Communication-based Swarming for Flying Robots

Sabine Hauert, Severin Leven, Jean-Christophe Zufferey, Dario Floreano

***Abstract*— We aim at implementing a swarm of Micro-Air-Vehicles for creating communication networks (SMAVNETs) in disaster areas. For this purpose, we propose strategies for steering flying robots using only communication hardware (e.g. WiFi module or radio modem) and a magnetic compass instead of location information derived from GPS or cameras. Because there is no deterministic methodology for the design of swarm controllers, we take inspiration from biology to implement controllers based on ant-foraging or resulting from artificial evolution. Finally, we show first steps towards the deployment of aerial ad-hoc networks in reality.**

I. INTRODUCTION

Swarms of flying robots can be used in disaster areas to autonomously create communication networks for rescuers and victims (Fig. 1). Flying robots have the advantage of rapidly overcoming difficult terrain and providing unobstructed wireless communication. To allow for a swarm composed of cheap, transportable and robust robots, we avoid using positioning sensors which typically depend on the environment (GPS, cameras) or are expensive and heavy (lasers, radars). Instead, robot behaviors react to local wireless communication with robots within transmission range. Using the radio module itself for controlling the behavior of the robot (communication-based behavior) is appealing since it directly relates to the capacity of the robot to send and receive radio messages [1]–[4].

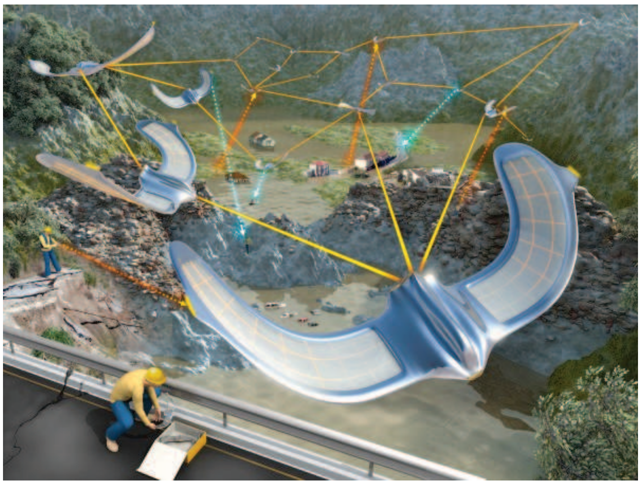

Fig. 1. Artistic view of the use of a group of flying robots for establishing communication networks between rescuers on the ground in a flood scenario.

Laboratory of Intelligent Systems, Ecole Polytechnique Fédérale de Lausanne, Switzerland {sabine.hauert, severin.leven, jean-christophe.zufferey, dario.floreano}@epfl.ch

However, there currently exists no methodology to design robot controllers resulting in the emergence of desired swarm behaviors. Here, we propose two bio-inspired techniques to overcome this problem. In the first approach, we use artificial evolution as a mean to automatically design simple, efficient and unthought-of controllers for robots [4]. We then reverse-engineer these controllers and reuse the discovered principles in different scenarios [5]. In the second approach, we look at the creation, maintenance and evaporation of army-ant pheromone trails during foraging and apply the same principles to the design of robot controllers for the deployment, maintenance and retraction of communication networks [3].

Finally, we present a first step towards experiments in reality by showing the steering of a single flying robot using only communication hardware (e.g. WiFi module or radio modem) and the current fleet of robots being developed in the scope of the SMAVNET project [6].

II. EVOLVED NETWORK DEPLOYMENTS

Artificial evolution has been extensively used for the development of robot controllers due to its capacity to automatically engineer solutions displaying complex abilities using simple and efficient behaviors [7], [8]. Systems of interest generally can not be solved using conventional programming techniques because they are highly non-linear, stochastic or poorly understood [9]. Subsequently, artificial evolution is particularly well suited for the design of controllers for swarms of robots. In addition, the mechanisms leading to the evolution of cooperation in natural and robotic systems have just recently been understood [10], [11]. In particular, genetic algorithms and genetic programming have successfully been used to design controllers for swarms of ground [12], [13] and aerial vehicles [4], [14]–[18] in simulation or on-board physical robots in research environments.

Designing swarm controllers for flying robots is especially challenging because of the lack of positioning information, which is unprecedented in the literature [19]–[23], and the dynamics of our fixed-wing flying robots that must always remain in motion to avoid stalling. To overcome these challenges, we use artificial evolution as a means to automatically design neural controllers for the robots.

