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Quantum information and Modelling & Simulation integration

Initial Concept

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This paper represent an initial study on Quantum information and Modelling and Simulation (M&S) integration. After an overview on quantum warfare, the document define the potential applications of this new technology in the M&S field and the advantages that could be reached through this technological integration.

Quantum technology is an emergent disruptive discipline, with the ability to affect future military operations. Quantum technologies for military applications introduces new capabilities, improving effectiveness and increasing precision, thus leading to "quantum warfare," wherein new military strategies, doctrine, policies and ethics should be established.

Particular military applications of quantum technology are described for various warfare domains (e.g. land, air, space, electronic, cyber and underwater warfare and ISTAR – intelligence, surveillance, target acquisition and reconnaissance) where related issues and challenges are articulated. Quantum technologies will not be a proper evolution but a real revolution of the modern devices working on classical physics. Nevertheless, it is important to highlight that the quantum and classical technologies are not mutually exclusive, meaning that hybrid devices, not pure classic and/or quantum devices will most likely dominate future scenarios. This is a possible situation for the spreading of quantum technologies and, through the concept of building hybrid devices, will be possible to see tangible effects on human lives in the near future. In order to navigate this possibility, the quantum engineer will have a key role in shaping the future of military quantum transformation, characterizing with a pragmatic approach, oriented to the devices' design, the quantum warfare implications in the Future Operating Environment.

Possible quantum applications in a warfare context will affect all military domains and they can be summarized in:

- Quantum cyber warfare;
- Quantum computing applications;
- Quantum computer;
- Quantum internet;
- Quantum underground mapping;
- Quantum inertial navigation;
- Quantum underwater warfare;
- Quantum underwater mapping;
- Quantum communication;
- Quantum magnetometer sensing;
- Quantum electronic warfare;
- Quantum chemical detection;
- Quantum radar.

The above technologies, whenever available, will determine the need to develop models, in terms of digital twins, to be used in simulation environments. From this perspective, the model can be developed even before building the real device, in order to test its behavior during the concept/capability development phase, fostering its effectiveness. The wide application area of quantum warfare will involve a multi factorial approach in the modelling and simulation of quantum assets.

For instance, there will be a particular impact will be in Quantum EMSO (ElectroMagnetic Spectrum Operations), where the role of a synthetic environment for studying and analyzing the Electromagnetic effect on a multi-domain battlefield is assuming a significant value. A future real implementation of quantum EM systems, often theorized as anti-jamming and/or anti-hacking devices, could be a strategic advantage for dominating the operating environment. For this reason, their innovative technological features have to be modeled and simulated in order to create or increase quantum situational awareness in military operations.

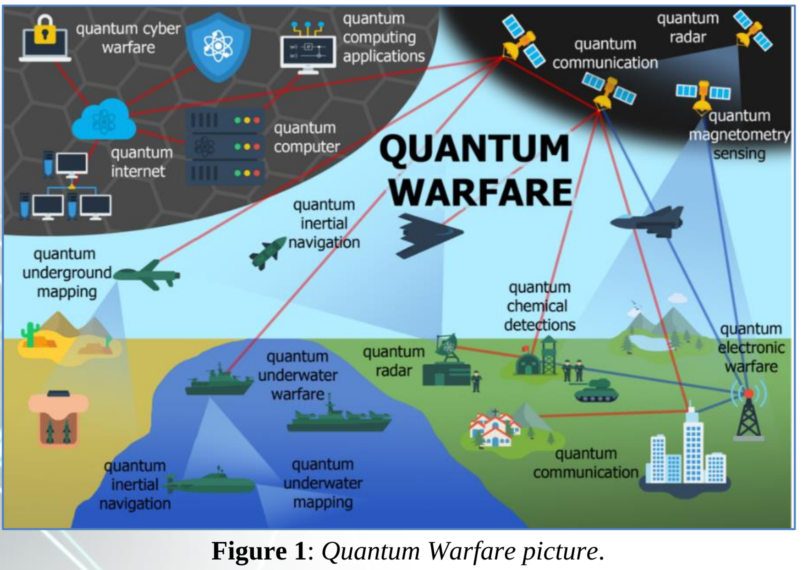

Figure 1: *Quantum Warfare picture.*

This is just an example of quantum computing applications, focusing on both technical aspects connected to the M&S tools and to the operative results supported through the employment of a synthetic environment. The M&S in support to the military operations involves different types of simulations, which can be performed at different level: tactical, operational, and strategic. The simulations that mostly characterize the strategic and operational level are constructive and/or virtual and, in this case, the tools and the algorithms used are stochastic. In particular, at each tick of the simulation, the computer takes decisions, according to the algorithms implemented in the simulator's engine, in a way similar to a digital roll of dice.

These decisions are taken according to doctrine elements (rules of engagement defined inside each side), operative and technical data (physical database related to the units/equipment modelling and behavioral database related to the autonomous attitude given to the simulated forces).

Surely, artificial intelligence is another emerging technology whose integration with the M&S will deliver promising results, especially for decision-making process purposes. Therefore, it is also important to assume that the quantum technologies are a booster for specific artificial intelligence applications, mostly regarding the machine learning algorithms resolution.

