Smart Monitoring Technologies for Defining Variability in Vineyard Microclimate, and Vinegrape Performances

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***Abstract*— In Europe, the vineyards cover about 3 million ha, and it produces 62.9% of the global wine representing an important sector in the European economy. Sustainability is playing a key role in viticulture and thanks to the development of new technologies based on sensors and measurements is possible to monitor environmental conditions in order to improve management efficiency in terms of quality and production. This review presents a brief state of the art of precision viticulture technologies, focusing on monitoring tools for vineyard microclimate, and vine grape performances.**

Keywords—Precision Viticulture, thermal, RGB, Lidar WMS, WSN.

I. INTRODUCTION

In Europe, the vineyards cover about 3 million ha and it product a 62.9% share of the global wine production, with 50% of the wine consumed locally, another 28% transported in the intra-Union market, and the remaining 22% exported globally [1]. Representing an important economic sector in the Europe economy, sustainability is playing a key role in the viticulture industry. In fact, in the last years, vineyards management is increasingly set to sustainable management using the new technologies for maximizing bunch quality, reduction and more efficient use of production inputs and well-organized water management.

Vineyards are characterized by a high variability due to several factors such as soil's physical and chemical properties affect plant growth and soil management: the climate condition and the agronomic treatments in canopy and in the soil. These factors cause different vine physiological response, with direct consequences on grape quality [2,3]. In the vineyard management, the winegrower, thanks to the introduction of new technologies, can monitor and control of many of these factors of vine growth, intervening where necessary. The application of this technologies falls within the concept of precision viticulture (PV) where spatial variability is considered providing recommendations to improve management efficiency in terms of quality, production, and sustainability [3].

Precision viticulture can be carried out thanks to the use of new technologies and sensors, such as global positioning systems (GPS), airborne and UAV (unmanned aerial vehicle), Terrestrial rover vehicle, remote sensing sensors (RGB, Thermal, Multi-Hyper spectral, Lidar) and geographic information systems (GIS) [4-6].

II. WSN IN PRECISION VITICULTURE

In recent years, in the field of precision viticulture thanks to the development of new technologies based on sensors is possible to monitor environmental conditions such as solar radiation, plant chlorophyll content and nitrogen concentration. The graininess of the information is essential to make information spatially accurate. To do this, we need to place a large number of sensors inside the field, independently of the physical entity that we want to study. The physical presence of many sensors in a same place poses a lot of management problems as i.e., the management of the power budget so as the management of the transmission channel that is a limited and shared resource between all the sensors. An emergent technology that can help to meet these needs is the Wireless Sensor Networks (WSNs) which can be applied in precision viticulture to monitor microclimatic parameters. Due to variety of applications [7-11] and potential ones [12,13], WSNs have gained a great attention among the researchers. Two main components of a WSN are the sensor nodes and the sink node. Despite the fact that the WSNs are capable of having a variety of topologies, e.g. star, mesh or ring, the signals generated by the sensor nodes are provided to the end users through the sink nodes [14-16]. Typically, the nodes in the work area communicate among themselves using radio frequency (RF) and once the data is acquired and processed, the user can monitor the state of the physical entity under control [17,18]. One of the great advantages of WSNs is that the sensors network can be positioned within a large area, like vineyards, monitoring in real time the microclimate parameters as well as air temperature, relative humidity, atmospheric pressure, rain, light intensity, dew and frost point. These microclimate parameters play an important role in precision viticulture. From the analysis of these parameters, using data processing software, we can optimize the management of the vineyards and improve the quality of the wines.

III. Techniques and Methodologies for Vineyard Analysis

In order to monitor some parameters concerning the health of plants, in these last years, an increasing number of techniques and methodologies have been used. Among them thermal, multispectral and hyperspectral techniques seem to become very promising in order to monitor the plants water stress, leaf temperature, vigour level of the plants, alterations in photosynthetic activity, presence of pathogens on leaf surface. Between multispectral and hyperspectral techniques, the main difference is represented by the number of spectral bands that can be acquired, fig.1.

