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Design of Precision Medicine Web-service Platform Towards Health Care Digital Twin

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Abstract—**Recently, there has been a growing interest in researching and developing personalized medical AI services. The previous AI medical systems rarely provided model output compared to multiple datasets and AI models. Currently, only few medical AI systems offer integrated platforms for multidisciplinary precision medicine services. Most existing medical AI systems include AI prognosis with a singular discipline in focus, such as elderly healthcare. This paper proposes a novel digital twin-based integrated precision medicine web-services platform. Our proposed system architecture can be easily implemented in hospital organization interfaces because of the ensured platform independence. Based on the prognostic requirements, we design the service interface with a broad spectrum of patient medical parameter selection (survival time, vital signs, etc.) made available for each medical service. The data related to each patient can be effortlessly updated in real-time. The services will predict and evaluate the accuracy of the visualized output along with the patient clinical information. To verify the feasibility of the proposed architecture, we implemented it with different AI medical services, such as 5 year lung cancer survival prediction, survival analysis with lung tumor segmentation and rapid response analysis. We observed that the architecture showed excellent performance. The architecture for this comprehensive precision medicine web-service platform (Comp-Med) is highly efficient and flexible. It is easily extensible to the new features, services, and updates that may get accommodated in the future.**

Index Terms–Medical AI, System Architecture, Micro-services, Digital twin

1. Introduction

To develop a medical decision support system based on digital twin for predicting clinical outcomes, such as overall survival time, with an AI model tailored for individual patients, it is essential to carefully consider the unique nature of data obtained from the physical world.

Digital twins can assist in representing and integrating these data into a digital replica of an individual while AI algorithms can be used to conduct patient prognosis and/or predictions by considering a multitude of risk factors to determine the patient's overall survival, and behavior of the disease throughout its lifecycle [1]. As more data becomes available, it can help in optimizing personalized recommendations. A diverse range of risk factors are likely to be considered in diagnostic, prognostic, predictive, and treatment monitoring decisions. Considering all risk factors simultaneously can be beyond the typical cognitive capacity of individual human decision-makers. Digital twins then emerge as a tool to help manage these massive datasets and provide more effective exploration and utilization of the data and the embedded key contextual insights [1]. Our vision of the digital twin in healthcare is illustrated in Figure 1.

Precision medicine is a rapidly evolving field that seeks to customize healthcare to individual patients by considering their unique genetic, environmental, and lifestyle factors. Recent advances in artificial intelligence (AI) have shown great promise in enabling personalized medical services. However, most existing medical AI systems lack a centralized platform that can integrate multiple datasets and AI models across different medical disciplines. Additionally, the output of most medical AI systems is rarely compared with multiple datasets and AI models.

We consider emergent and time sensitive aspects of the medical care including cancer survival, specifically 5-year lung cancer survival classification, survival time (days) analysis and rapid response analysis in the emergency care. We Propose a web-service system where these medical AI services are made available under an integrated platform along with secure access to the dynamic patient database for each service.

In this paper, we present a Comprehensive Precision Medicine web-services platform (Comp-Med), a novel digital twin-based architecture that offers an extensible and flexible platform supporting multiple precision medicine services for individual patients, designed to accommodate future updates, features, and services. The platform allows users to customize the parameters of the service according to the specific needs of the patient analysis, such as adjusting the time window for analyzing patient vital abnormalities in the case of a rapid response analysis or selecting different survival year features in the case of lung cancer classification. The platform also enables users to upload new patient

