# Using Drones for Resilience: A System of Systems Perspective

Boris Shishkov
University of Library Studies and Information Technologies, Sofia, Bulgaria; Institute of Mathematics and Informatics – Bulgarian Academy of Sciences, Sofia, Bulgaria; IICREST, Sofia, Bulgaria
b.b.shishkov@iicrest.org

Todor Branzov
Institute of Mathematics and Informatics – Bulgarian Academy of Sciences, Sofia, Bulgaria
todor.branzov@gmail.com

Krassimira Ivanova
Institute of Mathematics and Informatics – Bulgarian Academy of Sciences, Sofia, Bulgaria
kivanova@math.bas.bg

Alexander Verbraeck
TU Delft, Faculty of Technology, Policy and Management, Multi-Actor Systems Department, Delft, The Netherlands
a.verbraeck@tudelft.nl

## ABSTRACT

Disruptive Events (DE), such as disasters, virus outbreaks, and military conflicts, are often hugely affecting human life, and works featuring resilience against DE are receiving much attention. A key priority in this regard is the effective monitoring of the affected systems' state after a DE has occurred. Earlier work shows relevant strengths of drone technology for that purpose. In this paper, we take a functional perspective of this technology, for the sake of considering monitoring services and addressing DE. We conceptualize those services and provide explicit insight as it concerns the alignment between user needs and technological (drone-specific) solutions. Further, we zoom in, considering adaptation features, sensing features, and data analytics features accordingly. Finally, we present our general implementation vision that puts drones in a system-of-systems perspective. Since this is work-in-progress, validation is left for future research.

## KEYWORDS

Drone technology, Societal impact, Disruptive events, Resilience

**ACM Reference Format:**
Boris Shishkov, Todor Branzov, Krassimira Ivanova, and Alexander Verbraeck. 2021. Using Drones for Resilience: A System of Systems Perspective. In *10th International Conference on Telecommunications and Remote Sensing (ICTRS '21), November 15, 16, 2021, Virtual Conference, Bulgaria.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3495535.3495539

## 1 INTRODUCTION

*Disruptive events*, such as disasters, virus outbreaks, and military conflicts, are often hugely affecting human life [1–4, 7, 28]. Hence, we need **resilience** in this regard [5]. We argue that the main resilience-related functionality is **recovery** – bringing a system back to its normal state. **Monitoring** [13] is considered a key prerequisite here – we need situation-awareness during/after disruptions, such that we are adequately prepared to bring a system back to its normal state.

In the current paper, we consider monitoring for resilience (in general) and we study relevant strengths of Unmanned Aerial Vehicles (UAV) [33–36], inspired by previous work [5]. We use the label drones in the remainder of the paper. Why consider drones? Because, as studied in [6], drones are capable of: (i) replacing people in dangerous environments; (ii) effectuating advanced sensing capabilities allowing for situation-awareness; (iii) appearing in different sizes - the small ones can reach difficult to access places; larger drones can stay high in the sky for many hours, effectively monitoring buildings, cities, regions.

In this position paper, we take a **functional perspective** of drone technology, for the sake of considering monitoring services and addressing disruptive events. For the design of such services, it is important to use proper **conceptual modelling**, and here *the alignment of user needs and technology solutions* is a concern [12, 18].

In this, we state several key assumptions / deliberate restrictions:

- Our current work is about "drones for resilience" (of society) and not about "resilience of drones". Hence, with regard to the three adaptation perspectives we consider [19] - serving (i) user needs; (ii) system needs; and (iii) public values, we are essentially focusing on just serving user needs.
- Those user needs in turn concern people/organizations who are involved in the recovery from a disruptive event; this is not to be limited to people/organizations negatively impacted by the event

Further: touching upon system engineering [8] and resilience [9], we firstly conceptualize the monitoring service (see above), putting it in a broader perspective; secondly, we provide explicit insight as it concerns the alignment between user needs and technological (drone-specific) solutions.

On that basis we provide further conceptual elaboration that is three-fold:

- Adaptation features: They concern the delivery of services that depend on the situation at hand (the situation of the user as discussed above).


