ECGSmart: Revolutionizing Cardiovascular Disease Diagnosis and Management Through AI-Powered Real-Time Analysis and Personalized Health Guidance

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Abstract

Cardiovascular diseases (CVD) are a leading global health challenge, with delayed diagnoses creating worse outcomes [8]. ECGSmart uses AI to interpret diagnosis on ECG graphs, offering personalized health advice and a wide and accessible knowledge base. ECGSmart provides accurate and consistent results, allowing users to swiftly take action without needing to worry about the validity of the app. Unlike traditional methods requiring medical experts, ECGSmart introduces fast real-time analysis and guidance through the usage of AI [9]. ECGSmart helps educate users on how to manage their hearts and sets a new standard in the heart health field.

Keywords

Cardiovascular Diseases, Artificial Intelligence, Heart Health Management, Educational, Flutter

1. Introduction

Cardiovascular diseases (CVD) have been a significant concern over the past few decades. The diagnosis of CVDs is often overly complex, leading to delays in outcomes and diagnosis explanations. This trend results in the detection of end-stage diseases often occurring too late for prevention, as reflected in the rising global mortality rates from cardiovascular diseases.

CVD affects a wide range of populations, with one in five deaths in the United States being related to cardiovascular disease. Globally, CVD is one of the leading causes of death [1]. Although we have made progress in decreasing the rate of deaths due to CVD, they have risen again during and after the COVID pandemic, placing a heavy psychological burden on patients and their families, as well as significant pressure on the healthcare system, especially during post-COVID [2].

However, the mortality rate from CVD can be significantly reduced through early diagnosis and prompt treatment. Electrocardiography (ECG) is the most commonly used diagnostic method for CVD, as it records the heart's electrical impulses to produce a graph that displays the

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cardiovascular activity of the patient [10]. This graph - known as an electrocardiogram - can be used to interpret and diagnose important heart-related diseases in patients. ECG is considered the best method for diagnosing CVD because it poses a low risk to patients, is painless, and is safe [3]. However, many ECG graphs and CVD diagnoses do not provide sufficient information for patients on how to respond. Many patients lack follow-up guidance and specific health management advice after receiving ECG results, which hampers effective improvement in their health status.

Open Problem

Traditional ECG diagnosis takes time as it is complex, and relies on cardiologists, which can result in delayed results and limited guidance.

Solution

Our application, ECGSmart, uses artificial intelligence (AI) to interpret diagnostic results on ECG graphs to address this issue. Through image and text recognition, the app provides health advice, recommendations, and easy-to-understand information related to the diagnosis. This not only enhances users' understanding of their health but also guides them in taking proactive health management measures. Additionally, ECGSmart includes a terminology database with common ECG-related terms for users to reference, utilizing AI to offer in-depth explanations of the terms to help users better grasp medical knowledge.

ECGSmart will be accessible on multiple platforms, including Android and iOS. This will help solve the problem by enabling users to easily access the tool and stay informed about their ECG status in real-time, expanding their knowledge of ECGs. Regardless of their location, users can obtain the information they need anytime via their smartphones or tablets, enhancing the application's usability and flexibility. To ensure a positive user experience, ECGSmart is also very user-friendly, featuring simple usage and easy-to-understand language for analysis and terminology explanations. Especially with complex medical terminology, the application will provide clear definitions and examples to help users easily digest the relevant content.

2. CHALLENGES

Many challenges exist in creating ECGSmart, as we needed to make it well-rounded for users.

2.1. Ensuring the AI works accurately

A major challenge in creating ECGSmart is ensuring that the AI can accurately explain the diagnosis on ECG graphs and dive deeper into its meaning correctly, as interpretation is one of the main functions of ECGSmart. The interpretation system of ECGSmart primarily relies on the AI model it uses. The model provides the information needed for interpretation. However, the language used by the model may be overly complex, making it difficult for the average user to understand, and only professionals may grasp its meaning. At times, the model's accuracy may also be affected, as certain terms may originate from different fields of expertise, creating barriers to effective communication.