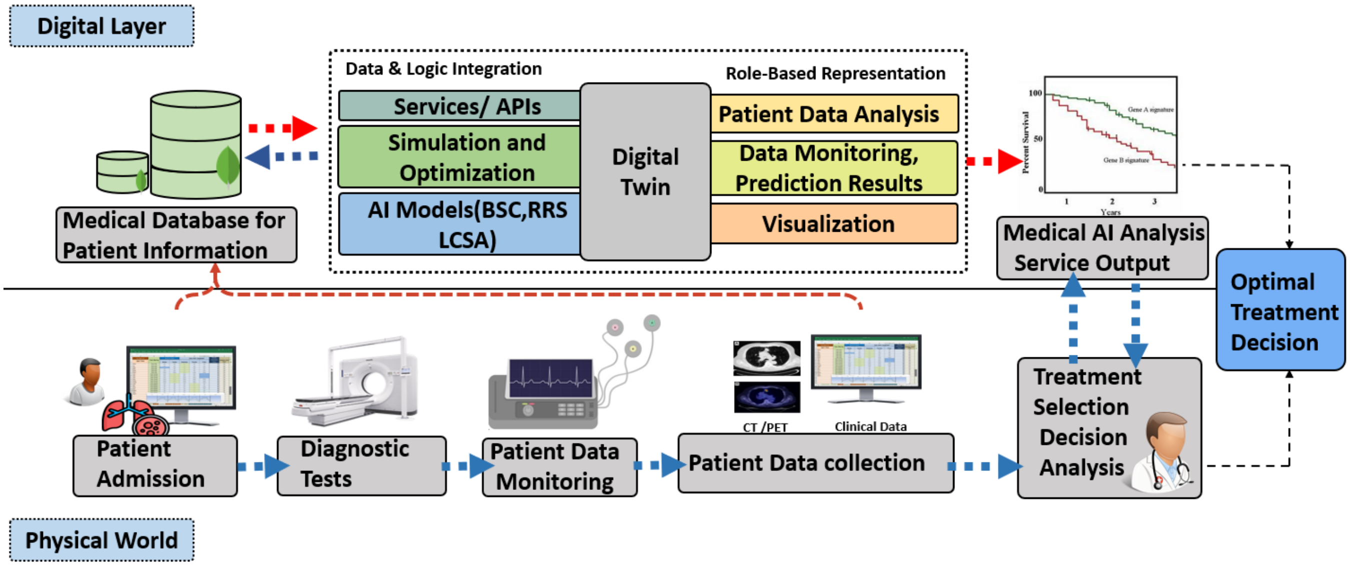

Figure 1. Conceptual framework of CompMed.

data to the database and visualize and process it in real-time for the service models.

This platform represents a significant advance in medical healthcare technology, enabling a broad spectrum of patient medical parameter selection and accurate output that can be visualized and evaluated based on patient clinical information. Overall, our contributions include the design of a flexible architecture for digital twin-based web-services platform that allows for customized precision medicine services and real-time data analysis.

2. RELATED WORKS

Although most of the concrete applications of digital twin can be found mainly in the industrial context, healthcare represents another relevant area where digital twins can have a disruptive impact [6], [7]. Digital twin technology has become increasingly popular in healthcare due to its ability to create virtual representations of patients and their diseases.

In recent years, there has been a growing interest in using digital twin-based web services to provide personalized healthcare solutions. Decision support systems for precision medicine such as a medical AI framework have been being developed. In this context we study the healthcare related artificial intelligence literature works. Y. Liu et al. proposes a cloud-based framework for the elderly healthcare services using digital twin [2]. The authors propose a cloud environment for monitoring, diagnosing, and predicting aspects of the health of elderly individuals of personal health management. This paper focuses on daily health monitoring consideration with the help of IoT devices. In another work, Croatti, Angelo, et al. proposes integration of digital twins with agents and Multi-Agent Systems (MAS) where trauma medicine and emergency care are at focus [9]. The authors proposed integration of digital twins with agents and Multi-Agent Systems where the system considers trauma medicine and emergency care elements. One of the works by Rivera, Luis F., et al. presents the concept of digital twins employed for continuous monitoring of the patient in the domain of personalized healthcare [11]. In this paper, they leverage the digital twin's capacity of self adaptive systems and autonomic computing to engineer smart and flexible software systems.

Enhancement in surgical AI techniques have led to the development of digital twins of anatomical structures, created by analyzing data from IoT devices. These digital twins enable real-time monitoring and study of disease progression. Based on this premise, Martinez-Velazquez et. al presents a cardio twin architecture for ischemic heart disease detection is designed to run on the edge [12].This architecture includes collection of data from sensors, medical records, social networks and external sensors to detect and report the abnormal cardiovascular behaviour. While, Corral-Acero, Jorge, et al takes a different approach by using digital twin concept to enable the vision of precision cardiology by providing AI support to individual treatment and prevention of cardiovascular disease [8]. In this work, AI support for individual treatment and prevention of cardiovascular disease based on accurate predictions of the deep learning model is studied.

These studies demonstrate the potential of digital twin-based precision medicine decision support web services in healthcare, and suggest that this technology could be an important tool for improving patient prognosis and personalized treatment decisions.