*ICTRS '21, November 15, 16, 2021, Virtual Conference, Bulgaria*

ACM ISBN 978-1-4503-9018-7/21/11...$15.00
https://doi.org/10.1145/3495535.3495539

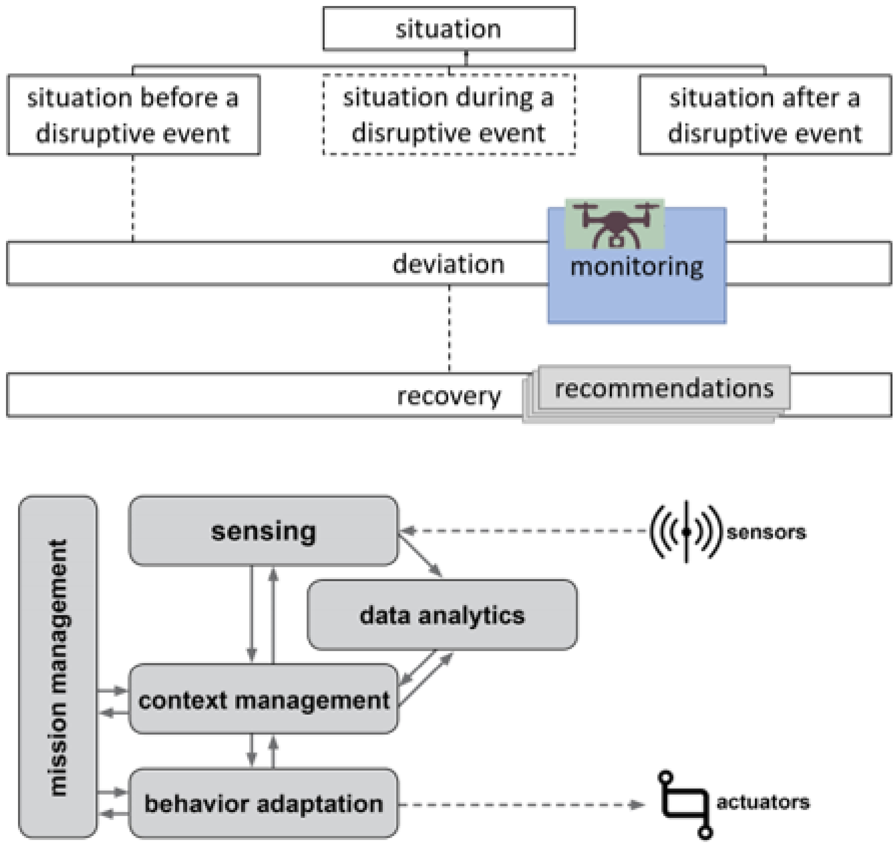


**Figure 1: (top) Disruptive events and monitoring requirements; (bottom) A drone as seen from a functional perspective**

- Sensing features: They concern the data supply mechanisms of a drone, in support of the abovementioned service adaptation.
- Analytics features: They concern AI, ML, and other relevant techniques considered helpful in extracting meaningful information from "big data", in support of the sensing.

Finally, even though we are presenting work-in-progress and are neither offering experimental results nor prototypes, we present our general implementation vision that puts drones in a **system-of-systems** (SoS) perspective [37]. This means that services can be delivered not only by a drone itself but also by a fleet of drones (centrally controlled, de-centrally controlled, or implicitly controlled by peer-to-peer adaptation). We argue that the SoS can offer synergetic solutions for effective and efficient monitoring after disruptive events.

The remaining of this paper is organized as follows: In Section 2 we present our conceptual modeling featuring monitoring as well as the desired functional solution featuring drone technology. In Section 3 we present solution elaborations, considering adaptation, sensing, and AI/ML. In Section 4 we discuss the relevance of cross-cutting concerns. In Section 5, we present our SoS realization vision. Finally, we conclude the paper in Section 6.

## 2 DRONE TECHNOLOGY – DESIGN VISION FOR MONITORING

When considering monitoring in the case of disruptive events, and possible relevant strengths of drone technology, two conceptual "milestones" surface to be addressed in the current section: (i) Answering the question WHAT type of monitoring is needed for the sake of mitigating the effects of disruptive events; (ii) HOW can this be (partially/fully) fulfilled by drone technology. Hence, the former mainly concerns the demands/requirements posed by Society while the latter is about our corresponding design vision. This is visualized in Figure 1

