The Swarm-Wall: Toward Life's Uncanny Valley*

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I. INTRODUCTION

Swarming animals such as ants, bees and wasps spark deep fascination in human observers. The reasons for this are many, ranging from the aesthetics of the structures they create, to disgust of the individual animals and their collective appearance of an order-less, swarming mess, to awe for their ability to create order from chaos. Whereas swarming animals [1] are among the most obvious representatives of "swarm-intelligent systems", closer inspection reveals that these concepts are ubiquitous in nature: atoms interact physically to form molecules and living cells, living cells form organs, amongst which the most fascinating and least understood is the human brain. Therefore, studying swarming systems, both in science and in the arts, is also an introspection of ourselves, leaving the observer with an uncanny feeling. We argue that these emotions are similar in nature to those observed in the "uncanny valley" effect observed in human-robot interaction [2] and first described by Freud as emotions that arise, simply put, when observing the familiar, yet strange [3]. Recent research [4] generalized this effect, suggesting that this phenomenon can be observed whenever perceptional tensions arise from conflicting cues at the boundary of categories. Indeed, while not necessarily invoking repulsion, artificial swarms might create an eerie feeling as they provide mixed perceptional cues on the category "alive".

This paper describes our recent work "Swarm Wall", an aural and visual robotic installation driven exclusively by distributed control (Fig. 1). Each actuator consists of a servo motor sweeping a helical plastic spring over a surface of vertical PVC pipes of different length and diameter, creating a noticeable aural effect. The position and velocity of the servo motor is calculated locally to be a weighted sum of those in its 4-neighborhood, inspired by the adjustment of heading in flocking and herding in animals [5]. In addition, each column of the installation is equipped with an ultrasound sensor detecting spectators whose presence alters parameters in the dynamical equations driving the system. As the individual nodes are networked, these interactions percolate into other parts of the wall, engaging the audience into playful interaction with a life-like, unpredictable organism. In combination with pre-programmed cycles of activity and rest, the behavior of the "Swarm Wall" has been systematically attributed with human moods ranging from humorous and happy to tired and angry by the audience.

Figure 1. The "Swarm Wall" a 40x12.5 square feet installation in the CU art museum during Summer 2012. Distributed control and local sensing created a life-like, interactive experience for the audience.

A. *Related work*

At first sight, "Swarm Wall" falls into a large group of robotic installations with periodic patterns, e.g., by Hye Yeon Name (Please Smile, 2011), France Cadet (Spina Family: Hunting Trophies, 2008), or more specifically lattice-based sensor-actuator networks such as the works of Justin Goodyre (Adaptive Bloom, 2010) or Nils Völker (One Hundred and Eight, 2010), which are highly interactive and more or less uncanny experiences for a variety of reasons. However, the operation of the "Swarm Wall" is fully distributed and functions without a central controller, making it amorphous, i.e., independent of shape and scale of the installation. These central properties of swarming systems have continuously served as inspiration in popular media ranging from the movies "The Swarm" (1978, Warner Brothers) in which mankind is attacked by swarms of killer bees, and "Terminator II" (1991, TriStar Pictures) in which a robot assembles from a smart liquid, allowing it to change shape, function and appearance, to books such as Michael Crichton's "Prey" (2002, Harper Collins), which describes a swarm of nano robots developing autonomy, including assembly into systems resembling humans. While these cultural references exclusively associate swarms with menaces and might bias the perception of swarms as uncanny, the "Swarm Wall" does not intend to invoke any perceptions that are attributed to menaces per se.

II. INSTALLATION

The installation consists of a wooden frame, PVC pipes, book-binding springs, printed circuit boards (PCB), servo motors (HiTec HS-645MG Ultra torque), and ultrasound sensors (Devantech SRF02). The PCBs are arranged in a

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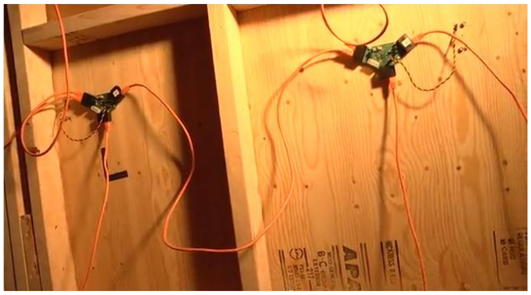

