Project
"Quantum sensors operating in extreme scenarios: novel applications of statistical inference, machine learning and control theory methods."

We are currently living in exciting times of the *2nd quantum revolution* with quantum mechanics no longer constituting "just" an intriguing theory that allows us to resolve puzzles of the micro-world. In contrast to the beginning of the 20th century and the *1st quantum revolution*, humanity has now reached a point when we can not only study quantum phenomena but also take advantage and exploit them in everyday tasks. Among such novel quantum technologies lies the field of quantum sensing and metrology, whose aim is to design and build devices that with unprecedented precision can, e.g., measure time (atomic clocks), probe electromagnetic fields (so-called SQUIDs, atomic or solid-state magnetometers) or sense external forces such as gravity (atomic interferometers). All these constitute examples of quantum sensors that have been demonstrated to spectacularly breach the corresponding *classical limits* on performance, either in proof-of-principle experiments or having been even commercialised. Still, the next big challenge that requires tremendous research commitment is to allow for coordinated operation of such devices in networks, so that they can be utilised in complex tasks of sensing, e.g., the magnetic activity of a human brain in real time or the seismic activity of Earth by tracking variations of the gravitational field across the planet surface.

Although quantum sensors are naturally associated with micro-scales, an atypical but spectacular example of such a device is the gravitational-wave detector. Despite its few-kilometre size it has allowed to resolve fluctuations of space-time as tiny as a proton, so that gravitational waves could have been registered for the first time. However, one shall not forget that the Noble prize, which was awarded in 2017 for this amazing achievement, would not be possible if not the state-of-the-art techniques of data processing. These have been developed over many years for such a gargantuan apparatus to allow for a gentle whisper of a black-hole-merger event to be heard in the wall of sound completely dominated by the noise. This experiment serves as a good example that signal-processing methods form a key link in any sensing protocol, especially quantum.

The main goal of this project is to make an important step in the direction of employing networks of quantum sensors in distributed sensing tasks. From the abstract perspective, as this is largely an uncharted territory, our aim is also to characterise the role of quantum correlations in such scenarios, in which the entanglement can be exhibited not only between, e.g., atoms forming a single sensor, but also in between the sensor nodes constituting the network. For this to be possible, we will construct sophisticated models of quantum sensors—in particular, of ones based on atomic ensembles, optomechanical devices and crystallographic defects—that will allow us to simulate operation of such devices in networks and real time, while applying directly the techniques of statistical inference, machine learning and control theory to process the sensor data and actively adjust its state in a feedback loop. Importantly, the aforementioned data-processing methods will be implemented within a versatile open-access software library that forms another important goal of this project. It will allow the user for flexible adaptation of the models and the data-inference tools, so that advanced sensing tasks can then also be explored such as, e.g., detection of anomalies or specific features (wavelets) within the signal probed, or hybrid sensing schemes that involve sensors of different types.

Last but not least, all our work will be regularly consulted with experimental groups developing particular sensing platforms—in the long term, capabilities of our solutions will be explicitly verified by processing actual output data of quantum sensors and using our software toolbox to control them.