AC/DC: Autonomic Computing to Maintain Drone Fleet Continuity

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Autonomic Computing Systemization of Knowledge Session

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- MSc A.I. Candidate at Ulster University
- Autonomic Computing interest from MSc A.I. module: COM760 Autonomic Computing and Robotics

- A manager in PWC’s Data & Analytics department in Belfast, Northern Ireland. With experience in data analysis, strategy & governance, Fiachra now leads a transformative initiative at PwC, steering the evolution of data and analytics services from ad-hoc consulting to a managed services approach.
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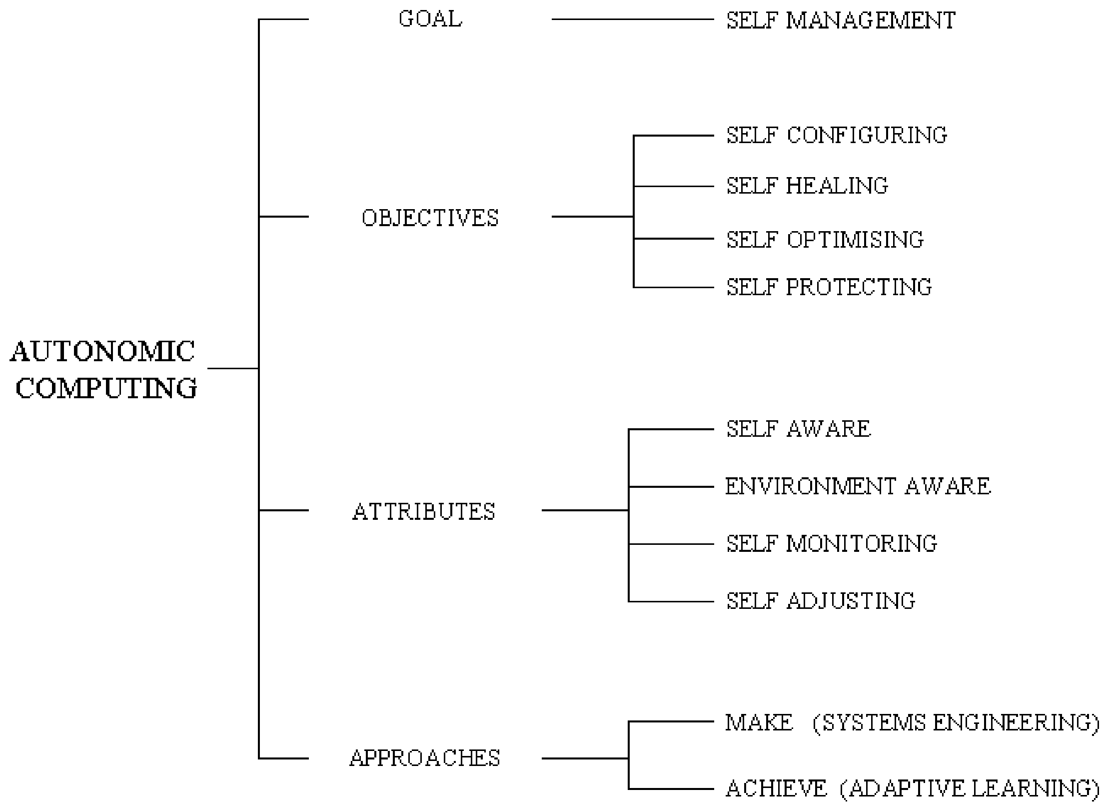
Overview

The main objectives of this paper are to:

