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SMART HEALTHCARE SYSTEM FOR CARDIOVASCULAR PATIENTS USING MACHINE LEARNING

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Abstract

Cardiovascular refers to anything relating to the heart and blood vessels. The flawed concept leads to multiple patients not receiving the right care depending on their current health status, which leads to critical cases and even death. Apart from the main objective of developing a smart healthcare system for cardiovascular diseases, other specific objectives include modelling a machine learning algorithm for natural language processing, modelling a machine learning algorithm for health recommendations, developing a preliminary diagnosis subsystem, developing a follow-up report management subsystem, integrating geolocation subsystem, and evaluating the system. The study has proposed a new method and the Recommendation and Optimization-Based Decision Support System Algorithm which constructs an expert system with an explicit knowledge base. The algorithm obtains knowledge through domain experts. In response to a query, the algorithm gives a customized recommendation, using an optimization step to help the patient maximize the probability of achieving the desired outcome. In the findings, the recommended behavioural factors are the optimal solutions that maximize the likelihood of the desired effects. With proper formulation, this expert system can combine multiple factors like age and body mass index to give support for a proper self-preliminary diagnosis at an individual level.

Key words: cardiovascular, machine learning, healthcare

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Introduction

AThe first president of the United Republic of Tanzania, the late Mwalimu Julius Kambarage, once stated the country's three main enemies were poverty, illiteracy, and diseases. A country must address multiple challenges for a stable economy so that its people's health is on the agenda. Diseases can slow the country's economy as countries depend on human resources to manufacture several economic tasks. A disease is a pathological process, most often physical, as in throat infection or cancer of the bronchus, which are sometimes undetermined in origin, as in the case of schizophrenia [1]. The disease manifests itself as a disorder and presents in the form of symptoms. Disease phenomena, cases of the disease, the clinical picture, and the course of a disease can be described, objectified, and classified [2]. Diseases are often known to be medical conditions associated with specific signs and symptoms [3]. The Tanzanian government has made several efforts through the Ministry in charge of health and social welfare and other organizations to improve the health sector in Tanzania. In 2019, the Ministry of Health, Community Development, Gender, the Elderly, and Children of the United Republic of Tanzania agreed to a new health policy. This policy was enacted to reduce the burden of medical costs by ensuring a shift in preventing diseases and infections [4]. The whole situation evolved because these costs affect citizens at a community and national level. Despite the immense efforts emphasized by Tanzania's government, the increase in cardiovascular disease cases in the country has still been a problem. Cardiovascular disease is a particularly abnormal condition that negatively affects all or part of an organism's structure or function but does not cause any immediate external injury [5]. Furthermore, it is an abnormal heart or blood vessel condition [6]. Cardiovascular disease (CVD) is a general term for conditions affecting the heart or blood vessels. It is usually associated with a build-up of fatty deposits inside the arteries and increased blood clots. It can also be associated with damage to arteries in organs such as the brain, heart, kidneys, and eyes. Cardiovascular diseases develop into conditions that last one year or more and require ongoing medical attention or limiting daily living activities or both [7].

The categories of cardiovascular diseases include coronary artery disease, or CAD, which is the most common form of heart disease; the hardening or narrowing of the arteries that lead to the heart characterizes this condition. A heart attack, or myocardial infarction, happens when the arteries leading to the heart become blocked, disrupting the blood flow. Congestive heart failure occurs when stiffness in the heart prevents the organ from pumping blood adequately through the body. Heart valve disease

happens when any of the four valves in the heart do not open or close properly and interrupt blood flow. Heart muscle disease, or cardiomyopathy, can lead to heart failure. It occurs when the heart muscle becomes more extensive and stiffens, preventing it from pumping blood away from the heart. Sometimes blood can pool in the lungs. Abnormal heart rhythms, or arrhythmia, cause a fluctuation in the heartbeat that happens while at rest [8].

