Distributed processing applications for UAV/drones: a survey

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Abstract – Distributed Processing Systems are the ones that include multiple devices (which could be of many types, such as PC computers, mobile devices etc.) that have computational and communication capabilities. Their computational power is jointly used for collaborative processing of variety of tasks – and this processing is realized in distributed manner. UAV - Unmanned Aerial Vehicles (also called drones) gain significant attention over recent years. They have been employed to realize multiple tasks such as surveillance or environmental monitoring. First implementations were based on single UAV, later the potential of multiple UAVs collaborating in a team was noticed. Many applications were implemented in distributed manner, using multiple collaborative UAVs and the distributed processing systems principles. In this paper we survey the applications implemented over cooperative teams of UAVs that operate as distributed processing systems.

Keywords: UAV, Unmanned Aerial Vehicle, cooperative, collaborative, swarms, drones, distributed processing, applications

1 Introduction

Distributed processing systems contain multiple devices (called *nodes*) equipped with processing capabilities (based on general purpose processor, ARM chips or any other processing unit) and communication unit providing the network communication. Nodes join the designated system, become its members and contribute with their processing power and any other capabilities they possibly might have – such as peripherals attached. The resources in the distributed system are limited [1]. All member nodes along with control element, communicating over common network layer – constitute the distributed processing system. Such system can process a common task that is internally split into sub-tasks (called *blocks*) that are further processed by different nodes – and the result is yield by the control unit. As the task is inputted to the control unit, and result appears there as well, the whole system can be perceived as a virtual machine – having the computation and communication infrastructure inside. Tasks processed by distributed processing systems can be of various types. Popular distributed processing systems such as grids [2] and public computation systems [3] usually perform the computing (such as signal processing, image analysis, etc.) and the result is the processing result, or some answer (e.g. “object found in the processed image”). The evolution of distributed processing systems brought a new task types – that produce the results that immediately affect the distributed processing system itself, modifying its operating parameters.

Unmanned Aerial Vehicles – UAVs (also called *drones*) are the flying objects that are not equipped with any pilot on board. They can be either controlled from the ground station, or by autonomous onboard control algorithms. Recently the small-sized drones are gaining very big attention both in research and commercial world. The researchers focus on optimization of onboard operational algorithms, swarming, navigation systems and many others, while industry companies try to employ drones for commercial applications, such as surveillance [4] or package deliveries [5]. The strong interest about UAVs and UAS (Unmanned Aerial Systems) is also expressed by the governments considered as long-term future systems with high potential [6]. Multiple drones communicating with each other and being commonly controlled are called *swarms* or *teams*. UAVs participating in such groups are often equipped with processing capabilities, various sensors (such as cameras) and connect to the common communication network. This way, such drone swarms fulfill the principles of distributed processing system – in which drones are the nodes, and the system fully manages by itself using its internal algorithms and mechanisms.

2 The goal of the survey

This paper describes the applications of distributed processing systems for UAV/drones swarms and teams. We focus on computer engineering aspects (and related), the implementation of collaboration mechanisms between nodes of distributed systems, communication, and principles of distributed processing that are used in analyzed distributed processing systems built over groups of UAVs. However, system participants are not limited to UAVs, structures including both UAV and UGV (Unmanned Ground Vehicles) participants are included in the survey too. Systems analyzed in this paper do not limit UAV size – we include systems using large drones, medium-sized UAVs, mini helicopters, micro-UAVs and others. For the purpose of this survey, we classify the distributed processing applications into following categories: 1) general purpose distributed processing applications, 2) object detection, 3) tracking, 4) surveillance, 5) data collection, 6) path planning, 7) navigation, 8) collision avoidance, 9) coordination, 10) environmental monitoring.

3 Distributed processing applications for UAVs

3.1 General purpose distributed processing applications

Many solutions dedicated to distributed processing in UAV systems are meant to provide under-the-hood functionalities – where other applications are built on top of them. Such architecture designated to manage the resources in the team of autonomous vehicles (aerial UAVs and ground UGVs) was presented in [7]. DFRA – Distributed Field Robot Architecture uses object-oriented approach and implements the interaction of software objects / agents through a decentralized group of vehicles. Each resource present at the vehicle member of the team can be discovered by any other vehicle or the human operator. DFRA was implemented using Java and Jini middleware and applied to the team containing both UAV and UGV units. More complex solution for the software platform was presented in [8]. Authors propose the modular infrastructure aimed to coordinate distributed control, vision control and communications. The communications layer is implemented using control flooding (broadcasting information) in which incremental data passing is used (UAV receiving the message from broadcaster, receives not only data related with broadcaster, but also sender's knowledge about other UAVs). Tasks are distributed among vehicles and assigned based on distributed collaboration of UAVs.

