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AI-Augmented Virtual Health Assistant: A Web-Based Solution for Personalized Medication Management and Patient Engagement

Ravi Shankar Garapati
Frontend Engineer, ORCID ID: 0009-0002-1945-5796

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Abstract—A web-based system employing open-source arti- ficial intelligence (AI) models is proposed to augment patient engagement and reduce preventable medication errors. The application fulfills fundamental requirements for medication management, incorporates basic instructions for commonly pre- scribed drugs, provides situational guidance for adverse effects, and includes a mood logging feature that facilitates mental well-being management. Planning each interaction within a broader management context aids patients in better addressing the complexities of medication adherence. Medication nonadher- ence and preventable medication errors are major challenges in healthcare delivery. Community pharmacists in particular have an important role in addressing these. A majority of patients on long-term medicines do not take their medication as prescribed. Conversations between pharmacists and patients who are nonadherent can be difficult, but engaging patients and establishing a trusting clinician–patient relationship are of prime importance.

Index Terms—Web-Based System, Artificial Intelligence, Pa- tient Engagement, Medication Errors, Medication Management, Open-Source AI Models, Drug Instructions, Adverse Effect Guidance, Mood Logging, Mental Well-Being, Medication Adher- ence, Nonadherence Challenges, Healthcare Delivery, Community Pharmacists, Clinician–Patient Relationship, Preventable Errors, Long-Term Medicines, Patient Support, Situational Guidance, Trust Building in Healthcare.

I. INTRODUCTION

Digital innovation is highly sought and embraced to ad- dress many of healthcare's practical difficulties. Artificial intelligence (AI) tools appear to provide powerful compu- tational abilities that can augment patient care and support responsibilities traditionally afforded to and assumed by the healthcare worker. An AI-augmented health system strives for intelligent and instant interaction, collaboration, and health solution suggestions within the entire healthcare ecosystem. Virtual Assistants have become popular in personal life pat- terns assisting with household chores, interacting with home IoT devices, reminder setups, or even answering questions on topics of general interest. Virtual Assistants are even recognized as a component of a Smart Home. Recognizing the problem of managing chronic diseases, it is feasible to extend the functions of virtual assistants with the use of AI into the Healthcare field, such as promoting patients' medicine Identify applicable funding agency here. If none, delete this. adherence and increasing patient engagement with healthcare.

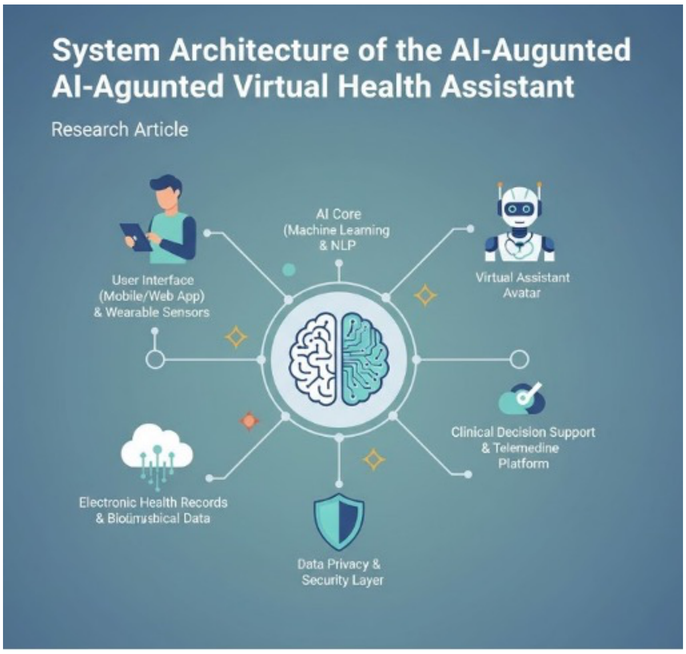

Fig. 1. System Architecture of the AI-Augmented Virtual Health Assistant

A. Purpose and Scope of the Study

This research presents a web-based AI-augmented virtual health assistant designed for medication management, treatment support, and patient engagement. Providing smart medication reminders and monitoring treatment adherence, the assistant addresses limitations and risks associated with traditional reminder systems. An interactive conversational agent interfaces with patients to anticipate and respond to medication-related inquiries, offering practical solutions to adherence barriers such as forgetfulness, complex regimens, and accessibility issues. The assistant also elicits and analyzes user-generated health data, including medication intake and wellbeing observations, to inform health management and provide preventive recommendations. The objective is to investigate the impact of the virtual health assistant on medication adherence and patient engagement, employing a web-based experiment and qualitative analysis of user experiences. The underlying rationale stems from recognition of medication non-adherence as a significant factor in global morbidity and mortality. Conventional reminder technologies demonstrate limited effectiveness, indicating a need for more personalized, context-aware, and interactive support systems. By integrating domain knowledge from a professional medical team, the assistant enhances the quality of response generation and engages patients more closely in their care. The ultimate goal is to empower patients to self-manage their health effectively and to foster productive communication with healthcare providers and caregivers.

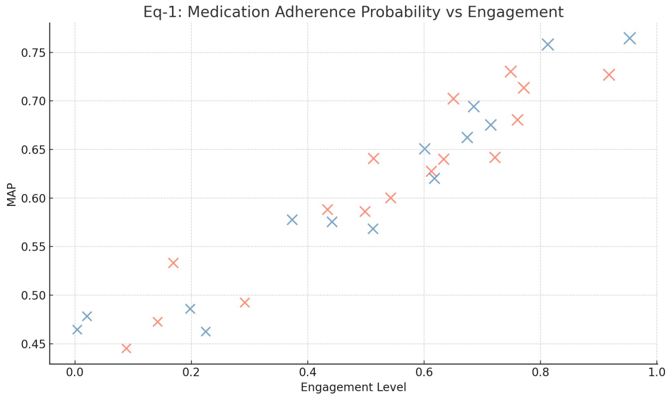

Fig. 2. Medication Adherence Probability vs Engagement

Equation 1:Medication Adherence Probability (MAP)

Model adherence odds linearly in predictors (logistic model):