Tanzania, like other developing countries, is experiencing a higher burden of cardiovascular diseases. According to recent estimates, approximately 33% of the Tanzanian population is affected by cardiovascular diseases. The probability of dying from cardiovascular diseases among adults aged 30 to 70 is approximately 16%. Cardiovascular diseases alone are responsible for 13% of Tanzania's total deaths, and adults aged 25–64 years are particularly affected. Age-standardized cardiovascular disease mortality rates showed higher death rates among Tanzanian men than women (473 versus 382 per 10,000). These rates can be further quantified by the cardiovascular disease death rates of 9–13% between 2012 and 2016. These have been driven by the growing trend of cardiovascular disease risk factors in the country. If there are no strategic measures taken, the mortality rates of cardiovascular diseases in Tanzania are expected to rise by 20 percent in 2020, and this will cause over one million deaths [9]. In other parts of Africa, in Nigeria, the World Health Organization (WHO) in 2016 revealed that non-communicable diseases were estimated to account for 29 percent of all deaths, of which CVDs contributed 11 percent. CVDs that have been increasing over the past 20 years in Nigeria include hypertension, heart failure, and stroke [10]. In South Africa, CVD is responsible for almost 1 in 6 deaths (17.3 percent). Two hundred fifteen (215) people die every day from heart disease or strokes. Every hour in South Africa, five people have heart attacks, ten people have strokes, and of those events, ten people will die [11].

On the North American continent, cardiovascular disease, including stroke, is the leading cause of illness and death in the United States. In this country, an estimated 62 million people have cardiovascular disease, and 50 million people have hypertension [12]. In Canada, about 1 in 12 (or 2.4 million) Canadian adults aged 20 and over live with diagnosed heart disease. Every hour, about 12 Canadian adults age 20 and over with diagnosed heart disease die. The death rate is three times higher in adults aged 20 and up with diagnosed heart disease compared to those who did not; four times higher in adults aged 20 and up who have had a heart attack compared to those who did not; and six times higher in adults aged 40 and up with diagnosed heart failure compared to those who did not [13]. Coronary heart disease (CHD) is the second leading cause of cardiovascular death in the Chinese population on the continent of Asia. It accounts for 22 percent of cardiovascular deaths in urban areas and 13 percent in rural areas. Although the mortality from CHD in China is relatively low compared with Western levels, the burden of CHD has been increasing [14]. In 2016, the estimated prevalence of CVDs in India was estimated to be 54.5 million. One in four deaths in India happens now because of CVDs, with ischemic heart disease and stroke responsible for >80 percent of this burden [15]. In Japan, there were 750,000 estimated cases of CHD, accounting for 38.7 percent of all heart disease cases, and 1,668,000 estimated cases of CVD, accounting for 65.8 percent of all cerebrovascular disease cases (2,534,000) [16].

On the continent of South America, in Brazil, CVD was responsible for 31 percent of all deaths, with ischemic heart disease (31 percent), and cerebrovascular diseases (30 percent) being the leading CVD causes. Studies have also shown that 37 percent of the 17 million premature deaths associated with non-communicable diseases (NCD) are caused by CVD [17]. Cardiovascular disease (CVD) is the leading cause of death and disability in Argentina. CVD causes approximately 30 percent of all deaths in the country, and ischemic heart disease is the cardiovascular condition with the highest morbidity and mortality rates [18].

Heart and circulatory diseases cause around a quarter of all deaths in the UK; more than 160,000 deaths each year – an average of 450 deaths each day, or one every three minutes in the UK. Around 7.6 million people live with a heart or circulatory disease in the UK, including 4 million men and 3.6 million women. Coronary heart disease (CHD) is the most common type of heart and circulatory disease. It is the most common cause of heart attack and was the single biggest killer of both men and women worldwide in 2019. There are more than 100,000 hospital admissions in the UK due to heart attacks; that is one every five minutes. Around 1.4 million people alive in the UK today have survived a heart attack. More than 900,000 people in the UK are living with heart failure. Strokes cause around 34,000 deaths in the UK each year and are the most significant cause of severe disability. People with a family history of coronary heart disease are much more likely to develop vascular dementia. There are more than 30,000 out-of-hospital cardiac arrests in the UK each year, with a survival rate of less than 1 in 10 [19]. One in three French people has significant risk factors for cardiovascular disease. Around 120,000 heart attacks occur in France every year; around 10% of the victims die within an hour [20].