In this paper, building upon the insights gained from the aforementioned works, we have proposed an integrated platform that leverages digital twin technology to provide multiple precision medicine services. The proposed platform

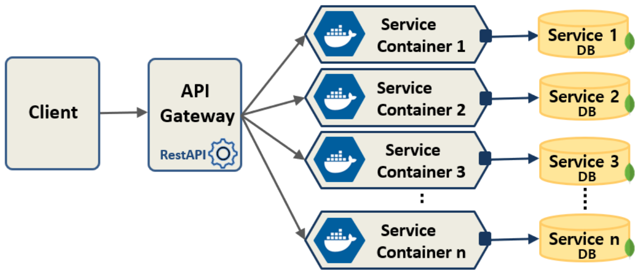

Figure 2. Micro-services Reference Architecture.

aims to improve patient outcomes by providing decision support analysis for personalized treatment plans based on the patient's unique characteristics,medical history. By using digital twin-based decision support systems, the platform will enable clinicians to make informed treatment decisions and provide better patient care.

3. Comprehensive Precision Medicine Web-services Platform

In this paper, we propose the CompMed web-services platform architecture based on containerized micro-services structure as illustrated in Fig. 2. This architecture considers system flexibility, reliability, and platform independence, and ensures that each service is contained within its individual container to avoid potential conflicts or dependencies, thereby reducing the time and effort required for integration and enabling faster deployment of new services. Furthermore, the portability and isolation provided by containerization employed in our proposed architecture offer greater flexibility in terms of infrastructure and deployment options of the healthcare organization, making it easier to adapt to changing requirements.

To provide a comprehensive understanding, we have divided our system architecture into four components. - precision medicine service containers, CompMed web server, patient database and System user interface.

3.1. Containerized Precision Medicine Services and its extensions

Our proposed architecture was primarily implemented on three precision medicine services into an integrated framework . The services include survival analysis based on lung tumor segmentation [3] , 5 Year binary survival classification of lung cancer patient with multi-modal data [5] and rapid response analysis [4] .

3.1.1. Survival Prediction based on 5 year Classification of lung cancer patient. In Binary Survival Prediction based on 5 year Classification (BSC) [5] implemented a survival prediction method with resnet-18 while training the model with clinical features and radiomic features such as three dimensional PET and CT images. Because lung cancer post prognosis has highest fatality rate within 5 years of time, clinical experts consider 5 year period to perform survival analysis task. The service considers clinical parameter - overall survival time (1to5 years) of each patient and trains 5 different deep learning models based on 5 year survival classification of the training data(CNUHH lung Cancer patients (private) dataset). The prediction accuracy was evaluated in comparison with state-of-art deep learning models with C-index score as it is thought to be most appropriate choice for evaluating the performance of BSC service models due to its intuitive interpretation of the probability that the model's predicted survival times are in concordance with the observed survival times, which is essential for clinical decision support and risk stratification.

3.1.2. Survival analysis based on lung tumor segmentation. In [3] , survival analysis method (LCSA) based on tumor segmentation to predict the hazard rate and survival time in each NSCLC patient has been implemented. The MAPTransNet model is proposed to predict lung tumor region on PET image and then use the output of this model for survival analysis task. The LCSA service observes that tumor information is essential for diagnosis. Hence, the tumor segmentation is employed to segment where the tumor cells are and where the normal tissues are in 3D PET/CT images. The output of MAPTransNet model as the region of interest (RoI) image for survival analysis task was utilized. The model incorporates the global context features, radiomic features (PET images) and clinical data of more than three thousand patients from CNUHH dataset (private dataset) as input of the MSNet model. In order to evaluate accuracy of the system, the metrics of Dice score for segmentation task while C-index, Brier score, Binomial Log-likelihood (IBLL) and Mean Absolute Error (MAE) were used for survival analysis task. The model proves to be superior than the state of the art models.

3.1.3. Rapid response analysis. We extend our system architecture by proposing integration of a medical deep learning application system [4] for the prediction of in-hospital clinical deterioration with high interpretability and diversity in input features. The use of the Transformer structure in the method has resulted in superior performance compared to other models when tested on a large and challenging data set, with a 0.652 F1-score, 0.77 sensitivity, 0.837 AUROC, and 0.839 AUPRC. The development of such a system is crucial in preventing treatment delays caused by an overload of hospitalized patients, and many previous studies have focused on developing risk scores to assess a patient's clinical condition. Through the application of deep learning and transformed architecture techniques, the service greatly supports predictive quality of rapid response analysis through a probability algorithm.

