PNRG: Knowledge Graph-Driven Methodology for Personalized Nutritional Recommendation Generation

Aminah Bilal Lodhi[1], Muhammad Abdullah Bilal[2], Hafiz Syed Muhammad Bilal[1(✉)], Kifayat Ullah Khan[2], Fahad Ahmed Satti[1], Shah Khalid[1], and Sungyoung Lee[3(✉)]

[1] National University of Sciences and Technology (NUST), H-12 Campus, Islamabad, Pakistan
{alodhi.mscs19seecs,bilal.ali,fahad.satti,Shah.khalid}@seecs.edu.pk

[2] FAST National University of Computer and Emerging Sciences, Islamabad Campus, Islamabad, Pakistan
{i190616,kifayat.alizai}@nu.edu.pk

[3] Kyung Hee University Global Campus, Yongin, South Korea
sylee@oslab.khu.ac.kr

Abstract. Chronic Diseases are a prevalent problem that affects millions of people worldwide. It is a prevalent health condition that requires careful diet and medication management and preventing chronic diseases. Traditional approaches to nutritional recommendation generation often rely on generic guidelines and population-based data, which may not account for individual dietary needs and preferences variations. In this paper, we propose a knowledge graph driven methodology for generating highly personalized nutritional recommendations that leverage the power of knowledge graphs to integrate and analyze complex data about an individual's health, lifestyle, and dietary habits. Our methodology employs a multi-step process that includes data collection and curation, knowledge graph construction, and personalized recommendation generation. We illustrate the effectiveness of our approach through a case study in which we generate personalized nutritional recommendations for a sample individual based on their specific health and dietary goals.

Keywords: Chronic Kidney Disease · Knowledge Driven Approach · Personalized Nutritional Recommendation System

1 Introduction

Chronic kidney disease (CKD) is a long-lasting condition that can lead to a range of complications, including cardiovascular disease, decreased immune response, anemia, fluid retention and bone disease. Chronic kidney disease accounts for a very high risk for cardiovascular diseases [1] among other diseases. The high probability of developing conditions like hypertension can be countered to some extent using lifestyle changes such as increased physical activity, better dietary habits, and regular monitoring of medical reports related to these conditions. On the other hand, medical conditions such as

K. Jongbae et al. (Eds.): ICOST 2023, LNCS 14237, pp. 230–238, 2023.
https://doi.org/10.1007/978-3-031-43950-6_20

hypertension and diabetes can be successfully managed by changes in lifestyle such as dietary restrictions. These lifestyle changes include recommendations such as reduced salt intake as well as an increase in the consumption of fruits and vegetables while decreasing the consumption of processed food items [3].

1.1 Effect of Diet on CKD Patients

Chronic kidney disease (CKD) is a condition in which the kidneys are not working as effectively as they should to filter waste products from the blood. Diet plays a critical role in managing CKD. Some of the effects of diet on CKD patients which we have taken Center of Disease Control and prevention [4] include sodium, protein, potassium, phosphorus, vitamins (such as vitamin D [5], iron [6], and calcium [7]), minerals, and fluids.

1.2 Knowledge Graph-Based Application for Nutritional Recommendations

In this paper, we propose a knowledge graph-driven methodology for generating highly personalized nutritional recommendations that leverage the power of knowledge graphs to integrate and analyze complex data about an individual's health, lifestyle, and dietary habits.

The development of applications that provide personalized health management and nutritional guidance [8] has the potential to improve the quality of life for CKD patients by facilitating self-management and providing access to specialized knowledge. In this paper, we present the development of an application that incorporates a range of features to support personalized health management for CKD patients.

The app also includes medication reminders, nutritional guidance, drug interactions, CKD stage Calculation, and a log of medical tests and Food. This research paper aims to evaluate the effectiveness of our healthcare app in managing CKD.

The application incorporates the following features:

1. Recommendation of nutrients depending on medical tests,
2. Log of medical tests,
3. Drug and Food interactions,
4. CKD stage calculation,
5. Noninvasive health data

2 Related Work

Previously work has been done regarding the implementation of tech-based solutions for chronic kidney disease most notably of which is the work done by Chatterjee et. Al [9] in his work they have taken a similar approach where lifestyle data can be logged into an app and because of it, a qualitative analysis of a patient's lifestyle can be performed. Although the methodology proposed by this paper includes lifestyle data, it builds upon that by adding dietary data as well as medical test data performed by hospitals as well. Due to the addition of these parameters, the purpose of this paper is not only to help patients better understand the effect of their lifestyle choices but also as an analysis tool for medical professionals.

