Navigation Phases Platform: Towards Green Computing for UAVs

Mariana Rodrigues*, Daniel F. Pigatto† and Kalinka. R. L. J. C. Branco*
*Laboratory of Critical Embedded Systems
Universidade de São Paulo (USP), São Carlos, São Paulo, Brazil
Email: rodrigues.mariana@gmail.com, kalinka@icmc.usp.br
†Federal University of Technology — Paraná (UTFPR)
Curitiba, Paraná, Brazil
Email: pigatto@utfpr.edu.br

***Abstract*—Energy efficiency is a topic with increasing relevance in the computing field. The *Green Computing* paradigm is a global concept that aims at energy efficiency, lowering greenhouse gas emissions, using less harmful materials, and encouraging reuse and recycling. For battery-powered embedded systems like Unmanned Aerial Vehicles (UAVs), energy efficiency increases their autonomy, resulting in tasks being realized with less power. With less power being consumed during each mission, the battery will require fewer recharges, thereby increasing its lifetime and reducing the waste. Even though some effort has been done in energy efficiency for UAVs, most published papers focus on finding alternative energy sources for those vehicles. In this paper, we present the Navigation Phases (NP) platform, which provides a very well-defined way of controlling the behaviour of UAV's internal components during a mission. The main concepts of NP are provided, as well as the results of an initial prototype for controlling the component's behaviour through different mission stages.**

***Index Terms*—Unmanned aerial vehicles, UAV, Navigation, Energy efficiency, Green computing**

I. Introduction

Embedded systems are a highly-integrated hardware and software set that are part of a larger system, usually performing real-time monitoring and control tasks. Embedded systems are considered safety-critical if eventual failure may result in loss of lives or high-value assets [1]–[3]. An Unmanned Aerial Vehicle (UAV) is a typical application of a critical embedded system. Several papers have demonstrated the feasibility of using such vehicles as tools for precision agriculture, reconnaissance & surveillance, tracking, location and target analysis, traffic monitoring, transport logistics, environment monitoring and others [4]–[11].

For battery-powered wireless embedded systems like UAVs, energy efficiency is a key challenge, with considerable research effort has been devoted to energy optimization of such systems [12]–[14]. Reducing energy consumption in UAVs leads to (1) increased autonomy and longer missions, encompassing bigger tasks, which results in (2) reduced number of flights to accomplish a task; (3) reduced battery disposal due to battery lifetime increase and (4) heavier payloads due to energy consumption reduction.

Energy saving is also a very important topic in Information Technology (IT) as a whole. The deployed infrastructure consumes significant amounts of electricity, placing a heavy burden on our electric grids and contributing to greenhouse gas emissions [15]. For that, the *Green Computing* paradigm investigates models and applications to reduce the cost and power consumption of IT systems to promote sustainable development of technology [16]. Green IT benefits the environment by improving energy efficiency, lowering greenhouse gas emissions, using less harmful materials, and encouraging reuse and recycling.

In UAV domain, most published papers regarding energy efficiency focus on finding alternative energy sources (e.g. solar panels, piezoelectric-based approaches). Another solution would be the optimization of tasks to reduce the energy consumption and increase battery times [17].

In this paper, we present the Navigation Phases (NP) platform, which provides a very well-defined way of controlling the behaviour of UAV's internal components during a mission to (1) reduce energy consumption; (2) increase the control of active modules; and (3) increase the system's overall security and safety by dynamically reducing the attack surface and making it feasible to create jointed approaches from specialized security and safety management units. The remainder of this paper is organized as follows: Section II presents some works related to Green Computing and UAV; Section III presents the Navigation Phases platform, with its prototype being discussed in Section IV. Section V concludes the paper.

II. Related work

Improved energy consumption approaches allowing longer autonomy to unmanned vehicles and mobile embedded systems in general is one of the biggest challenges faced in the field [18], [19].

The authors acknowledge the support granted by CAPES and FAPESP under process 2012/16171-6.

Research was also sponsored by the Army Research Office and was accomplished under Grant Number W911NF-18-1-0012. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Army Research Office or the U.S. Government. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation herein.

Several research reports focus on providing additional energy supply to unmanned vehicles. Energy scavenging concepts were reviewed and analyzed by [20] to determine their potential for supplementing the on-board energy of small electric unmanned systems. Experiments were performed with photonic (solar), kinetic-flow (wind), thermal, electromagnetic sources of energy, and autophagous structure-power concepts that allow for energy generation through self-consumption of system structure. Similarly, [21] analyzed solar and piezoelectric energy harvesting techniques along with their basic functions, [22] analyzed piezoelectric energy harvesting with an application to UAVs, and [23] analyzed vibration and solar energy in a mini UAV. Moreover, [24] proposed an energy management of fuel cell/battery/supercapacitor hybrid power source for vehicle applications, which goes on the same direction of aforementioned works. Finally, another approach has considered acquiring energy from wind on UAVs [25]. Conclusions provided by these investigations were promising, however focused solely on acquisition of more energy supply during vehicle's operation.

