On the Design of the Quantum-Classical Hybrid-Service Architecture

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***Abstract*—As one of the latest advancing technologies, quantum computing shows its potential to rapidly solve problems that are too complex for traditional computing methods. However, due to its unique nature, such as its complicated principles of quantum mechanics, quantum computing is still not widely used in many fields. In the software engineering domain, one of the challenges is the lack of methodologies for constructing applications that use both quantum and classical computing environments. This study proposes an innovative Hybrid-Service architectural design approach for constructing hybrid quantum-classical applications. The design approach is then applied to the construction of a hybrid quantum Magnetic Resonance Imaging (MRI) application to accelerate MRI speed as a case study to demonstrate the effectiveness of the design approach.**

***Index Terms*—Quantum-classical development, Hybrid-service architecture, Magnetic Resonance Imaging (MRI), Quantum computing, quantum GRAPPA**

I. Introduction

Quantum computing, one of the latest advancing technologies, shows potential for solving problems too complex for traditional methods. However, due to its unique nature, it is not widely used in many fields. Operating with quantum bits instead of classical bits makes it impossible to directly apply classical computing algorithms and design methodologies to the quantum environment [1].

With the current quantum technique, it is impossible to develop a complete software system, especially those requiring graphical user interfaces with input and output, solely in the quantum environment. A common solution to this challenge is to develop hybrid quantum systems. A hybrid quantum system integrates classical and quantum components: using classical computing for inexpensively computing and user interfaces, and applying quantum computing for complex computational tasks. However, in the field of software engineering, there is a lack of mature architectural design methods for developing such hybrid quantum systems. The current state-of-the-art research is still limited to preliminary studies [2]–[6].

The overarching goal of this study is to develop a methodology for designing the architecture of hybrid quantum systems. We will then apply the proposed architecture in the design of a quantum-enhanced Magnetic Resonance Imaging (MRI) application as a case study.

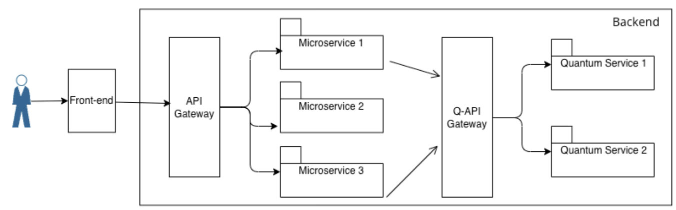

Fig. 1. Preliminary design of the Hybrid-Service Pattern.

II. Hybrid-Service Architectural Pattern

We propose the Hybrid-Service architectural pattern to structure classical and quantum components as services and define their communication strategies. Classical components are designed as microservices [7], and quantum components as Quantum-as-a-Service (QaaS) [2]. Microservices communicate via APIs, and to maintain consistency, microservices and quantum services will also communicate via API, referred to as Q-API. Fig. 1 shows the preliminary Hybrid-Service pattern, featuring two API gateways: one for frontend-to-microservice communication and a Q-API gateway for microservice-to-quantum service communication. This pilot study limits the API protocol to REST API [8].

A preliminary study [9] proposes a Q-API gateway with functions for obtaining quantum machine recommendations and providing execution time feedback. However, these functionalities are insufficient for practical hybrid quantum applications. Our study expands the Q-API gateway's responsibilities to include service discovery, authentication, and authorization. It involves defining components, designing functionalities, implementing the Q-API gateway, a sample microservice, and a sample quantum service, and testing their effectiveness and communication.

III. Case Study

In the medical field, Magnetic Resonance Imaging (MRI) [10] has provided invaluable insights into the soft tissues of the human body and revolutionized diagnostics and the monitoring of therapy. Despite its profound clinical utility, MRI presents challenges: slow imaging speed, high costs, and patient discomfort due to the long scanning time [10].

The GRAPPA method [12] is widely used in clinical MRI to reconstruct undersampled data. However, radiologists find it almost impossible to read results of a scan in real-time mode due to the lengthy reconstruction time required by conventional computing, which can take up to several hours or even days. The computational load arises from solving numerous linear equations within a Linear Time-Invariant (LTI) system framework. With quantum LTI systems [13] successfully implemented and established in quantum computing, there is strong potential to exponentially accelerate the GRAPPA reconstruction process.

Motivated by the successful implementation of linear regression on D-Wave quantum computers [14], we design the Quantum GeneRalized Autocalibrating Partially Parallel Acquisitions (Q-GRAPPA) algorithm and test it in the D-Wave quantum environment. The development process involves translating the LTI system of the GRAPPA algorithm into a quantum algorithmic structure suitable for execution on a quantum annealer. This translation includes encoding the MRI signal reconstruction problem into a Quadratic Unconstrained Binary Optimization (QUBO) framework to enable the use of quantum annealing to efficiently find solutions. Key to this process is converting the LTI system of GRAPPA method into an energy minimization problem that quantum annealers can natively solve.