Figure 2. Inside of the "Swarm Wall" showing the wooden structure, PCBs and Ethernet cables.

lattice and connected with their four neighbors (up, down, left and right). The wooden frame extends over 42 feet by 12.5 feet and was sloped at approximately 75 degrees to create sufficient contact between the coils and the PVC pipes. PVC pipes of diameter 1.0", 2.0" and 2.5" were cut to lengths from 0.5" to 2", using a total of 20 feet of 2.5" pipe, 720 feet of 2" pipe, and 1440 feet of 1" pipe. Roughly 150 random pipe elements were glued onto panels of 3 x 2.5 square feet, arranged around a central pipe element holding a servo motor. Panels in the lowest row were equipped with an ultrasound sensor that could measure ranges between 1-5.5m. PCBs are mounted on the back of each panel. All PCBs are wired using off-the-shelf Ethernet cable after the panels were mounted. Five off-the-shelf ATX power supplies feeding into the bottom row serve groups of up to 15 nodes each.

Each PCB consists of an Atmel Xmega 128A3 and auxiliary electronics. This microcontroller was chosen for its seven hardware serial ports, which allows communication with up to six neighbors in addition to debug output. These connections (two wires, one for sending, the other for receiving data) are made available via standard 8-pin RJ45 jacks, which allows using off-the-shelf Ethernet cabling for connections. The remaining six pins of the Ethernet cable are used for power and ground (three pins each). By this, all boards share a common power supply. Servos are connected to the microcontroller's built-in pulse-width modulation (PWM) module, and the ultrasound sensors are connected to the microcontroller's built-in two wire interface (I^2C).

Software is written using Atmel's compiler toolchain and builds up on a viral bootloader (x-grid), which was developed within the course of this project. X-grid provides basic message passing functionality as well as the ability to re-program the microcontroller's flash using data obtained from a neighboring microcontroller with a newer version of the program. The main loop of all the controllers used in this exhibition consists of the following steps: receive servo angles, velocities, and proximity values from all neighbors, determine the new state in a finite state machine governing the local behavior, calculate desired servo angle as a function of the current state, send out own servo angle and value of proximity sensor, if available, and the value of the neighbor underneath otherwise.

The "Swarm Wall" periodically switches between "sleeping" and "active" modes. Active modes consist of synchronous sweeping motions, which eventually become chaotic and then settle down. Detection of a person via the ultrasound sensor let the wall react with a ripple first going through a column and then propagating through the rest of the wall. The overall behavior was strongly affected by side-effects of hardware and software. For example, the wall occasionally "wakes up" due to individual programs freezing and consequently rebooting (watchdog timer), sensor events being missed or altered due to cross-talk between neighboring ultra sound sensors, or communication packages being corrupted. In addition to the coupling between individual controllers, particularly these effects made the behavior of the wall unpredictable and let it closer resemble to a living organism than to a machine.

III. User experience and The Uncanny

"Aliveness" of the installation was driven by a series of perceptional cues: motion inspired by flocking in herd animals and resembling peristaltic motion, obvious response to user interaction, additional sources of randomness due to limitations in hardware, and the organic appearance of the backdrop and helices. Although conflicting perceptional cues that suggest both aliveness and material nature created eerie feelings in the audience and us, uncanniness was not a lasting perception with the wall quickly emerging as a "friendly beast". Following the reasoning in [4], we conjecture that by adding additional cues for the aliveness category, e.g., by adding cues pertaining to a heart-beat or breathing, or moving from a rectangular to an amorphous display, will increase familiarity with respect to the category "alive" and therefore bring the experience closer to the uncanny valley as well as amplify category perception, much like motion does in humanoid robots. In future work, we would like to more systematically study emotions that swarm-intelligent robotic art evokes by administering short surveys among the audience in upcoming installations that will use different cues. In particular, we would like to demonstrate that the "uncanny valley" observed in human-robot interaction is indeed not limited to too close to be comfortable human *appearance*, but can be generalized to other categories, capturing what we believe making swarms uncanny: the realization that life can be reduced to complex interactions that are individually simple.

IV. References

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