Although efficient, the acquisition of power during operation may increase the weight of an unmanned vehicle and reduce its endurance time. Thus, some approaches focused on dealing with communication protocols towards the reduction of energy consumption. As pointed out by [26], for disruptively boosting network energy efficiency, hardware enhancements must be integrated with ad-hoc mechanisms that explicitly manage energy saving, by exploiting network-specific features. Concerning routing protocols that can take into account energy constraints in embedded systems, [27] described the power and associated heat management challenges in routers, considering making power-awareness a primary objective in the design and configuration of networks, and in the design and implementation of network protocols.

Reduction of unnecessary energy consumption is a major concern in wired networking, due to the potential economical benefits and its expected environmental impact, as discussed by [28]. Other works have focused on wired communications, such as [29] who provided energy minimization techniques for high-speed communication over optical networks. However, wired approaches when designed for UAVs may increase weight and become limiting too, leading to a natural interest in wireless communications.

Therefore, there is a growing tendency on replacing wired cables on internal communications in unmanned vehicles, specially UAVs [30], [31] and few researches have been focusing on energy-aware wireless communications challenges as summarized by [18] and also generally addressed in [32], [33]. The gap which was not yet properly addressed on energy efficiency techniques for UAVs is the provision of a mission-aware approach that can potentially reduce energy consumption by specifying very strict flight phases along with aircraft modules behavior regarding energy usage. This paper will address Navigation Phases, which was first proposed and validated in [34], showing latest developments and progress towards the platform implementation.

III. The Navigation Phases Platform

The Navigation Phases Platform is part of HAMSTER (HeAlthy, Mobility and Security based data communication archiTEctuRe). HAMSTER [35], [36] is a data communication architecture for unmanned vehicles designed for improving mobility, security and safety of the overall system. HAMSTER can be specialized into specific versions depending on the vehicle type: aerial (Flying HAMSTER), ground (Running HAMSTER) and aquatic (Swimming HAMSTER).

HAMSTER contains four different platforms: ***Cloud*–SPHERE** (Security and safety Platform for HEteRogeneous systEms connected to the Cloud) [37] controls both security and safety aspects of the vehicle; **NIMBLE** (NatIve MoBiLity platform for unmanned systEms) aims at mobility aspects of those vehicles; the **NCI** (Node Criticality Index) module evaluates the criticality of the vehicle as a hole and of each of its components individually through a rich index; finally, the **NP** (Navigation Phases) platform aims at managing the vehicle components to provide efforts towards energy efficiency.

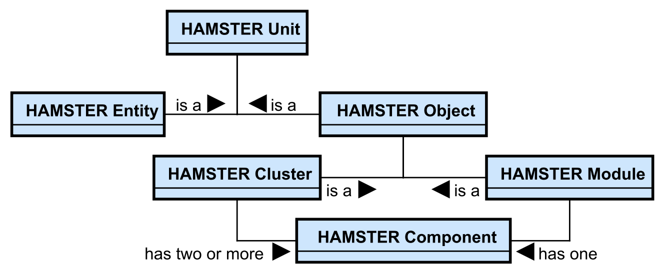

Fig. 1: HAMSTER Units conceptual model.

Fig. 1 presents the conceptual model of the architecture. HAMSTER functionality is implemented by a *HAMSTER Unit*, which can be applied to a single vehicle component (forming a *HAMSTER Module*), to a set of components (forming a *HAMSTER Cluster*), or to a vehicle (forming a *HAMSTER Entity*). We call a *HAMSTER component* any sensor or actuator of the vehicle, as well as any equipment like cameras, GPS receiver, autopilot, etc. Each type of Unit has within itself the necessary implementation of HAMSTER platforms.

Fig. 2 shows an inner view of a HAMSTER Unit with the platforms that compose the architecture. The **`NP Unit`** implements the NP Platform within an unit; **`Node Criticality`** implements the NCI platform and **`Cloud-SPHERE`** implements the *Cloud*–SPHERE platform. The actual implementation of each platform is dependent upon the HAMSTER Unit type.

A more flexible functionality is obtained by abstraction. The **`HAMSTER ID`** is a generic, unique Unit identifier. Any adopted strategy needs to provide (1) the identification itself; (2) a validation strategy and (3) other procedures such as serialization. The **`Communication Interface`** abstracts the connection and message exchange between units and manages active connections and peer information, as well as

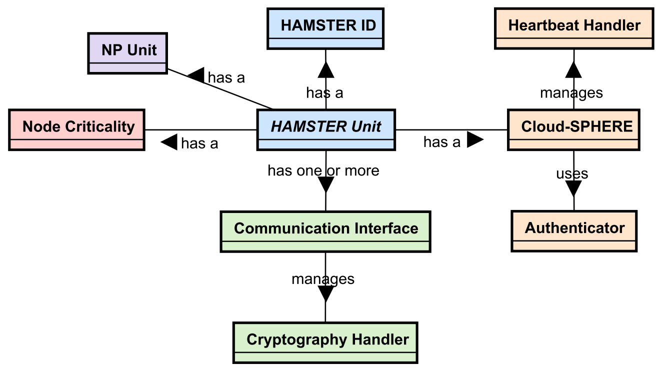

Fig. 2: Inner view of a HAMSTER Unit [37].

performing message encryption and decryption, provided by any **`Cryptography Handler`**.

