The Incorporation of Drones as Object of Study in Energy-aware Software Engineering

Luis Corral[1], Ilenia Fronza[2] and Nabil El Ioini[2]
[1]*Monterrey Institute of Technology and Higher Education / Autonomous University of Queretaro*
E. Gonzalez 500, 76130, Queretaro, Mexico
[2]*Free University of Bozen-Bolzano*
Piazza Domenicani 3, 39100, Bolzano, Italy

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Abstract: As drones expand their ability to perform longer and more complex tasks, one of the first concerns that rise is their capacity to perform those tasks in a reliable way. Reliability can be understood from different aspects: the ability of the drone to perform accurately, safely and autonomously. In this paper, we focus on understanding the current efforts to ensure the last quality, autonomy, from the point of view of energy-awareness for drone systems. It emerges that drones as object of study in energy aware Software Engineering is still an emerging, unexplored area, which requires to learn from advances and experimentation in other mobile and ubiquitous devices like cellular phones or tablets. Still, it is required to understand the opportunities and limitations of drones as computational targets. A research agenda should be set and followed to leverage software as an opportunity to foster drones as energy-aware devices.

1 INTRODUCTION

Unmanned aerial vehicles, more popularly known as drones are aircraft that have no on-board, human pilot (Clarke, 2014). The drone industry has been an interesting topic for the past years, and the focus of many discussions in the technology sector. The synergy between hardware and software, the continuous evolution in drone technologies and the identification of novel application fields have consolidated drones as an opportunity for innovation and an interesting object of study.

Large drones have been used for years by many countries, mainly for military purposes. After their consolidation as a tool for defense industry, the capabilities of drones have increased, and their manufacturing costs have been greatly reduced. Therefore, drones have attracted many parties to consider their capabilities for civil applications. Moreover, applications in non-critical fields have expanded to field recognition, entertainment or air delivery, which is already a reality that several companies are experimenting (de Fatima Bento, 2008). The use of drones in mission-critical applications is also expanding: drones have been used in disaster zones, recognition of sites unreachable by land, mapping, delivery of vital goods and medical aid (Starr, 2014).

Research and experimentation on drones have received a good amount of attention from academics, practitioners and enthusiasts. The areas of application for unmanned aerial vehicles span from simple entertainment to professional fields.

As drones expand their ability to perform longer and more complex tasks, one of the first concerns that rise is their capability to perform those tasks in a dependable way. Reliability can be understood from different points of view, for instance the ability of the drone to perform accurately, safely and autonomously (Wong, 2015). In that sense, the autonomy of a drone depends highly on the energy that its power source (i.e., a battery) can provide, in conjunction with the weight, payload and other operational aspects of the drone itself.

In those aspects, we may include the software that operates the drone. In the field of non-stationary, energy dependent systems, Software Engineering for energy-aware applications is a seasoned research area that has helped to accomplish important goals leveraging software to reduce the energy consumption in mobile targets (e.g., cellular phones, tablets, wireless sensors, wearables, and others). Like all these devices, drones must rely on their battery capacity, which is as well one of the most important limitations to their operation. As a result, the potential useful-

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ness of drones is prevented by the energy constraint. Therefore, there is a clear need to accomplish a more efficient battery usage to reduce the power demand of drone targets.

The goal of this paper is to understand the introduction, growth and status of drones as an object of study in energy-aware Software Engineering, focusing on understanding the current efforts to ensure the last quality, autonomy, from the point of view of energy-awareness for drones.

The rest of the paper is structured as follows: Section 2 reviews the development of drones and their consolidation as energy-aware systems; Section 3 identifies the current available literature on energy-aware Software Engineering for drones; Section 4 maps and discusses the current research literature that crosses the roads between drone development and energy-aware Software Engineering; Section 5 discusses identifiable trends in this research track. Finally, Section 6 sets tracks for future research and draws conclusions.

