Swarm Intelligence in Mine Detection:

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Mine detection is an extremely complex process. These days, more than 2'000 construction types of landmines exist around the world. They appear in different sizes, designs and material compositions. A similar diversity exists for the areas where landmines are hidden away and form a major threat to the population. Nowadays, regions from all climate zones are mine-infested, showing large topographical varieties, different soil types and vegetation zones. The diversity of landmines and the diversity of environmental factors makes it extremely difficult to define simple and general mine detection features.

Modern mine detection makes use of many distinct sensor systems, technical and non-technical ones. However, each sensor type also has its limitations. Animals, such as dogs, rats or even bees which are trained to detect landmines by olfaction, fatigue very soon. A metal detector of course will fail to detect mines constructed without any metal parts. It further may have problems to distinguish the metallic mine parts from the metal clutter found in many grounds. Microwave sensors, such as ground penetrating radars (GPR), may work well in moist or wet soils, but become more insusceptible in dry and sandy desert grounds. The list of uncertain or ambiguous sensor signals could be continued arbitrarily. However, using different sensor modalities concurrently, the chances for true positive detections obviously will increase.

First key message: A multi-sensory approach increases the success of mine detection under heterogeneous environmental conditions.

Considering a system of distinct sensors working simultaneously, rises the question of how individual sensor informations could be compiled and fused to get a more conclusive overall result. Here the concept of swarm intelligence comes into play, with many paradigms found in nature.

Swarming honey bees, for instance, are forced to find very rapidly a new nest site. A group of specialised scout bees is assigned to this task. After finding a nest site - for example a hollow trunk that matches all necessary conditions - individual scout bees return to the swarm. There, they inform other scout bees on the swarm surface about the quality of the potential nest site they have found and its location. Reporting good nest site qualities attracts the attention of much more scout bees and causes them to visit the reported nest site by themselves. Essentially, this positive feedback mechanism in the bee swarm guarantees the optimal nest site decision. High quality nest sites attract more scout bees which in turn attract even more scout bees after reporting their positive impressions, whereas nest sites of inferior quality will not be visited that much. The decision for a particular nest site is taken if a minimal number of scout bees accommodates simultaneously in that nest site place. This sort of decision finding works optimally in natural swarms of bees.

If we transfer the swarm scenario to our mine detection system, it is straightforward to imagine, that an individual sensor, say a metal detector, reports to all other sensors its findings. Other sensors with different sensory modalities, like GPR, infrared, gas sensor, etc. are attracted and enforced to investigate the reported location depending on the initial information. We can imagine an unmanned aerial system composed of drones with distinct sensor types. Such a drone swarm would offer many opportunities to implement different search strategies and for fine tuning the rules of collective, intelligent behaviours. The positive feedback loop, as described above in the bee swarm example, would also represent the basic ingredient of the drone swarm, and the fusion of sensory data would provide reliable decisions in the mine detection task.

Second key message: Swarm intelligence offers concepts for more reliable decision criteria in the mine detection process.

Unaffected by the impressive technical progress in recent years, mine detection is challenged by a fundamental but non-technical problem: trust or confidence. Whenever the UN is preparing a mine clearing project, they start to train in the first place local people for the mine sweeping actions. This is not coincidence, since only local domiciled experts can supply the confidence for the mine detection outcomes. Even a technologically ideal solution with 100% clearance rate would not guarantee the necessary confidence that concerned people need to re-access or re-cultivate a reportedly demined area. If we consider the swarm approach described above as an agent-based model, it would be easy to integrate the human capabilities as additional agents into the swarm system. All sensors, purely technical ones, animals or persons, would then act as agents in the swarm network, exchanging their findings and reacting to inputs from other agents.

Agent-based models are currently considered as a promising approach in order to understand and manage complex systems. Different from the current hype in (deep) machine learning, agent-based models offer a much better explainability of the decision criteria, since the working rules and constraints of individual agents are much better traceable.

Third key message: Integrating human capabilities into the mine detection process is fundamental to gain confidence in the results of demining processes. The swarm approach, viewed as an agent-based model, offers easy integration of technical and non-technical sensors, e.g. human agents, to facilitate these confidence-building measures.