To address this issue, the system can use specific prompts to request that the model provide suggestions and explanations that can be easily understood. By simplifying the language, the AI can help users better understand their health status. Specific prompts can also inform the model to follow certain parameters to minimize inaccuracies by staying in the medical field.

The accuracy of the interpretations can also be improved by asking users for information such as age, gender, and medical history, ensuring that the content better aligns with the user's background and needs. Once the AI understands the user's basic situation, it can adjust its interpretation strategy to provide personalized health advice, helping users take effective preventive measures based on their specific living environments and conditions.

2.2. Accessibility and Usability

Another challenge that ECGSmart will face is accessibility and usability. In terms of accessibility, the application should be available to users across multiple platforms. This can be easily achieved by using a multi-platform engine, ensuring that users can smoothly access the application's features regardless of their device. Additionally, the application should be easy to understand and control. To achieve this, the design of the user interface needs to be friendly and easy to navigate.

A simple and intuitive user interface was created, and users will be able to customize it in the future. For example, users could adjust the color scheme and font according to their preferences to enhance visual comfort. Furthermore, considering the needs of users from different age groups, the application could offer a senior mode that features larger fonts and higher contrast to help users with impaired vision use the application more easily.

3. SOLUTION

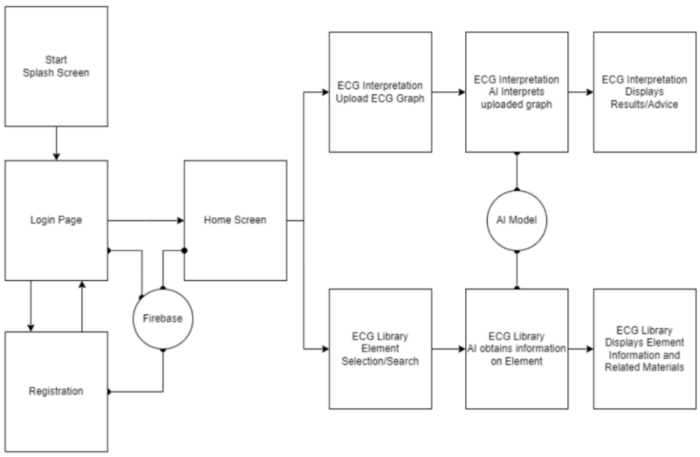

Figure 1. Overview of the solution

ECGSmart includes various elements such as the user interface, which consists of the splash screen, login/register screen, home screen, knowledge base(library) screen, interpretation screen, and results screen, as seen in Figure 1 [14]. Upon launching the application, users will first see the splash screen, followed by the login and registration process. After that, they can choose to enter either the knowledge base screen or the interpretation screen from the main screen. Each screen is carefully designed to ensure that users can easily find the functions and information they need.

Users can scan ECG images on the interpretation screen for the image recognition AI to interpret. The interpretation process is quick and efficient, allowing users to receive results within minutes. On the knowledge base screen, users can browse accessible terms related to ECGs, enhancing their understanding and awareness of heart health.

ECGSmart is user-friendly, enabling users to access the application's features immediately after logging in or registering, providing two options. Whether one is seeking general cardiology knowledge or obtaining ECG graph interpretations, users can make choices based on their needs. Navigation is also straightforward, with a return button always available in the top left app bar, allowing users to easily go back to previous pages and avoid getting lost in the application's various functions.

Home Screen

The home screen is a crucial component of the ECGSmart application, serving as the navigation hub that connects the application's primary features [15]. After logging in or registering, users will access this page, which welcomes them and allows them to choose between the knowledge base feature and the interpretation feature, as seen in Figure 2. The home screen is designed to be simple and clear, enabling users to quickly find certain functions, ensuring a smooth and uninterrupted user experience.