2 DEVELOPMENT OF DRONES AS ENERGY-AWARE SYSTEMS

There is no official, standard classification of unmanned aerial vehicles. We can outline a division on the basis of private use for recreation or use for air work. Nevertheless, one of the most important characteristic upon which to make a categorization is the size. A very clear distinction exists between large and small drones. In the small category, there is further classification into nano, mini and micro drones. Further distinction is made upon the endurance and range values. Table 1 shows a categorization of drones which is based on (Sydney, School of Surveying & Spatial Information Systems Faculty of Engineering, 2016; Abdullah, 2016; Watts et al., 2012).

Table 1: Drones classification.

Category name	Load (kg)	Range (km)	Alt. (m)	Life (hrs)
Nano	0.1	1	100	0.5
Micro	5	<10	250	1
Mini	<25	<10	300	2
Close range	25-150	10-30	3000	2-4
Mid-range	50-250	30-70	3000	3-6
High range	>250	>70	>3000	>6

In terms of operation, airworthiness is one of the most important qualities for drones (Corral et al., 2015). This term is used to point out the suitability of the aircraft for a safe flight. A drone is said to execute a safe flight when its attitude and manageability stay within its operating parameters. One of the key attributes that drive drones airworthiness is to have sufficient power to assure height, movement and operability for all the duration of the flight. Other important characteristics of drones are size, maximum altitude, endurance and range of the device's data links, as stated by (de Fatima Bento, 2008). Technological advances have led to great capabilities of drones rising many beneficial ways in diverse application fields.

The market has grown enough as to offering to the user different types of drones which respond to specific needs and provide specific capabilities. Also, hardware accessories, such as GPS chips, enable the aircraft to be always aware of its position, cameras allow observation capture of image and footage, built-in torch lamps permit drone operation at night. Lightweight energy sources (such as LiPo batteries, which are among the most common batteries used to power drones) provide the possibility for other on-board facilities.

Nowadays, small drones are able of carrying and delivering load: the first air delivery from Amazon is already a reality, and an Australian start-up used a drone to carry 4.5 kg of medical aid from Virginia to a clinic about a mile away in a 3-minute flight[1]. Aerial photography is no longer just a hobby: many product advertisements include aerial footage and companies pay generous amount of money to make their products attractive. For example, drones have been proposed as tool for real estate sales; also, big-budget Hollywood movies are moving towards drones which offer economic aerial footage. Drones have also been used during sports and cultural events to provide full coverage of them. Sochi 2014 Winter Olympics was the first sports event to offer footage of snowboarders in action thanks to the operation of drones.

However, using drones in all these targets require them to be unquestionably airworthy. For instance, there was an event where a drone was used to provide full coverage (the 3-Tre FIS Alpine Ski World Cup 2016 in Madonna di Campiglio, Italy). A drone crashed out of the sky, landing barely behind the skier as he made his way down the track. The hypothesis is that the battery was discharged (Trentino, 2015).

Compared to large flying devices, drones reflect a wider range of technical limitations such as load capacity they can carry, flight duration (10-20 minutes), and limited flight range and speed. As drones are increasingly being used all over the world, their usage must fit a regulatory framework. Many basic national

[1] http://www.australiaunlimited.com/business/the-rise-of-the-drones

safety rules apply, but are not the same all over Europe. The European Aviation Safety Agency (EASA) has published a Technical Opinion on the operation of drones which will be used as the basis for all future work related to drone usage[2]. The American Federal Aviation Administration (FAA) requires that anyone who owns a drone of a certain weight (more than 250 gr and less than 25 kg) must register it before flying outdoors[3].

3 DEVELOPMENT OF DRONES AS ENERGY-AWARE SYSTEMS

In the last years, the economization of energy in computer equipment has become a popular research topic because of the high impact of power consumption in different computing ecosystems. For example, there is a big need of reducing power usage on battery-powered equipment (e.g., phones, tablets, wearables, drones, etc.) considering that power consumption directly impacts the device's operation and autonomy. At the same time, it is not desired to decrease performance, dependability and other operational qualities in favor of saving energy (Boucher, 2014).