3.2 Object detection

The most popular application of UAV swarms implementing distributed processing is the object detection – based on the data gathered by data sources such as cameras and radars. This application, also called ATR (automatic target recognition), strongly employs the image processing and signal processing algorithms.

The use of Bayesian search (and also localization) in a distributed manner was presented by the authors of [9]. The search and localization algorithm uses the process of filtering multiple observations coming from the pointed-down cameras attached to vehicles. In the target localization process (single objects are considered), the probability of a true detection of an object is a function of the image resolution (at the target's location), and the visibility of the target. The multiple-target search was presented in [10] – where, similarly, the team of UAVs in which each one is equipped with the camera is employed. The monitoring area is divided into regions, and the probability of target existence in each of the regions is calculated. The distributed UAV platform uses the sharing of measurement information, information updates due to environmental factors and changes, keeping in mind the limited communication and sensing capabilities. Based on the existence probability and the shared data fusion, the distributed probability map updating model is implemented. The important aspect regarding the distributed processing algorithms is that the UAVs communicate only the neighboring vehicles in their range – i.e. the overlay communications network is not used in this case.

3.3 Tracking

Tracking is the application related to object detection – often times the mission goal states, that once the target is detected, then it is being tracked by the same UAV team. The object detection and tracking can be implemented as one application. The high level definition of the distributed tracking system was given in [11]. The description contains the technical details of such elements as: vehicle, object tracker, flock guidance and geolocation – and the relations between them. The implementation details and parameters are also provided, along with possible algorithms. The example of the search & tracking application was presented in [12]. The proposed system can switch between search & tracking modes and still use the information that was gathered during past operation. It deals with the scenario where the tracked target is lost – then the search is performed again and the recursive Bayesian filtering is used. Vision measurements were used in [13] and [14] to build the collaborative distributed tracking system. In [13] the information gathered by multiple UAVs is fused along with the goal of minimizing the data transmitted between vehicles. Cameras are directed to POI (Point Of Interest) with the necessary adjustment according to the vehicle/target movement. The geolocation of POI is calculated by vehicle, also including the vehicle/target movement, however due to the collaborative nature of the system, the dynamics of POI is recalculated so it is not a function of any UAV state.

3.4 Surveillance

Area surveillance operated by teams of UAVs is considered as one most perspective distributed processing applications, remaining one of most controversial at the same time. The use of dynamic task reconfiguration (also mentioned in section 3.1) was employed to perform the surveillance task through the team of heterogeneous UAVs equipped with various sensors. Multiple tasks require significant computing power so maximizing the use of processing resources brings the valuable profit. Another approach to the distributed surveillance application – perimeter surveillance – is described in [15]. The proposed approach of the cooperative perimeter surveillance employs the team of UAVs (each having limited connectivity capability) and allows insertion/deletion of team members. Even though the distributed processing fashion is used for the surveillance process, the results are communicated to the ground station that constitutes the central element of the system. Vehicles communicate only with their neighbors met at the same location – so depending on the relations of positions of UAVs there are many communication schemes – what adds the another aspect to the distributed processing problem. The algorithm implementing the distributed processing perimeter surveillance includes such parameters as: perimeter length, number of UAVs to the ‘left’ of given vehicle, and to the ‘right’ of a given vehicle. Another aspect of the surveillance is the prioritization of area sections taken into the consideration.