Another study that targeted the same domain created a web-based platform for helping women living in rural areas with obesity [10]. They used a web-based system to provide guidance tailored specifically to people living in hard-to-reach places. One of the limitations of that paper was that only participants that were interested in physical activity and nutrition were only interested in using the system. We have tried to solve the problem by taking proper input from the doctors as well and trying to incorporate the system into the treatment regimen of the patients.

Another similar study [11] done related to this field provided a similar system to ours regarding the fact that the platform proposed by them had the ability to keep track of medical reports, physical activity, and dietary data and the data could be shared with medical professionals, but the platform was only targeted to meet the needs of pregnant women having diabetes.

3 Methodology

3.1 Overview

Using an algorithmic approach, we developed a tool that generates personalized lifestyle recommendations for CKD patients based on their individual test results. The web application was developed using a combination of open-source tools and programming languages, the architecture includes NodeJS, Express, MongoDB, React, and Tailwind CSS, D3 library and Knowledge graphs as shown in Fig. 1. The user data has been stored in MongoDB while the knowledge base is used to represent the interactions between the drugs, food etc. successfully divide the application specific data and the domain specific data. Along with this, patients will be able to log their non-invasive health data such as blood pressure, heart rate, and blood sugar levels. This would allow patients to monitor their health condition using a graphical user interface. The patients would also be able to log in to their medications to get drug interaction information about the medicine that they are taking.

3.2 Server Side

This system's aim would be to ultimately provide recommendations regarding their health data and allow them a safe mechanism for self-monitoring that can also help the doctor regarding their medical decisions. We designed the prototype of this system using the agile methodology and as per the recommendations provided by it, we divided the development of the prototype into five parts: requirement gathering, requirement design, development iterations, testing, and finally feedback.

3.3 Data Storage

First, we collect data from various sources, such as medical records, wearable devices, and food intake logs, to create a profile of the individual's health, lifestyle, and dietary habits. Finally, we generate personalized nutritional recommendations for the individual based on their specific health and dietary goals, using a combination of rule-based and data-driven approaches.

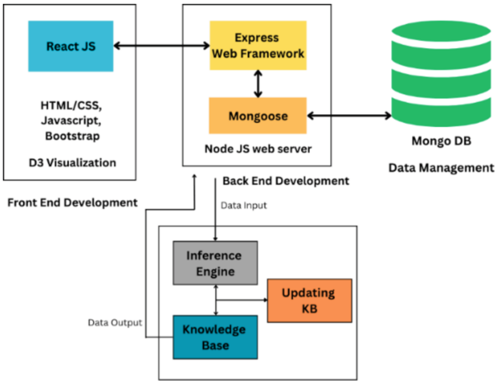

Fig. 1. Application Architecture

Fig. 2. Ontology Design Methodology

We have constructed a knowledge graph that represents the relationships between different entities in the data, such as foods, nutrients, health conditions, and lifestyle factors. To design the ontology, we used OD101 as the knowledge base would be domain specific as shown in Fig. 2. We have used an RDF-based knowledge base that uses RDF, RDFS, and OWL to represent concepts in an interconnected form. Using an RDF triple store as shown in Fig. 3 allows us to publish the data in 4-star format according to Tim Berner Lee's linked data criteria. This would also allow us to use the reasoning engines like the HermiT or Pellet reasoner which allows us to make decisions based on knowledge instead of data which helps us explain the reasoning behind the recommendations that are made. These reasoning engines also provide the advantage of finding associations in data that are not perceivable by the layman.

Knowledge bases also provide a better and more natural format for drug interactions. In our application, this is best seen by the fact that drug interactions naturally have a symmetric property as shown in Fig. 4. That knowledge bases can very easily present while other data storage systems fail to do so. Domain and range restrictions also provide a check for drug interaction data. The symmetric and reflexive axioms also provide a more natural representation of the knowledge represented in the knowledge base as all entities in a drug or food interaction inherently have a symmetric and reflexive relationship.

The methodology followed by the recommendation system follows the following steps:

1. The patients would log their health data including medical test reports, prescribed medications, etc. into the system which would be stored in a NoSQL database.
2. Using the health data of the patient, the application would determine the medical test report values that fall out of the normal ranges.