Many research works share as major goal the development of techniques to economize the power consumption of computer equipment. We can group these projects in two families, considering their field of application. The first group focuses on architectures, materials and manufacturing techniques, whilst the second one concentrates on the reducing consumption of energy resources driven directly by the execution of software.

The first family is purely hardware-oriented, in which the main topics include semiconductor technologies, microprocessor arrangement, prevention of heat and power dissipation, and other similar topics. They analyze how electronic components can be designed and manufactured in such fashion to deliver the highest processing capabilities without demanding the usual loads of energy required by electronic components. This research track belongs to the fields of electrical engineering, electronic engineering, semiconductor technology and similar disciplines.

On the other hand, a second family of research works focuses in understanding the impact of software in power usage. That is, they study and analyze how software products can contribute to have a perceptible effect on the demand of energy of the system. Consequently, some of those works also concern on studying how software products can be prepared to utilize more efficiently the available hardware resources. In this way, from the design and execution of the software point of view, the hardware should receive instructions previously engineered to maximize its capabilities while using less energy.

In this field, it has been analyzed the influence of the different stages of software execution in the overall power consumption in a machine, including compiling techniques, context switching, memory accesses, etc. (Min et al., 2012; Vallina-Rodriguez and Crowcroft, 2013; Vieira et al., 2012).

Drones with increasing operative capabilities open a wide range of service and revenue opportunities where energy consumption can be an important roadblock and can prevent the drone from accomplish its mission. In consequence, it is necessary to have both hardware and software strategies to administrate better the way in which the drone will invests its energy resources for the best benefit of its operation.

4 SOFTWARE ENGINEERING RESEARCH ON ENERGY AWARENESS FOR DRONES

To understand better the current progress of energy-aware Software Engineering applied to drones, we surveyed three major digital libraries (i.e, IEEE Xplore, ACM Digital Library and ScienceDirect) looking for research papers that cover different perspectives for designing and implementing energy aware software. To make a final selection of the most relevant research works, we established as criteria:

1. research works should describe a technique for the design, implementation, evaluation, measurement or optimization on energy consumption in drones;
2. the proposed technical approach should have been put in practice in at least one case study.

To ensure a current orientation of the topic at hand, we considered only papers published from 2015 to the date. The selection of this date is not arbitrary, but it represents a turning point in the number of research works in this topic, according to the volume found in the mentioned libraries.

As exclusion criteria, potential duplicated instances shall be dismissed. Research papers that do not relate to software design, development and implementation shall be dismissed as well. The initial retrieval of the available literature was done using a series of keywords to search, as shown in Table 2.

[2]https://www.easa.europa.eu/document-library/opinions/opinion-technical-nature

[3]https://registermyuas.faa.gov

Table 2: Survey in energy awareness for drones: keywords and numeric results before the exclusion criteria is applied.

Keyword	IEEE	ACM	Science Direct
Drone	476	163	1301
“Drone consumption”	0	0	0
“Drone optimization”	0	0	0
“Drone energy”	1	3	2

Table 2 also shows the numeric results of the analysis of the state of the art in this field. The number of references about drone development (including energy aspects) in non-academic sources is large. Newsrooms, divulgation sources, technology magazines and several more references cover different aspects of drone development in a way that the topic is appealing to a general audience. This high volume of information confirms the broad interest of drones and their application. However, this number of sources contrasts with the low number of academic references available in the referred libraries. Despite the large number of papers about drones, from Table 2 we can also understand that as a research topic, energy awareness for drones is still emergent, and that professional research about it is uncommon.

Taking as starting point the papers surveyed from the digital libraries, we had to handpick the research papers about drones that also concerned about energy consumption. We also extracted a second group of papers from relevant citations and references. The result of this selection is a group of 10 research papers distributed as shown in Table 3.