3.5 Data collection

Wireless sensor networks (WSN) are the structures of multiple data sources that are spread over the area for the data gathering purposes – and captured information is sent to the central unit (such as computing center). They usually register environmental quantities such as temperature, air pressure, wind, etc. – but are not limited to. The technological advance in WSNs first allowed the bidirectional sensor-central unit communication – sensors started to be capable not to only send gathered data to the central unit, but also to receive various information, including the control messages. Second, it allowed to consider UAVs as the autonomous sensors – or more to say – the units handling multiple sensors onboard, but still filling the WSN unit paradigm. The automated sensing platform employing multiple UAVs was presented in [16]. The data gathered is analyzed at UAVs, to process the noise and other uncertainties introduced by the airborne operation of UAV. Then the data fusion is performed, also in cooperative distributed manner at UAVs – unlike other approaches in which it takes place in the central unit (usually ground-based), so the result is provided by the team of UAVs autonomously. The problem of decentralized data fusion is also deliberated in [17], where authors put special attention at decentralization of the presented sensing network. Therefore, no common communication unit is used, fusion is done in a distributed manner at UAVs and sensors know only about neighboring network connections. Decentralization was implemented using Kalman filter that requires the fully connected network (i.e. each unit in the network is connected to every other one), that in practice can be implemented only for small sized systems (or the concept of overlay network can be used). Authors used the tree algorithm and showed that it will be sufficient for this application, regardless the full-connectivity requirement.

3.6 Path planning

The swarms of UAVs operate in diversified environment – that can contain various ground and aerial obstacles that need to be taken into the consideration in the path planning process. Multiple obstacles on a way of multiple collaborative UAVs, each equipped with sensor(s) form the distributed processing problem. The generation of optimal path is usually not possible in the feasible time, thus the path planning applications are trying to produce the solution as close to optimal as possible, but in a very short time. Authors of [18] presented the algorithm that uses the particle swarm optimization and delivers the path of quality dependent on the computation time. The UAVs that are the members of the distributed processing structure concerned, are considered to have the limited-sensor and limited-communication capabilities. The outcome of the UAV-based distributed system is a set of paths, each assigned to single UAV – so the swarm can reach the geographical goal without collision with ground and aerial obstacles, and the other UAVs as well. Each UAV computes the path for itself, and if the communication distance allows – it shares its plan with others. Vehicles sharing information during the flight, update their paths if necessary (e.g. because of predicted collision with other UAV). In [19], the team of UAVs forms the monitoring structure that supplies the information for path planning adaptive algorithms. In this solution, also the exceptional events are supported, such as: vehicle leaves or joins the network, sensor enters/leaves the network. UAVs communicate with each other, so the path is created in the distributed collaborative manner.

3.7 Navigation

The path planning is closely related to the application of navigation – both of these involve directing the UAV in some direction or position. Usually, the path planning is considered as flying from one position to another, while navigation is considered as determining the actual position of the vehicle(s). Nowadays GPS satellites provide a way to calculate the position of the GPS signal receiver, however this calculation might be not accurate enough, or the GPS receiver might be impossible to place on the UAV (e.g. due to energy consumption). Therefore various variants of navigation are still in consideration. The distributed processing navigation framework was presented in [20] where the data from image sensors is the base for applied algorithms. A swarm of vehicles monitors the environment and takes multiple targets in the consideration – the image data is processed in the distributed manner and each target is labeled with a signature (containing various elements, such as position on the image focal plane, time, and optionally the position obtained from GPS). Data from multiple vehicles is fused to get the greater picture of the area. The approach presented in [21] uses the multiple ground stations that cooperate with UAVs and together form the distributed processing system (unlike the [20], where all the processing is done airborne). Each vehicle is associated with a ground station, and gathers the data from sensor that it is equipped with – and the images (and other sensor data) are filtered and fused by the ground station (using Extended Kalman Filter) what produces the detailed information about vehicles' motion. Next, the information about all UAVs is fused and the state of each vehicle is estimated.

3.8 Collision avoidance

The algorithms for the collision avoidance must be implemented in the cooperative swarm of UAVs, as the vehicles operate in close vicinity of each other and some of vehicles might need to change the spatial position in the swarm formation. Collision avoidance is often used interchangeably with obstacle avoidance. For the purpose of this paper we consider collision avoidance as avoiding the physical contact between UAVs in one swarm. The comprehensive collision avoidance study, including various types of vehicles was presented in [22]: two cases for AGVs (Autonomous Ground Vehicles) and one for UAV. The distributed application for UAVs considers that vehicles share their information between each other about location and anticipated direction of movement. Communication algorithm keeps these information up to date, so it's ready for use in critical moments. The application works in a distributed manner, so each UAV is controlled by separate agent that implements several avoidance algorithms, combining cooperative and non-cooperative methods. The CSM (Collision Solver Manager) unit is defined to manage both collision detection and collision solving – it manages the results from individual collision solvers to produce the final avoidance result. There are many solutions presented in the literature that address the collision avoidance aspect – but in non-distributed manner. The [23] uses lateral acceleration to avoid detected collisions, multiple collisions are also supported. System presented in [24] is fully decentralized, but assumes that the data about other vehicles is known to each UAV (obtained from radar, or other source of information) – what can be problematic in real systems. Small amount of work in this topic exposes the potential of distributed processing applications dedicated to mutual collision avoidance.