$\log 1\text{-}pp = \beta_0 + \beta_1 \cdot \text{Reminder} - \beta_2 \cdot \text{RegimenComplexity} -$
(1)
$\beta_3 \cdot \text{SideEffectSeverity} + \beta_4 \cdot \text{Engagement}$
(2)
Solve for probability p via the inverse-logit (sigmoid) to keep $0 \leq p \leq 1$:
$p = MAP = \sigma(\cdot) = 1{+}\exp(-(\beta_0{+}\cdots{+}\beta_5 \cdot \text{Accessibility}))1.$
(3)

II. BACKGROUND AND RATIONALE

The COVID-19 pandemic has reshaped the healthcare sec- tor, accelerating the adoption of technology-driven care that surpasses the limited reach of physical hospitals. Digital technologies are now enabling the delivery of care anywhere in a manner that is cost-effective, highly efficient, and per- sonalized. Despite serving as a relief for healthcare systems, self-care management demands higher levels of understanding and engagement from patients. In particular, medication man- agement after hospital visits presents significant challenges for patients. Non-compliance with medication guidance not only leads to higher rates of hospital readmission but also exerts additional pressure on healthcare providers. Inadequate medication management is thus a primary factor contributing to patient readmissions and escalates the overall cost of healthcare. Empowering patients to better manage their health during recovery—by comprehending health conditions and adhering to medication reminders—can lead to increased self- efficacy. Extensive studies have been conducted to develop interventions that improve medication adherence for various diseases in diverse contexts. Constraints of time and resources, however, limit the ability to provide service for every indi- vidual at any time. Also, medication adherence is just one component of patient engagement that health providers strive to facilitate. The focus is now shifting towards supporting all aspects of patients' healthcare journey, rather than addressing specific challenges in isolation. To accommodate these ex- panded healthcare objectives, a virtual health assistant powered by a large language model (LLM) was conceived. This AI- augmented virtual health assistant could be accessed through an online platform and configured for automated interactions. It is capable of delivering personalized medication reminders in the patient's chosen language and dialect. It can also engage in question-and-answer conversations about patients' health, guided by information provided by healthcare professionals.

A. Significance and Justification for Research

The healthcare industry is facing an era of unprecedented change. Growing numbers of patients who are chronically ill face difficulties managing their conditions and medications. Healthcare services around the world face severe capacity challenges; in some countries, patients may need to wait weeks or months to see a doctor. With the ubiquity of mobile phones, patients now expect assistance to be available whenever and wherever they need it. Yet, using systems designed for ser- vice providers to build and support a growing population of patients with chronic illness is practically impossible. Virtual Health Assistants (VHAs) can address many of these issues by providing personalized healthcare services to individuals online. They can tailor digital support to the specific needs and concerns of patients, answering queries, guiding them step- by-step through processes, and encouraging and reminding them about medication or other activities. Indeed, a large-scale study has demonstrated that chatbots can play a critical role in enhancing medication adherence. Patient engagement goes beyond supporting medication adherence. Questions such as "How does this tablet make me feel? Is it working?" represent real-life concerns that evidence has shown matter greatly to patients, but in practice, these queries are challenging to pose during a consultation, let alone to answer. VHAs can provide sensitive, personalized responses quickly and confidentially. By communicating with its users in these ways, a VHA supports a sense of empowerment and control The service described here has been implemented as a single-page web application, designed to address a significant gap in healthcare. It provides patients with personalized medication reminders, answers medication-related questions, monitors general well- being and progress toward health goals, and encourages users to be actively involved in managing their condition.

III. LITERATURE REVIEW

More than 40% of patients do not take their prescribed medication at the correct dose or at the right time. Medication management is inefficient. Patients do not have an easy way of accessing information related to their illness. As a result, patients do not feel empowered enough to manage their illness and hence do not actively engage with healthcare professionals. Virtual assistant technologies currently assist patients by providing medication reminders and by educating those patients on their respective illnesses. These assistants are usually phone- or tablet-based applications that provide either reminders for medications or education on the given condition. Current technologies are deficient in supporting medication compliance by providing personalized answers to patients' questions, monitoring patient health and hospital appointments, and facilitating timely intervention by health- care professionals. The system integrates patient notes and medication schedules with a virtual assistant response system in order to alert patients when they should be taking their medications and answer questions related to their medications, disease, and general health. Medication non-adherence affects both the patient and healthcare systems adversely. It can negatively affect the patient's health and clinical outcomes, sometimes leading to death. Non-adherence can result in additional hospital admissions, delay in hospital discharge, and readmittance. The World Health Organization estimates that non-adherence can lead to 30–50% failure of treatment results. Non-adherence is a complex and multifaceted problem and requires support at different levels. The reasons for non- adherence are categorized into different groups based on the occasion, type of medication, or the medication-related behavior. The reasons can be broadly categorized as related to the healthcare system, socio-economic factors, disease, condition of the patient, or therapy related. Regardless of these factors, the approach of reducing non-compliance has largely concentrated on communication-based behavior change and education of patients. This approach aims to increase patients' knowledge and understanding of their conditions and medication with the goal of increasing long-term adherence. Various digital technologies such as SMS text messaging, telephone calls, mobile applications, and smart device–based medication reminders have been tested with different groups of patients. These approaches have been effective in improving patient adherence to treatment over a long period.