To further enhance the user experience on the home screen, dynamic content such as welcome messages or health tips could be considered to increase user engagement. Additionally, users could customize the home screen according to their preferences, selecting the most frequently used features to enhance their personalized experience.

The chunk of code in Figure 3 is from the Select.dart file, and represents the Library button, which best represents the purpose of this page. You can see the design of the button and its functionality through the GestureDetector. This is also used for the Interpretation button underneath this one.

The code runs when the user logs into the app, and when the user decides to press the Library button. It then brings the user to the Library page. The same would apply to the Interpretation button.

Figure 2. Screenshot of ECGSmart

```
GestureDetector(
  onTap: () {
    Navigator.push(context,
        MaterialPageRoute(builder: (context) => const Library()));
  },
  child: Card(
    color: softBlueColor,
    child: Padding(
      padding: const EdgeInsets.all(12),
      child: SizedBox(
        width: width * 0.85,
        child: Column(
          mainAxisSize: MainAxisSize.max,
          children: <Widget>[
            CircleAvatar(
              backgroundImage:
                  const AssetImage('assets/library.png'),
              radius: height * 0.06,
            ),  // CircleAvatar
            const Text("Library",
                style: TextStyle(
                    fontSize: 22,
                    fontWeight: FontWeight.bold,
                    fontStyle: FontStyle.italic)),  // TextStyle, Text
            const SizedBox(height: 5),
            const Text(
              "Learn and Search for Common ECG Terms",
              style: TextStyle(
                  fontWeight: FontWeight.bold, fontSize: 16),  // TextStyle
              textAlign: TextAlign.center,
```

Figure 3. Screenshot of code 1

Library

The next key feature of the application is the Library. The Library provides a list of terms related to the cardiology field, allowing users to click on each term to view its detailed explanation. This feature not only serves as a tool for learning different terms but also helps users better understand health-related knowledge in their daily lives. By providing this educational resource, ECGSmart aims to enhance users' medical literacy, empowering them to take a more proactive approach to health management [13].

The design of the Library includes an easily navigable categorization system, enabling users to quickly search for specific terms either alphabetically or by topic, as seen in Figure 4. Additionally, the knowledge base can be updated regularly to add new terms and definitions. This reflects the latest medical research and developments. This way, users can access cutting-edge information, ensuring that their knowledge base remains up to date.

The code in Figure 5 is in the Library.dart file, representing the search feature in the Library and how the big list of terms on the page works. The list of items is made using GridView, with the builder calling the LibraryHelper file, and producing a term with a button on screen for the amount of terms there are [12]. The search feature asks the user for input in the TextField, and if it matches one of the terms, it will show on the GridView.