3.2. Patient Database

The deep learning models from medical services integrated in our proposed framework were trained, tested,

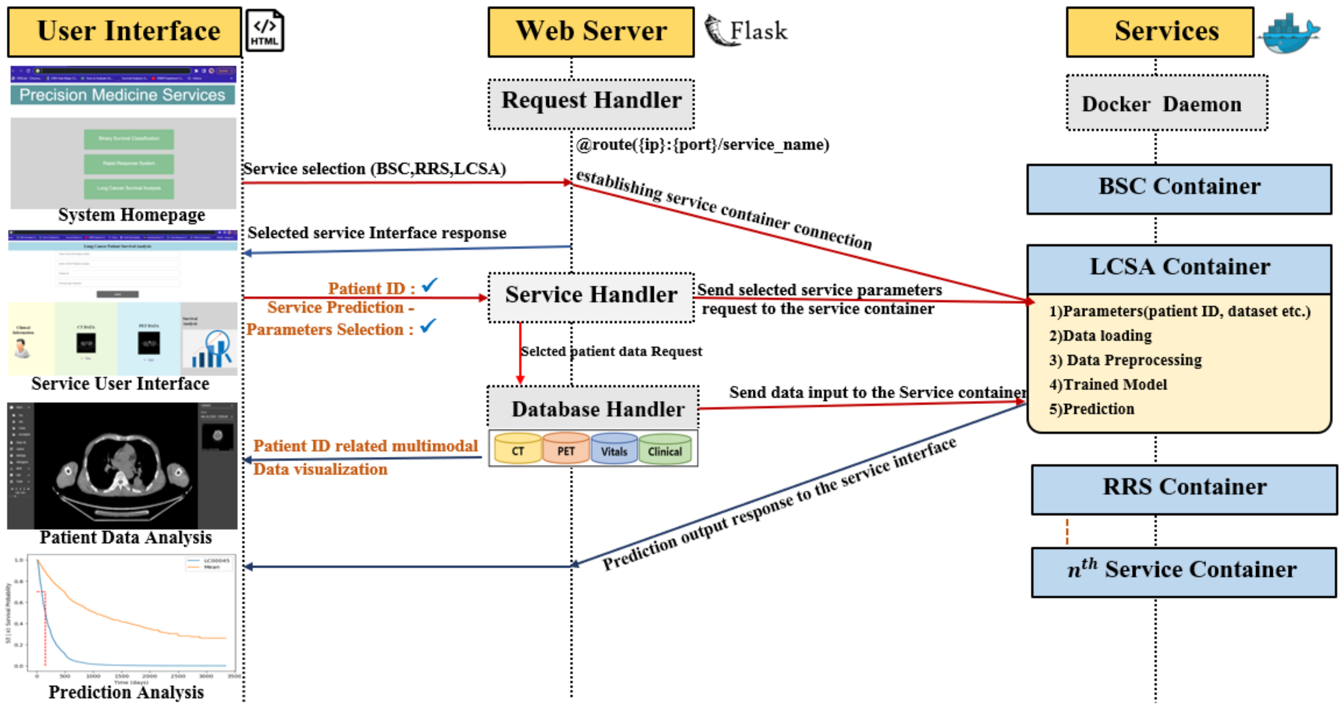

Figure 3. CompMed Request-Response processing for LCSA.

and evaluated using extensive datasets, including the private patient database cleaned and collected from Chonnam National University Hwasun Hospital (CNUHH) in South Korea under expert supervision. The lung Cancer Patients (LC-CNUHH) dataset consists of clinical features such as overall TNM staging and average daily smoking count along with radiological images from both positron emission tomography (PET) scans and a computed tomography (CT) scans from 4,591 patients.

To evaluate the performance of lung cancer related models, they were tested separately on the LC-CNUHH dataset, which includes 4,591 patients with lung cancer. This dataset was divided into two groups: NSCLC (Non-small Cell lung Cancer) patients, which comprised 3,470 cases, and SCLC (Small Cell lung Cancer) patients, which comprised 1,121 cases.