A. Current Trends in Virtual Health Assistants

Virtual assistants (VAs) are virtually everywhere, and they are being used to book airline tickets, find a good restaurant in town—even to control smart-home devices. VAs such as Alexa, Siri, and Google Assistant are becoming commonly used, and software is increasingly moving toward that kind of natural interface. Currently, commercial health-focused Vas target two groups: healthcare providers and patients. Microsoft has developed a Healthcare Bot service intended to be used by respondents to rapidly create natural-language–based health-care virtual assistants. Google has a Clinical Sufferer Virtual Assistant, built for the detection of coughs and sores of the throat with the use of smart devices. One of the world's largest healthcare technology companies, GE, has partnered with Orbita to build the GE Health Bot—a VA that is constantly getting trained on the historical data of other patients in order to improve decision-making about patients' current health. The Company Babylon has created Healthcheck, a VA that can build a relationship with patients and provide consultation and triage services and medication reminders. Furthermore, Alexa, Apple's Siri, and Google Assistant also include capabilities oriented toward probing symptoms to help determine the necessary actions and whether a visit to a healthcare facility is needed. Consumption of smart devices with health-focused applications is growing rapidly. The Healthcare Information and Management Systems Society (HIMSS) defined four pri- mary use cases for voice assistants in healthcare: delivering healthcare information, patient self-management, scheduling and managing health, and assisting care providers in clinical settings. Although VAs can currently address all four of these use cases, the study prioritizes aiding patients in their self- management of health. Patients need convenient access to per- sonalized care advice and related information in order to know how to best cope and stay healthy. Patients' interactions with the care-delivery system and their providers greatly influence their self-management behavior. A VA can help bridge these interactions by engaging the patient previsit and postvisit and during episodes of care, while acting as a "sidekick" that answers their health-related questions.

B. Medication Management Challenges

Efficient medication management is a cornerstone of patient care, but complex treatment regimens and human factors often lead to sub-optimal health outcomes. Studies demonstrate that over 50% of patients do not take their medications as prescribed, with medication non-adherence identified as the primary cause of preventable deaths, hospital admissions, and emergency room visits. Patients frequently struggle to keep track of their medications, comprehend dosing instructions, monitor side effects, or determine when refills are needed.

Moreover, certain adverse health events are time-critical and demand immediate formal healthcare interventions. Notably, a single medication-related adverse event can account for more than 5% of annual hospital admissions. In recent years, digital health services have continually integrated medication man- agement solutions; however, the rates of adverse medication events remain consistently high. Existing medication manage- ment systems may provide valuable features, but patients often require person-centric and individualized support throughout their entire medication lifecycle. According to the Global Mobile Market Report 2018, 75% of global health app uses are health-related, and 88% of health apps are aimed at consumers.

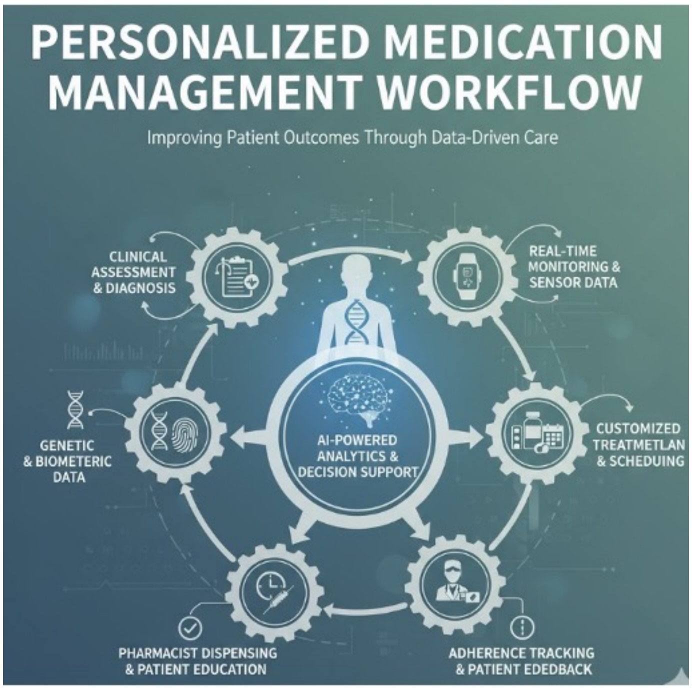

Fig. 3. Personalized Medication Management Workflow

Furthermore, it is estimated that by 2020, 70% of consumers will manage their own health routines using technology.

C. Patient Engagement Strategies

Patients did not start their medication when it was prescribed due to lack of information, side effects, and cost. Strategies that could increase usage of preventative medication included input from and detailed discussion with their doctor, understanding the risk and benefits of treatment, and how it would help with disease management or in preventing disease. Adherence to long-term medication was a major barrier to effective management of existing health conditions and preventative medication for healthy individuals. Patients were more likely to continue therapy when they could see the desired results or long-term benefits or by partnering with their physician in disease management. Barriers to adherence included limited understanding of side effects and their management, concerns about long-term effects, competing routines, lack of symptoms or feeling healthy, and cost of medication. Improving the way patients and physicians interact was regarded as key to supporting adherence. Patients valued structured side effect information that was succinct yet detailed and segmented into easily understandable categories. Women were more likely to ask for support from their doctor and wanted more information and appropriate training for pharmacists. Serious visual side effects were a major concern for both men and women. Incorporating treatment information that can build patient knowledge and empower patients to work in partnership with their healthcare provider for disease management would support the initial decision to be prescribed medication and

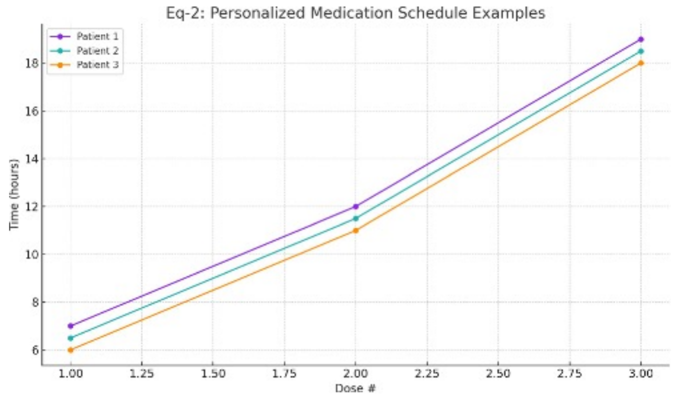

Fig. 4. Personalized Medication Schedule Examples

help maintain adherence to prescribed therapy.