3.9 Coordination

While many of applications mentioned in this paper operate on high level and realize the actual mission goal, it's impossible to disregard the coordination application that serves on the basic level and is indirectly used by other, higher level applications. The coordination mechanisms may provide the following: team formation, attitude alignment, rendezvous problem, coordinated decision making, flocking, coupled oscillators, position synchronization [25], [26]. The decentralized optimization of UAV swarm control was presented in [27], showing the methods to coordinate vehicles with multiple decision markers. The communication for solution passing in the system is also a part of the model and includes the uncertainty of messages delivery. Consensus problems in multi-node systems were discussed in [25] and lists the shared knowledge as one of main problems in for distributed control. The distributed processing system must adjust to the changes – consensus is the convergence to a common value. Authors list the following aspects as the key ones to address in consensus problems: finding the equilibrium state to which the consensus protocol converge, information uncertainty, communication delays and others.

3.10 Environmental monitoring

The environmental monitoring is the wide research field for single UAV solutions, where the monitoring of the environment is realized just by one vehicle [28]. Later the approach was extended into multi-vehicle systems. The partnership of University of Colorado, University of Alaska, MIT and University of Oklahoma proposed the Center of Collaborative Mobile Sensing Systems to design the distributed system for environmental monitoring [29]. This work describes the design aspects of environment monitoring with distributed systems, focusing on: wildfire (fire-fighting operations, increased capabilities of wildfire modeling and prediction); polar (heterogeneous mixes of UAVs equipped with sensor used for data acquisition); storm (in-situ data acquisition in severe storms – in altitudes from the ground to the cloud) [29]. The following areas were identified as the critical to implement environmental monitoring systems: assured ad hoc communication; collaborative guidance, navigation and control; data fusion and visualization; regulatory issues and societal response; robust airborne platforms; sensor integration.

Fire detection and monitoring.
The need of monitoring of frequent delivery of high-quality information was addressed in [30] and authors propose the team of LASE (low attitude short endurance) to cooperatively monitor the propagation of forest fires and fire perimeter. Each vehicle can gather that much of information to navigate autonomously, it also has IR camera and has limited communication range (can communicate only with UAVs within the range of both). The described approach uses the centralized way, in which UAVs send the data to the ground station, but also the vehicles share the information while rendezvous meeting during perimeter search. The solution for both fire detection and extinguishing was presented in [31]. It contains the monitoring and planning station where all the control is concentrated, but also the image processing algorithms. The communication layer implements the BBCS (Black Board Communication Systems) that implements the distributed shared memory (blackboard) in which each network node has its own local copy of the blackboard portion it is accessing. The task allocation is done either

by manual allocation or distributed task allocation module that manages the allocation autonomously in the group of robots.

Pollution detection & Water management.
Unlike other objects or phenomenon, the pollution can't be detected in a distance – therefore the UAV has to reach the immediate vicinity of the pollution to detect. The system presented in [32] uses UAVs equipped with attractive beacon that activates when the sensor is in contact with chemical pollution. Once it happens, other vehicles are informed and follow the attractive beacon to reach the pollution area. Next, the swarm of UAVs encloses the contaminated area and follow the cloud.

The work presented in [33] presents the use of distributed team of UAVs applied to water management and distributed irrigation control. Vehicles measure the electromagnetic radiation and are equipped with imagers operating at different wavelength. System operates in the distributed manner with the ground-based station that serves as the data aggregator and the image processing unit.

4 Conclusion

Many collaborative teams of UAVs run the applications that are using the principles of distributed processing systems. Depending on the specific requirements, limitations and goals – various approaches are implemented. The research mentioned in this survey shows, that cooperative swarms of UAVs are demonstrating great usefulness and have much better properties and operational parameters than applications running on single UAVs. The work described above often concentrates on the mission-specific aspects, leaving the distributed processing 'under-the-hood' layer as the secondary area, sometimes full of assumptions and issues to solve. Therefore we consider the work on the distributed processing layer applicable to UAV teams as the promising future research field.