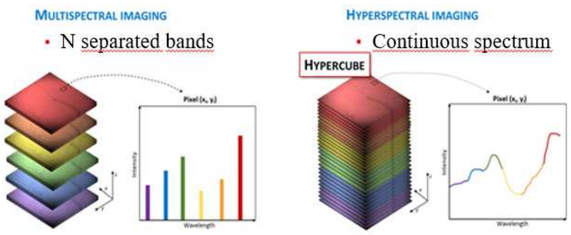

Fig.1: the hyperspectral image records a complete spectrum whereas the multispectral image records a discretely sampled spectrum.

In fact, with a multispectral instrument, we can acquire images in a very small number of spectral bands, from 3 to 14. Differently, a hyperspectral sensor has the potential to acquire images in hundreds contiguous spectral bands and this allows to obtain more information than multispectral sensor. An example of the applicability of multispectral and thermal instruments was conducted in [19]. In their research, they have used both a multispectral sensor to detect the spectral signature of the vineyard and a handheld thermal infrared camera to acquire information about the water status of the vegetation through the Crop Water Stress Index (CWSI). Fig. 2A shows the orthophotograph, while, on the right, it is shown the multispectral image processing, which has been represented in false colours. Fig. 2B shows the different levels of vegetation health based on the variations of the colour red. At the same time, from the canopy temperature of the grapevine was derived the water stress status, using a handheld infrared camera. An example of thermal image is shown in Fig. 3A for a grapevine row. It shows the visible image with the thermal map overlapped. Instead, the thermal map is displayed as CWSI map in Fig. 3B. CWSI values over the foliage are mainly in the 0.2−0.4 range indicating a low to moderate degree of water stress.

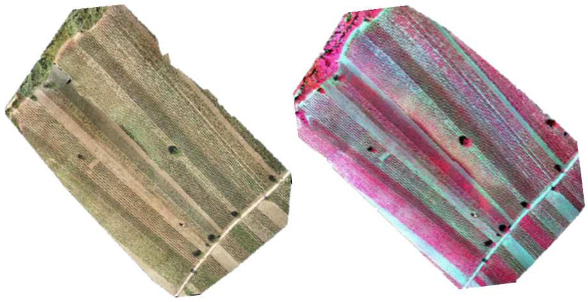

Fig.2: (A) Orthophotograph; (B) multispectral image processing represented in false colours of a vineyard parcel

Recently, non-destructive techniques operating in THz band were applied in precision agriculture. Terahertz radiation has interesting features: the low energy of the photon combined with its non-ionizing nature makes it not harmful for biological tissues. Moreover, THz radiation is strongly absorbed and reflected by water, and this characteristic has been exploited to determine water content in biological tissues [20,21].

Currently the most used techniques operating in THz band are imaging and THz spectroscopy. Both techniques can be modified to operate in transmission and reflection mode.

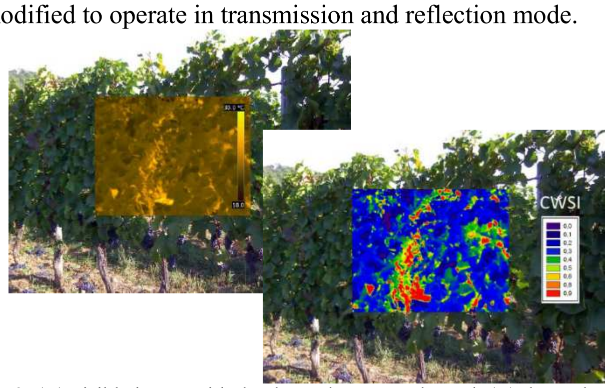

Fig.3: (A) visible image with the thermal map overlapped; (B) thermal map displayed as CWSI map

However, operating in the transmission geometry, we are limited due to such strong water absorption of the plants. So the reflection geometry was usually used applied to test ticker biological samples [22,23]. Nevertheless, leaves are usually used for the testing in transmission geometry because of its thin thickness [24].

Fig. 4: Grapevine, lens system.

In precision viticulture, in [25] conducted an interesting study measuring the reflectivity at the trunk in the terahertz band, Fig. 4.

Another example of THz application in vineyard was conducted in [26]. This study examines the possible use of an advanced THz-QCL (quantum cascade lasers) device to measure the water content of leaves belonging to the species Vitis vinifera L. (cv. Sangiovese). In this case, THz measurements were performed using a simple transmission setup, Fig. 5, with a 2.55 THz cryo-cooled QCL as the light source and a Golay cell detector to measure the THz signals.