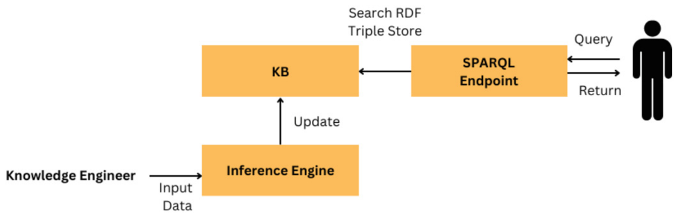

Fig. 3. RDF Architecture

3. Using this information, the application would query the knowledge base to find food items recommended for the patient given their medical test reports as shown in Fig. 5. This step is made possible mainly by the following object property:
   - interacts_with: this object property handles the interactions that take place between drugs and food items as well as drugs with other drugs. This object property is symmetric and hence has the advantage that the inference engine would complete any missing links in the knowledge base.

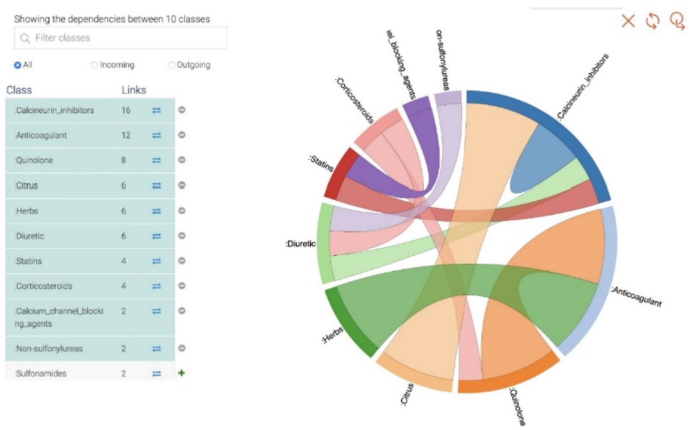

Fig. 4. Drugs/Food Interaction

3.4 Domain Specific Features

The most used method for calculating the stage of CKD is based on the estimated glomerular filtration rate (eGFR), which is calculated using the serum creatinine level, age, gender, and race of the patient. The eGFR provides an estimate of the rate at which the kidneys are filtering waste from the blood. The stages of CKD are classified based on the eGFR and the presence of kidney damage.

Fig. 5. Relationship between drugs and foods

4 Evaluation Methodology

We had 10 volunteers of different genders, heights and weights and age groups, and through CKD stage calculation we have grouped them into 5 groups as shown in Table 1.

Table 1. Details of Volunteers

Subject	Age	Gender	Height (cm)	Weight (kg)	CKD Stage
S1	24	Male	182	74	3B
S2	29	Female	162	59	2
S3	61	Male	177	95	4
S4	37	Male	179	84	3A
S5	57	Female	160	82	2
S6	49	Male	170	70	3A
S7	55	Female	158	70	4
S8	72	Male	174	80	3B
S9	42	Male	176	70	1
S10	66	Female	163	72	2

We recommended nutrients based on their medical tests and recorded their noninvasive health data e.g., blood pressure and heartbeat for 6 weeks. Over this specific period, with proper recommendations and logging of their health data and medical records, they were able to control their disease in a more efficient way, as the feedback taken from the survey, we conducted from the volunteers as shown in Table 2.

Table 2. Survey conducted of volunteers for reusability of application.

Points	Min	Max	Average
User Friendliness	7	10	8.6
Effect on general lifestyle	7	10	8.3
How likely to keep using the app	8	10	8.4
Recommend to a friend	8	10	8.3

5 Result

The development of a prototype done through the agile methodology allowed us to regularly obtain feedback from patients as well as health professionals. The product contained proper visualizations of both types of data: numerical and categorical. This allows the patients as well as health professionals to quantitively assess the lifestyle of a patient during a normal day. The prototype can also provide the possibility for patients to set goals for their day which includes exercise time etc.

6 Conclusion

By leveraging the power of knowledge graphs to integrate and analyze complex data, our approach can generate highly personalized recommendations that are both effective and sustainable. Our research findings suggest that personalized recommendations can significantly improve patient outcomes and reduce the progression of CKD. By using the app, patients can track their progress, receive guidance, and support, and connect with their healthcare provider. We believe that our healthcare app has the potential to revolutionize CKD management by providing patients with a comprehensive and personalized approach to their care. We encourage CKD patients to download and use the app to take control of their health and manage their condition effectively. With the right tools and support, CKD patients can lead fulfilling and healthy lives. Personalized lifestyle recommendations based on individual test results can improve the outcomes of CKD patients.

Further research is needed to evaluate the effectiveness of this approach in a clinical setting.