Heart disease and stroke cause nearly 1 in 3 deaths in the US each year. At least 200,000 of these deaths could have been prevented through changes in health habits, such as stopping smoking, more physical activity, and less salt in the diet; community changes to create healthier living spaces, such as safe places to exercise and smoke-free areas; and managing high blood pressure, high cholesterol, and diabetes [21].

Cardiovascular diseases will be addressed using machine learning and knowledge discovery techniques to create automated, personalized health recommendations that consider patient characteristics and preferences. This type of problem can be found in many domains. Experts are

often consulted because they know how to maximize the desired results while considering multiple and sometimes competing factors. The proposed algorithm can simulate these experts by recommending actions that maximize the likelihood of the desired result [22]. Linear regression is a statistical procedure for calculating the value of a dependent variable from an independent variable. Linear regression measures the association between two variables. It is a modelling technique where a dependent variable is predicted based on one or more independent variables. Linear regression analysis is the most widely used of all statistical techniques [23]. The use of regression techniques can determine the relative importance of variables by observing the coefficients' sign and magnitude. Sensitivity analysis provides a way to observe how sensitive a result is to variations in the variables of interest, thus determining the importance of these variables. The proposed algorithm is a decision tool that can provide suggestions by utilizing captured knowledge and optimizing the chosen action's effectiveness. This algorithm can recommend an action based on multiple variables and the interactions among them.

Instances with known outcomes are used to capture knowledge in the form of a predictive model (classifier) and a validation map that estimates the probability of the desired outcome for any patient/action pair. A query will activate an optimization method that finds the best course of action using the captured knowledge, feasible choices, and information provided about the patient. The optimization process will combine the provided information with the captured knowledge to generate individualised health customization [24]. The knowledge extraction tool's objective is to find a proper recommendation under the constraints the patient has provided. The user provides information regarding a patient's characteristics, and then the system can generate a customized health recommendation. This customized recommendation satisfies the given characteristics and identifies the recommendations with the highest probability of the desired outcome. A sound decision-making system should also consider patient factors like tolerance. Practical problems will arise if the only consideration is medical phenomena, and it may get even more challenging if there are other practical concerns like a variety of symptoms. The solution to this is the need to have a knowledge-based system (KBS) [25]. This knowledge exists in the form of atomic facts about the domain of interest and rules for inferring new facts, but may also be in the form of graphs, trees, or networks. This data is stored in a specific location known as a "knowledge base." Together with the inference engine, the knowledge base system is used to make inferences. Another technique used in case-based reasoning, instead of using a knowledge base, is using case libraries, which contain all previously solved cases. The new case's solution working mechanism involves finding the most similar problems in the case library and knowledge to a generate customized health customization [24]. The knowledge extraction tool's objective is to find a proper recommendation under the constraints the patient has provided. The user provides information regarding a patient's characteristics, and then the system can generate a customized health recommendation. This customized recommendation satisfies the given characteristics and identifies the recommendations with the highest probability of the desired outcome. A sound decision-making system should also consider patient factors like tolerance. Practical problems will arise if the only consideration is medical phenomena, and it may get even more challenging if there are other practical concerns like variant symptoms. The solution to this is the need to have a knowledge-based system (KBS) [25]. This knowledge exists in the form of atomic facts about the domain of interest and rules for inferring new facts, but may also be in the form of graphs, trees, or networks. This data is stored in a specific location known as a "knowledge base." Together with the inference engine, the knowledge base system is used to make inferences. Another technique used in case-based reasoning, instead of using a knowledge base, is using case libraries, which contain all previously solved cases. The new case's solution working mechanism involves finding the most similar problems in the case library.

