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On The Exploitation of Sensor and Actuator Network Technologies in Forest-Fire Perception

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The beginning of the XXI century is characterized by the massive incorporation of advanced information and communication technologies in a high variety of applications and sectors. Technologies such as robotics, sensor networks, personal mobile computing or ubiquitous computing are leaving the laboratories and factories and are being applied in an exponentially increasing number of real-world applications and sectors. Nowadays, the level of maturity of these technologies enables their use and effective exploitation in a number of unprecedented applications, which were constrained to human capabilities only some few years ago. All prospective reports, white books and strategic research agendas developed by the most relevant scientific and technology institutions agree in concluding that these technologies will be extended to a very high variety of applications deeply impacting human life, society and economy.

If we analyze how forest-fire related activities are currently performed it is easy to conclude that up to now the level of technification in most activities is low or very low. Of course, there are many activities that can hardly be automated and require intensive human workload. In others related to data gathering, processing and decision support systems, however, the application of advanced sensor and actuator network technologies could revolutionize traditional activities drastically improving the levels of effectiveness and efficiency.

Sensor and actuator networks consist of a high number of low-cost nodes equipped with sensing, actuating, computing and communication capabilities that organize autonomously into networks to achieve a global mission in a cooperative or coordinated manner. Multi-robot networks, camera networks or Wireless Sensor Network (WSN) are some examples. Besides its real-time operation and reactivity, sensor and actuator networks have two main characteristics that make them very convenient in forest-fire applications. The first one is related to their modularity, flexibility and scalability. These networks are devised to allow scalability and to be composed of as many nodes as necessary, allowing being extensively used in large areas.

The second characteristic is robustness. Nodes are designed to be low cost, i.e., engineered to have low energy consumption, equipped with low sensing/actuating resources and low computing capabilities. However, in contrast to the individual fragility of each node, the strength of this technology derives from the cooperation and coordination between many nodes. Many successful techniques to improve the global robustness and efficiency of the network have been developed and are currently available. Failures of network nodes and changes in conditions originate the re-organization of the rest of the nodes, network structure or communications resulting in significant robustness and performance stability. During decades the use of sensor and actuator networks was constrained mainly to research or to applications in controlled conditions mainly in home, office and manufacturing environments. In the last years the improvements in mechanics, sensing and hardware miniaturization, the development of new protocols and algorithms to improve robustness, the definition of new standards and a significant cost reduction have originated an explosion of an increasing number and variety of applications in wide range of sectors.

The implementation of these technologies in forest applications does not necessarily involve deploying new infrastructures but to make use of existing systems using a smarter approach. For instance, the use of cameras on watchtowers for surveillance and forest-fire detection is very common all around the world. However, in most cases, the images are used only for human visualization. The adoption of the aforementioned approach would involve considering the set of cameras as a network of cameras. The idea is not only to automatically process the images from the individual cameras but to combine their results using sensor fusion techniques in order to improve perception. Some R and D projects have successfully demonstrated the advantages of using these schemes. In the DEDICS project, a low false alarm rate forest-fire detection system combining images and data from a network of stations equipped with infrared and visual cameras as well as meteorological stations was developed and experimentally validated in operational conditions within the INFOCA plan in Andalusia (Spain). The system demonstrated its capability of discarding 99% of the false alarms raised by traditional automatic forest fire detection systems while keeping 100% detection rate.

The use of networks of cameras for forest-fire real-time monitoring and measuring was experimentally validated in UE funded projects such as SPREAD and INFLAME. Estimations obtained automatically from processing images from infrared and visual cameras were combined –applying sensor fusion techniques-with estimations from the processing of images taken by aerial means in order to obtain real-time accurate 3D geo-referenced fire geometrical models. The 3D fire models were transmitted for its real-time representation on a Geographical Information System. The system, although experimental, was tested in series with more than 120 real-fire experiments in realistic conditions in which a total of more than 300 hectares of shrub-land were burned. The experiments, organized by Prof. Domingos X. Viegas from the University of Coimbra (Portugal), were performed each Spring for more than a decade in Center Portugal.

In other cases the implementation of the sensor and actuator approach would originate an important reduction of cost together with high improvements in efficacy and efficacy. Forest-fire activities employ

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extensive aerial means. Many of them are directly involved in fire extinguishing but others are used for data gathering in activities such as forest surveillance, fire detection and confirmation, fire monitoring, and fire damage evaluation, among others. In these problems the use of Unmanned Aerial Vehicles (UAVs) instead of traditional manned aerial involves important advantages that have been made evident in many publications and reports. The use of single high-performance UAVs equipped with all necessary sensors and devices has been the main approach researched in the last years. These large UAVs are very expensive and require well trained personnel for their operation. Besides, they require significant infrastructure including long runways for take-off and landing.

Instead of one single high-performance UAV, the adoption of the sensor and actuator approach involves a fleet of simple small UAVs that cooperate in order to perform the task. These low-cost UAVs can take off manually by throwing the UAV or using small catapults and require fewer infrastructures and lower training for their operation. The availability of many UAVs makes up for their lower individual capabilities. The use of low-cost UAVs is also convenient due to the damage risks inherent to forest-fire activities.

Each of these UAVs could be equipped with different -but complementary- sensors. For instance, in forest fire detection, one low-payload UAV is equipped with a simple sensor to perform a first detection of potential alarms. These alarms are used to command other UAVs equipped with specific fire confirmation sensors that are specifically sent to the location of the potential alarm. The data gathered by all the UAVs is combined using data fusion techniques for automatically confirming or discarding the alarm. Some research projects such as COMETS have been devoted to exploiting these types of multi-UAV synergies. Furthermore, the results from UAV perception could also be combined with results of the processing performed with static cameras. For instance, when the network of static cameras detects a potential alarm, an UAV is launched for alarm confirmation.

In fire monitoring UAVs equipped with visual and infrared cameras can execute automatic image processing and interpretation methods in order to compute in real-time the fire-front location, geometry and speed. In this case the advantages of the sensor and actuator network approach are even more evident. Each UAV of the fleet is assigned to a certain zone of the fire and can perform detailed monitoring of the fire zone, resulting in higher spatial resolutions and higher fire measurements frequencies, which directly impact on improving safety and efficiency of fire-fighting.

Technology by itself is useless without a clear advantage that justifies its use. I am convinced that similarly as sensor and actuator networks are already revolutionizing other applications and sectors, the above examples are just the tip of the iceberg of how a technology with countless potential uses can be applied in forest-fire perception. It is not science fiction; many of these technologies are mature and have demonstrated their feasibility in close-to-operational conditions. Many of the techniques and technologies have been developed in the robotics, multi-robot, sensors and data fusion domains in the last years and are already available. Others, on the other hand, are still to be analyzed, explored, implemented, experimented and validated. It is a responsibility for us to keep researching and to offer the society the best scientific and technological tools to preserve our environment and our forests.