The Navigation Phases platform manages the operation of all vehicle components depending on the mission stage. Fig. 3 presents the conceptual model of the Navigation Phases platform. Every *Unmanned Vehicle* has components represented by a *HAMSTER Component* and performs a *Mission*. The mission is planned by a *Mission Planner*, which could be a local (embedded into the vehicle's firmware or a file), or a remote agent, human or non-human.

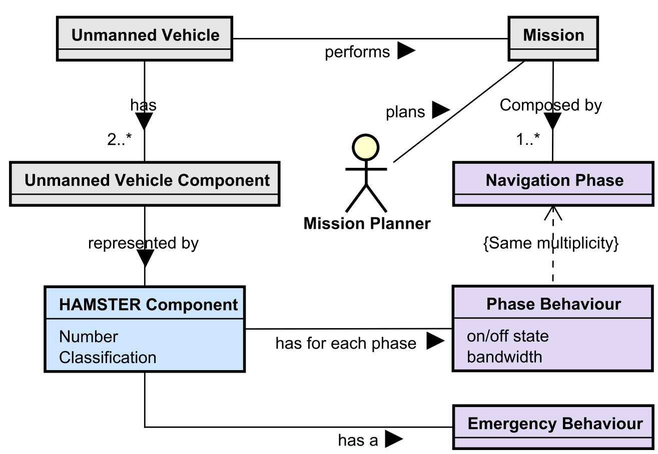

Fig. 3: Navigation Phases (NP) platform conceptual model.

Each Mission is divided into stages described by a *Navigation Phase*. A Navigation Phase is a very well defined mission stage for which every vehicle component has a *Phase Behaviour*. The Phase Behaviour describes how each component is supposed to function during a Navigation Phase, with information such as the component's ON/OFF state, the transmission rate permissions, among others.

The Phase Behaviour of a component will depend on its *classification*. Most common classification splits components into *mission-specific* (the component is not essential for the vehicle's operation, but necessary to perform the mission) and *main* components (essential for the vehicle's operation) [38]. Each HAMSTER Component also has an *Emergency Behaviour* that describes its operation in emergency situations.

The functionality of NP platform is distributed among HAMSTER Entities and Objects, as shown by Fig. 4. In a HAMSTER Entity, the *NP Manager* is responsible for (1) receiving the Navigation Phases from the Mission Planner; (2) sending the Phase Behaviour to authenticated HAMSTER Objects and notify them of a new Navigation Phase; (3) sending ON/OFF commands to the non-authenticated HAMSTER Objects; and (4) notifying all HAMSTER Objects of an Emergency Phase.

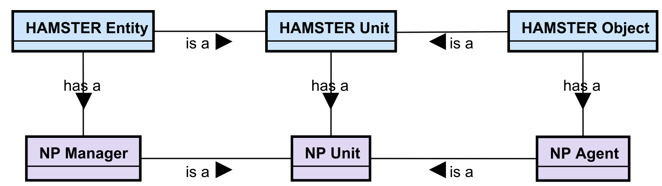

Fig. 4: NP implementation in different Units.

In a HAMSTER Object the *NP Agent* is responsible for receiving from the NP Manager (1) the Phase Behaviour for each Navigation Phase in authenticated modules; (2) ON/OFF commands in non-authenticated HAMSTER Objects and (3) Emergency Phases notifications. NP Agents also are responsible for invoking HAMSTER Objects methods to turn ON or OFF the vehicle's components.

IV. The HAMSTER/NP Prototype

In this Section, preliminary results obtained from the prototype are described. The objective of this test is to demonstrate the general functionality and protocol of NP platform on mission configuration and execution.

Fig. 5 shows how a mission is configured. The mission planner (which can be a remote controller or the UAV own firmware) configures the mission in **`NPManager`** through message `MISSION_CONFIGURATION`. The message payload contains the total number of phases and the behaviour of mission-specific and/or main components for each phase.

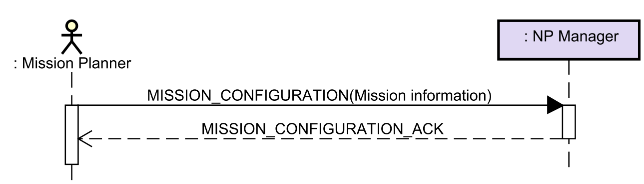

Fig. 5: Mission configuration protocol.

The mission information distribution takes place after the connection of all **`HAMSTERObjects`**. **`NPManager`** relays the mission information for Objects which were successfully authenticated, as shown by Fig. 6.