As suggested by Figure 1 – top, we are always to essentially (explicitly or implicitly) consider three situations with regard to Disruptive Events (DE), namely: the normal situation (what it is without any DE having occurred), the "during DE" situation (how things are changing during the disruptive event), and the situation after the DE. Further, the "during DE" situation is kind of "in-between" in the sense that not all negative DE effects have yet manifested themselves (this is indicated by the dashed line in the corresponding rectangle on the figure). Hence, we are to be mainly focused on capturing and analyzing the before-DE situation and the after-DE situation, extracting the negative "deviations" that have taken place. As it concerns the before-DE situation, it is expected to be well documented in system archives, logs, and so on. Hence, monitoring is to be essentially focused on the after-DE situation, and drones have a role to play here, as also visualized in Figure 1 (top). Replacing people in dangerous environments, the situation-awareness capabilities, and the device diversity (see the Introduction) are among the arguments in this direction. Finally, monitoring is not to be done just for the sake of realizing monitoring. It needs to be done for the benefit of those generating recovery-related recommendations. It would be those recommendations that are supposed to play a central role in achieving mitigations. This all helps us formulate several key requirements accordingly. Requirement 1: Effective monitoring shall be realized, featuring the situation after the occurrence of a disruptive event. Requirement 2: The captured monitoring information shall be sufficient for establishing the actual "deviations" from before the disruptive event. Requirement 3: The monitoring output shall be sufficient to generate recovery recommendations.

Actually, the output from a drone monitoring [13] can also be used to intervene in the affected system. E.g., sending a rescue mission to a certain location after the drone has sensed trapped people in a collapsed building. We also have "enablers" supporting the drone in its delivering monitoring services, such as GPS satellites, cellular services with radio towers and supporting networks, and a ground station with an operator, launch pads, and so on. This allows the drone to obtain instructions about the objects or region of monitoring, and to get sufficiently close to it. On that basis the recording or real-time data feed can start that provides useful monitoring output, needed by members of Society. Two important functions exist in this regard: (1) the operation of the drone, encompassing mission definition, power management, steering and safety during the mission, and drone recovery after the mission (which is beyond the scope of this paper). (2) the operation of the monitoring function during the mission, including real-time data feed processing, starting/stopping recording functions, and providing guidance to the drone operator on adapting the mission based on the data feed. Finally, the core entity that provides the monitoring functionality is the drone itself (considered as a system). This concerns the instruments through which it is delivering its monitoring services. Examples are the power subsystem (batteries and/or fuel), the propulsion subsystem (engine/rotors), the control subsystem (featuring the avionics and navigation), the sensing subsystem (comprising the sensors that allow the drone to function effectively and safely), the communications subsystem (radio, wi-fi, GPS satellite communication), and the monitoring subsystem (providing the function for the purpose we discuss, with different types of cameras, radar, microphones, and other sensors). We make a specific distinction between the sensors used for operating the drone and those needed for the monitoring function. The monitoring sensors are modular and flexible, and linked to people and services engaged in the operation of the data feed, whereas the sensors used for drone's safe operation are often fixed, linked to its control system, and further controlled by the drone operator.

These services are, in the end, all delivered for the benefit of those who are "suffering" from the effects of the disruptive event(s) and/or those who are involved in the recovery from the disruptive event. These are mainly persons, but it can also be organizations. For this, we will reserve the term "End User" in the current paper.

Functionally: (a) The End User is impacted by the disruption, for example: a person is trapped in a collapsed building; a group of inhabited houses is approached by a fast-moving fire. (b) What the End User needs therefore is MITIGATION for the situation at hand, for example: a rescue team is sent to the collapsed building; a firefighting team or water dropping plane is sent to the fast-moving fire. (c) Each mitigation is situation specific. (d) Special services, such as rescue services, are supposed to deliver such mitigation. (e) And finally, drones can support those services, by delivering useful output of the monitoring action, e.g., photo/video recordings, infra-red images, temperatures, sound recordings, levels of toxic gases, or radar images.

And in the end, we also need vision beyond the purely functional requirements discussed already in this section. We need to also consider crosscutting concerns of non-functional nature, such as technical aspects and public values whom we would need to reflect in functional solutions; this will be considered in Sect. 4.

In Figure 1 – bottom, we have presented our design vision inspired by the requirements. There has been quite some literature about architectures for autonomous systems, with a nice overview in [15]. In this position paper, we mainly focus on the design choices that are essential for positioning the drone monitoring system between societal demands and governance, as well as the technical capabilities of the drone. In this, we view a drone as AGENT, in the category of Multi-Agent Systems, referring to Wooldridge [16]. As such, the drone is autonomous to some degree and adaptive, and is driven by three key features, namely: (i) The ability to gather relevant contextual information by means of sensing; (ii) The ability to analyze this data (and possibly generate conclusions and/or decisions), by means of algorithms; (iii) The ability to adapt its behavior in response to changes in the environment. This is visualized (inspired by previous work [5, 14], Wooldridge [16], and [17]) also in Figure 1

Hence, drones essentially count on context management for realizing their pro-active behavior, driven by a pre-defined mission. In this, it is necessary for a drone to get relevant information (for the sake of determining the "current" situation) and be able to adapt its behavior accordingly (for the sake of delivering situation-specific services); as it concerns the former/latter, a drone counts on sensors/actuators, while sensing in turn needs further "mappings" towards usable meaningful information, for which data analytics is to count on.