Equation 2: Personalized Medication Schedule (PMS):

Minimize squared deviations between adjacent doses and the target spacing W/n:

$$\min_{t_1,\ldots,t_n} \sum_{i=1}^{n-1} \left((t_{i+1}-t_i)-W/n\right)^2 \quad \text{s.t. } s \le t_1 < \cdots < t_n \le e. \quad (4)$$

First-order conditions give equal spacing at optimum:

$$t_i^{\star} = s + (i-1)nW \qquad (5)$$

To personalize for engagement $E \in [0, 1]$, shift slightly toward earlier reminders when engagement is low:

$$t_i = t_i^{\star} + n\kappa(1-E), \quad \kappa > 0 \qquad (6)$$

IV. METHODOLOGY

The study was prompted by appreciation among healthcare providers for innovative technologies that can address patient needs and improve service quality. A pilot survey involving a general population of 75 respondents confirmed the motivation and supported progression toward delivering a web-based virtual health assistant. The objective of the virtual health assistant is to support medication management and promote active patient engagement in personal health. To assess its effectiveness in a clinical context, the assistant was pilot tested with patients undergoing chemotherapy for colorectal cancer. The administration of the virtual assistant was informed by the Consolidated Standards of Reporting Trials (CONSORT) statement.

A. Research Design

Designing a medication regimen that enhances adherence, especially for LTCs requiring consistent medication intake, is a formidable challenge. Many patients face practical difficulties in managing their medication effectively. Moreover, patients often seek information and advice on various aspects of their conditions from multiple sources, desiring instant and reliable

Fig. 5. Patient Engagement and Feedback Loop Model

responses. They also recognize the importance of monitoring clinical parameters and test results but struggle to assess their significance. Non-adherence to prescribed medications not only poses a major health risk but is also associated with substantial avoidable financial burdens. Personalised medi- cation reminders and education, combined with monitoring, offer promising avenues to mitigate these challenges. Realising these shortcomings, a web-based AI-augmented Virtual Health Assistant has been developed to assist patients on long-term medication treatments. The system enables caregivers and patients to establish and maintain personalised, daily med- ication reminders. Detailed instructions and information on the relevant condition or medication can be accessed through an intuitive question-and-answer portal. Additionally, patients can submit their clinical parameters and test results over time, which are then analysed to provide context-sensitive feedback and suggestions for follow-up.

B. Participant Selection

Selection of virtual assistant users was based on the fol- lowing inclusion and exclusion criteria. Participants utilizing a virtual assistant capable of responding intelligibly to questions concerning chosen topics were included. Selection proceeded via an iterative approach in which the initial batch of vol- unteers was identified by matching a set of predetermined search queries against a specificity criterion. Queries had to be formulated such that their search results accurately identified potential participant candidates. The aim was to curate an initial set of virtual assistants that collectively represented a broad topical spectrum, thereby minimizing selection bias. Subsequently, additional interviewees were identified based on their responses to information requests. Exclusion criteria encompassed virtual assistants whose outputs were confined to mere navigation-related explanations.

C. Data Collection Methods

The implemented web-based patient support system for medication management clearly demonstrates how an AI- augmented virtual health assistant can improve the understand- ing, monitoring, and management of specific health conditions.

In addition, the system can also play the role of an AI life coach and contribute to improving treatment adherence. Currently, an extended final implementation version of the system is in testing and validation, following the lines de- scribed in Table 5. The implementation tests serve to evaluate both technical and technological aspects of the system. Once enough users have evaluated the system and experienced its main functionalities, the patient usage and satisfaction tests seek to assess its impact on a particular clinical problem as well as users' general perceived satisfaction—the user rating. Moreover, the COVID-19 outbreak has interrupted the planning and scheduling of clinical studies supporting future implementations. When the situation returns to normal, the fact that the selected focus area—the management of exacerbations in bronchiectasis—is one facet of the COVID-19 disease could make it easier to launch a study that complements the initial tests.

D. Data Analysis Techniques

When available, audio, visual, and textual analysis was conducted on user questions posed to the web-based AI- augmented Virtual Health Assistant using different techniques. Detected speech confidence levels delivered by Azure Cogni- tive Speech Services were used as a filtering criterion to retain only reliable audio inputs for analysis and troubleshooting purposes. Speech confidence describes the likelihood that the recognized text corre-sponds to the spoken input. Ideally, speech confidence values range between 0 and 1; conver-sation turns with speech confidence below 0.6 were disregarded. Speech confidence was available only for English conversation turns. On one hand, FAQ retrieval enables QnA Maker to identify the most rele-vant FAQ based on a user question. On the other, Smart Assistants are exposed to a wide range of Q&A pairs beyond the limited scope of a given FAQ and, thus, resort to more generalised knowledge bases, such as ConceptNet, which can be used as a source by causality-aware recommender systems. The Jaccard similarity coefficient J was used in textual analysis according to Equation (1), where, for any pair of finite sample sets A and B, the Jaccard index $J(A, B) = |A \cap B|/|A \cup B|$ is defined as the size of the intersection divided by the size of the union of the sample
sets.

Equation 3: Engagement Score (ES):

Weighted additive index (weights sum to 1):
$ES = w1I + w2M + w3Q + w4A, wi \geq 0, \Sigma wi = 1.$ (7)

V. SYSTEM ARCHITECTURE

Medication nonadherence contributes to approximately 100,000 deaths and 69 billion dollars in hospital expenditures annually in the United States. Patients cite a multitude of barriers to adherence, including complicated medication reg- imens and challenging side effects. These barriers contribute to nonadherence along the whole patient education journey,

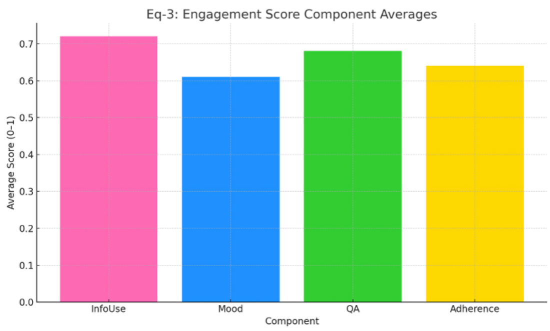

Fig. 6. Engagement Score Component Averages

from filling prescriptions to refilling, and merely understanding these medications. An Automated Medication Assistant can help overcome these barriers by enhancing patient engagement through personalized education, reminders, and monitoring. To address these barriers, the research team developed a web- based AI-augmented virtual health assistant that interfaces with the patient and integrates with the electronic health record (EHR). The system architecture supports personalized medication management, patient education, and health moni- toring, along with robust medication adherence support. The assistant provides clinically valid information, reminders, and monitoring to enhance patient engagement. The Automated Medication Assistant communicates with the patient and in- corporates an AI language model to parse natural language questions and return answers. It also facilitates management of a user-provided medication list. The server-side application is developed in Python, utilizing a web micro-framework with Jinja2 templates for web page generation. A secure, persistent medication database maintains the medication list. The application implements asynchronous static web push notifications to deliver reminders and enables simple logging of patient responses. For greater utility, the assistant can send notifications directly to the patient's device; nonetheless, for privacy reasons, answers to natural language questions do not include patient-specific data.