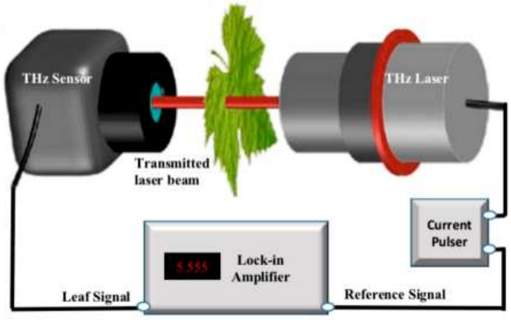

Fig.5: THz transmission measurement setup.

As shown in these two examples, THz sensors could be used to control the irrigation, and this could be improve the quality of the products. The possibility of mounting these sensors on terrestrial platforms will allow us to monitor in real time these parameters and thus avoiding that periods of drought can compromise the harvest and therefore the quality of the wine.

Therefore, using different types of sensors we can obtain information about microclimate parameters such as soil humidity, vigour level of the vegetation, plants water stress, but also the water content in the leaves. In particular, will be possible to detect fundamental data that allow to evaluate the state of health of crops: the use of this data could reduce the human work in the fields, ensuring greater quality in operations, such as monitoring activities, as well as limiting the use of resources, like fertilizers and herbicides.

In precision viticulture, another important factor is to optimize the use of water, ensuring significant savings thanks to monitoring constant soil moisture and irrigation management. This parameter would lead the plants not to be subjected both water stress conditions and to avoid wasting water, an increasingly precious and expensive resource. In this perspective, the sensors for measuring the water status of the cultivation substrate constitute an important decision support for irrigation.

Finally, winegrowers could reduce production costs by using less water, fertilizers, chemical treatments as well as to prevent outcome of parasites and diseases. In fact, for all winegrowers who want to monitor the level of ripeness of the grapes, but above all to determine the optimal time for the harvest, this would solve various problems related to this sector, thus optimizing both the quality and quantity of the product.

IV. Unmanned Aerial Systems Used In Vineyard

Aerial mapping of vineyard is functional to estimate the vegetative vigour of the crop and their production as well as for monitoring the progress over time [3]. This Information of vegetative states can be used for accurate homogeneous zoning of fields so that proper management applications can be imposed. For reaching these objectives, the use of the unmanned aerial vehicle (UAV) has progressively increased in the last decade and nowadays the use of UAV for the acquisition of RGB, multispectral and thermal images start to be considered a basic research instrument for obtaining information over a study area. The advantages are several, but the main is the high spatial resolution of the images with respect to the satellite and aircraft systems [26].

Furthermore, the UAV systems can fly under clouds, providing new opportunities for monitoring broad scale and a more economical solution capable of providing high-quality images. There are some different types of UAVs:

1) Multi-Rotor UAVs (Fig. 6): These types are most used for different applications like aerial surveillance, photography etc. These are the most economic and easy to flight UAV [27]. In function of the numbers of the motors, there are some different categories of Multi-Rotor UAVs as Tricopters, Quadcopter, Hexacopter and Octocopter. The main limitations are flying time (30 minutes), the limited speed, so these type of UAV are useful for mapping small areas.

Fig. 6: Multi-Rotor UAVs (ww.dji-store.it).

2) Fixed-wing UAVs: These UAVs are complete controlled autonomously, and they have a flying time more of than 2 hours [28]. The fixed-wing UAVs are useful for long-distance operations. The main limitations are so expensive and highly skilled training to operate (see Fig. 7).

Fig. 7: Fixed-wing UAVs (www.parrot.com).

3) Single Rotor UAVs: These type of UAVs are very similar to the helicopters, in fact, these have one rotor and another smaller rotor adjacent to the tail of the UAV [24].

Fig. 8: Single Rotor UAV (www.auav.com.au)

Single Rotor UAVs have an elevated amount of flight times with respect to multi-rotor UAVs. The limitations are the complexity of flight operation and the high cost of the UAV system (see Fig. 8).

In viticulture, the major implementations of the use of UAVs can be summarized in these categories:

1) Sky-farmers: the farmers use the UAV systems for monitoring the entire vineyard. The sky observations provide the current vegetation status, possible pest infestations and soil variability. The information collected in this way helps the winegrover to detect problems in priority and managing the solutions to do not lose the productivity of the grapevine [29].