During mission operation (Fig. 7), **`NPManager`** notifies the authenticated modules of the current phase

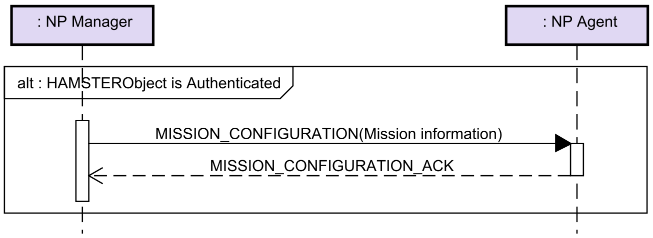

Fig. 6: NP Mission Phases Distribution protocol.

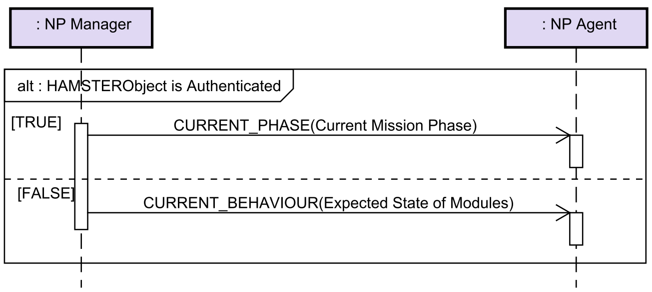

Fig. 7: NP operation during a mission.

through message CURRENT_PHASE, and commands the ON/OFF state of unauthorized components through message CURRENT_BEHAVIOUR. The prior distribution to authenticated (and probably more critical) Objects make the process of phase switching very brief, contributing to time-constrained operation scenarios. After the mission is finished, the HAMSTER Objects are notified through message MISSION_FINISHED (Fig. 8).

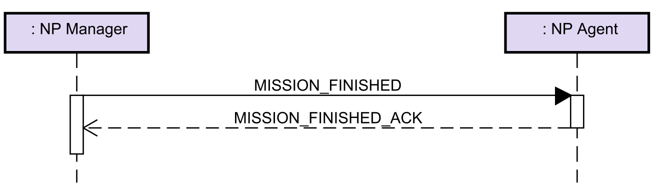

Fig. 8: NP operation at the end of the mission.

A. Environment Setup

To demonstrate the Navigation Phases operation in mission configuration, phase distribution and mission operation, it was necessary to provide concrete implementations for HAMSTER prototype abstractions discussed in Section III. HAMSTER ID abstraction was resolved in an Universally Unique Identifier (UUID), and the Communication Interface abstraction was implemented using network TCP sockets. At the moment, no cryptography is used, but the extra security measure is planned to be included in a near future.

The test environment is composed by a HAMSTER Entity (UAV) containing four HAMSTER Objects (Autopilot, RGBCamera, MultispectralCamera and SensorUnit) summarized by TABLE I. The Sensor Unit is a HAMSTER Cluster with three sensors: an Altitude Sensor, a Dynamic Pressure Sensor and a Temperature sensor. The first two are considered necessary for UAV operation. Also, MultispectralCamera is the only module that do not authenticate itself. Since it is not considered crucial for UAV operation, the mission can be executed.

Object	Unit Type	Classification
Autopilot	HAMSTER Module	main
RGB Camera	HAMSTER Module	mission-specific
Multispectral	HAMSTER Module	mission-specific
Sensor Unit	HAMSTER Cluster	main

TABLE I: HAMSTER Objects included in the demonstration.

The UAV mission and detailed information on active components for this demonstration is shown by TABLE II. During initialization, all modules are ON. During cruising to mission site and back to base, mission-specific modules are turned OFF. Once the vehicle arrives at mission site, all modules are turned ON and the mission performed. Back to base, all modules stay ON for health checking and mission data acquisition.

Number	Phase	Active Objects
1	Initialization	All
2	Cruising	Main only
3	Mission execution	All
4	Return to base	Main only
5	Finalization	All

TABLE II: Mission Phases for the demonstration.

B. Obtained Results

Test results shown in logs (Fig. 9 – 11 — Some lines were suppressed for better readability) shows the messages exchanged between **NPManager** and **NPAgents**. Fig. 9 shows the log for the HAMSTER Entity (UAV). It is possible to see the connection of the four HAMSTER Objects in different ports. Once all of them are connected, the **NPManager** distributes the mission to all three authenticated modules through MISSION_CONFIGURATION / MISSION_CONFIGURATION_ACK message pair. During the mission, three messages CURRENT_PHASE are sent to the authenticated HAMSTER Objects, while message CURRENT_BEHAVIOUR is sent to the Multispectral camera. When the mission finishes, **NPManager** notifies **NPAgent** through MISSION_FINISHED / MISSION_FINISHED_ACK message pair.