References.

1. Zydek, D., Chmaj, G., Chiu, S.: Modeling Computational Limitations in H-Phy and Overlay-NoC Architectures, The Journal of Supercomputing. (2013) doi: 10.1007/s11227-013-0932-9
2. Baker, M., Buyya, R., Laforenza, D.: Grids and Grid technologies for wide-area distributed computing, Software: Practice and Experience, vol. 32, Issue 15, pp. 1437–1466. (2002)
3. Chmaj, G., Walkowiak, K.: Decision Strategies for a P2P Computing System, Journal of Universal Computer Science, vol. 18, no. 5, pp. 599–622. (2012), doi: 10.3217/jucs-018-05-0599
4. Wada Akihisa, Yamashita Toshiaki, Maruyama Masaaki, Arai Takanari, Adachi Hideo, Tsuji Hirokazu,: A Surveillance System Using Small Unmanned Aerial Vehicle (UAV) Related Technologies, Special Issue on Solving Social Issues Through Business Activities, NEC Technical Journal, Vol.8, No.1. (2013)
5. Mayerowitz, S.: Amazon.com sees delivery drones as future, Phys.org, The Associated Press, 2013

6. Winnefeld, J.A., Kendall, F.: Unmanned Systems Integrated Roadmap FY2013-2038, Department of Defense, 14-S-0553, DIANE Publishing Company. (2014)
7. Long, M., Gage, A., Murphy, R., Valavanis, K.: Application of the Distributed Field Robot Architecture to a Simulated Demining Task, Proceedings of the 2005 IEEE International Conference on Robotics and Automation, pp. 3193-3200 (2005), doi: 10.1109/ROBOT.2005.1570602
8. Ryan, A., Xiao, X., Rathinam, S., Tisdale, J., Zennaro, M., Caveney, D., Sengupta, R., Hedrick, J.K.: A Modular Software Infrastructure for Distributed Control of Collaborating UAVs, Proceedings of the AIAA Conference on Guidance, Navigation and Control, (2006)
9. Tisdale, J., Ryan, A., Kim, Z., Tornqvist, D., Hedrick J.K.: A multiple UAV system for vision-based search and localization, American Control Conference - ACC, pp. 1985-1990 (2008), doi:10.1109/ACC.2008.4586784
10. Hu, J., Xie, L., Xu, J.: Vision-Based Multi-agent Cooperative Target Search, 12th International Conference on Control Automation Robotics & Vision (ICARCV), pp. 895-900, 2012, doi:10.1109/ICARCV.2012.6485276
11. Wheeler, M., Schrick, B., Whitacre, W., Campbell, M., Rysdyk, R., Wise, R.: Cooperative Tracking Of Moving Targets By A Team Of Autonomous UAVs, 25th Digital Avionics Systems Conference, IEEE/AIAA, pp. 1-9 (2006), doi:10.1109/DASC.2006.313769
12. Furukawa T., Bourgault, F., Lavis, B., Durrant-Whyte, H.F.: Recursive Bayesian Search-and-Tracking Using Coordinated UAVs for Lost Targets, Proceedings 2006 IEEE International Conference on Robotics and Automation, pp. 2521-2526 (2006), doi:10.1109/ROBOT.2006.1642081
13. Campbell, M.E., Whitacre, W.W.: Cooperative Tracking Using Vision Measurements on SeaScan UAVs, IEEE Trans. Contr. Sys. Techn. vol. 15, no. 4, pp. 613-626, (2007)
14. Bethke, B., Valenti, M., How, J.: Cooperative Vision Based Estimation and Tracking Using Multiple UAVs, Advances in Cooperative Control and Optimization Lecture Notes in Control and Information Sciences, vol. 369, pp. 179-189 (2007)
15. Kingston, D., Holt, R., Beardy, R., McLain, T., Casbeer, D.: Decentralized Perimeter Surveillance Using a Team of UAVs, IEEE Transactions on Robotics, vol.24, no.6, p.1394-1404 (2008)
16. Teacy, W.T.L., Nie, J., McClean, S., Parr, G., Hailes, S., Julier, S., Trigoni, N., Cameron, S., Collaborative Sensing by Unmanned Aerial Vehicles, Proceedings of the 3rd International Workshop on Agent Technology for Sensor Networks
17. Durrant-Whyte, H., Stevens, M.: Data Fusion in Decentralised Sensing Networks, Technical report, Australian Centre for Field Robotics, The University of Sydney, 2001
18. Sujit, P.B., Beard, R.: Multiple UAV Path Planning using Anytime Algorithms, In proceeding of: American Control Conference, (2009)
19. Cunningham, C.T., Roberts, R.S.: An Adaptive Path Planning Algorithm for Cooperating Unmanned Air Vehicles, IEEE International Conference on Robotics and Automation, vol. 4, pp. 3981-3986 (2001)
20. Deming, R.W., Perlovsky, L.I.: Concurrent multi-target localization, data association, and navigation for a swarm of flying sensors, Journal Information Fusion, vol. 8, Issue 3, pp. 316-330 (2007), 10.1016/j.inffus.2005.11.001
21. Rigatos, G.G.: Distributed filtering over sensor networks for autonomous navigation of UAVs, Intelligent Service Robotics, vol. 5, Issue 3, pp. 179-198 (2012)
22. Vrba, P., Mařík, V., Přeučil, L., Kulich, M., Šišlák, D.: Collision Avoidance Algorithms: Multi-agent Approach, Holonic and Multi-Agent Systems for Manufacturing Lecture Notes in Computer Science, vol. 4659, pp. 348-360 (2007)