A. Overview of the AI Model

Socratic questioning is a form of disciplined questioning used for many purposes, including exploring complex ideas, getting to the truth of things, opening up issues and problems, uncovering assumptions, analysing concepts, distinguishing what we know from what we don't know, and analysing the consistency of beliefs, analysing the quality of evidence, and as a method of intellectual probing. It is named after the classical Greek philosopher Socrates and generally follows a series of specific steps to explore philosophical issues and seek the truth. Within Socratic questioning, AIA-DRL-SQ represents a Web-based AI-augmented virtual health assistant. It aims to aid medication management by scheduling personalized

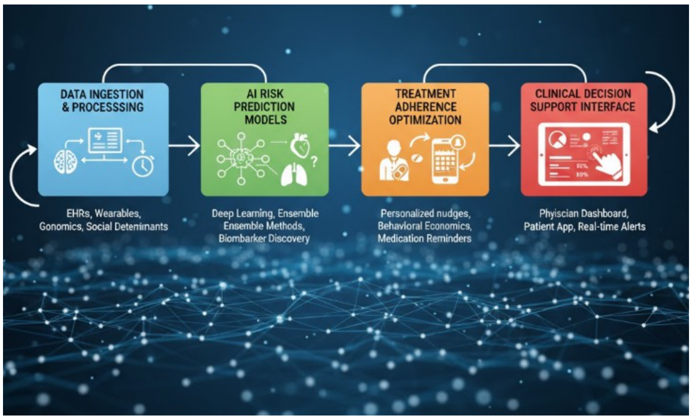

Fig. 7. AI Decision Support Pipeline for Risk Prediction and Adherence Optimization

reminder missions to help patients overcome particular chal- lenges. It also supports patient engagement and interaction by encouraging a two-way patients-and-healthcare-professionals communication via a Socratic questioning framework

B. User Interface Design

The user interface of the digital assistant serves to assist patients by facilitating interactions with the clinical care team and improving medication management strategies, while also helping patients keep track of medication schedules. It is designed as a text-based conversation, optimized for web and mobile browser use, and capable of device-agnostic task execution. The interface offers personalized medication plans based on e-prescribing data and enables users to ask ques- tions about medications, treatments, and risk factors. Users can also share key clinical measurements for adverse event monitoring. An optional connection to the patient's electronic health records retrieves structured data for a comprehensive medication safety profile, specifically from the Longitudinal Health Record (LHR). The assistant can administer simple health screens focused on adverse medication events of varying severity. The entire interaction is secure and authenticated via the OneWelcome Digital Identity & Access Management (IAM) solution, allowing users to either log in using their healthcare provider's credentials or proceed as guests. The underlying Language Learning Model (LLM) ingests user input, extracts relevant information, and formulates responses tailored to the individual, in compliance with GDPR and privacy regulations. Emerging regulatory considerations for AI also influence the design and implementation of the interaction service dedicated to the virtual health assistant.

C. Integration with Health Records

Integrating health data is a critical component of the IVHA. Currently, data have been stored locally within the VHA in CSV and JSON files. However, the system is designed to connect and access different health services, such as the Electronic Health Record (EHR) or Patient Health Record (PHR), to provide real-time health information. Healthcare services, providers, hospitals, and insurance companies have been developing and storing patients' data digitally in different systems as EHRs. Being able to access patient health records will allow the IVHA to extract and use past clinical data about diseases, medications, allergies, and family history. Most existing healthcare systems allow only patients to enter their data for diagnosis. However, this functionality is not available in popular health records such as EHR and PHR, which allow only healthcare providers to enter data. Patients can only view their health information in these systems. Even if the patient has entered their symptoms in the IVHA, the system will recognize patients from the database and extract their medical history and personal information from their health records.

VI. FEATURES OF THE VIRTUAL HEALTH ASSISTANT

AI-augmented virtual health assistants present novel oppor- tunities to address common challenges in medication manage- ment and enhance patient engagement in healthcare processes. Assisted living residents typically take multiple prescribed medications and may experience adverse medication events, diminished health-related quality of life (HRQoL), and in- creased hospitalizations. In response to these issues, the design of a web-based, AI-augmented virtual health assistant was undertaken to support medication management and patient en- gagement. The web interface accessed via smart-home devices or a desktop computer enables assisted living residents and patients recently discharged from the hospital to monitor their health through a series of personalized questions. The in-home, interactive patient health survey services benefit assisted living residents by serving as a cognitive behavioral tool that guides everyday actions and decisions. For recently discharged pa- tients, the web-based health assistant monitors their medication adherence and health status through customized queries. The intelligent virtual assistant is capable of answering medication- and health-related questions while also assisting with life-style coaching. A snapshot of the virtual assistant's capabilities in- cludes displaying the current medication list, providing infor- mation about drug–drug interactions, explaining the pharmacy search process, offering guidance on diet during medication use, and supplying details about the COVID-19 pandemic. The AI augmented virtual health assistant provides an integrated, interactive web solution that improves medication management and reduces unwanted hospital readmissions.