In Section 3, we will "zoom in" with regard to each of those three essential directions.

## 3 ELABORATION

Monitoring represents complex behavior where numerous viewpoints need to be synchronized and prioritized – What is to be monitored? How risky is the monitoring? Which are the regarding priorities, and so on. Hence, the drone needs to be situation-aware in the sense that it adapts to the constantly evolving environmental changes. And what it needs in this regard is proper input data that helps determining the situation and the actual current needs – this is delivered by sensors. What the drone also needs is capabilities to extract higher-level meaningful information based on the sensor data. All those three crucially important issues are elaborated further in the current section.

**Context Management**

As studied in previous work [18, 19, 32], context-awareness essentially concerns adaptive service delivery. User needs (see Sect. 2) are primarily the needs of the End User (EU): those who are affected by a Disruptive Event (DE) and/or those who are involved in the recovery from the DE. EU are hence not the drone users / ground navigators. Further, CONTEXT is anything concerning the drone environment that is relevant as it concerns the EU situation. Hence, essentially, the EU is part of its context. Also, the EU has user needs but at the same time, the user context has many possible context situations. If this is the case, then we should expect that each context situation corresponds to a particular user need. Thus, the context-awareness "feature" of a drone is to be about DETECTING the "current" context situation (which is similar to detecting a situation change) and then when it is "known" which the situation at hand is, the drone is to offer a corresponding situation-specific service that in turn is to fulfill corresponding user needs. In this the drone (being context-aware) interacts with its context; also, the user "consumes" the situation-specific service(s) delivered in this way. The SITUATION DETECTION is to be enabled by: **sensors** that are the drone's "eyes and ears", and **data analytics modules** that would translate raw sensor data into higher-level meaningful information, do data filtering and preprocessing, "re-build" missing data, do quality-of-data checks, and so on (see further below). The delivery of SITUATION-SPECIFIC SERVICES is about the behavior adaptation that the drone is to carry out in response to changing context. We argue that all this could be implemented, by counting on four key components relevant to the context management: Data acquisition and pre-processing component, Situation detection component, Adaptation to situation component, and the Service delivery component.

As studied by Shishkov & Van Sinderen [18], in order to be useful, a context-aware system's services should fulfill the user needs in different context situations. Complications are possible nevertheless, threatening the validity of this utility even if the technical system design is correct. For example: (i) The situation-specific services may not fulfill the user needs – possibly because of "tensions" among different user perspectives, with no clear criteria which perspective to "prevail": Imagine that a drone should follow one "monitoring route" if the goal is supporting those who are affected by a DE and another "monitoring route" if the goal is supporting those involved in the recovery. Hence, clear prioritization is needed in this regard. (ii) The relationship between user needs and context situations may be unclear – Imagine that a drone approaches a person and starts blurring its videorecording because of privacy issues, but would this be necessary if this person is a border police officer whose face is recorder all the time anyway, during work hours? Hence, it is necessary to be clear for whom the user needs apply. (iii) It may be that a context situation is not properly defined, for example, what would be meant by "endangering third parties" when approaching a person – hurting the person, or making noise that may possibly cause stress with the person, or something else? Hence, each envisioned context situation is to be properly defined. (iv) The measuring methods used for an indicator may not always provide reliable value of the indicator – this would often concern the "mission completed" measurement. Is it adequately "explicated" for a drone how it is to establish that the mission goal has been achieved? Is this to be determined by the drone or by the "mission owner" and how do we deal with precision in this regard? Those are only several possible validity threats and in order to be adequate in delivering context management for drones, we need to be aware of such threats, and know how to resolve them as part of the design.

**Sensing**

The principal payload that provides the monitoring capability of the UAV drone may broadly be categorized as "sensors". The drone is used as a vehicle that carries one or more devices (sensors) that observe characteristics of the environment and objects in it, and gather data related to those objects. Several authors already described drones as a suitable platform that allows development and optimization of various remote sensing methods - some of those even proclaiming drones as "the third-generation source of remote sensing data" (the first and second one being, respectively, manned aircraft and satellites) [20].