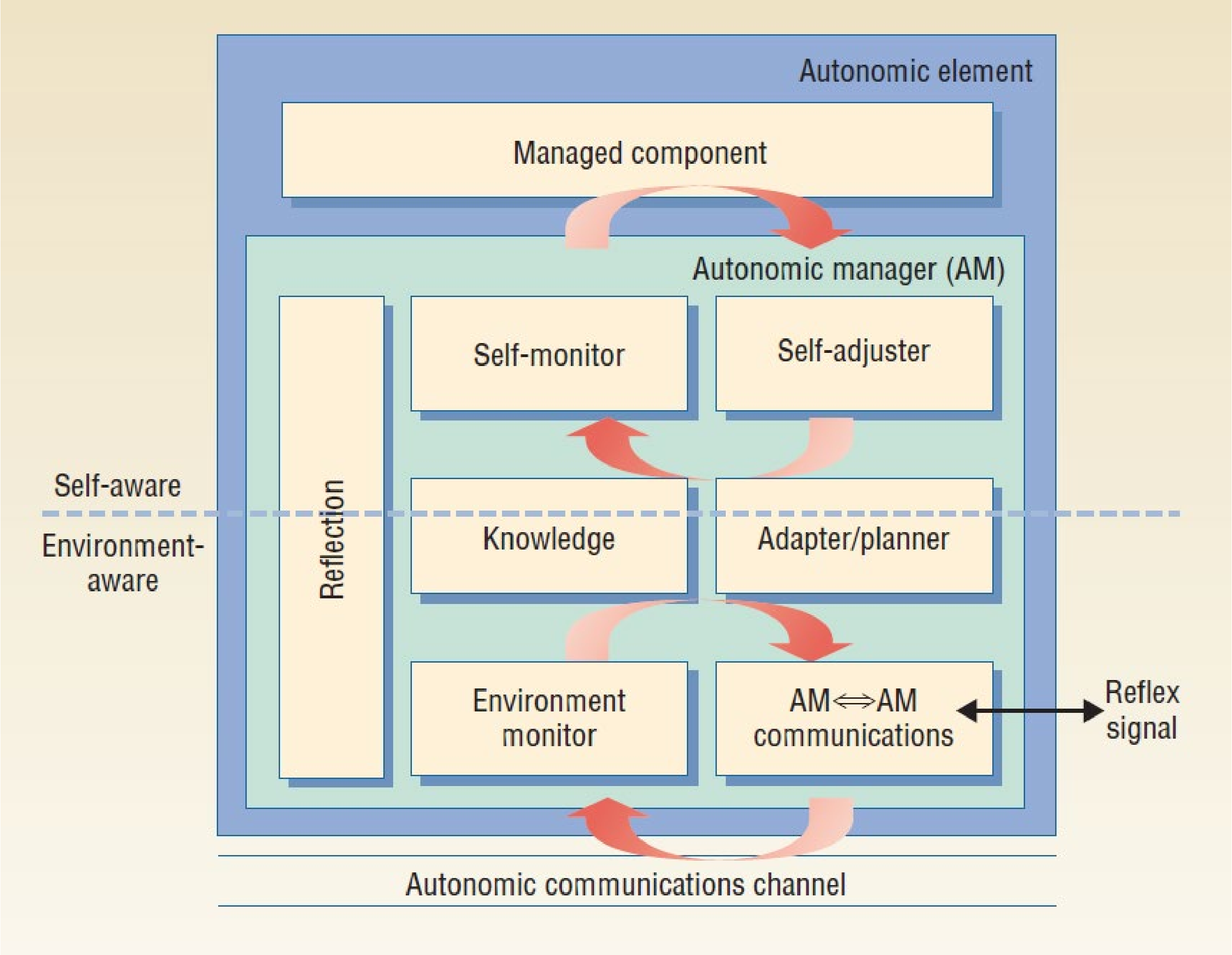
- Identify the current state of the art in UAV surveillance technology
- Outline requirements of an autonomic system as it relates to a surveillance system comprising of multiple UAV’s
- Propose an autonomic solution to ensure appropriate self-management as fleets of UAV’s begin to scale
- Consider both the suitability and ethical implications of this proposal

Autonomic Computing – Autonomic Tree



R. Sterritt and D. Bustard, “Autonomic Computing - a means of achieving dependability?,” *10th IEEE International Conference and Workshop on the Engineering of Computer-Based Systems,* pp. 247-251, 2003.

