AÉRO 2019 Extended Abstract:

UAV Swarm Control and its Influence on Cognitive Workload: A Field Experiment

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Since the beginning of space exploration, Mars and Moon have always been targets for orbiters, landers, and rovers. With varying degrees of success, over 40 missions have attempted to reach Mars, and even more tried to reach the Moon. The space agencies around the world are looking for novel strategies to further explore celestial bodies. Analogue exploration missions are used as a proving ground for new technologies and mission concepts that could aid in space exploration missions. In fall 2018, the European Space Agency invited our team to take part in their astronaut field training to demonstrate how swarm intelligence can be leveraged for such missions. We brought a heterogeneous fleet of ten Unmanned Aerial Vehicles (UAVs) to compare two different control modalities with respect to how human factors are influenced during the operation of the system. While conducting exploration missions using the swarm, the operators wear eye-tracking glasses to monitor their cognitive load via pupillometry. The first control mode is a waypoint-based approach and the operator has to send target coordinates to each UAV individually. The second control approach is swarm-based and uses self-organizing behaviour to explore the environment with an increased level of autonomy. The results suggest that the operators' cognitive load can be reduced by giving more intelligence and autonomy to the robotic system. We believe these findings to be applicable to any mobile autonomous system and therefore indicate a promising future for swarm intelligence deployment in planetary exploration missions.

I. INTRODUCTION

The space agencies around the world are looking for novel strategies to further explore celestial bodies. NASA, for instance, is planning to extend human spaceflight operations to lunar orbit and the Moon's surface to train for human missions to Mars [1]. The European Space Agency (ESA) is working towards their "Moon Village" vision which includes human and robotic activities on the Moon. Analogue exploration missions are used as a proving ground for new technologies and mission concepts that could aid in space exploration missions. The European Space Agency tasked our team (shown in Fig. 1) with the design of an experiment to take part in such analogue mission: the PANGAEA-X (Planetary ANalogue Geological and Astrobiological Exercise for Astronauts eXtension). The task itself was to familiarize their astronauts with the use of multi-robot aerial systems for planetary exploration. We developed deployment mechanisms for UAV teams that are able to gather aerial images and provide ground units with a fleet-wide communication link over kilometres. This in itself is a contribution to applied space robotics. Taking advantage of this field experiment, we expanded our research towards the field of human-robot interaction (HRI) tackling the following question: Does adding embedded autonomy decrease the load on the operator? To do so, we created two control modes with different autonomy levels. We monitored and assessed the operator's cognitive load while governing the fleet.

II. UAV CONTROL MODES

The main interface to control the swarm is a tablet based command center. During the experiments, operators were asked to use the swarm and explore an environment containing hidden ground features using two different control modes: the dynamic waypoint control mode, and an autonomous deployment mode.

Fig. 1. PANGAEA-X field deployment team in Lanzarote, Spain: five engineers, a neuroscientist, five DJI Matrice 100 and five Pleiades Spiri. (Image: ESA)

II.I DYNAMIC WAYPOINTS

In the dynamic waypoint control mode, the operators use the tablet and click on a map to select which robot should head to which location. While the control strategy is centralized on the user, i.e. sending an absolute goal location to each of the robots independently, the communication leverages our decentralized system to ensure robustness (information propagation throughout the swarm).

II.II AUTONOMOUS DEPLOYMENT

The second control mode is based on computational geometry and gives more intelligence to the fleet. Instead of assigning individual waypoints, the user defines a region of