A. Personalized Medication Reminders

Medication adherence is crucial for disease management and prevention of complications and hospitalizations. How- ever, the ability to follow medication guidance is affected by many factors and there are still shortcomings in the current provision of medication management services. A web-based AI-augmented virtual health assistant could be an important component in a future digital health ecosystem for medication management and engagement. The virtual health assistant enables more personalized, interactive engagement and support for medication-related information. It is designed to help over- come known medication management difficulties, such as un-intentional over- or under-dosing, and enhance communication between patients and healthcare providers. By complementing digital personal assistants like Alexa and Google Assistant, this solution offers medication-specific articles and question- and-answer functionality that together act as an ongoing information resource, assist with routine self-care, and facil- itate earlier recognition of patient deterioration. Testing with asthma patients has demonstrated especially positive feedback regarding the personalized medication reminders feature.

B. Interactive Q&A Functionality

The AI-augmented web-based Virtual Health Assistant facil- itates healthcare management with natural-language questions, enabling users to explore topics such as COVID-19 and associ- ated symptoms. The assistant leverages a question–answering model that interprets free-text queries and returns pertinent responses, ensuring consistent and reliable information de- livery. Constructed on a UnifiedQA-base architecture with reinforcement learning from human feedback (RLHF), the model is trained on over 500,000 questions from more than 20 datasets across diverse domains. Collected sources include reputable institutions and government agencies, such as AMT, DMV, Reddit, SCPedia, Amazon, Madlibs, Wikipedia, DBpe- dia, TREC, and SQuAD

C. Health Monitoring Tools

Digital health solutions have been playing an increasingly important role in the post-pandemic retrospect. Mental well- being and physical fitness remain a mentionable factor in any person's health journey and lifestyle, thus reminding users of their daily step goal and encouraging them to maintain a healthy activity level could provide meaningful help toward a healthier life. Reminding fitness schedules and suggesting outdoor activities for a less sedentary lifestyle encourage users to get a better body. However, before suggesting workouts and activities, the AI model must screen for the following conditions to ensure it is appropriate to encourage physical fitness and activities for a user: • Whether the user suffers from high body temperature (or fever) • Whether the user is immunocompromised • Whether the user takes any medication that limits physical activity • Whether the user has muscle fatigue or low activity level due to drug side effects Those conditions are screened beforehand to avoid worsening any adverse effects or symptoms. Furthermore, the assistant can guide the user through meditation exercises when stress or anxiety level surveys suggest it is needed.

Equation 4 : Risk Alert Function (RAF)

Logistic mapping to probability:

$RAF = \sigma(\gamma0+\gamma1\cdot MissedDoses7d+\gamma2|z|+\gamma3\cdot \text{Side Effect Severity})$

(8)

VII. IMPLEMENTATION

AI-augmented virtual health assistants have garnered sig- nificant attention as practical solutions to support patients

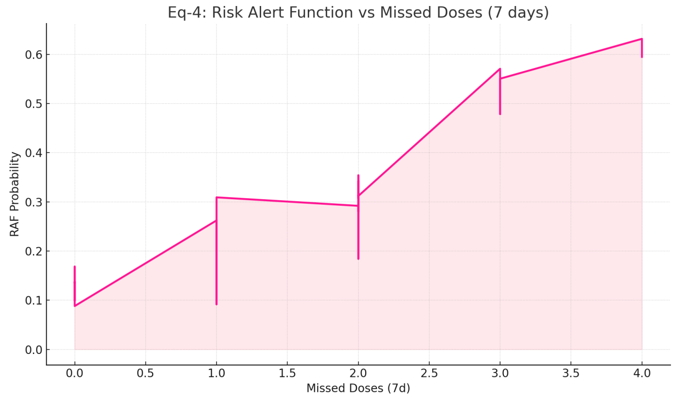

Fig. 8. Risk Alert Function vs Missed Doses (7 days)

and caregivers in managing their own health. These tools employ conversational AI models and can be easily accessed from smartphones or any web browser. Emerging digital technologies such as Artificial Intelligence (AI), Machine Learning, Internet of Things (IoT), and Deep Learning (DL) are becoming integral in the ongoing digitalization of the healthcare industry. Interactive Assistant Systems utilizing conversational AI models have been developed for assisting healthcare professionals in managing hospitals and the wider medical domain. Conversation Elements with Contextual and Emotional Understanding in these AI Systems help improve patient experience. Such systems gradually build empathy and sympathy for the patients and caregivers, using sensitive and specific language for different types of illnesses. An intelligent healthcare system, implemented in a web-based Virtual Health Assistant, addresses two key issues in the healthcare domain. The first is the inability of older patients or those undergo- ing rehabilitation to manage their medications, resulting in medication non-adherence or overdose. The second is the lack of patient support in managing their health or well- being. Recent developments in the COVID-19 pandemic have emphasized the importance of patient engagement; with few doctors available, patients must engage in self-care and self- check-up, supported by their caregivers. The AI-augmented Virtual Health Assistant provides a Web Application giving Medication Reminders and Patient Engagement in Self-Health Care and Self-Management of the treatment during and after any ailment or medical procedure.

A. Development Process

The AI-augmented virtual health assistant was developed to improve medication management and patient engagement. It represents a Web-based solution custom-tailored to the needs, preferences, and lifestyle of each individual. Its key objective is to address specific factors of non-adherence, including an information gap about one's medication and illness, lack of confidence when communicating with people from the healthcare sector (e.g., Concerns about privacy or stigmati- zation), and difficulties in understanding medical terms or asking health-related questions. Designed to be intuitive, easily accessible, and friendlier than existing systems, the assistant makes the necessary medication information readily available through an interactive platform capable of answering users' health-related questions, available 24 hours a day and in both voice and text modalities. Starting from these premises, it is connected with the electronic health record of the patient, from which it extracts the medication plan to generate reminders to take and renew medicines at specific times.

B. Pilot Testing

Pilot testing constitutes a critical phase in the development of the AI-augmented virtual health assistant prototype. It enables the identification and correction of errors at an early stage and provides an opportunity to gather valuable end- user feedback that informs further refinement of the virtual health assistant. Such a testing phase is essential for the successful deployment of an innovative digital healthcare system. Seven evaluators, all employees of a Queensland University of Technology (QUT) personnel department and aged above 18, were involved in assessing performance and basic functionality. However, the target user group comprises older adults and chronic disease patients who require tailored medication support and intervention. Potential pilot partici- pants were identified via a clinician referral. The inclusion criteria were: (a) age 65+ years; (b) taking medication for long-term health conditions; (c) residing independently in the community; and (d) possessing suitable English language pro- ficiency. Table 7.1 presents the demographic data of seven pilot testers, with respondents originating from Australia (n=4), the USA (n=2), and Afghanistan (n=1). The current prototype, developed during the study's implementation phase, could be tested only by the QUT employees due to the limited technical interface designed for such purposes. Subsequent user testing with the broader patient cohort will be conducted following the completion of the full functional system.