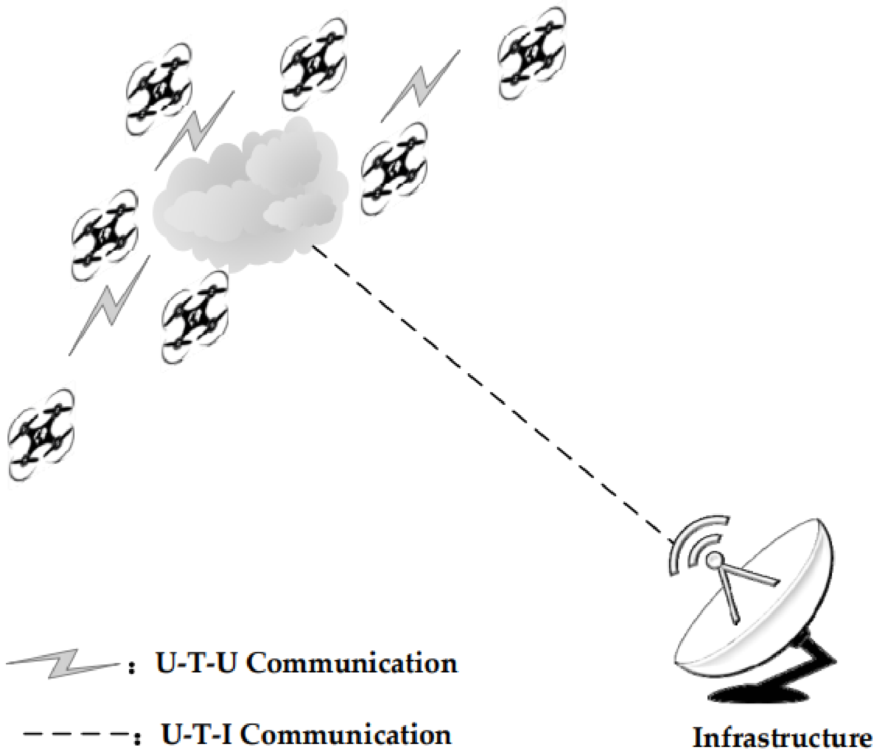
Autonomic Computing –
Control loops in an autonomic element



M. G. Hinchey and R. Sterritt, “Self-Managing Software,” Computer, vol. 39, pp. 107-109, 2006.

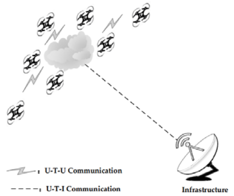
AC/DC Architecture

- A comprehensive review of UAV swarm communication architectures is provided in [1].
- The "Single-Group Swarm Ad hoc Network" architecture is used as the baseline architecture in this proposal and will be enhanced using lessons learned from [2].
- A schematic of the infrastructure is shown in Figure, where U-T-U stands for UAV-to-UAV communication and U-T-I stands for UAV to base infrastructure communication.



[1] X. Chen, J. Tang and S. Lao, "Review of Unmanned Aerial Vehicle Swarm Communication Architectures and Routing Protocols," Applied Sciences, vol. 10, p. 3661, 2020

[2] C. Saunders, R. Sterritt and G. Wilkie, "Computer Vision Techniques for Autonomic Collaboration between Mobile Robots," The Seventh International Conference on Adaptive and Self-Adaptive Systems and Applications, pp. 51-57, 2015.



AC/DC Architecture

- In a “single-group swarm Ad hoc network”, there is no dependence on the base station infrastructure providing communication to all UAVs, therefore eliminating a single point of failure in the system. At any given instant, the closest UAV to the base station infrastructure, known as the “gateway UAV” sends and receives information at high power, with only low power transmission being required to transmit and receive information between the remaining UAVs.

- Although “UAVs in the swarm can share situation information in real time to optimize collaborative control and improve efficiency”, [1] loss of the gateway UAV may constitute a single point of failure if the loss is not managed appropriately, and this is where an autonomic solution fits in perfectly to maintain the continuous deployment of the swarm without human intervention. This is due to the fact that the gateway UAV contains additional transceivers to allow it to communicate at high power to the base station infrastructure.

- An enhancement is proposed for this infrastructure by including heartbeat monitoring, similar to that described in [2][3]. Autonomic elements, as per algorithm (next slide), will be incorporated in each individual UAV of the swarm, as well as the base station infrastructure.

- The concept is that each UAV in the swarm will be emitting an “I am alive” signal. This will be received by both surrounding UAVs using the U-T-U communication and by the base station infrastructure using the U-T-I communication, for the UAV sending the high-power transmission. If this signal is not received at any instance, then an algorithm, as specified in Figure 4, will be executed.