Fig. 10 show the exchange messages for the Sensor Unit. The mission is received by **NPAgent** in message MISSION_CONFIGURATION. During mission execution, both altitude and dynamic pressure sensors stay turned on during the entire UAV operation, while the temperature sensor goes off during cruising. The end of the mission is signaled by message MISSION_FINISHED.

```
0000001 ~ [EVENT] New connection, client port = 1049
0000003 ~ [EVENT] New connection, client port = 1561
0000005 ~ [EVENT] New connection, client port = 2073
0000008 ~ [EVENT] New connection, client port = 2585
0000019 ~ [EVENT] Message MISSION_CONFIGURATION sent.
0000020 ~ [EVENT] Message MISSION_CONFIGURATION sent.
0000021 ~ [EVENT] Message MISSION_CONFIGURATION sent.
0000022 ~ [EVENT] Message MISSION_CONFIGURATION_ACK received.
0000023 ~ [EVENT] Message MISSION_CONFIGURATION_ACK received.
0000024 ~ [EVENT] Message MISSION_CONFIGURATION_ACK received.
0000025 ~ [EVENT] Current phase number = 1
0000026 ~ [EVENT] Message CURRENT_PHASE sent.
0000027 ~ [EVENT] Message CURRENT_BEHAVIOUR sent.
0000028 ~ [EVENT] Message CURRENT_PHASE sent.
0000029 ~ [EVENT] Message CURRENT_PHASE sent.
0000030 ~ [EVENT] Current phase number = 2
                                      ...
0000045 ~ [EVENT] Current phase number = 5
0000046 ~ [EVENT] Message CURRENT_PHASE sent.
0000047 ~ [EVENT] Message CURRENT_BEHAVIOUR sent.
0000048 ~ [EVENT] Message CURRENT_PHASE sent.
0000049 ~ [EVENT] Message CURRENT_PHASE sent.
0000050 ~ [EVENT] Message MISSION_FINISHED sent.
0000051 ~ [EVENT] Message MISSION_FINISHED sent.
0000052 ~ [EVENT] Message MISSION_FINISHED sent.
0000053 ~ [EVENT] Message MISSION_FINISHED_ACK received.
0000054 ~ [EVENT] Message TERMINATE_MISSION sent.
0000055 ~ [EVENT] Message MISSION_FINISHED_ACK received.
0000056 ~ [EVENT] Message MISSION_FINISHED_ACK received.
0000057 ~ [EVENT] Message MISSION_FINISHED_ACK received.
```

Fig. 9: Message Log for **NPManager** within the UAV.

```
0000005 ~ [EVENT] Message MISSION_CONFIGURATION received.
0000006 ~ [EVENT] Message MISSION_CONFIGURATION_ACK sent.
0000007 ~ [EVENT] Message CURRENT_PHASE received.
0000008 ~ [EVENT] Current phase number = 1
0000009 ~ [EVENT] Component Altitude Sensor ON.
0000010 ~ [EVENT] Component Dynamic Pressure Sensor ON.
0000011 ~ [EVENT] Component Temperature Sensor ON.
0000012 ~ [EVENT] Message CURRENT_PHASE received.
0000013 ~ [EVENT] Current phase number = 2
0000014 ~ [EVENT] Component Altitude Sensor ON.
0000015 ~ [EVENT] Component Dynamic Pressure Sensor ON.
0000016 ~ [EVENT] Component Temperature Sensor OFF.
0000017 ~ [EVENT] Message CURRENT_PHASE received.
0000018 ~ [EVENT] Current phase number = 3
0000019 ~ [EVENT] Component Altitude Sensor ON.
0000020 ~ [EVENT] Component Dynamic Pressure Sensor ON.
0000021 ~ [EVENT] Component Temperature Sensor ON.
0000022 ~ [EVENT] Message CURRENT_PHASE received.
0000023 ~ [EVENT] Current phase number = 4
0000024 ~ [EVENT] Component Altitude Sensor ON.
0000025 ~ [EVENT] Component Dynamic Pressure Sensor ON.
0000026 ~ [EVENT] Component Temperature Sensor OFF.
0000027 ~ [EVENT] Message CURRENT_PHASE received.
0000028 ~ [EVENT] Current phase number = 5
0000029 ~ [EVENT] Component Altitude Sensor ON.
0000030 ~ [EVENT] Component Dynamic Pressure Sensor ON.
0000031 ~ [EVENT] Component Temperature Sensor ON.
0000032 ~ [EVENT] Message MISSION_FINISHED received.
0000033 ~ [EVENT] Mission finished.
0000034 ~ [EVENT] Message MISSION_FINISHED_ACK sent.
```

Fig. 10: Message Log for **NPAgent** within the Sensor Unit.

Fig. 11 shows the messages received by the Multispectral camera, which did not authorize itself. Instead of receiving mission information, the **NPAgent** receives message `CURRENT_BEHAVIOUR` for each mission phase with the necessary behaviour information.

V. Conclusion and future work

Energy saving for a sustainable development is currently an important topic in our lives and in the computing field as well. For battery-powered devices such as UAVs, energy efficiency increases the vehicle autonomy, and also potentially increases the battery lifetime and reduces waste. In this paper, we presented the Navigation Phases (NP) platform, a well-defined way of controlling the UAV's internal components behaviour during a mission. Preliminary prototype results were presented, showing how the modules will be controlled.