An example showing the behavior of the evolved swarm forming an ad-hoc network between two rescuers can be seen in Fig. 2. The strategy adopted by the swarm consists in forming a tight chain of robots which grows as long as additional robots are launched from the rescuer to the South. Once all flying robots have been launched, the chain shifts along the communication range of the launching rescuer,

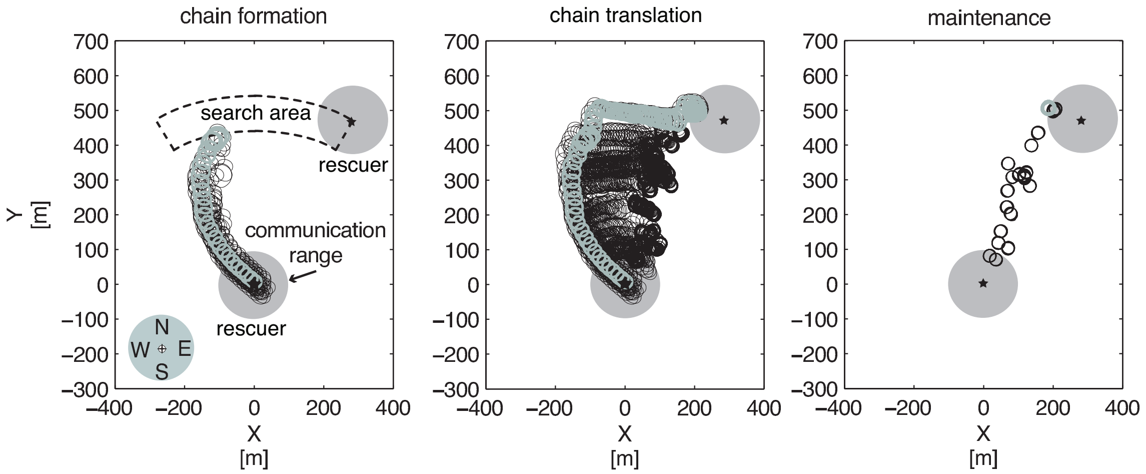

Fig. 2. Trajectories performed by the evolved robots during a 30 min mission. In this mission, robots are launched from a rescuer at regular intervals and must self-organize to search for the second rescuer to the North-East. Robots form chains that can translate from West to East until the second rescuer is found. Robots then maintain the connection by turning on the spot. The trajectory of the first launched robot is shown by a light grey line.

sweeping the area from West to East until a second rescuer is found. The communication link between the two rescuers is then maintained by having all robots turn on the spot with the smallest possible radius given the dynamics of the aircraft [4].

However, evolved controllers are often unable to adapt across different scenarios without being re-evolved. This process takes time and is unrealistic for robot swarms which are intended to be used out-of-the-box in critical applications. Instead we propose to reverse-engineer evolved controllers so as to capture the simplicity and efficiency found through evolution in hand-designed robot controllers whose parameters can easily be optimized for various scenarios. For our application, reverse-engineered controllers resulted in three simple local-interactions responsible for the emergent behavior of the swarm, namely chain formation, translation and communication maintenance. Such rules form the basis for controllers which will be adapted to real-life scenarios with wind, varying robot dynamics or mobile rescuers [5].

III. Ant-based Network Deployments

Army ant colonies display complex foraging raid patterns involving thousands of individuals communicating through chemical trails (pheromone). These structures are thought to reflect an optimized mechanism to explore and exploit food resources in nature [24].

By taking inspiration from the foraging mechanism found in army ants, we want to create, maintain and retract aerial ad-hoc networks between rescuers. However, in real-life applications, it is often undesirable to modify the environment in which robots deploy (by physically depositing chemicals or objects) and the deploying substrate is often unstable (e.g., air, water and quickly modifiable environments). Also, depositing virtual pheromone on a map is not possible when no global positioning is available [25]–[27]. To solve this issue in our system, pheromone is virtually deposited on the robots (pheromone robotics [28]). The approach proposed here consists of separating the flying robots into two types, namely "nodes" and "ants". Nodes constitute the environment on which pheromone can be virtually deposited and read from. Ants are capable of navigating through a grid of nodes while depositing virtual pheromone on them through the use of local wireless communication. Furthermore, robots can dynamically change between both categories.

An example of an ant-based swarm behavior in simulation can be seen in Fig. 3. Observed behaviors include the formation of grids composed of several short branches deployed in multiple directions or longer chain-like grids capable of searching in a single direction for distant rescuers. The overall network changes between different configurations until a rescuer is found. The network is then optimized and maintained by attracting robots to useful positions in the network using pheromone. Finally, because pheromone evaporates, robots eventually retract to the nest where they are either told to redeploy or land.

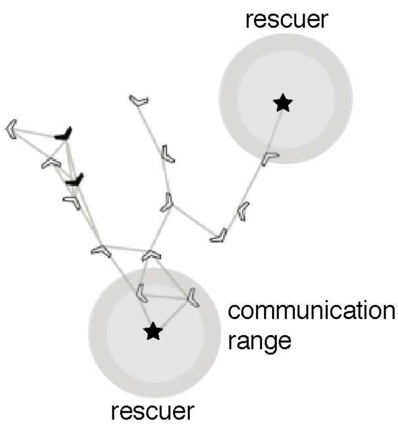

Fig. 3. Simulator screenshot showing the successful ant-based deployment of flying robots forming an ad-hoc network between two rescuers. Nodes are white with black borders, ants are in solid black and lines represent local communication links.