[1] X. Chen, J. Tang and S. Lao, “Review of Unmanned Aerial Vehicle Swarm Communication Architectures and Routing Protocols,” Applied Sciences, vol. 10, p. 3661, 2020
[2] M. G. Hinchey and R. Sterritt, “Self-Managing Software,” Computer, vol. 39, pp. 107-109, 2006.
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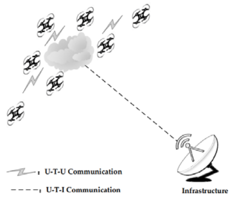
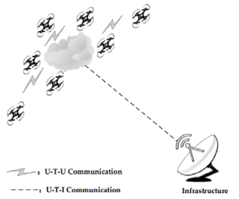


AC/DC Architecture

Proposed algorithm for reflex signal, inspired by [1]

```
Swarm autonomously performing surveillance of environment
if "I am Alive" signal not received then
    Determine last known GPS position
    Closest UAV to the GPS position self identifies
    Closest UAV moves to within imaging range of the gps position
    Closest UAV runs computer vision algorithm for detection of obstacles and UAVs
        If unexpected objects found by computer vision then
            Relay signal to reconfigure the route planner for the swarm
        Elsif threat is identified by computer vision then
            Relay signal to reconfigure the route planner for the swarm
            Report threat findings to base station operator
            Endif
        If lost UAV found by computer vision then
            Send communication of updated GPS location and video for recovery team
        Endif
    If signal received by base station then
        Dispatch new Gateway UAV to replace lost UAV
        Establish new connection between the gateway UAV and the swarm and base station
    Else
        Dispatch generic UAV to replace the lost UAV
    Endif
Endif
```

[1] C. Saunders, R. Sterritt and G. Wilkie, "Computer Vision Techniques for Autonomic Collaboration between Mobile Robots," The Seventh International Conference on Adaptive and Self-Adaptive Systems and Applications, pp. 51-57, 2015.



AC/DC Architecture

The successful implementation of this algorithm will rely on the swarm of UAVs and the base station operating as autonomic managers and it aims to:

1) Dispatch a new UAV: This will ensure self-healing of the system is achieved, specifically addressing the issue of gateway UAV loss and re-establishing the connection between the swarm and the base station infrastructure

2) Send the closest UAV by GPS position: This is carried out to monitor the location of the lost UAV and identify any obstacles or threats and the location of the lost UAV. This ensures the system achieves the self-protection objective, if threats or new obstacles do exist.

3) If applicable, update the routing plan for the swarm: Based on the findings from point 2, this aspect will help achieve the self-configuration and self-optimisation of the autonomic system by ensuring repetition of the UAV loss will not occur due to special or external threats

4) If applicable, send information on lost UAV: Also, based on the findings from point 2, this aspect will help achieve self-healing to a degree, although the underlying motivation for the execution of this procedure is for an operator to use this data for physical retrieval and inspection of the site of the loss.

[1] C. Saunders, R. Sterritt and G. Wilkie, “Computer Vision Techniques for Autonomic Collaboration between Mobile Robots,” The Seventh International Conference on Adaptive and Self-Adaptive Systems and Applications, pp. 51-57, 2015.

Conclusion & Future Work

- The proposed autonomic solution is an enhancement to the current state of the art of UAV swarm communication technology, as informed by the reviewed literature. The main advantage of incorporating an autonomous computing element to the swarm architecture is ensuring self-configuration and self-healing of the system, particularly in the case where the gateway UAV is lost.

- The heartbeat reflex signal methodology is a good fit for the autonomic elements of this architecture, as it is imperative for UAVs to consume as little power as possible and a simple signal achieves that requirement. The result of the implementation, which achieves the self-CHOP objectives will be UAV swarms operating without operator intervention, for the most part, though it is noted that the physical nature of robotic swarms will always require some physical involvement.

- Although this enhancement will improve upon swarm route optimisation and threat avoidance, a real ethical concern is raised, as military usage of these swarms is inevitable. It is difficult to state, prior to implementation, if this could be used purely defensively, or offensively also. However, it is clear from both the research carried out and the reasons behind implementation of the autonomic elements of the system, such as healing due to loss of UAVs and optimisation after identification of threats to the system, that military use is the use case that would ultimately benefit the most.

- Autonomic computing and its implementation in systems is not as widely known or publicised as autonomous implementations, however it is clear from the research carried out for this paper and the potential implication of the implementation of the proposal in this paper, that without autonomic computing, the autonomous algorithms may be rendered useless.

Acknowledgements

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Thank You

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