The NP platform can be expanded with other control parameters besides the ON/OFF state, such as bandwidth and radio power, for example. A feedback on the commands would also improve the system's safety and point to potential problems or attacks — if, for instance, a HAMSTER Object is ordered to be turned OFF and stays ON. Artificial intelligence strategies can be applied together with NCI and *Cloud*–SPHERE platforms for identifying and acting on emergency situation.

Given the flexibility of both HAMSTER architecture and the NP platform, the solution provided can be combined with many other strategies of energy efficiency for UAVs, making the green computing goal more attainable for these vehicles.

```
0000003 ~ [EVENT] Message CURRENT_BEHAVIOUR received.
0000004 ~ [EVENT] Component Multispectral Camera ON.
0000005 ~ [EVENT] Message CURRENT_BEHAVIOUR received.
0000006 ~ [EVENT] Component Multispectral Camera OFF.
0000007 ~ [EVENT] Message CURRENT_BEHAVIOUR received.
0000008 ~ [EVENT] Component Multispectral Camera ON.
0000009 ~ [EVENT] Message CURRENT_BEHAVIOUR received.
0000010 ~ [EVENT] Component Multispectral Camera OFF.
0000011 ~ [EVENT] Message CURRENT_BEHAVIOUR received.
0000012 ~ [EVENT] Component Multispectral Camera ON.
0000013 ~ [EVENT] Message TERMINATE_MISSION received.
```

Fig. 11: Message Log for **NPAgent** within the Multispectral Camera.

References

[1] L. Lazić and D. Velašević, "Applying simulation and design of experiments to the embedded software testing process," *Software Testing, Verification and Reliability*, vol. 14, no. 4, pp. 257–282, Dec. 2004. [Online]. Available: http://dx.doi.org/10.1002/stvr.299

[2] W. Dunn, "Designing safety-critical computer systems," *Computer*, vol. 36, no. 11, pp. 40–46, nov 2003. [Online]. Available: http://dx.doi.org/10.1109/MC.2003.1244533

[3] S. P. Kumar, P. S. Ramaiah, and V. Khanaa, "Architectural patterns to design software safety based safety-critical systems," in *International Conference on Communication, Computing & Security (ICCCS)*. New York, USA: ACM Press, 2011, p. 620. [Online]. Available: http://dx.doi.org/10.1145/1947940.1948069

[4] D. Jacques, "Modeling considerations for wide area search munition effectiveness analysis," in *Proceedings of the Winter Simulation Conference*, vol. 1. San Diego, USA: IEEE, 2002, pp. 878–886. [Online]. Available: http://dx.doi.org/10.1109/WSC.2002.1172974

[5] K. D. Mullens, E. B. Pacis, S. B. Stancliff, A. B. Burmeister, and T. A. Denewiler, "An automated UAV mission system," Space and Naval Warfare Systems Command, San Diego, USA, Tech. Rep., 2003. [Online]. Available: http://www.dtic.mil/dtic/tr/fulltext/u2/a422026.pdf

[6] L. Merino, F. Caballero, J. Martínez-de Dios, J. Ferruz, and A. Ollero, "A cooperative perception system for multiple UAVs: Application to automatic detection of forest fires," *Journal of Field Robotics*, vol. 23, no. 3-4, pp. 165–184, mar 2006. [Online]. Available: http://dx.doi.org/10.1002/rob.20108

[7] J. L. Drury, L. Riek, and N. Rackliffe, "A decomposition of UAV-related situation awareness," in *ACM SIGCHI/SIGART conference on Human-robot interaction*. New York, USA: ACM Press, 2006, p. 88. [Online]. Available: http://dx.doi.org/10.1145/1121241.1121258

[8] J. Cooper and M. A. Goodrich, "Towards combining UAV and sensor operator roles in UAV-enabled visual search," in *International conference on Human robot interaction (HRI)*. Amsterdam, The Netherlands: ACM Press, 2008, p. 351. [Online]. Available: http://dx.doi.org/10.1145/1349822.1349868

[9] R. R. Pitre, X. R. Li, and D. DelBalzo, "A new performance metric for search and track missions 2: Design and application to uav search," in *International Conference on Information Fusion*, July 2009, pp. 1108–1114. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/5203758/

[10] I. Maza, K. Kondak, M. Bernard, and A. Ollero, "Multi-UAV Cooperation and Control for Load Transportation and Deployment," *Journal of Intelligent and Robotic Systems*, vol. 57, no. 1-4, pp. 417–449, jan 2010. [Online]. Available: http://dx.doi.org/10.1007/s10846-009-9352-8

[11] A. Bentivoglio Colturato, A. Benjamin Gomes, D. F. Pigatto, D. Bentivoglio Colturato, A. S. Roschildt Pinto, L. H. Castelo Branco, E. L. Furtado, and K. R. Lucas Jaquie Castelo Branco, "Pattern Recognition in Thermal Images of Plants Pine Using Artificial Neural Networks," in *Engineering Applications of Neural Networks. EANN 2013.*, L. Iliadis, H. Papadopoulos, and C. Jayne, Eds. Springer, Berlin, Heidelberg, 2013, vol. 383, pp. 406–413. [Online]. Available: http://link.springer.com/10.1007/978-3-642-41013-0_42

