press, Princeton, NJ, 2001.

[2] M. Daily, Y. Cho, K. Martin, D. Payton, "World Embedded Interfaces for Human-Robot Interaction". *In Proc. of the 36th Annual Hawaii International Conference on System Sciences (HICSS'03)* - Track 5 - Vol. 5, IEEE Computer Society, Hawaii, 2003, pp. 125.

[3] K. Baizid, Z. Li, N. Mollet, R. Chellali, "Human Multi-robots Interaction with High Virtual Reality Abstraction Level." *In Proc. of the 2nd International Conference on Intelligent Robotics and Applications (ICIRA '09)*, Springer-Verlag, Singapore, 2009, pp. 23-32.

[4] J. McLurkin, J. Smith, J. Frankel, D. Sotkowitz, D. Blau, B. Schmidt, "Speaking Swarmish: Human-Robot Interface Design for Large Swarms of Autonomous Mobile Robots", *AAAI Spring Symposium: To Boldly Go Where No Human-Robot Team Has Gone Before*, AAAI, 2006, pp. 72-75.

[5] C. Pinciroli, V. Trianni, R. O'Grady, G. Pini, A. Brutschy, M. Brambilla, N. Mathews, E. Ferrante, G. Di Caro, F. Ducatelle, T. Stirling, A. Gutirrez, L. M. Gambardella, M. Dorigo, "ARGoS: a Modular, Multi-Engine Simulator for Heterogeneous Swarm Robotics." *In Proc. of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS '11)*, IEEE Computer Society Press, Los Alamitos, CA, 2011, pp. 5027-5034.

[6] J. Brooke, "SUS - A Quick and Dirty Usability Scale Industrial Usability Evaluation." *Usability evaluation in industry*, P. W. Jordan, B. Thomas, B. A. Weerdmeester and I. L. McClelland. London, UK, Taylor & Francis, 1996, pp. 189-194.

[7] A. Naghsh, J. Gancet, A. Tanoto, and C. Roast, "Analysis and design of human-Robot Swarm Interaction in Firefighting," *In Proc. Robot and Human Interactive Communication*, RO-MAN'08. The 17th IEEE International Symposium on. IEEE, Munich, Germany, 2008, pp. 255-260.

[8] R. A. Brooks, "Elephants dont play chess.", *Robotics and Autonomous Systems*, Vol. 6, 1990, pp. 3-15.

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