C. Feedback Mechanism

A special feature of the web-based service is its ability to evaluate responses and provide meaningful user feedback in cases of complexity and uncertainty. For instance, when a user asks "Is it safe to take Ibuprofen for my condition?" the service first confirms the user's condition and subsequently categorizes the question as an off-prompt question. Based on the anticipated answer, an opinion can be offered only if it is supported by high confidence levels. This strategy, which hinges on assessing the level of complexity, is complemented by response diversification grounded in confidence scores. While a response is furnished despite low confidence, subsequent steps seek alternative answers. If the second answer again exhibits low confidence and category mismatch, the service politely declines to answer. This methodology can be adaptively applied to the interactive questioning processes of various system components.

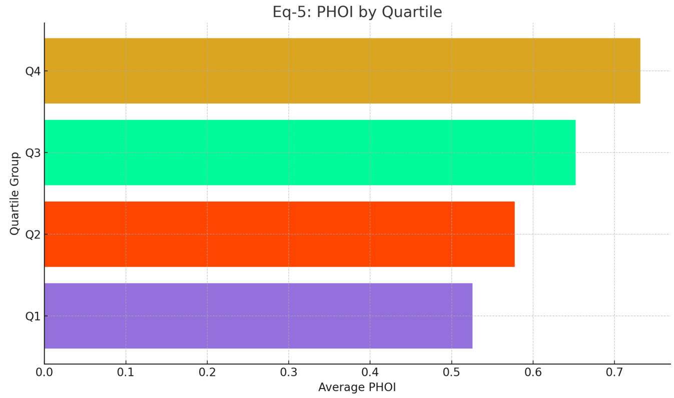

Fig. 9. PHOI by Quartile

Equation 5 : Patient Health Outcome Index (PHOI)

Use a geometric aggregator to penalize any weak link:

α β γ δ 1

studies can be conducted with patients to comprehensively evaluate the solution and further improve the functionalities.

A. Potential Enhancements to the System

Based on the implementation experience and patient feed- back, several potential enhancements can be considered to im- prove the virtual health assistant's practicality, comprehensive- ness, and interactivity. Optimizing screen-reader compatibility will make the system more accessible to visually impaired pa- tients. Allowing logical operators such as AND, OR, and NOT in the context of medication-related questions can broaden the range of inquiries that the assistant handles reliably. Additional improvements include extending the question types to cover information about other health conditions, such as diabetes, depression, and asthma. Enabling patients to continuously enter their health conditions will allow them to receive more personalized support and information. Furthermore, engaging users with continuous questions about their medication intake could encourage compliance and provide support to individu- als with poor medication habits, risk of medication error, or

PHOI = (MAP

with α, β, γ, δ > 0

·(1−RAF)

·Control

·ES) /α + β + γ + mδ ental illnesses such as schizophrenia. (9)

B. Broader Applications in Healthcare

Healthcare has long been a sector in which language-based

VIII. FUTURE DIRECTIONS

Enhancing medication management and patient engagement through artificial intelligence in healthcare is an active research area with many open challenges and opportunities. Forthcoming developments can therefore extend AI-based virtual health assistant functionalities in several directions. First, natural lan- guage processing capabilities can be considerably improved by exploiting state-of-the-art solutions based on the Transformer architecture, such as the models in the BERT or GPT series. Compared with the current BERT-Large model, these models require fewer parameters owing to transfer learning, reduce training time, and improve the overall prediction performance. Second, in addition to dialog generation, keyword recognition, automatic speech recognition, and text- to-speech modules can be integrated to create a voice-enabled solution that is accessible to a broader population of users, including those with limited computer literacy or poor vision. Third, the search and retrieval process of the health information feature can be optimized by leveraging large generative language models (e.g. ChatGPT) to provide responses directly instead of relying on fact retrieval and ranking modules. Fourth, statistical analyses and natural language descriptions could be added to the vital signs feature to provide users with clear information about their health conditions. Fifth, a symptom monitoring function can be developed that enables users to input COVID-19 symptoms, dates, and durations. The system can then classify the symptoms as “possible,” “likely,” or “COVID-19 cases” based on risk and suggest appropriate medical treatments and testing. Sixth, the Web application can be connected to electronic health records of health organizations for a true life-long medication management experience. Finally, clinical artificial intelligence systems could play a truly transformative role, and the ramifications of such technology are beginning to take shape. Certain applications are so obviously useful that it is worthwhile examining their implementation in emerging models to gauge strengths and weaknesses. The web-based Virtual Health Assistant provides a general platform for user and staff engagement through natural-language interactions, then hones in on medication management. Users override the straightforward English-chat functionality to input details about prescribed medications, setting reminders and enabling additional monitoring. The resulting personalized notifications increase adherence and allow users to explore potential health implications for missed or late doses. Access to Medica- tion Guides and interactions with Medication FAQs serve to contextualize the prescribed therapies, educating users and enabling informed decision-making. By deploying the system in a closed beta-release mode at Houston Methodist Hospi- tal, controlled results evaluate its effectiveness at increasing medication adherence and promoting patient engagement

IX. ETHICAL CONSIDERATIONS

Interest in artificial intelligence (AI) applications in the digital health sector is increasing exponentially, attracting many stakeholders from different countries. Development of artificial intelligence through virtual health assistants and conversational agents facilitates efficient patient interaction and care tailored to patients’ diverse healthcare needs. Enabled by machine learning and natural language processing, virtual health assistants offer a more personalized experience and can engage patients in their healthcare journey. AI chatbots can perform various tasks, from managing patient health, providing health-related information and services, acting as mental health professionals, health advisors, and caregivers, to scheduling doctor appointments. Despite their potential, few well-documented deployed systems exist in practice.