One of the most common types of sensors carried by drones is those that produce imagery. Even most of the consumer class drones have a camera that produces images or video in the visible spectrum (400-700nm wavelength). Along with that, several vendors provide multispectral sensors which produce series of images of an object (usually 5-10) representing several regions of the 400-1000 nm spectral range and hyperspectral sensors that produce a large number (in some cases tens of thousands) of imagery of contiguous spectral bands in the 400-2500 nm range. The generalized use case of these sensors is for the observation of objects which have important characteristics, that cannot be perceived in just one spectrum region.

Radiometric infrared sensors (RIS) produce thermograms that can be used to identify temperature differences. A key advantage is that the images are not obstructed by smoke, haze, vegetation - factors that do not allow optical observation. RIS are small enough to be carried by medium drones. Along with defectoscopy [21] and some applications in archaeology [22], the drone carried RIS have been successfully used for the detection of living organisms [23] or their use was proposed to detect people with abnormal temperature (possibly ill) in a crowd [24] - which are use cases that can be adapted and applied to various activities during or after disruptive events.

Another sensor that is available for drone deployment is the LiDAR, using laser waves to determine distance to an object. The drone carried LiDARs are widely used in the construction industry for creating digital models of existing structures and buildings. It is also cited as a "prevalent active remote sensing technique for the direct measurement of the effects that close-to-surface buried archaeological remains have on the topography of a landscape" [25] RADAR sensors are similar in principle, but their usage is limited by their size and they are used prevalently in military drones. However, there are studies for the development of low-cost drone carried mini-RADAR sensors with rapid deployment and the ability to easily focus on selected spots as the key advantages [23].

All of the cited authors argue that the key advantages of the drone platform are its inexpensiveness and ability for quick deployment. Along with that, we propose that several drones can be used to quickly deploy a sensor network that could provide the data necessary for early-warning decision support systems (before the disruptive event) or disaster management systems (during or after the event). Another opportunity during and after the disruptive event is the integration of drone data with data obtained by satellites or planes. Also, small drones with inexpensive sensors can be deployed for gathering preliminary observation data - before eventually focusing better, but much more expensive remote sensing capabilities of the satellites and airplanes.

A key advantage for adopting drone based remote sensing methods is the existence and employment in the practice of methods that actually use most of the sensors. For example, thermography is used by the firefighters and handheld sensors are used at least since 1990s. The clear advantage that the drones (actually, in that particular case "drones" is not restricted to UAVs only) will provide is not risking the lives of the firefighters to obtain the information, that they already know how to use in their work. Multispectral and near-infrared imagery is used "for decades" in archeology [26].

**Data Analytics**

At present, AI (Artificial Intelligence) technologies support the work of drones both in the organization of their independent flight and in the implementation of their mission to identify various objects.

In the context of a system of systems, information processing is done locally in the drone but also in the ground station when executing (parts of) algorithms. For example, just getting the GPS coordinates for departure and destination points is not enough to perform the flight correctly. GPS navigation alone is also not enough to ensure an unobstructed flight. Hence, computer vision based on high-performance on-board image processing mainly supports the functions of object tracking and self-navigation, which is important especially in the environment where continuous communication cannot be guaranteed. On the other hand, drone training for recognizing a variety of static and dynamic objects is done on the basis of a large amount of annotated data sets, which due to their volume are positioned in the ground station.

Machine Learning technologies and especially Deep Learning technologies play an important role in solving many of the tasks facing the drone to fulfill its mission such as: semantic mapping of the environment; visual analysis to find a goal / obstacle / point of interest; 2D / 3D target tracking [27].

## 4 CROSSCUTTING CONCERNS

As it is well-known, crosscutting concerns with respect to software development are security, distribution, recoverability, logging, performance monitoring, and so on [10]. They are often labelled "aspects". They are essentially non-functional, requiring nevertheless functional solutions [30]. This makes them crosscutting in the sense that those functional solutions would affect numerous system modules. We argue that each of the abovementioned aspects are drone-relevant: (i) Security is of key importance, especially for military drones – it would be much undesired if third parties are able to access mission-related information. (ii) Distribution is important as well, especially when multiple drones are used in a mission, this posing needs for coordination and synchronization, assuming distributed processes. (iii) As it concerns recoverability, it is crucial in drone systems because failures may take place but still the system should be able to adequately recover, such that the mission continues. Otherwise, the reliability of drone solutions would be considered low. (iv) Logging is also important since in case of an accident, it would be needed to analyze what happened and log files would be essential in this regard. (v) Also, performance monitoring is of relevance because this would help identifying "upcoming" tech problems early enough to allow effective measures. Such monitoring could be established counting on performance indicators, for example.