7 Future Work

RDF being a non-proprietary format, also has the advantage that by providing access through the SPARQL endpoint, the knowledge base can potentially act as an open-source repository. This would allow a centralized repository containing all drug data as well as data related to their interactions with other drugs, food items and medical conditions.

Although our current ontology has been designed to only accommodate use cases for drug-drug and drug-food interactions, the ontology can be expanded to accommodate interactions between drugs and medical conditions as well as drug and genetic variations. This presents the opportunity to increase the scope of the application in the future from assisting doctors with providing them with insights about the patient's lifestyle and providing recommendations related to the food and drug recommendations, to the system providing personalized recommendations based on the patient's invasive as well as non-invasive medical data such as genetic data. An example of a drug interaction with genetic properties individuals is where the optimal dosage of Warfarin, an anticoagulant that acts by reducing the activity of vitamin K, is dependent on the patients CYP2C9 and VKORC1 genotype [12]. The same principle applies with medical conditions affected by drugs. Acetaminophen, commonly known as Tylenol if taken in high doses can have adverse reactions in kidney disease patients [2].

Acknowledgments. This research was supported by the MSIT(Ministry of Science and ICT), Korea, under the Grand Information Technology Research Center support program(IITP-2022–2020-0–01489) supervised by the IITP(Institute for Information & communications Technology Planning & Evaluation) and by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government(MSIT) (IITP-2022–0-00078, Explainable Logical Reasoning for Medical Knowledge Generation), (IITP-2017–0-00655, Lean UX core technology and platform for any digital artifacts UX evaluation).

References

1. Said, S., Hernandez, G.T.: The link between chronic kidney disease and cardiovascular disease. J. Nephropathol. **3**, 99 (2014). https://doi.org/10.12860/jnp.2014.19
2. Kanchanasurakit, S., Arsu, A., Siriplabpla, W., Duangjai, A., Saokaew, S.: Acetaminophen use and risk of renal impairment: a systematic review and meta-analysis. Kidney Res. Clin. Pract. **39**(1), 81–92 (2020). https://doi.org/10.23876/j.krcp.19.106.PMID:32172553;PMCID:PMC7105620
3. Diet & Nutrition for Adults with Advanced Chronic Kidney Disease. National Institute of Diabetes and Digestive and Kidney Diseases. https://www.niddk.nih.gov/health-information/kidney-disease/chronic-kidney-disease-ckd/eating-nutrition/nutrition-advanced-chronic-kidney-disease-adults
4. Diabetes and Kidney Disease: What to Eat? Center of Disease Control and Prevention. https://www.cdc.gov/diabetes/managing/eat-well/what-to-eat.html
5. Vitamin D: The Kidney Vitamin? National Kidney Foundation. https://www.kidney.org/news/kidneyCare/spring10/VitaminD
6. Your Kidneys and Iron. National Kidney Foundation. https://www.kidney.org/atoz/content/iron
7. Kidney Failure Risk Factor: Serum Calcium. National Kidney Foundation. https://www.kidney.org/content/kidney-failure-risk-factor-serum-calcium#:~:text=Low%20serum%20calcium%20is%20also,and%20heading%20toward%20kidney%20failure
8. https://dynamicdnalabs.com/pages/the-benefits-of-personalized-nutrition (n.d.). The Benefits of Personalized Nutrition. Dynamic DNA Laboratories. https://www.kidney.org/content/kidney-failure-risk-factor-serum-calcium#:~:text=Low%20serum%20calcium%20is%20also,and%20heading%20toward%20kidney%20failure

9. Chatterjee, A., Prinz, A., Gerdes, M., et al.: ProHealth eCoach: user-centered design and development of an eCoach app to promote healthy lifestyle with personalized activity recommendations. BMC Health Serv. Res. **22**, 1120 (2022). https://doi.org/10.1186/s12913-022-08441-0
10. Atkinson, N., Saperstein, S., Desmond, S., Gold, R., Billing, A., Tian, J.: Rural eHealth nutrition education for limited-income families: an iterative and user-centered. https://doi.org/10.2196/jmir.1148
11. Pais, S.: Integrating patient-generated wellness data: a user-centered approach. In: Australasian Computer Science Week Multiconference (2020). https://doi.org/10.1145/3373017.3373052Laura. Dean, M. (n.d.). Warfarin Therapy and the Genotypes CYP2C9
12. Dean, L.: Warfarin therapy and VKORC1 and CYP genotype. 2012 Mar 8 [Updated 2018 Jun 11]. In: Pratt, V.M,, Scott, S.A., Pirmohamed, M., et al., (eds) Medical Genetics Summaries [Internet] (2018)