Tailored systems are typically more effective at assisting patients with specific or complex diseases by offering personalized medi- cation prompts, specific Q&A, and interactions aligned with individual patient profiles. A web-based virtual health assistant offers an accessible solution without requiring installations or mobile devices. Implementation of such a system, combin- ing virtual health assistant functionality with a personalized medication management system, can serve as a medication assistant for patients. By reminding patients when to take their medications through an easy Q&A chat interface and allowing recording of vital health parameters such as chest pain, blood glucose, blood pressure, heart rate, body tempera- ture, and heartburn, the system enhances patient-centered care. Automation of medication schedules and reminders improves medication management and patient engagement with their healthcare journey.

A. Data Privacy Issues

Protected health information has long been subject to a variety of safeguards and regulations administered by the U.S. Department of Health and Human Services. These regulations include the Health Insurance Portability and Accountability Act of 1996 (HIPAA), Security Awareness and Training, Breach Notification Rule, Privacy Rule, Audit Controls, Busi- ness Associate Agreements, and Health Information Technol- ogy for Economic and Clinical Health Act (HITECH). Before any private data in this assistant can be used, they must be anonymized and hashed by suitable software tools. Users of the AI healthcare assistant also need be aware that they must consent before their personal protected health information can be disclosed. Indeed, patients, residents, students, and employees of the healthcare organization may use the assistant, which is intended to minimize the costs and difficulties in providing care. Therefore, they can expect to have all relevant information in a convenient and easy-to-get-from fashion with a healthcare provider. To understand the inherent risks of using the AI healthcare assistant, the user must review, acknowledge, and agree to an electronic consent form that clearly states the limitations of the responses, the types of information that will be provided, that this is not an emergency service, and not a substitute for a visit to a provider.

B. Informed Consent Protocols

Personal health data is very sensitive; therefore, patients must give their freely informed consent for data collection, analysis, and storage. The Virtual Health Assistant system includes an informed consent protocol integrated into its User Interface. This ensures that the participants of the pilot study are fully aware of the objective of data collection and storage, as well as their rights and options. The consent screen contains the selection and confirmation buttons. The “I do not consent” button disables all active features of the Virtual Health Assistant and shows an alert message on the

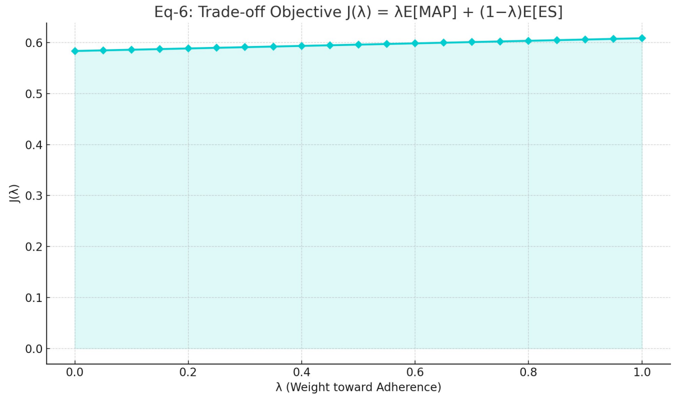

Fig. 10. Trade-off Objective J() = E[MAP] + (1)E[ES]

screen, while the "I consent" button enables the features and displays a welcoming message. The users can revoke their submission at any time by clicking the "Withdraw consent and delete all information" link.

Equation 6 : Model Optimization for Engagement & Adherence:
Define a scalarized objective with trade-off $\lambda \in [0, 1]$:
$\max J(\lambda) = \lambda E[MAP] + (1 - \lambda)E[ES]$ (10)

X. CONCLUSION

Digital health innovation continues to address the threefold challenge, of controlling rising health care costs, providing easy access to quality of care and improving health outcomes, through the development of AI-augmented virtual health as- sistants. This study developed a web-based AI-augmented virtual health assistant, capable of proactively reminding pa- tients to take their medications and guiding patients through personalized conversations about their medication, condition or general health, in order to increase engagement, education, and medication adherence. The evolution of the field suggests a range of applications to relieve, support and augment over- strained health care providers, while simultaneously empower- ing patients to take control of their own care journey. Generic features that align with the Creating Compliance Sidekick formulation include providing general medication information, condition information and supporting documentation, contact information, answering patient queries and reporting home- monitored health vitals. Proactive patient engagement facil- itates improved care outcomes, by informing and educating patients about their condition and care plan, in addition to gently nudging for improved medication adherence.

A. Summary of Key Findings and Implications

Research and developments on Artificial Intelligence (AI) have recently taken important steps forward. Among the many benefits brought by moving into the AI domain, Virtual Health Assistants that increase the engagement of individuals within the healthcare system contribute towards decreasing costs and lowering long-term morbidity, mortality, and sequelae as a consequence of medical conditions. AI-augmented Vir- tual Health Assistants are quickly becoming a key area in many applications within the healthcare industry, including personalised medication management and reminders, patient engagement and education, health monitoring, patient con- dition and medication-related adherence analysis, and many more.

Medication non-adherence is acknowledged in the lit- erature as a significant clinical and economic problem. It is estimated that between approximately 20% and 54% of patients do not take their medications as prescribed, a factor that can contribute to the failure of achieving the desired therapeutic outcomes. Poor medication adherence is a public health problem that negatively impacts patient outcomes and has a large financial burden on healthcare systems. Non- adherence results in increased complications, management of adverse events or worsening of disease, more visits to gen- eral practitioners and emergency departments, and additional hospitalisations. It is estimated that between C125 billion and C200 billion of healthcare costs are directly attributed to non- adherence in Europe (1.25% to 2% of the gross domestic product). Various reasons for non-adherence exist, including the individual forgetting to take their medication, disliking the side effects, or lacking confidence that the medication is right for them. These difficulties can exist alongside factors related to healthcare provision or health system determinants. Despite the challenges of adherence, the National Institute for Health and Clinical Excellence and other guidelines recommend that health professionals should support and educate individuals about the importance of taking their medications and assist with the identification of optimal medication regimens.

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