Next to aspects, we need to take into account as well the so-called public values ("values" for short) that are also crosscutting [11]; values represent desired system features that are not so technical (as aspects) but are more oriented towards societal relevance [30]. Hence, values are about all societal norms (implicit or explicit) that pose societal expectations towards corresponding (technical) artefacts. Among the most widely considered values are privacy, transparency, and accountability [31]. We argue that they are all relevant as it concerns drone technology: (i) In many situations, privacy may pop up as an important issue because a drone is fast moving and hence passing through many context situations – some of them may concern nearby persons whose privacy should be respected. (ii) Transparency is also of importance because the "mission owner" should always be able to prove that in what a drone has "done", no criminal or other societally unacceptable actions had taken place. (iii) Finally, as we have studied in previous work [14] the accountability concerns related to drone technology are of huge relevance mainly because it should be possible to establish who is responsible something bad caused by a drone.

## 5 TOWARDS SYSTEM-OF-SYSTEMS IMPLEMENTATIONS

In [37], Sauser at al. list five characteristics of Systems of Systems (SoS): autonomy, belonging, connectivity, diversity and emergence (ABCDE). All five play an important role in drone monitoring systems for disruptive events. **Autonomy** is important, because in a crisis situation, a drone has to be able to make independent decisions on the path to follow and on where and when to monitor; not all can be preprogrammed or tightly controlled. **Belonging** is especially important when multiple drones have to work together. There has to be the notion of a joint mission, to which every drone belongs, and that the group of drones tries to fulfill together. **Connectivity** plays on two levels: drone-drone communication in the case of a swarm of drones, and drone-mission control communication to allow feedback, control, and adaptation of the mission. **Diversity** can be utilized maximally by not having the drones in a mission be all the same: they could be deployed with different sensors, have different sizes and flight ranges, and different levels of autonomy. Heterogeneity increases the chance of the mission being successful, by exploiting the complementarities within the fleet of drones. **Emergence** is an important property, but one of the hardest to implement. Learning and adapting during the mission can have enormous benefits, but it is not easy to decide how much freedom would still keep the drone(s) within the bounds of safe operations. Emergence and autonomy also link closely to the notion of context-awareness (see Sect. 3).

As it concerns multi-drone systems, a discussion is needed from a data analytics perspective. This concerns situations when: (i) tasks are to be coordination among "members" of a drone fleet (utilizing low-power close-range communication and maintaining the desired inter-drone distance); (ii) multiple targets are to be localized; (iii) the sub-goal of each drone is to be defined (based on the common fleet goal); and so on. Here technologies featuring Artificial Intelligence and Machine Learning are broadly used, especially in the processes of forming the so called "collective intelligence" (also labelled "swarm intelligence") of the fleet [29].

Finally, "System-of-Systems" is different from "System-of-Subsystems" [37]. The ABCDE characterization above makes the system-of-systems more independent, adaptable, de-centralized and heterogeneous as compared to a regular system-of-subsystems. This asks for a network-centric implementation, where the focus is on peer-to-peer communication rather than on top-down central control. Given the nature and unpredictability of disruptive events, following the System-of-Systems characteristics results in a more resilient and robust drone-based solution than a homogeneous, centralized and pre-configured system.

## 6 CONCLUSIONS

Acknowledging the importance of monitoring with regard to system recovery (the main resilience-related functionality) as it concerns Disruptive Events (DE), we have taken a functional perspective of drone technology, for the sake of considering monitoring services and addressing DE. For the design of such services, it is important to use proper conceptual modeling; here the alignment of user needs and technology solutions is a concern.

In tackling this and taking a drone technology perspective, we have considered system engineering and resilience, in order to (i) conceptualize monitoring services; (ii) provide explicit insight as it concerns the abovementioned alignment. Further, we have provided a conceptual elaboration accordingly, that is three-fold: adaptation features, sensing features, and data analytics features; this is about using sensor data, by reflecting it (supported by data analytics) in higher-level meaningful information, such that this information is used for system behavior adaptation.

Moreover, we have presented our general implementation vision that puts drones in a system-of-systems perspective.

Our proposed design vision is reflecting research-in-progress and as such is not backed by corresponding validations – this is left for future research.