2) UAVs in Precision Viticulture: the images are generally captured by small UAVs with the help of hyperspectral and multispectral cameras. These images are used to calculate the vegetation indices (VI) permitting the winegrovers to monitor the vegetation vigour variability [3,30].

3) UAV in Irrigation Monitoring: efficient irrigation management is very important for better productivity. Hence, irrigation is one of the most important issues in viticulture [31]. The UAVs helps in acquiring the irrigation data at any point in time and in every point of the field. For irrigation monitoring, the UAVs can upload RGB, thermal and infrared cameras able to identify the crop water stress index [32].

V. TERRESTRIAL ROVER VEHICLE USED IN VINEYARD

In the Precision Viticulture technologies, the terrestrial rover is able to help winegrowers in the vineyard health monitoring.

Here, we show a new kind of terrestrial rover currently

The rover is composed of several parts: the rover, the sensors, and data analysis. In this context, several rovers were developed able to work in a hard environment as the vineyard. One of these is reported in Fig. 9. This rover is able to provide precision agronomic information in the various phases ranging from image acquisition to data extraction and analysis and is able to perform the assigned tasks, with the following fundamental characteristics and performances:

- high mobility at both low and high maneuvering speeds (the drone, among other things, rotates on itself);
- size optimized for carrying out activities. The prototype has a maximum width of 130 cm, determined by the width of the two wheels - 58 cm - and by a further 14 cm of inter axle;
- a central body housing mechanical parts, brackets, devices and potentially a robotic arm;
- a height of 120 cm (height of the wheels); this size allows optimal use of the terrestrial drone;
- operational multifunctionality to allow the execution of different types of activities, including control, monitoring, alarm/reporting and analysis;
- ability to perform precision operations such as sprinkling, selecting the most appropriate type of chemical product;
- operation every time and 24 hours a day on any type of terrain;
- ability to deal with steep and/or uneven terrain thanks to the intrinsic lightness of the system and the low center of gravity that characterizes its structure.

Fig. 9: Terrestrial rover vehicle

On the environmental level, the Rover is characterized by:

- high energy efficiency which results in low operating consumption;
- very low environmental impact characterized by: zero emissions (such as fumes, CO_2, contamination from lubricating oils, battery fluids, etc.);
- very low pressure on the ground (which guarantees the maximum protection of any underlying elements such as, for example, biologically relevant environments);
- high operational autonomy;
- high degree of modularity simplicity of control.

The central body is equipped with an appropriate gimbal for the orientation of the sensors consisting of two RGB cameras, a thermal camera and a multispectral camera (Parrot Sequoia). The RGB cameras are on the sides, the Parrot Sequoia in the centre vertically and the thermal camera is located under the Parrot sensor.

Coming from a SETEL's Patent, the developing is the fruit of a collaboration from SETEL and some Universities as Università degli Studi "Roma Tre" and University of Tuscia.

VI CONCLUSION

The use of UAV in viticulture is an approach that reduces field farming labour and permitting an accurate observation of the crops below the coverage of clouds. The main advantages obviously include the capturing of high-resolution images with minimal cost and maintaining the performance of an aircraft piloted at high altitude craft more expensive. The UAVs system are equipped with sensors that make them immensely powerful in capturing images of high spatial and temporal resolution.

Precision viticulture is a very new technology able to help winegrowers to produce high-quality grapes increasing yield with minor environmental impacts. These technologies can take under control the different parameters that affect spatial and temporal variability, such as soil fertility, fertilizer, disease, water, weed, and harvesting. Robotics is also developing in the precision viticulture context, and it will be one of the most important agriculture challenges in the next years.

ACKNOWLEDGMENT

The study was supported by the project LIFE WINEgROVER - Precision Agriculture System to limit the impact on the environment, on health and on air quality of grape production (LIFE19 ENV/IT/000339) funded by LIFE PROGRAMME.

REFERENCES

[1] Litskas, V., Mandoulaki, A., Vogiatzakis, I. N., Tzortzakis, N., & Stavrinides, M. (2020). Sustainable Viticulture: First Determination of the Environmental Footprint of Grapes. Sustainability, 12(21), 8812.

[2] Smart RE. Principles of grapevine canopy management microclimate manipulation with implications for yield and quality. American Journal of Enology and Viticulture. 1985;36(3):230–239.