Table 3: Survey in energy awareness for drones: keywords and numeric results after the exclusion criteria are applied.

Keyword	IEEE	ACM	Science Direct	Other Cited
Drone energy	1	3	2	4

(Park et al., 2016) identified the low volume of research works in energy aware techniques for drones, discussing that energy efficiency and battery aging affect the drone delivery business. Authors discuss that no prior work has extensively assessed the problem for energy awareness in the drone business. In their paper, authors propose a holistic and detailed analysis on the profitability and time to delivery of the drone delivery business.

(Clarke, 2014) outlines critical attributes for the airworthy operation of a drone. Even though almost all the characteristics concern the maneuverability, safety, and other airborne conditions of the drone, the author also mentions characteristics related to the resource usage of the device; for instance, providing “a sufficient source of power to maintain movement, to implement the controls, and to operate sensors and data feeds, for the duration of the flight” and “the ability to navigate to destination locations within the operational space”.

In software-based approaches used for battery optimization in drones, currently there is no software solution available on the market to optimize the battery consumption in a target platform as drones. A suggested research agenda is identified by (Corral et al., 2015), whose paper aims at establishing a methodology to design and implement software-driven approaches to measure and optimize drone’s energy consumption. The same authors also present research works that exemplify methods to measure the energy consumed by drones (Corral et al., 2016a) and to optimize energy consumption in drones using preset flight profiles (Corral et al., 2016b). Following this approach, authors claim to accomplish savings up to about 5.6 seconds of the total flight time, showing a very low but noticeable contribution to the overall drone autonomy.

(Zorbas et al., 2013) studied a mathematical formulation for minimizing the total energy consumption of a fleet of camera-enabled drones, depending on the localization and height of the event they should cover. Following their proposed algorithm, authors claim savings up to 150% of the total energy consumed.

In a similar track proposed by Corral and Zorbas, (Di Franco and Buttazzo, 2015) proposes an energy-aware path planning algorithm that minimizes energy consumption while satisfying a set of other requirements, such as coverage and resolution. The algorithm is based on an energy model derived from real measurements. The algorithmic approach considers the description of the covered area and the points that are relevant for the survey, to design a path for optimal scan.

The research works (Pace et al., 2015; da Silva and Nascimento, 2016; Huang et al., 2015) also concern about algorithms to plan missions in a way that the return home is guaranteed.

5 RESEARCH TRENDS

Our literature review shows that there are still numerous opportunities for research on the field of energy awareness for drones. Although energy-awareness for non-stationary mobile devices is a consolidated research field, the inclusion of drones as an object of study is still emerging. In a dynamic area like energy-aware mobile systems, new methods, technologies and tools are developed with a very fast pace; however, after carefully surveying the current state of the art we found the need for further exploration of power measurement and estimation techniques for drones, as well as researching and discussing deeply in optimizations at application level, due that the majority of the works concentrate at mobile targets of a different nature, out of the scope of the operative ecosystems usually found in drones.

Speaking of energy-aware Software Engineering, existing strategies are mostly based on common non-stationary devices like smartphones. Still, in mobile devices of this kind, software-driven solutions appear to be slow, trend that can be applied to the case of drones. The core of research for energy optimization based on software, currently concentrates on designing and implementing algorithmic solutions to design better routes or drone handling. There is a big gap in research and implementation of software-driven solutions at operative or application level, that is, software that can operate the drone in a way that can help the complete system to work investing less energy, much like current research in mobile devices.

Software designers and programmers for drones can learn from the extensive work that has been done for energy-aware software in other mobile targets: to cite just a few, (Paul and Kundu, 2010) shows a quantitative review of energy consumption of Android software routines, compared with the energy spent by the same routine in Angstrom Linux. In this paper, authors survey the energy required by the execution target under the premise that mobile devices should concern on optimizing the battery utilization. The work of Vieira et al. (2012) presented a performance and energy consumption evaluation of applications of Android OS to find a pattern of energy consumption depending on the executed algorithm. The authors identified what kind of algorithms lead to improved energy efficiency on this operating system. Other work, without implementing software benchmark the way in which mobile apps can affect the total energy consumption of the system, providing a profound discussion on design factors that could impact software energy efficiency (Capra et al., 2012).