23. Manathara, J.G., Ghose, D.: Reactive collision avoidance of multiple realistic UAVs, Aircraft Engineering and Aerospace Technology, vol. 83, no. 6, pp. 388-396 (2011), doi:10.1108/00022661111173261
24. Lalish, E., Morgansen, K.A.: Decentralized Reactive Collision Avoidance for Multivehicle Systems, 47th IEEE Conference on Decision and Control, pp. 1218-1224 (2008), doi:10.1109/CDC.2008.4738894
25. Ren, W., Beard, R.W., Atkins, E.M.: A Survey of Consensus Problems in Multi-agent Coordination, Proceedings of the 2005 American Control Conference, vol. 3, pp. 1859-1864 (2005), doi:10.1109/ACC.2005.1470239
26. Ren, W., Cao, Y.: Overview of Recent Research in Distributed Multi-agent Coordination, Distributed Coordination of Multi-agent Networks, pp. 23-41 (2011), doi:10.1007/978-0-85729-169-1_2
27. Inalhan, G., Stipanovid D., Tomlin, C.J.: Decentralized Optimization, with Application to Multiple Aircraft Coordination, Automatica, vol. 40, no. 8, pp.1285-1296 (2004)
28. Harris, A., Sluss Jr., J.J., Refai, H.H.: Alignment And Tracking Of A Free-Space Optical Communications Link To A UAV, The 24th Digital Avionics Systems Conference, vol. 1 (2005), doi:10.1109/DASC.2005.1563300
29. Argrow, B., Lawrence, D.: UAV Systems for Sensor Dispersal, Telemetry, and Visualization in Hazardous Environments, AIAA Aerospace Sciences Meeting and Exhibit (2005)
30. Casbeer, D.W., Kingston, D.B., Beard, R.W., Mclain, T.W.: Cooperative forest fire surveillance using a team of small unmanned air vehicles, International Journal of Systems Science, pp. 1-18 (2005)
31. Viguria, A., Maza, I., Ollero, A.: Distributed Service-Based Cooperation in Aerial/Ground Robot Teams Applied to Fire Detection and Extinguishing Missions, Advanced Robotics 24, pp. 1–23 (2010)
32. Scheutz, M., Schermerhorn, P., Bauer, P.: The Utility Of Heterogeneous Swarms Of Simple UAVs With Limited Sensory Capacity In Detection And Tracking Tasks, Proceedings 2005 IEEE Swarm Intelligence Symposium, pp. 257-264 (2005), doi:10.1109/SIS.2005.1501630
33. Chao, H., Baumann, M., Jensen, A., Chen, Y., Cao, Y., Ren, W., McKee, M.: Band-reconfigurable Multi-UAV-based Cooperative Remote Sensing for Real-time Water Management and Distributed Irrigation Control, International Federation of Automatic Control World Congress, 2008