[12] V. Raghunathan, A. Kansal, J. Hsu, J. Friedman, and M. Srivastava, "Design considerations for solar energy harvesting wireless embedded systems," in *International Symposium on Information Processing in Sensor Networks (IPSN)*. Boise, USA: IEEE, 2005, pp. 457–462. [Online]. Available: http://dx.doi.org/10.1109/IPSN.2005.1440973

[13] Sravanthi Chalasani and J. M. Conrad, "A survey of energy harvesting sources for embedded systems," in *SoutheastCon*. Huntsville, USA: IEEE, apr 2008, pp. 442–447. [Online]. Available: http://dx.doi.org/10.1109/SECON.2008.4494336

[14] J. Huang, R. Li, J. An, D. Ntalasha, F. Yang, and K. Li, "Energy-Efficient Resource Utilization for Heterogeneous Embedded Computing Systems," *IEEE Transactions on Computers*, vol. 66, no. 9, pp. 1518–1531, sep 2017. [Online]. Available: http://dx.doi.org/10.1109/TC.2017.2693186

[15] S. Murugesan, "Harnessing Green IT: Principles and Practices," *IT Professional*, vol. 10, no. 1, pp. 24–33, 2008. [Online]. Available: http://dx.doi.org/10.1109/MITP.2008.10

[16] Q. Li and M. Zhou, "The Survey and Future Evolution of Green Computing," in *IEEE/ACM International Conference on Green Computing and Communications (GreenCom)*. Sichuan, China: IEEE, 2011, pp. 230–233. [Online]. Available: http://dx.doi.org/10.1109/GreenCom.2011.47

[17] P. Ranganathan, "Recipe for efficiency," *Communications of the ACM*, vol. 53, no. 4, pp. 60–67, apr 2010. [Online]. Available: http://dx.doi.org/10.1145/1721654.1721673

[18] Y. Zeng, R. Zhang, and T. J. Lim, "Wireless communications with unmanned aerial vehicles: opportunities and challenges," *IEEE Communications Magazine*, vol. 54, no. 5, pp. 36–42, may 2016. [Online]. Available: http://dx.doi.org/10.1109/MCOM.2016.7470933

[19] A. Goldsmith and S. Wicker, "Design challenges for energy-constrained ad hoc wireless networks," *IEEE Wireless Communications*, vol. 9, no. 4, pp. 8–27, aug 2002. [Online]. Available: http://dx.doi.org/10.1109/MWC.2002.1028874

[20] J. P. Thomas, M. A. Qidwai, and J. C. Kellogg, "Energy scavenging for small-scale unmanned systems," *Journal of Power Sources*, vol. 159, no. 2, pp. 1494–1509, sep 2006. [Online]. Available: http://dx.doi.org/10.1016/j.jpowsour.2005.12.084

[21] K. C. Magoteaux, B. Sanders, and H. A. Sodano, "Investigation of an energy harvesting small unmanned air vehicle," in *Proc. SPIE 6928, Active and Passive Smart Structures and Integrated Systems 2008*, vol. 6928, San Diego, USA, mar 2008. [Online]. Available: http://dx.doi.org/10.1117/12.775851

[22] A. Erturk, J. M. Renno, and D. J. Inman, "Modeling of Piezoelectric Energy Harvesting from an L-shaped Beam-mass Structure with an Application to UAVs," *Journal of Intelligent Material Systems and Structures*, vol. 20, no. 5, pp. 529–544, mar 2009. [Online]. Available: http://dx.doi.org/10.1177/1045389X08098096

[23] S. R. Anton and D. J. Inman, "Vibration energy harvesting for unmanned aerial vehicles," in *SPIE 6928, Active and Passive Smart Structures and Integrated Systems 2008*, vol. 692824. SPIE, mar 2008. [Online]. Available: http://dx.doi.org/10.1117/12.774990

[24] P. Thounthong, S. Raël, and B. Davat, "Energy management of fuel cell/battery/supercapacitor hybrid power source for vehicle applications," *Journal of Power Sources*, vol. 193, no. 1, pp. 376–385, aug 2009. [Online]. Available: http://dx.doi.org/10.1016/j.jpowsour.2008.12.120

[25] N. Lawrance and S. Sukkarieh, "Wind Energy Based Path Planning for a Small Gliding Unmanned Aerial Vehicle," in *AIAA Guidance, Navigation, and Control Conference*, no. August. Chicago, USA: American Institute of Aeronautics and Astronautics, aug 2009. [Online]. Available: http://dx.doi.org/10.2514/6.2009-6112