The logic element of quantum computing is the qubit, which represents a specific quantum state and is associated to a vector on a sphere (the so-called Bloch sphere). For this reason, the theoretical information carried by a qubit is wider with respect to the binary information of a classical bit, mostly associated to an electric level (1 high and 0 low). The quantum information is a linear combination of a number state, expressed as orthonormal base in Wigner space, where it can be associated to a specific quantum of energy according to Plank's law. The qubit is thus a superposition of many quantum states. Moreover, the information of a qubit can be projected in a Cartesian diagram as a position and a momentum component, where photons are characterized by un-deterministic principles (Heisenberg), described by a probabilistic function.

This concept is the key to understand that the quantum information, depending on the quantum state, is described by a specific probability function according to the average number of particles carrying the information.

The probabilistic nature of the quantum information is a good starting point to conceptualize the integration of quantum information with M&S applications. An implementation of this integration can be realized through a quantum processor, composed of logic gates (such as Controlled NOT and/or Hadamard ports) with programmability capabilities, in order to have something similar to a Field Programmation Gate Array (FPGA) in the classical world.

An important element in this discussion is that, regarding the information, quantum is not always better than classical. On the contrary, classical computation has reached very high performances and therefore, an effective way for spreading quantum applications lies in hybrid technologies, meaning that the information revolution likely brought by quantum has to be searched in the conjunction with existing classical hardware and algorithms. The merged results have to be characterized by a reciprocal performance enhancement, looking at a comprehensive mixed approach.

In order to consolidate this idea, could be useful to prepare a comparison test between a classic processor and a quantum processor, with the same hardware logical and computational capabilities. At this point, it could be possible to provide, as the input of each processor, the execution of typical M&S algorithms and monitor the outcomes, in terms of elapsed time to finish the calculations.

For this purpose, quantum processor means to identify and to circumscribe the borders both hardware and software which can be used for the performance comparison test, contextualizing the expected results to the defined quantum and the corresponding classical elementary cell. That means that a quantum processor can also be implemented on a board realized with a hybrid approach and, for this reason, the definition of logic elementary cell borders is a paramount aspect in order to correlate results to the quantum part of the processor. The elementary cell can be simple or complex, depending on the technological readiness level of quantum processors under test. By logic cell we mean a portion of logic circuits that define the architecture of the processor able to compute algorithm processes.

This concept is useful to obtain a direct association between the performance effectiveness measurements and the used technology under test, limiting a comparative analysis to the logical elements actually employed during the computational phases and obtaining results directly linked to logic function resolution capability of the circuit elements. However, a preparatory phase is fundamental for searching the quantum hardware and software inside the elementary cell according to M&S algorithm implementations. This analysis phase is a cornerstone for identification of quantum technology benefits applied to synthetic environment processes and logics.

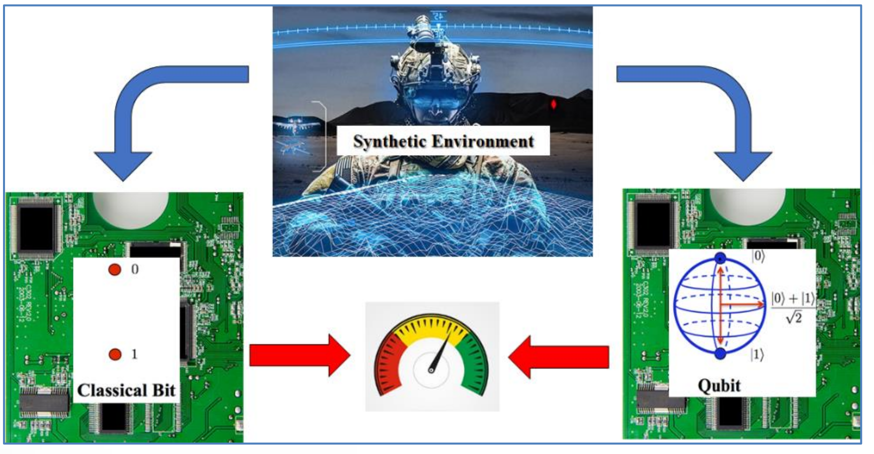

Figure 2: *Conceptual framework of quantum information and Modelling & Simulation integration.*

For instance, the execution of Lanchester equations represent an adequate candidate for starting this comparison, which are the basis algorithms used by modern simulators. The Lanchester equations are differential equations describing the time dependence of the forces of two armies A and B as a function of time that depend only on A and B.

This process can also be iterated for other algorithms, in order to classify the computational results according to logical processes executed, focusing particularly on the stochastic behavior of the simulation engine itself.

In this scope, it is meaningful to analyze if and how a quantum processor, governed by stochastic processes, can be used to increase the M&S applied to military operations.

In this case, it has been theorized a specific quantum application for M&S, based on the availability of a quantum processor, through the identification of specific algorithms implemented by a simulation engine and a comparative analysis conduction with respect to a "classical hardware/software twin". This is the starting point for exploring potential integration between quantum and M&S and is necessary for implementing further technical feasibility studies for a proof of concept realization.