Worth to mention, we can include the research and development in materials that can provide the drone with frames, structures and batteries, which in addition to be long-lasting, they can be as well very light in a way that they do not contribute severely to the overall weight of the drone.

Somatis Technologies Inc. worked on a kinetic energy composite that turns the interaction of wind pressure and vibrations into an electrical power energy source and suggests that it could triple the battery life for handheld and gliding drones[4]. The chip maker Qualcomm which means to provide an optimization to the chipset SnapDragon Flight for drones; the goal is to extend the battery lifetime from 20 to 40 to 60 minutes[5]. Other experiments were carried out using the number of batteries as a control variable. An hexacopter was used and the battery count was optimized by incrementally adding 6000 mAh batteries (first 1 battery was added, then 4, 5 and 6) and calculate the flight time based on the current draw and vehicle charge capacity (Scaramuzza et al., 2014).

6 FUTURE WORK AND CONCLUSIONS

Drones play a key role in the future technology landscape. However, their potential is limited due to battery capacity, which represents a major constraint. For a real and profitable application in mission-critical, highly dependable environments, in addition to improving battery technology, a research agenda should focus on implementing hardware and software driven techniques to optimize the power demand of the drone system. These techniques should relate directly to the optimization of the energy resources available for a mission, considering that power enables not only the flight, but also the onboard facilities that are powered (camera, webcam, beacons, etc.), as well as the ability of the drone to complete its mission successfully or to abort it and find a landing place in a safe manner.

Based on the results of our literature review we can conclude that the inclusion of drones as object of study in energy-aware Software Engineering is still in an initial phase with much work yet to be done. To expand this horizon, we propose the following research tracks to leverage the power of software to economize power usage in a mission:

- generation of energy efficient executable code for drone applications,
- offloading of methods or computational routines to minimize processor usage in drones,
- software-controlled presetting of economic profiles that can enable or disable built-in energy-hungry components in the drone.

A critical quality and operative principle of drones is their ability to perform at the highest standards

[4]http://readwrite.com/2012/08/07/energized-new-batteries-could-triple-drone-airtime/

[5]https://developer.qualcomm.com/hardware/snapdragon-flight

away from a permanent energy supply. Software Engineering is facing a rich yet challenging opportunity to take an active role in discovering better ways to invest better the limited energy resources of a drone. The challenge is simple: embrace drones as object of study to foster software as a tool to optimize the overall power consumption of a drone system.

REFERENCES

Abdullah, Q. (2016). Classification of the unmanned aerial systems. https://www.e-education.psu.edu/geog892/node/5. Accessed on March 10th, 2017.

Boucher, P. (2014). Civil Drones in Society, Societal and Ethics Aspects of Remotely Piloted Aircraft Systems. Technical report, European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen.

Capra, E., Francalanci, C., and Slaughter, S. A. (2012). Measuring application software energy efficiency. *IT Professional*, 14(2):54–61.

Clarke, R. (2014). Understanding the drone epidemic. *Computer Law & Security Review*, 30(3):230–246.

Corral, L., Fronza, I., and El Ioini, N. (2015). The future of energy-aware software: The case of drones. *Cutter IT Journal*, 28(8):19–23.

Corral, L., Fronza, I., El Ioini, N., and Ibershimi, A. (2016a). A measurement tool to track drones battery consumption during flights. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 9847:334–344.

Corral, L., Fronza, I., El Ioini, N., and Ibershimi, A. (2016b). Towards optimization of energy consumption of drones with software-based flight analysis. volume 2016-January, pages 543–546.

da Silva, R. I. and Nascimento, M. A. (2016). On best drone tour plans for data collection in wireless sensor network. In *Proceedings of the 31st Annual ACM Symposium on Applied Computing*, pages 703–708. ACM.

de Fatima Bento, M. (2008). Unmanned Aerial Vehicles: An Overview. *Inside GNSS*, 3(1):54–61.