While the Rapid Response Team (RRT-CNUHH) dataset aggregates clinical data with vital signs features of 25,329 patients. The use of these datasets enabled us to provide deep learning models with superior evaluation performance, thus providing reliable and effective personalized medical services.

This paper proposes an architecture that incorporates the NoSQL document database platform MongoDB, designed to store structured or unstructured data with encryption and supports evolving data schemas using a JSON-like format. The overall CNUHH dataset is stored using MongoDB, guaranteeing automatic failover with replica sets. The proposed architecture ensures efficient and scalable data management, taking advantage of the built-in automatic failover feature. Users can easily update the database with new patient information, without redundancy formation, ensuring efficient and effective data management.

3.3. CompMed Web Server

We utilize web server module in our proposed architecture to handle request-response transmission between users and services.

We implement the CompMed Web Server with Flask-RESTful (Representational state transfer) API due to its robust features and ease of use. We define services and their corresponding URLs (@routeip:port/service-name) by utilizing its resourceful routing features and create service endpoints. We validated efficiency of the ComMed web server with rigorous testing. The service request-response operation was successfully verified by submitting every input combination available.

Lets consider that, a user submits a request for BSC service for 5th year survival prediction of a lung cancer patient with patient ID, LC00261. First, the request input data (selected prediction parameters, clinical data, CT,PET images of patient) will be parsed and validated by the web server before updating the database with latest patient information. This helps to improve the accuracy of our service predictions and reduce errors caused by incorrect input data. The selected input features and patient data are routed to the BSC container through the container URL (server_IP:service_port).

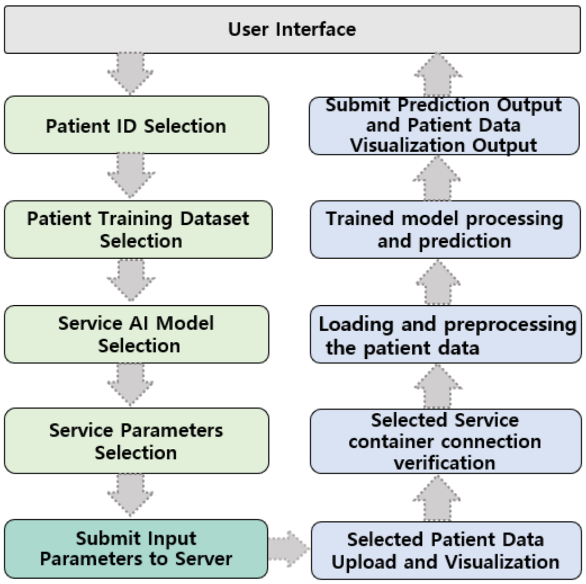

Figure 4. Service Interface-server Workflow.

After loading, storing and pre-processing the patient data, the service container uses it for output prediction with trained deep learning model of BSC. The predicted output from BSC service container is received in JSON format as a response by the web server. The web server routes and visualizes the predicted survival graph to the user interface as shown in Fig.5 where highest probability of happening an event is observed in 5 years of time.

3.4. System User Interface

CompMed web-services platform currently provides three precision medicine services including but not limited to 5-year binary survival classification of lung cancer patient (BSC), lung cancer survival analysis (LCSA) and rapid response analysis for the sensitive emergency care patient. The services are explained briefly in 3.1.2. We facilitate patient radiomic data visualization and clinical information analysis to the clinical experts.

We utilize the web development tools including HTML, JavaScript and Flask to create system user interface (UI). The UI is effectively easy to use because it is designed according to individual patient information access and requirements of the provided service parameters. This means that the UI is tailored to meet the specific needs of each patient and service, making it more intuitive and user-friendly.

The workflow for the system interface is described in Fig. 4, which simplifies the process for the user to select inputs and visualize predicted output. This allows the user to easily navigate the system and get the information they need quickly and efficiently. Finally, the framework supports patient data analysis through visualization on the user interface. This means that the user can analyze clinical information and CT, PET scans of the patient, which can help them to make informed decisions about their treatment plan. Overall, the UI is designed with the user's ease of use in mind, while the Flask RESTful API implementation and well-defined workflow make the system straightforward and efficient to use.

4. Performance of the current precision medicine services

To achieve a deeper understanding, we provide performance analysis with survival analysis based on lung tumor segmentation (LCSA) [3], and 5 Year binary survival classification of lung cancer patient with multi-modal data(BSC) [5].To evaluate the survival prediction models various metrics can be used including brier score, Precision-Recall curves and mean absolute error. The Brier score primarily measures the accuracy of the model's predicted probabilities, while Precision-Recall curves assess the trade-off between sensitivity and positive predictive value.

