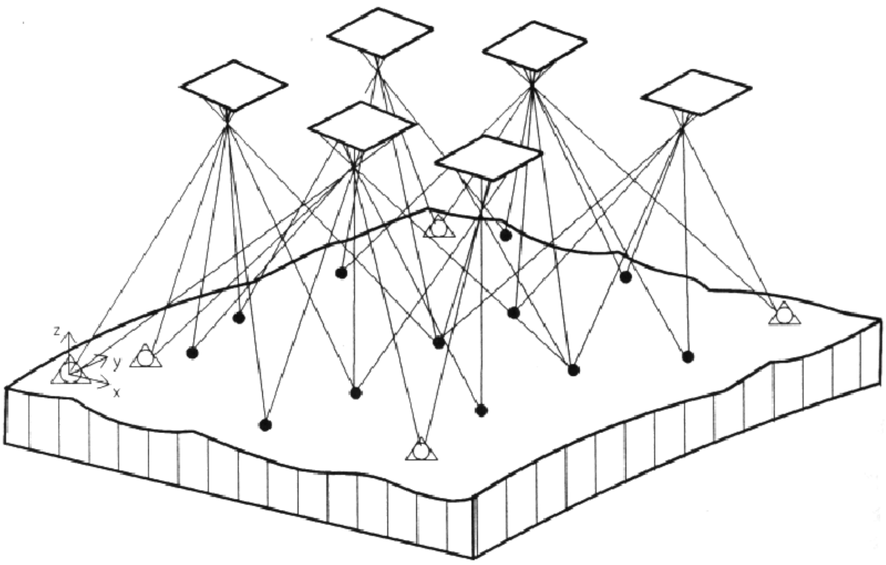
Quantum Computing for Earth Observation (QC4EO) Study

Summary of UC2 Multiple-view Geometry on Optical Image



Multiple images of a given area of interest can be retrieved as satellites orbit around the planet. These images may be obtained from different satellites or from a single satellite during a long enough opportunity window or multiple passes. An important task is to analyze the changes that have occurred on the area of interest as time has passed and perform terrain reconstruction. To do so, these images are compared with each other. However, the agility of the satellites and their different orbits result in the acquisition of different views of the area of interest: images may be rotated or translated, the illumination or scale may differ from one image to another. This problem can be tackled with bundle adjustment, which consists in estimating the different changes by minimizing the re-projection error, a single functional with a high number of parameters due to the high number of degrees of freedom. These calculations must be executed in a limited time to allow for more accurate approaches for terrain reconstruction and reduce constraints on the satellite platform localization. This method is conducted by first extracting keypoints that characterize well the different images, then by matching those that are common to multiple images. In this study, we have addressed the keypoint extraction and the feature matching problem using an optimization formulation and by utilizing both gate-based quantum computers and quantum annealers. The keypoints extraction procedure is conducted using two different clustering approaches: quantum k-medoids clustering and quantum kernel density clustering. In the first case, the problem is formulated as a Quadratic Unconstrained Binary Optimization (QUBO) to select k distinct objects located in the center of the image. In the second case, the problem is also formulated as a QUBO but the kernel matrix is computed by evaluating a quantum circuit on a gate-based quantum computer. Feature descriptors such as Scale Invariant Feature Transform (SIFT) are added to gain more information about the different scaling and rotations between images before performing the feature matching operation that uses quantum annealing as well as the kernel matrix computed a priori. We envision that ion-trap quantum computers and superconducting quantum computers and annealers are the most promising platforms for this use-case considering the needs for high qubit connectivity and for many qubits. The small size problem, which addresses images of tens of pixels, can already be solved efficiently using this quantum approach even though no clear advantage is demonstrated. However, extracting keypoints directly from the original image of a full-size problem would require a substantial number of qubits and high connectivity from the hardware architecture chosen. Such achievements seem unrealistic without scalable error corrected quantum computers and thus extend beyond 15 years. Nevertheless, an iterative approach that consists in solving the keypoint extraction problem on batches of medium-size images seems very promising. While the solution quality might slightly differ from that of the original approach, this process reduces greatly the resources needed for practical implementation on real hardware and may be possible within 5 to 10 years.

	Problem size	**Hardware requirements**	**Timeline**		
			Up to 5 years	**Up to 10 years**	**Up to 15 years**
Minimum-size problem	Extraction of 10 keypoints on 8x8 patches Feature matching of 10 keypoints	Analog hardware (superconducting, neutral atoms): 8x8 qubits. Additional digital hardware needed with 4 qubits.	Problem implemented on NISQ devices	Problem implemented on NISQ devices	Problem implemented on NISQ devices
Full-size problem	Extraction of 10 keypoints on 30.000x30.000 pixel images Feature matching of 10 keypoints	Analog hardware (superconducting, neutral atoms): 30.000x30.000 qubits. Error correction required. Additional digital hardware needed with 4 qubits.	No feasible implementation envisioned	No feasible implementation envisioned	Problem implemented if fully scalable error correction on superconducting devices becomes available