[26] R. Bolla, R. Bruschi, F. Davoli, and F. Cucchietti, "Energy Efficiency in the Future Internet: A Survey of Existing Approaches and Trends in Energy-Aware Fixed Network Infrastructures," *IEEE Communications Surveys & Tutorials*, vol. 13, no. 2, pp. 223–244, 2011. [Online]. Available: http://dx.doi.org/10.1109/SURV.2011.071410.00073

[27] J. Chabarek, J. Sommers, P. Barford, C. Estan, D. Tsiang, and S. Wright, "Power Awareness in Network Design and Routing," in *IEEE Conference on Computer Communications (INFOCOM)*. Phoenix, USA: IEEE, apr 2008, pp. 457–465. [Online]. Available: http://dx.doi.org/10.1109/INFOCOM.2008.93

[28] A. P. Bianzino, C. Chaudet, D. Rossi, and J.-L. Rougier, "A Survey of Green Networking Research," *IEEE Communications Surveys & Tutorials*, vol. 14, no. 1, pp. 3–20, 2012. [Online]. Available: http://dx.doi.org/10.1109/SURV.2011.113010.00106

[29] A. Shaabana, Fangyun Luo, Ying Chen, and A. Jaekel, "Green networking strategies for distributed computing," in *IEEE Consumer Communications and Networking Conference (CCNC)*. Las Vegas, USA: IEEE, jan 2014, pp. 29–34. [Online]. Available: http://dx.doi.org/10.1109/CCNC.2014.6940503

[30] Dinh-Khanh Dang, A. Mifdaoui, and T. Gayraud, "Fly-By-Wireless for next generation aircraft: Challenges and potential solutions," in *IFIP Wireless Days*. Dublin, Ireland: IEEE, nov 2012, pp. 1–8. [Online]. Available: http://dx.doi.org/10.1109/WD.2012.6402820

[31] O. Elgezabal Gomez, "Fly-by-wireless: Benefits, risks and technical challenges," in *CANEUS Fly by Wireless Workshop*. Orono, USA: IEEE, aug 2010, pp. 14–15. [Online]. Available: http://dx.doi.org/10.1109/FBW.2010.5613788

[32] T. Kim and J. M. Chang, "Enhanced Power Saving Mechanism for Large-Scale 802.11ah Wireless Sensor Networks," *IEEE Transactions on Green Communications and Networking*, vol. 1, no. 4, pp. 516–527, dec 2017. [Online]. Available: http://dx.doi.org/10.1109/TGCN.2017.2727056

[33] H. Ghazzai, M. Ben Ghorbel, A. Kadri, M. J. Hossain, and H. Menouar, "Energy-Efficient Management of Unmanned Aerial Vehicles for Underlay Cognitive Radio Systems," *IEEE Transactions on Green Communications and Networking*, vol. 1, no. 4, pp. 434–443, dec 2017. [Online]. Available: http://dx.doi.org/10.1109/TGCN.2017.2750721

[34] E. Aramizu, D. F. Pigatto, and K. R. L. J. C. K. Branco, "Reducing energy consumption on internal communications of unmanned vehicles with HAMSTER's Navigation Phases," in *V Workshop on Communications in Critical Embedded Systems (WoCCES 2017), XXXV Simpósio Brasileiro de Redes de Computadores (SBRC 2017)*, 2017, pp. 12–24.

[35] D. F. Pigatto, L. Goncalves, A. S. R. Pinto, G. F. Roberto, J. Fernando Rodrigues Filho, and K. R. L. J. C. Branco, "HAMSTER - Healthy, Mobility and Security-based Data Communication Architecture for Unmanned Aircraft Systems," in *International Conference on Unmanned Aircraft Systems (ICUAS)*. Orlando, USA: IEEE, 2014, pp. 52–63. [Online]. Available: http://dx.doi.org/10.1109/ICUAS.2014.6842238

[36] D. F. Pigatto, L. Gonçalves, G. F. Roberto, J. F. Rodrigues Filho, N. B. Floro da Silva, A. R. Pinto, and K. R. Lucas Jaquie Castelo Branco, "The HAMSTER Data Communication Architecture for Unmanned Aerial, Ground and Aquatic Systems," *Journal of Intelligent & Robotic Systems*, vol. 84, no. 1-4, pp. 705–723, dec 2016. [Online]. Available: http://dx.doi.org/10.1007/s10846-016-0356-x

[37] M. Rodrigues, D. F. Pigatto, and K. R. L. J. C. Branco, "*Cloud*—SPHERE: A Security Approach for Connected Unmanned Aerial Vehicles," in *International Conference on Unmanned Aircraft Systems (ICUAS)*, Dallas, USA, 2018, (Accepted for publication).

[38] D. F. Pigatto, A. F. de Castro, K. C. Branco, and T. Martin, "Aplicação de Fuzzy para a redução do consumo de energia de módulos internos em veículos aéreos não tripulados," in *Euro American Conference on Telematics and Information Systems (EATIS)*. Cartagena, Colombia: IEEE, apr 2016, pp. 1–7. [Online]. Available: http://dx.doi.org/10.1109/EATIS.2016.7520139