The QuantumMRI application is designed by applying the Hybrid-Service architectural pattern and integrating the quantum annealing-enhanced GRAPPA algorithm to calibrate the images, expediting the MRI reconstruction speed. QuantumMRI receives input data from a client, reads and preprocesses the data using Fourier transform, sends the data to the quantum GRAPPA service for calibration, returns the calibrated data for prediction, and displays the reconstructed image after reverse Fourier transform. The architectural design of the QuantumMRI system is illustrated in Fig. 2.

The backend of the system contains four microservices: *DataInput*, *FTProcessor*, *Prediction*, and *Display*, along with one quantum service, *QGRAPPAImager*, corresponding to the functionalities. *QGRAPPAImager* encapsulates the implemented Q-GRAPPA algorithm and defines endpoints with an API. The QuantumMRI system will be developed and deployed in Github CodeSpace. Since the microservices within a system can be developed in different programming languages, the *QGRAPPAImager* service will be implemented in Python and use the quantum cloud service provided by D-Wave's Leap, while the other microservices will be developed in Java Spring Boots.

IV. Conclusion

This ongoing study proposes an innovative Hybrid-Service architectural pattern for constructing hybrid quantum-classical applications, addressing the integration challenges of quantum and classical computing in software development. As a case study, we are developing a hybrid quantum Magnetic Resonance Imaging (MRI) application using the Hybrid-Service pattern and integrating the quantum GRAPPA algorithm to

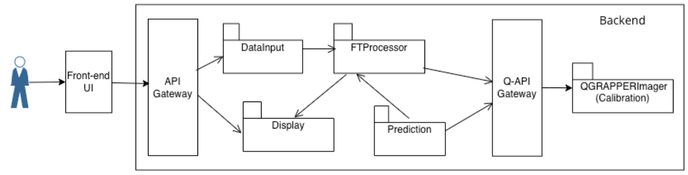

Fig. 2. Architectural design of the QuantumMRI application.

accelerate MRI speed. The project's significant outcomes are twofold: the novel architectural design approach provides a pattern for future hybrid quantum systems, and the quantum-enhanced MRI application significantly improves imaging efficiency, potentially enhancing clinical diagnostics by enabling real-time modes.

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References

[1] M. De Stefano, F. Pecorelli, D. Di Nucci, F. Palomba, and A. De Lucia, "Software engineering for quantum programming: How far are we?", Journal of Systems and Software, Volume 190, 2022, 111326.

[2] M. A. Martínez-Prieto, J. Tapiador-Morales, and J. M. Moya, "Quantum service-oriented computing: current landscape and challenges," Software Quality Journal, vol. 30, pp. 983–1002, 2022.

[3] M. Piattini, G. Peterssen, and R. Pérez-Castillo, "Quantum computing: A new software engineering golden age", ACM SIGSOFT Software Engineering Newletters vol. 45, no. 3, pp: 12-14, 2021.

[4] M. Piattini, M. Serrano, R. Perez-Castillo, G. Petersen, and J. Luis Hevia, "Toward a quantum software engineering." IT Professional, Vol. 23, no. 1, pp: 62-66, 2021.

[5] J. Rojo, D. Valencia, J. Berrocal, E. Moguel, J. GarcíaAlonso, and J. M. M. Rodriguez, "Trials and tribulations of developing hybrid quantum-classical microservices systems," in 2nd Quantum Softw. Eng. Technol. Workshop, QSET'21, CEUR Workshop Proc., vol. 3008, 2021, pp. 38–53.

[6] D. Valencia, J. Garcia-Alonso, J. Rojo, E. Moguel, J. Berrocal, and J. M. Murillo, "Hybrid classical-quantum software services systems: Exploration of the rough edges," in Quality of Information and Communications Technology - 14th International Conference, QUATIC 2021, Proceedings, Ser. Communications in Computer and Information Science. Cham, Switzerland: Springer, 2021, pp. 225–238.

[7] X. Larrucea, I. Santamaria, R. Colomo-Palacios and C. Ebert, "Microservices," in IEEE Software, vol. 35, no. 3, pp. 96-100, May/June 2018.

[8] R. T. Fielding, "Architectural styles and the Design of Network-Based Software Architectures," University of California, Irvine, 2000.

[9] J. Alvarado-Valiente, J. Romero-Álvarez, E. Moguel, and J. M. Moya, "Quantum software as a service through a quantum API gateway," IEEE Internet Computing, vol. 26, no. 1, pp. 34-41, 2022.

[10] Z. Liang and P. C. Lauterbur, "Principles of magnetic resonance imaging: a signal processing perspective," Wiley-IEEE press, 1999.

[11] S. Sammet, "Magnetic resonance safety", Abdominal Radiology, vol. 41, no. 3, pp. 444-451, 2016.

[12] Y. Chang, H. A. Pham, and Z. Li, "A dual-interpolator method for improving parallel MRI reconstruction," Magnetic Resonance Imaging, vol. 92, pp. 108-119, 2022.

[13] K. Li, H. Dai, F. Jing, M. Gao, B. Xue, P. Wang, and M. Zhang, "Quantum algorithms for solving linear regression equation," Journal of Physics: Conference Series 1738 012063, 2021.

[14] P. Date and T. Potok, "Adiabatic quantum linear regression," Scientific Reports, vol. 11, pp. 21905, 2021.