## REFERENCES


[1] Reuters. 2020. Italian PM orders businesses to close all operations. In The Guardian - International Edition, London, UK.
[2] K. Takizawa. 2019. Resilience of Communities Affected by the Great East Japan Earthquake and Restoration of Their Local Festivals. In Bouterey, S., Marceau, L. (eds.) Crisis & Disaster in Japan and N. Zealand. Palgrave Macmillan, Singapore.
[3] M. Zare, A. Abbaspour, M. Fotuhi-Firuzabad and M. Moeini-Aghtaie. 2017. Increasing the resilience of distribution systems against hurricane by optimal switch placement. In Proceedings of the Conference on Electrical Power Distribution Networks Conference (EPDC '17). Semnan.
[4] Srilaya Sriperumbuduru; Velampalli Sirisha, "12 COVID-19 Pandemic: A New Era in Higher Education," in Use of AI, Robotics, and Modern Tools to Fight Covid-19, River Publishers, 2021.
[5] Boris Shishkov, Stefan Hristozov, and Alexander Verbraeck. 2020. Improving Resilience Using Drones for Effective Monitoring after Disruptive Events. In Proc.: 9th Int. Conference on Telecommunications and Remote Sensing (ICTRS 2020). Association for Computing Machinery, New York, NY, USA.
[6] Ged F. Griffin. 2014. The Use of Unmanned Aerial Vehicles for Disaster Management. Geomatica Vol. 68, No. 4, 265 – 281.
[7] WHO, The World Health Organization. https://www.who.int
[8] Ian Sommerville. 2016. Software Engineering, 10$^{th}$ Edition. Pearson, Essex.
[9] Boris Shishkov and Alexander Verbraeck. 2020. Making enterprise information systems resilient against disruptive events: a conceptual view. In Proceedings of the Tenth International Symposium on Business Modeling and Software Design (BMSD '20). Springer - Lecture Notes in Business Information Processing (vol 391), Cham, Switzerland.
[10] Senthil Velan S. 2019. Introducing Artificial Intelligence Agents to the Empirical Measurement of Design Properties for Aspect Oriented Software Development. Amity International Conference on Artificial Intelligence (AICAI).
[11] Van den Hoven, J. 2013. Value Sensitive Design and Responsible Innovation. In: Owen, R., Bessant, J., Heintz, M. (eds.) Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society. Wiley, Hoboken.
[12] Shishkov B. (2020) Social Theories. In: Designing Enterprise Information Systems. The Enterprise Engineering Series. Springer, Cham.
[13] Z. Hu *et al.* 2010. Remote sensing and GIS application in environmental effect monitoring of great engineering: Indicators and method. Proc.: 18$^{th}$ International Conference on Geoinformatics.
[14] Boris Shishkov, Stefan Hristozov, Marijn Janssen and Jeroen Van den Hoven. 2017. Drones in land border missions: benefits and accountability concerns. In Proceedings of the 6$^{th}$ International Conference on Telecommunications and Remote Sensing (ICTRS '17). ACM, New York, NY, USA.
[15] Hualong Chen, Yuanqiao Wen, Man Zhu, Yamin Huang, Changshi Xiao, Tao Wei and Axel Hahn. 2021. From Automation System to Autonomous System: An Architecture Perspective. Journal of Marine Science Engineering 9, 645.
[16] R. H. Bordini, M. Fisher, M. Wooldridge and W. Visser. 2004. Model checking rational agents. In: IEEE Intelligent Systems, vol. 19, no. 5, pp. 46-52, Sept.-Oct.
[17] Alexander M. Meystel and James S. Albus. 2002. Intelligent Systems: Architecture, Design and Control. Wiley.
[18] Shishkov B., van Sinderen M. (2021) Towards Well-Founded and Richer Context-Awareness Conceptual Models. In: Shishkov B. (eds) Business Modeling and Software Design. BMSD 2021. Lecture Notes in Business Information Processing, vol 422. Springer, Cham.
[19] B. Shishkov, J.B. Larsen, M. Warnier and M. Janssen. 2018. Three Categories of Context-Aware Systems. Proc.: Eighth International Symposium on Business Modeling and Software Design (BMSD '18). Springer - Lecture Notes in Business Information Processing (vol 319), Cham, Switzerland.
[20] Anita Simic Milas, Arthur P. Cracknell & Timothy A. Warner. 2018. Drones – the Third Generation Source of Remote Sensing Data, International Journal of Remote Sensing, 39:21, 7125-7137.
[21] H. Kayan, R. Eslampanah, F. Yeganli and M. Askar. 2018. Heat Leakage Detection and Surveillance Using Aerial Thermography Drone. Proc.: 26th Signal Processing and Communications Applications Conference (SIU).
[22] Casana, J., Wiewel, A., Cool, A., Hill, A., Fisher, K., & Laugier, E. 2017. Archaeological Aerial Thermography in Theory and Practice. Advances in Archaeological Practice, 5(4), 310-327.
[23] Dario Tarchi, Michele Vespe, Ciro Gioia, Francesco Sermi, Vladimir Kyovtorov, Giorgio Guglieri. 2017. Low-Cost Mini Radar: Design Prototyping and Tests. In: Journal of Sensors, vol. 2017, Article ID 8029364, 15 pages, 2017.
[24] Pandey S., Barik R.K., Gupta S., Arthi R. 2021. Pandemic Drone with Thermal Imaging and Crowd Monitoring System (DRISHYA). In: Tripathy H.K., Mishra S., Mallick P.K., Panda A.R. (eds) Technical Advancements of Machine Learning in Healthcare. Studies in Comput. Intell., vol 936. Springer, Singapore.
[25] Adamopoulos, Efstathios, and Fulvio Rinaudo. 2020. UAS-Based Archaeological Remote Sensing: Review, Meta-Analysis and State-of-the-Art. In: Drones 4, no. 3: 46.
[26] Hill, Austin C., Elise J. Laugier, and Jesse Casana. 2020. Archaeological Remote Sensing Using Multi-Temporal, Drone-Acquired Thermal and Near Infrared (NIR) Imagery: A Case Study at the Enfield Shaker Village, New Hampshire. In: Remote Sensing 12, no. 4: 690.
[27] Carrio, A., Sampedro, C., Rodriguez-Ramos, A., Campoy, P. 2017. A Review of Deep Learning Methods and Applications for Unmanned Aerial Vehicles. In: Journal of Sensors, Volume 2017, Article ID 3296874.
[28] Ping He. 2020. Study on Epidemic Prevention and Control Strategy of COVID-19 Based on Personnel Flow Prediction. Proc.: Int. Conference on Urban Engineering and Management Science (ICUEMS '20). IEEE, Zhuhai, China.
[29] Schranz M., G.A. Di Caro, Th. Schmickl, W. Elmenreich, F. Arvin, A. Şekercioğlu, M. Sende. Swarm Intelligence and cyber-physical systems: Concepts, challenges and future trends Swarm and Evolutionary Computation, Vol. 60, 2021, art. N 100762.

