Raman Sensors for Stand-off-Detection and Analysis of Explosive: Fundamental Aspect, State-of-the-Art and Perspective

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Most hazardous chemicals are molecules, consisting of several different atoms. Each molecule bears vibrational modes with individual and characteristic energies. Sensing these energies provides a fingerprint of the substance and hence allows its unambiguous identification. Raman spectroscopy is an elegant way to take advantage of this physical effect in sensors: Photons are sent onto the substance under investigation. They are absorbed and re-emitted. After this process, they may have the same energy as before (elastic scattering), or they may gain or lose energy (inelastic scattering) if they de-excite or excite a molecular vibration. Thus by quantifying the energy shift of the inelastically scattered photons one can get the "Raman spectra". The advantage of the method is that it is very versatile. Just with one laser beam, where the wavelength does not need to be resonant to an excitation and hence can be selected freely in a wide range, the full vibrational molecular fingerprint can be obtained. However, there are also some disadvantages and limitations. The most severe one is that the probability for inelastic scattering is relatively small, i.e. the so-called "Raman transitions" are weak. This might be compensated just by increasing the laser power, but there are limitations stemming from safety issues, energy supply, and weight. In addition, suppression of the much stronger signal originating from the elastically scattered light must be considered. There exist methods to enhance the Raman signal, e.g. by plasmonic resonances on surfaces, but for stand-off detection the possibilities are pretty limited compared to measurement devices that can be positioned in the re-

gion of interest. Another sophistication comes from the fact that the optical properties of the environment, like scattering of the pump-light by the ground, largely influence the signal, making quantitative measurements non-trivial.

The authors have extensive experience in Raman spectroscopy and its application to a broad variety of fields. After a short introduction to Raman spectroscopy they will present estimates which technical effort would be needed to achieve specifications suitable for integration into an unpiloted aerial vehicle (UAV) with multimodal sensing for mine detection. Furthermore, the state of the art of this field in science and industry will be reviewed. At the end a conclusion will be drawn whether, according to the opinion of the authors, it makes sense to intensify the activities in this field.