[3] Brunori, E., Maesano, M., Moresi, F.V., Antolini, A., Bellincontro, A., Forniti, R., ... & Mencarelli, F. (2020). Using UAV - based remote sensing to assess grapevine canopy damage due to fire smoke. Journal of the Science of Food and Agriculture, 100(12), 4531-4539.

[4] Matese, A., & Di Gennaro, S. F. (2015). Technology in precision viticulture: A state of the art review. International journal of wine research, 7, 69-81.

[5] Francesconi, S., Harfouche, A., Maesano, M., & Balestra, G. M. (2021). UAV-Based Thermal, RGB Imaging and Gene Expression Analysis Allowed Detection of Fusarium Head Blight and Gave New Insights Into the Physiological Responses to the Disease in Durum Wheat. Frontiers in plant science, 12, 551.

[6] Maesano, M., Khoury, S., Nakhle, F., Firrincieli, A., Gay, A., Tauro, F., & Harfouche, A. (2020). UAV-Based LiDAR for High-Throughput Determination of Plant Height and Above-Ground Biomass of the Bioenergy Grass Arundo donax. Remote Sensing, 12(20), 3464.

[7] M.P. Durisic, Z. Tafa, G. Dimic, and V. Milutinovic, "A survey of military applications of wireless sensor networks", in Mediterranean conference on embedded computing (MECO). p. 196–9.

[8] K. Jeong Gil, L. Chenyang, M.B. Srivastava, J.A. Stankovic, A. Terzis, and M. Welsh, "Wireless sensor networks for healthcare", Proc. IEEE 2010;98 (11):1947–60.

[9] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): a vision, architectural elements, and future directions", Futur Gener Comput Syst 2013;29(7):1645–60.

[10] Leccese, F., Cagnetti, M., Tuti, S., Gabriele, P., De Francesco, E., Đurović-Pejčev, R., Pecora, A. Modified leach for Necropolis scenario (2019) IMEKO International Conference on Metrology for Archaeology and Cultural Heritage, MetroArchaeo 2017, pp. 442-447.

[11] Leccese, F., Cagnetti, M., Sciuto, S., Scorza, A., Torokhtii, K., Silva, E. Analysis, design, realization and test of a sensor network for aerospace applications (2017) I2MTC 2017 - 2017 IEEE International Instrumentation and Measurement Technology Conference, Proceedings, art. no. 7969946, . DOI: 10.1109/I2MTC.2017.7969946.

[12] J. Huang, Y. Meng, X. Gong, Y. Liu, and Q. Duan, "A novel deployment scheme for green Internet of things" IEEE Internet Things J 2014;1(2):196–205.

[13] Y.K. Tamandani, M.U. Bokhari, and M.Z. Kord, "Computing geometric median to locate the sink node with the aim of extending the lifetime of wireless sensor networks", Egyptian Informatics Journal (2017) 18, 21-27.

[14] T. Ojha, S. Misra, N. S. Raghuwanshi, "Wireless sensor networks for agriculture: The state-of-the-art in practice and future challenges", Review, Computers and Electronics in Agriculture 118 (2015) 66-84.

[15] Cagnetti, M., Leccisi, M., Leccese, F. Reliability comparison of routing protocols for WSNs in wide agriculture scenarios by means of ηl index (2020) SENSORNETS 2020 - Proceedings of the 9th International Conference on Sensor Networks, pp. 169-176.

[16] Cagnetti, M., Leccisi, M., Leccese, F. A modified MPRR protocol for WSN in agricultural scenario (2021) SENSORNETS 2021 - Proceedings of the 10th International Conference on Sensor Networks, pp. 143-150.

[17] Leccese, F., Cagnetti, M., Ferrone, A., Pecora, A., Maiolo, L. An infrared sensor Tx/Rx electronic card for aerospace applications (2014) 2014 IEEE International Workshop on Metrology for Aerospace, MetroAeroSpace 2014 - Proceedings, art. no. 6865948, pp. 353-357. DOI: 10.1109/MetroAeroSpace.2014.6865948.

[18] Leccese, F., Leccisi, M., Cagnetti, M. Cluster layout for an optical wireless sensor network for aerospace applications (2019) 2019 IEEE International Workshop on Metrology for AeroSpace, MetroAeroSpace 2019 - Proceedings, art. no. 8869643, pp. 556-561. DOI: 10.1109/MetroAeroSpace.2019.8869643.