Materials and methods

A. Data Collection

The following methods of data collection are used in this project: a questionnaire, a series of questions designed to elicit/draw specific information about an area of study or interest; an interview, a conversation with a purpose; and Focus Groups, which are simply a group interview of people who all have something in common. Records and Documents, is the process of examining existing documents and records of an organisation for tracking changes over a period of time.

B. Methodology

Rapid application development is a software development methodology that uses minimal planning in rapid prototyping. RAD methodology is designed to adapt to changes and accept new inputs, like features and functions, at every development process. RAD uses an Iterative Incremental Model. The Iterative Incremental Model is a particular implementation of a software development life cycle (SDLC) that focuses on initial, simplified implementation, progressively gaining more complexity and a broader feature set until the final system is complete.

The first step is to go through an initial planning stage to map out the specification documents, establish software or hardware requirements, and generally prepare for the upcoming stages of the cycle. The purpose of this phase is to perform a preliminary investigation to evaluate an IT-related business opportunity or problem. The second stage, analysis is performed to nail down the appropriate business logic, database models, and the like required at this stage in the project. The third stage includes the beginning of the actual implementation and coding process. All planning, specification, and design docs up to this point were implemented into this initial iteration

of the project. After the database design, an understanding of the variables, entities, and their corresponding attributes, the focus shifted to bringing this project to life by developing and integrating different system components.

The fourth stage, after a build iteration was coded and implemented, and underwent a series of testing procedures to identify and locate any potential bugs or issues that cropped up. After all prior stages were completed, a thorough evaluation of development up to this stage was performed. This evaluation allowed the entire team and clients or other outside parties to examine where the project is at, where it needs to be, what can or should change, and so on.

C. Tools used

MySQL is an Open Source, high performance, feature-rich relational database management software. MySQL performs well as the data size grows, from GB to several TB of data. XAMPP server (X-Cross platform Apache MySQL PHP server). This gives a local host for hosting the web based locally before hosting to the online servers. VS CODE IDE analyses the code, looking for connections between symbols across all project files and languages. Colaboratory, or "Colab" for short, is a product from Google Research. Colab allows anybody to write and execute arbitrary python code through the browser, and is especially well suited to machine learning, data analysis and education. AutoML Vision enables anyone to perform supervised learning, which involves training a computer to recognize patterns from labelled data. Using supervised learning, we can train a model to recognize the patterns and content that we care about in images.

D. Languages used

PHP (Hypertext Pre-processor), is used to build up the web contents part of the project such as database connection, inserting and retrieving data from a database.

JavaScript has its libraries like JQuery. It is a client-side scripting language which can be used to handle all events in client-side like validation and loading some part of the page. HTML (Hypertext Markup Language) used to build and display web contents. CSS (Cascade Style Sheet) used styling the layout of the webpages. Python is a general-purpose programming language, so it can be used for many things.

E. Libraries and Web Services

Bootstrap is a free and open-source CSS framework directed at responsive, mobile-first front-end web development. Jquery is a lightweight, JavaScript library. Font-Awesome is a popular way to add font icons to your website. NumPy is the fundamental package for scientific computing in Python. Scikit-Learn is a free software machine learning library for the Python programming language.

Sendgrid API offers a Web API that allows customers to retrieve information about their accounts such as statistics, bounces, spam reports, and unsubscribes. Teachable Machine is a web-based tool that makes creating machine learning models fast, easy, and accessible to everyone. OpenWeatherMap provides a range of weather-related products in a variable combination of depth and steps of measurement to millions of clients globally.

Results and discussion

Different platforms and applications have performed different approaches to solve this problem.

• Ada Health

Ada is a global health company based in Berlin that operates Ada, an end-user self-assessment app. Additionally, the company offers enterprise solutions - Assess, Connect, Handover, and COVID-19. It was founded by Claire Novorol, a British paediatrician, Martin Hirsch, and Daniel Nathrath. Nathrath is a graduate of the University of Houston Law Center. The app, developed by Ada Health, uses a medical knowledge database with artificial intelligence technology to help users understand what might be causing their symptoms and provide guidance about what they should do next [26].