IV. Reality

A fleet of flying robots is currently being produced and tested to allow for the creation of SMAVNETs in reality. Such robots will be used to validate algorithms currently developed in simulation. To our advantage, the platforms were specifically designed for the safe, inexpensive and fast prototyping of aerial swarm experiments.

In particular, we use light weight (420 g, 80 cm wingspan) and safe fixed-wing platforms shown in Fig. 4. They are built out of Expanded Polypropylene (EPP) with an electric motor mounted at the back and two control surfaces serving as elevons (combined ailerons and elevator). The robots are equipped with an autopilot for the control of altitude, airspeed and turn rate [29]. Embedded in the autopilot is a micro-controller that runs a minimalist control strategy based on input from only 3 sensors: one gyroscope and two pressure sensors.

Fig. 4. Current fleet of swarming MAVs being built in collaboration with spin-off company SenseFly (http://www.sensefly.com/).

The communication-based controllers are implemented on a Toradex Colibri PXA270 CPU board running Linux, connected to an off-the-shelf USB WiFi dongle. The output of these controllers, namely a desired turn rate, speed or altitude, is sent as control command to the autopilot. In order to log flight trajectories, the robot is further equipped with a u-blox[1] LEA-5H GPS module.

For the WiFi communication, Netgear[2] WNDA3100 dongles were used that implement the 802.11n standard and transmit in the 5 GHz band. This is interesting with respect to transmissions in the 2.4 GHz band because it allows for less interference with the considerable number of devices currently used in this band. Dongles are configured for ad-hoc mode and have a communication range of nearly 500 m line-of-sight which can be reduced by modifying the drivers depending on the needs of the experiment. The same Linux computer and WiFi dongle are used by the rescuers.

As a first step towards the fully autonomous deployment of these robots in reality, we show that a single robot can indeed be steered using only wireless communication. In particular, we show the leashing of a flying robot to a rescuer on the ground [6]. For this purpose, the rescuer broadcasts small "hello messages" at a regular interval. The robot then measures the rate of incoming messages, which is always feasible regardless of the radio module used and drivers. The signal-to-noise ratio (SNR) of incoming messages has also been used in the literature [2], although its availability is product-dependent.

The robot is then leashed to the rescuer by allowing it to move freely as long as the message rate is high, and pulling the robot back towards the rescuer when the extent of the leash has been reached (low message rate). The manner in which the leashing is performed highly depends on the dynamics of the platform and the noise present in the environment. Real-life conditions are such that there are often disturbing relative displacements between the rescuer and robot due to wind or rescuer mobility. To compensate for displacements and disconnections from the rescuer, logarithmic spirals are used because of their ability to expand with equal speed in all directions. The resulting trajectory of a real flying robot can been seen in Fig. 5.

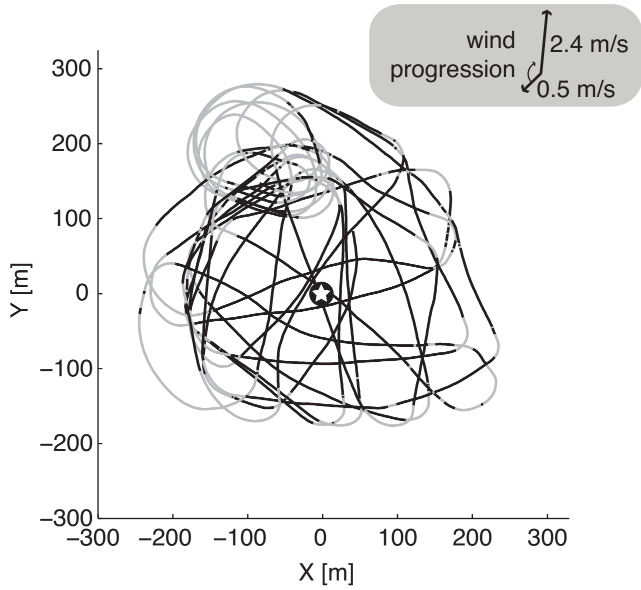

Fig. 5. 20 min trajectory of a single fully autonomous flying robot leashed to a rescuer (star) in an outdoor experiment with 0.5 m/s to 2.4 m/s wind between 220° and 10° from the North. Here the robot flies at constant speed and 70 m altitude. Light grey lines indicate sections of the trajectory where the robot is reconnecting to the rescuer using a logarithmic spiral trajectory while black lines indicate that the robot is receiving messages from the rescuer.

V. Conclusion

Current research in the SMAVNET project opens the way towards the deployment of aerial communication networks in reality in terms of controller design, and hardware implementation. Unlike current aerial research that heavily relies on global or relative positioning and planning to function, robots here react to local communication with neighboring robots as a control paradigm. The creation of ad-hoc networks is the result of these local interactions designed using artificial

[1] http://www.u-blox.com
[2] http://netgear.com

evolution or ant-inspired algorithms. In the future, we aim at investigating the optimization of ad-hoc networks through robot mobility and demonstrating controllers designed in simulation on board a fleet of real aerial robots.

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