[19] G.Tanda, and V. Chiarabini, "Use of multispectral and thermal imagery in precision viticulture", 36th UIT Heat Transfer Conference, IOP Conf. Series: Journal of Physics: Conf. Series 1224 (2019) 012034 doi:10.1088/1742-6596/1224/1/012034.

[20] R. Gente, N.Born, N. Voß, W. Sannemann, J.Léon and E.C. Camus, "Determination of leaf water content from terahertz time-domain spectroscopic data", Journal of Infrared, Millimeter, and Terahertz Waves 34, 316–323 (2013).

[21] B.B. Hu, M.C. Nuss, "Imaging with terahertz waves", Opt Lett. 1995;20 (16):1716–8. doi:10.1364/OL.20.001716.

[22] D.M. Mittleman, R.H. Jacobsen and M.C. Nuss, "T-ray imaging". Sel Top Quantum Electron, IEEE J. 1996; 2 (3):679–92. doi:10.1109/2944.571768.

[23] B. Li, R. Wang, J. Ma, and W. Xu, "Research on Crop Water Status Monitoring and Diagnosis by Terahertz Imaging", frontiers in physics, published: 29 September 2020 doi: 10.3389/fphy.2020.571628.

[24] R. Gente, N. Born, A. Velauthapillai, J.C. Balzer and M. Koch, "Monitoring the water content of plant leaves with THz time domain spectroscopy". In Proceedings of the 2015 40th International Conference on Infrared, Millimeter, and Terahertz waves (IRMMW THz), Hong Kong, China, 23–28 August 2015; pp. 1–2. [CrossRef].

[25] V. Torres, I. Palacios, J. C. Iriarte, I. Liberal, L. G. Santesteban, C. Miranda, J. B. Royo and R. Gonzalo, "Monitoring Water Status of Grapevine by Means of THz Waves", J Infrared Milli Terahz Waves (2016) 37:507–513 DOI 10.1007/s10762-016-0269-6.

[26] Pagano, M., Baldacci, L., Ottomaniello, A., Dato, G.D., Chianucci, F., Masini, L., Carelli, G., Toncelli, A., Storchi, P., Tredicucci, A. and Corona, P.,"THz water transmittance and leaf surface area: An effective nondestructive method for determining leaf water content". Sensors (Switzerland), (2019) 19(22), DOI:10.3390/s19224838.

[27] Maddikunta, P.K.R., Hakak, S., Alazab, M., Bhattacharya, S., Gadekallu, T.R., Khan, W.Z., & Pham, Q.V. (2021). Unmanned aerial vehicles in smart agriculture: Applications, requirements, and challenges. IEEE Sensors Journal.

[28] M. Ezuma, F. Erden, C.K. Anjinappa, O. Ozdemir, and I. Guvenc, "Detection and classification of UAVs using RF fingerprints in the presence of Wi-Fi and Bluetooth interference," IEEE Open Journal of the Communications Society, vol. 1, pp. 60–76, 2019. DOI: 10.1109/OJCOMS.2.

[29] A.W. Malik, A.U. Rahman, T. Qayyum, and S.D. Ravana, "Leveraging fog computing for sustainable smart farming using distributed simulation," IEEE Internet of Things Journal, vol. 7, no. 4, pp. 3300–3309,2020.

[30] J. Torres-Sánchez, J.M. Peña, A.I. de Castro, and F. López-Granados, "Multi-temporal mapping of the vegetation fraction in early-season wheat fields using images from uav," Computers and Electronics in Agriculture, vol. 103, pp. 104–113, 2014

[31] H. Aasen, A. Burkart, A. Bolten, and G. Bareth, "Generating 3d hyperspectral information with lightweight uav snapshot cameras for vegetation monitoring: From camera calibration to quality assurance," ISPRS Journal of Photogrammetry and Remote Sensing, vol. 108, pp. 245–259, 2015.

[32] H. Chao, M. Baumann, A. Jensen, Y. Chen, Y. Cao, W. Ren, and M. Mc-Kee, "Band-reconfigurable multi-uav-based cooperative remote sensing for real-time water management and distributed irrigation control," IFAC Proceedings Volumes, vol. 41, no. 2, pp. 11 744–11 749, 2008.