• Samsung Health

Samsung Health (originally S Health) is a free application developed by Samsung that serves to track various aspects of daily life contributing to well-being, such as physical activity, diet, and sleep. Launched on July 2, 2012, with the new Samsung smartphone, the Galaxy S3, the application was installed by default only on some smartphones of the brand. It could also be downloaded from the Samsung Galaxy Store [27]. Samsung Health is more than just a glorified step or calorie tracker. It can track weight, calorie intake/burn, steps, runs, heart rate, stress levels, caffeine intake, blood pressure, sleep, blood glucose, bike rides, hikes, and a lot more. It is worth noting that not all features are available on all smartphones. So, while one can install it on a wide range of Android phones, not every phone can take advantage of things which are enabled by the hardware on the Samsung Galaxy line-up. Samsung Health's main page is where one can start with the app, as well as where likely spend most of the time. It can be a bit overwhelming at first, but users get used to it quickly. It is worth noting that some do not use the phone to get their data, like blood pressure or glucose, for example. This feature assumes that one has a third-party monitor to track this particular data. Then input it to Health app manually. It is also likely that one can find apps that work with external devices (like blood pressure monitors) and sync with the Health app to track things more automatically [28].

• Healthy Heart App

The Healthy Heart app is a prevention/monitoring app for high blood pressure / high cholesterol patients at risk of heart diseases and their caretakers. It tracks blood pressure, pulse, cholesterol, blood glucose, potassium, medications, and behavioural and environmental factors. This data is invaluable in helping one's doctor pinpoint the cause of the sickness and evaluate the effectiveness of medications. It also provides moti-

vation for individuals to live healthier. The data can be saved to the Ringful online service for backup, analytics, and easy sharing with doctors and family members. In addition, the app provides news articles on the latest research/news on heart conditions every day, and one can share those articles via Facebook [29].

• Heart Pal

Heart Pal connects with a separate handheld ECG monitor to record one's heart and help one's medical team determine a diagnosis. Users can see the results, historical data, and waveform for analysis and review. The app uses AI technology to determine whether or not there is an arrhythmia [30]. Heart Pal is a helpful tool for patients and doctors to use to monitor their average blood pressure. The app allows one to log information, display it in charts, and share it with the doctor. One can even monitor the medication with a built-in scheduling feature. The reminders it offers also provide a slew of additional benefits [32].

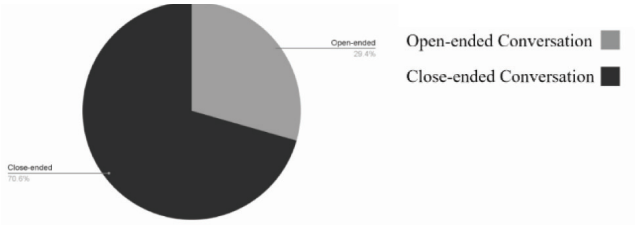
• Withings App

WITHINGS creates devices embedded in easy-to-use everyday objects that connect to a unique app and act as powerful daily health check-ups, and provides tools to help master long-term health goals. With a health companion, users are empowered to take action and start mastering vitals, track one's vitals, weight & body composition monitoring as well as reach weight goals with advanced insights, including weight, weight trends, and BMI & body composition. Users can also automatically track their daily activity and workout sessions with in-depth insights, including steps, heart rate, multisport tracking, connected GPS & fitness level assessment. Users are also able to improve sleep with sleep-lab-worthy results (sleep cycles, sleep score, heart rate, snoring & more) and uncover breathing disturbances. They can also monitor hypertension from the comfort of their own home with medically accurate systolic and diastolic blood pressure results, plus reports which can be shared with their respective doctor to monitor the efficacy of treatment [33].

Data analysis

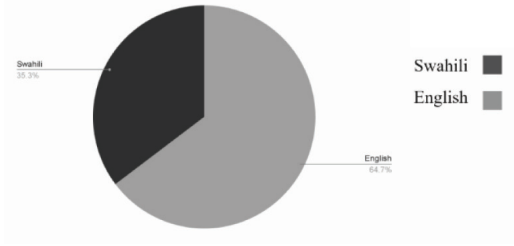
From the findings, it can be concluded that the nature of the conversation between the patient and doctor is mostly close-ended, as depicted by Fig-1.