Di Franco, C. and Buttazzo, G. (2015). Energy-aware coverage path planning of uavs. In *Autonomous Robot Systems and Competitions (ICARSC), 2015 IEEE International Conference on*, pages 111–117. IEEE.

Huang, Y.-T., Ho, Y.-H., Chu, H.-h., and Chen, L.-J. (2015). Adaptive drone sensing with always return-to-home guaranteed. In *Proceedings of the 1st International Workshop on Experiences with the Design and Implementation of Smart Objects*, pages 7–12. ACM.

Min, A. W., Wang, R., Tsai, J., Ergin, M. A., and Tai, T.-Y. C. (2012). Improving energy efficiency for mobile platforms by exploiting low-power sleep states. In *Proceedings of the 9th conference on Computing Frontiers*, pages 133–142. ACM.

Pace, P., Aloi, G., Caliciuri, G., and Fortino, G. (2015). Management and coordination framework for aerial-terrestrial smart drone networks. In *Proceedings of the 1st International Workshop on Experiences with the Design and Implementation of Smart Objects*, pages 37–42. ACM.

Park, S., Zhang, L., and Chakraborty, S. (2016). Design space exploration of drone infrastructure for large-scale delivery services. In *Proceedings of the 35th International Conference on Computer-Aided Design*, page 72. ACM.

Paul, K. and Kundu, T. K. (2010). Android on mobile devices: An energy perspective. In *Computer and Information Technology (CIT), 2010 IEEE 10th International Conference on*, pages 2421–2426. IEEE.

Scaramuzza, D., Achtelik, M. C., Doitsidis, L., Friedrich, F., Kosmatopoulos, E., Martinelli, A., Achtelik, M. W., Chli, M., Chatzichristofis, S., Kneip, L., et al. (2014). Vision-controlled micro flying robots: from system design to autonomous navigation and mapping in gps-denied environments. *IEEE Robotics & Automation Magazine*, 21(3):26–40.

Starr, M. (2014). Ambulance drone delivers help to heart attack victims. http://www.cnet.com/news/ambulance-drone-delivers-help-to-heart-attack-victims/. Accessed on January 10th, 2016.

Sydney, School of Surveying & Spatial Information Systems Faculty of Engineering (2016). UAV mapping concept. http://www.sage.unsw.edu.au/currentstudents/ug/projects/Salameh/Physical%20Characteristics.htm. Accessed on February 5th, 2016.

Trentino (2015). Precipita un drone, dramma sfiorato alla 3tre di campiglio. http://trentinocorrierealpi.gelocal.it/trento/cronaca/2015/12/22/news/. Accessed on December 26th, 2015.

Vallina-Rodriguez, N. and Crowcroft, J. (2013). Energy management techniques in modern mobile handsets. *IEEE Communications Surveys & Tutorials*, 15(1):179–198.

Vieira, A., Debastiani, D., Agostini, L., Marques, F., and Mattos, J. C. (2012). Performance and energy consumption analysis of embedded applications based on android platform. In *Computing System Engineering (SBESC), 2012 Brazilian Symposium on*, pages 59–64. IEEE.

Watts, A. C., Ambrosia, V. G., and Hinkley, E. A. (2012). Unmanned aircraft systems in remote sensing and scientific research: Classification and considerations of use. *Remote Sensing*, 4(6):1671–1692.

Wong, K. V. (2015). Research and development of drones for peace?high power high energy supply required. *Journal of Energy Resources Technology*, 137(3):034702.

Zorbas, D., Razafindralambo, T., Guerriero, F., et al. (2013). Energy efficient mobile target tracking using flying drones. *Procedia Computer Science*, 19:80–87.