In survival prediction based on 5 year classification [5], a survival prediction method was implemented using resnet-18 and training the model with clinical and radiomic features from CNUHH dataset. The study focused on the highest fatality rate of lung cancer within 5 years of diagnosis, using overall survival time (1-5 years) as the clinical parameter for training five different deep learning models. The model achieved a C-index score of 0.97, outperforming state-of-the-art deep learning models. We can observe the predicted probability of a 5-year survival for a patient with the ID LC00261, indicating the highest probability of an event occurring in the fifth year post-prognosis. The service of survival analysis based on lung tumor segmentation performance was evaluated by calculating dice score performance. The deep learning was trained and compared with LC-CNUHH dataset variations (583,834 and 2687 patients). LCSA achieves a C-index of 0.8169 and a MAE (Mean Absolute Error) of 260 days at a survival probability of 0.7 in the CNUHH dataset. While, Fig. 6 shows predicted output

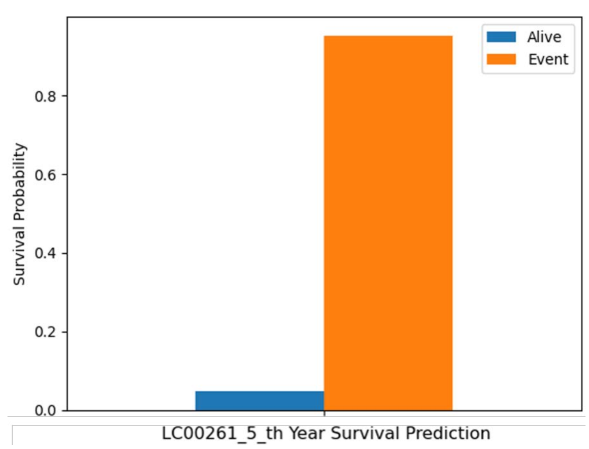

Figure 5. Binary survival classification of a lung cancer Patient Result.

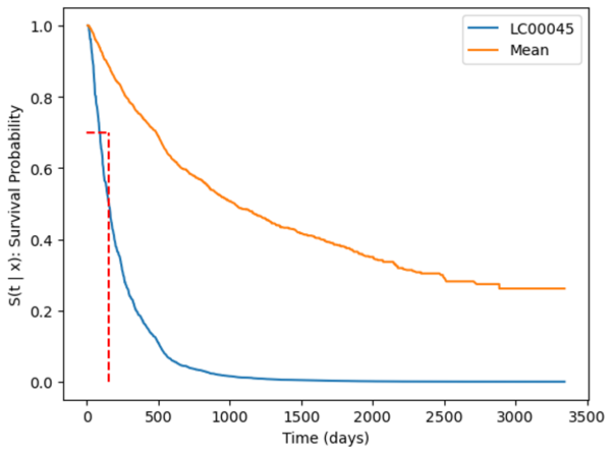

Figure 6. Survival analysis based on lung tumor segmentation Result.

of a NSCLC patient with ID LC00045 for survival period analysis after the diagnosis. The output is a graphical representation of survival probability prediction in comparison with mean survival time of NSCLC patient and the ground truth survival time. It can be observed that the survival probability drops drastically within 600 days. The clinical experts can analyze the predicted probability along with the patient data visualization into making the optimal treatment plan.

5. Conclusion

In this paper, we propose CompMed web-service platform as a solution to the challenge of creating an intuitive and reliable AI medical web-service framework that can be flexible and widely applicable to diverse AI healthcare services. The platform offers real-time updates and visualization of patient data which accurately represents each patient's medical condition with clinical data analysis and provides decision support for personalized treatment planning. We validated the performance by implementing proposed architecture with comprehensive precision medicine services from multiple disciplines. Through a series of extensive experiments, we were able to confirm that the proposed architecture is adaptive, scalable, and highly flexible for integrating new services effortlessly in the future. Overall, our proposed comprehensive precision medicine web-service platform represents a promising step forward in the development of AI-driven healthcare services, offering a efficient and flexible integrated decision support framework for healthcare professionals to deliver personalized, data-driven treatment plans to their patients.

Acknowledgments

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