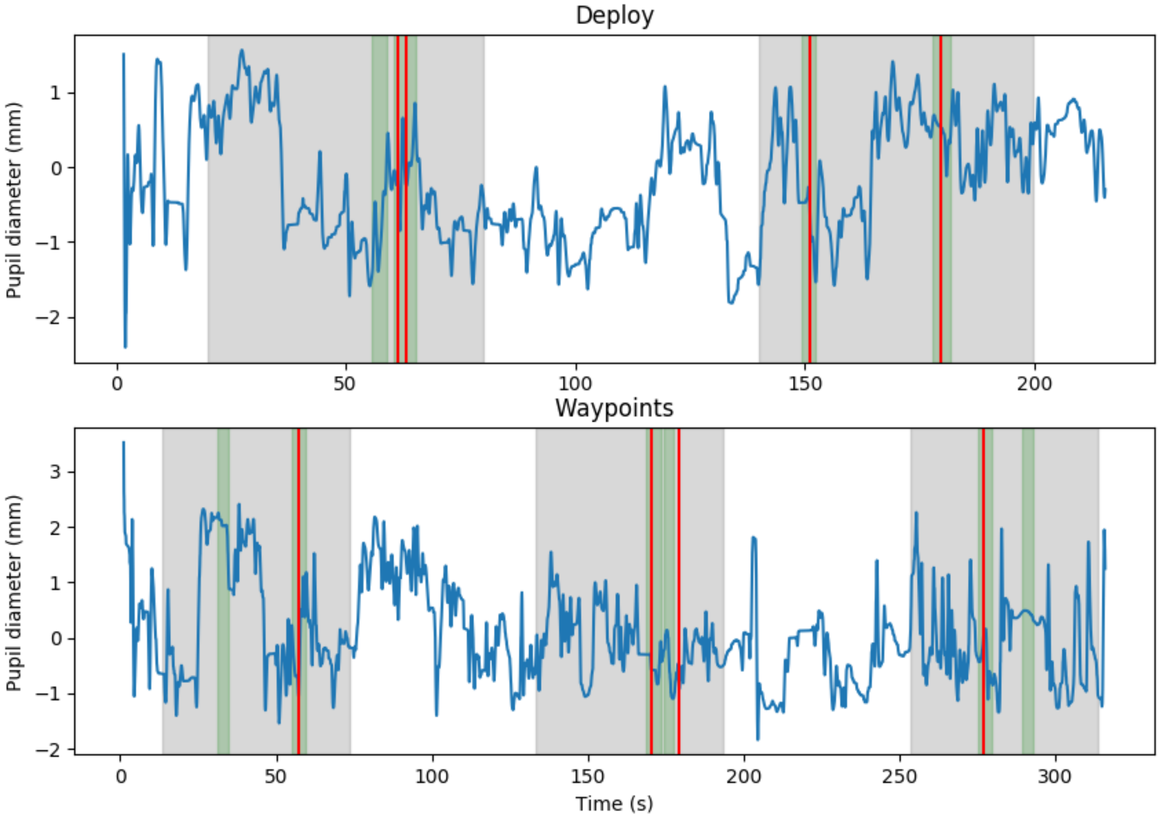

Fig. 2. Pupil diameter variations for both control modes for one participant. Background discussion periods are shown in gray, the green bars show the direct questions asked to the operator. Each time the 'acknowledge' button of the interface was hit by the participant, a red bar is plotted.

interest on the map. The swarm members then split the region among themselves using a process called Voronoi tesselation [2], which has been studied extensively for multi-robot deployment.

III. WORKLOAD ASSESMENT

Commanding a robotic system for planetary exploration missions is challenging. To make the mission more realistic, we take into account that operators may need to accomplish multiple tasks in parallel. For this, we design a simulated team discussion, which is played via earphone to the operator directly. The audio sequences contain background discussions, such as "Come on, there are some interesting things here.", and mission specific questions which address the operator directly, such as "Operator, how far is robot number one from the initial point?". By alternating periods of background discussion, periods of questions, and periods of silence, we aim to compare the variation of cognitive load associated with the robot team control modes.

In this work, we present the results of an objective measurement: pupil dilatation captured via a wearable eye-tracker. This measurement has recently gained new interest in the field of Psychology because pupils have been found to dilate as a response to increased cognitive activity and other influences, like brightness and fixation [3]. In a different study [4] dilatation of the pupil was recently shown to be a good measurement of pilot cognitive load when dealing with auditory-visual interference on a visual piloting task. The main limitations of pupil dilatation measurements are that the diameter varies across subjects and that it is highly sensitive to luminance variation [5]. While the first constraint can be dealt with median filtered data, the second requires a static scene light or to compensate the effect of ambient scene light from a second camera.

IV. RESULTS

After a series of runs on our team members (beta testers), we ran the experiment with two members of the ESA crew (men) and a journalist (woman) as operators. In the short time window available in the PANGAEA-X schedule, these three runs were a great accomplishment, considering that: 1. setting up the UAVs for a trial can take up to 30 minutes, 2. each trial has the duration of one hour, 3. we had to ensure the winds were below 30km/h, and 4. weather and visibility had to be in good conditions (neither raining, nor too dark).

We collected live measurements of the operators pupil diameter using an eye-tracking device from Pupil Labs. The eye-tracker was calibrated for each participant before conducting their first UAV mission. The raw pupil data is noisy and required to filter out the outliers ($> \frac{\sigma}{2}$), remove the median diameter value and filter out the high frequency variation (low-pass filtering). The resulting curves of the two missions for the same participant are shown in Fig. 2. We highlight the periods with background discussions (gray), direct verbal question to the operator (green) and operator replies (red) in the graph.

Does more autonomy on the fleet decreases the load on the operator and increase the performance?

The resulting pupil diameter variations show that the operator's pupil is on average more dilated for the waypoint control. This shows a higher cognitive load for this control mode, while the background discussions and questions have a similar effect on both missions. Interestingly, the operators in both control modes acknowledged only half of the questions directed at them, most likely because the operators were already overwhelmed with the mission itself.

V. CONCLUSION

It may seem trivial that more autonomy reduces the workload on the operator, but the objective pupillometry measurements need to be validated in future work. We think this encourages more extensive testing with a larger number of participants, which will then address the shortcoming of statistical significance of the current results. We believe the overall findings are applicable to any mobile autonomous robot team and therefore indicate a promising future for swarm intelligence deployment in planetary exploration missions.

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