[30] Shishkov, B. 2020 Designing Enterprise Information Systems Merging Enterprise Modeling and Software Specification. Springer, Cham.
[31] Friedman, B., Hendry, D.G., Borning, A.: A survey of value sensitive design methods. In: A Survey of Value Sensitive Design Methods, 1, Now Foundations and Trends, 76 p. (2017).
[32] Boris Shishkov and Marten van Sinderen. 2008. From user context states to context-aware applications. In: Filipe J., Cordeiro J., Cardoso J. (eds) Enterprise Information Systems (ICEIS '07). Springer - Lecture Notes in Business Information Processing (vol 12), Berlin-Heidelberg, Germany.
[33] Milan Erdelj, Enrico Natalizio, Kaushik R. Chowdhury and Ian F. Akyildiz. 2017. Help from the sky: leveraging UAVs for disaster management. In IEEE Pervasive Computing, vol. 16, no. 1, pp. 24-32.
[34] J. Homola, M. Johnson, P. Kopardekar, A. Andreeva-Mori, D. Kubo, K. Kobayashi and Y. Okuno. 2018. UTM and D-NET: NASA and JAXA's collaborative research on integrating small UAS with disaster response efforts. Atlanta, GA, USA.
[35] P. Kopardekar, J. Rios, Th. Prevot, M. Johnson, J. Jung and J.E. Robinson III. 2016. Unmanned aircraft system traffic management (UTM) concept of operations. In Proceedings of the 16$^{th}$ AIAA Aviation Technology, Integration, and Operations Conference, Washington, D.C., USA.
[36] American Red Cross. 2015. Drones for Disaster Response and Relief Operations. Retrieved from: https://www.issuelab.org/resources/ 21683/21683.pdf.
[37] B. Sauser, J. Boardman, and A. Gorod. 2008. System of Systems Management. In: M. Jamshidi (Ed.). System of Systems – Innovations for the 21st Century. Wiley. pp 191-217.