Fig. 1. : Nature of the diagnosis conversation between doctor and patient.



It can be acknowledged that most doctors prefer Swahili to English as a medium of conversation due to the familiarity of the patients to the vocabularies of Swahili language, as depicted by Fig-2

Fig. 2. : . Language most preferable during diagnosis.



During these conversations the following can be learnt from the patients: sentiment, emotions, symptoms, background information, and behavioural factors. In addition to that the key factors that one should monitor in cardiac--patients daily lives include: diet and nutrition, exercise, and weather. In case of emergencies, the immediate measures to be taken include; ventilation, performing CPR if necessary, and seeking medical attention.

The symptoms of the disease and stage of the disease are the key factors that lead to recommending changes to the patient. The kind of data is to be stored to help with the recommendations: height, weight, age, and location of the patient. The risk level of the patient in a preliminary diagnosis can be calculated using; symptoms (stage of the disease), by using Framingham heart failure score and Dukes criteria and using the CHADVAS score.

Framingham criteria is used to come to conclusions which means that the patient exhibits two major criteria or one major and two minor criteria based on history and symptoms. The kinds of question asked during diagnosis involve the following: heartbeat rhythm, family history of heart diseases, lifestyle risk factors, easy fatigability, limb swelling (Oedema), history of hypertension, chest pain, chronic diseases, and difficulty breathing.

During follow-up, the following processes should be considered; the severity of signs and symptoms, adherence to meds, modification of lifestyle (diet and exercise), improvement of patient's symptoms (difficulty breathing and easy fatigability) as well as adherence to nutrition adjustments and medication given.

From diagnosis there will be 3 consecutive follow-ups at 7, 14 and 21 days from diagnosis. Thereafter, it will be monthly and if resolved, then every 6 months. However, the patient can come to the clinic when his/her condition worsens at any time. The nature of a patient follow-up begins with specific scope and ends with a general scope, and a summary of the whole process, which has no place for bringing up new ideas nor redundancy. Report details are represented through elaboration and translation of medical parameters into an understandable simple language to the patient, so he/she can understand what the findings were during the investigations and suggestions for his/her treatment.

• Proposed System

The proposed system is the smart healthcare system for cardiovascular diseases. The system will manage all users seeking cardiovascular medical assistance. The medical assistance can elaborate medical information regarding a balanced diet that is various nutritious foods which can help improve the user's well-being. The other type of medical assistance can be in the form of recommendation of different behaviours and general conduct of the user, such as daily exercise, self-diagnosis, and level of activities.

Conclusion

Machine learning is at the centre of a new enterprise to build computational models of intelligence. The main assumption is that intelligence can be represented in terms of symbol structures and symbolic operations which can be programmed in a digital computer. There is much debate as to whether such an appropriately programmed computer would be a mind, or would merely simulate one, but machine learning researchers need not wait for the conclusion to that debate, nor for the hypothetical computer that could model all of human intelligence. Aspects of intelligent behaviour, such as solving problems, making inferences, learning, and understanding language, have already been coded as computer programs, and within very limited domains, such as identifying diseases of soybean plants, machine learning algorithms can outperform human experts. Now the great challenge of machine learning is to find ways of representing the common-sense knowledge and experience that enable people to carry out everyday activities such as holding a wide-ranging conversation, or finding their way along a busy street. Conventional digital computers may be capable of running such programs, or we may need to develop new machines that can support the complexity of human thought. Generally, this report has provided all basic information concerning the existence of the problem and the procedures for solving it. Using these procedures, The system has been designed and realized using machine learning algorithms. Moreover, the system has been tested and appeared to give the expected results. Considering these results obtained after repeated testing, the overall performance of the designed system is good. Therefore, it can be concluded that the designed system is expected to solve the existing problem.

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