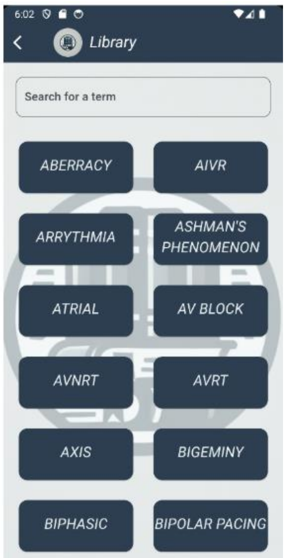

Figure 4. Screenshot of the library

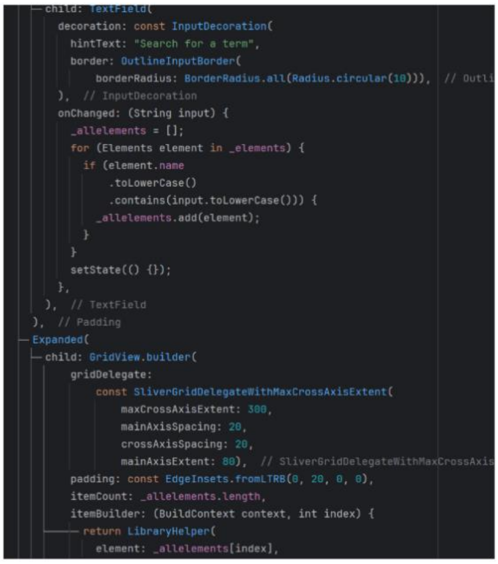

Figure 5. Screenshot of code 2

The ECG interpretation page is another key feature of the application. Users can upload an ECG image or take a direct photo for interpretation as shown in Figure 6. After clicking the interpret button, users will be guided to a page containing their interpretation, providing medical advice, specific tips, and basic information on their diagnosis, as shown in Figure 7. This feature is designed to help users gain a deeper understanding of their heart health and what they can do to improve their lifestyle.

On this page, the user can access basic interpretation information, such as what specifically causes their problem, and what they can improve on. This comprehensive information enhances users' understanding of their health and encourages them to adopt a more proactive attitude in their daily lives. To further this goal, social features could be considered, allowing users to share their experiences and stories to gain more support and encouragement within the community.

The code in Figure 8 is in Results.dart, where the user lands after inserting an image, and where the app gives the interpretation results. The code chunk shows one of the 3 different outputs the interpretation gives - the interpretation. A similar code is used in the other 2 outputs, where the respective part of _advice will be shown. _advice comes from earlier, where we gave our AI model a prompt, and it gave us results using a JSON format, which we stored into _advice.

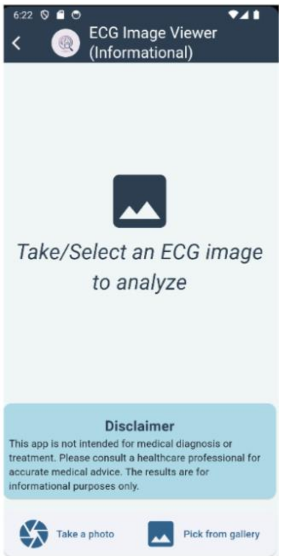

Figure 6. Screenshot of the image viewer

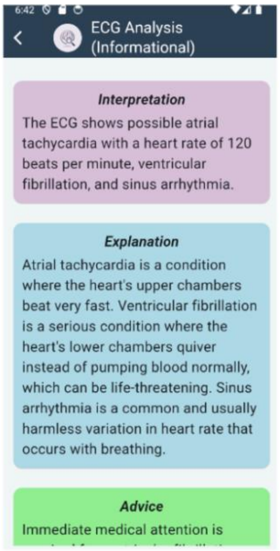

Figure 7. Screenshot of analysis

```
Card(
  color: lightPurpleColor,
  child: Padding(
    padding: const EdgeInsets.all(12),
    child: Column(
      children: [
        const Text(
          'Interpretation',
          style: TextStyle(
              fontSize: 20, fontWeight: FontWeight.bold, fontStyle: FontStyle.italic),
        ), // Text
        const SizedBox(height: 4),
        Text(
          _advice['interpretation'],
          style: const TextStyle(
              fontSize: 20, ), // TextStyle
        ), // Text
      ],
    ), // Column
  ), // Padding
), // Card
```

Figure 8. Screenshot of code 3

4. EXPERIMENT

A potential blind spot for ECGSmart is the accuracy of AI interpretation of ECG diagnosis. While AI excels at processing large amounts of data and pattern recognition, its interpretation results may still be influenced by various factors, such as the limitations of the model and its accuracy. Inaccurate explanations and advice may lead to untrustworthy information, which will negatively affect users.

To test for the AI's accuracy, we could test multiple ECG graphs with the same or similar diagnosis, and check if the AI is accurate and consistent in its interpretation [11]. To accomplish this task, we will specifically use some common ECG diagnosis, create a control group for each one, and create a graph to see how consistent the AI is.

The graph in Figure 9 shows the average percentage of similarity of interpretation and advice given by the AI compared to a control group for three specific diseases. The averages for each of the diseases vary around the 75% mark. This suggests that the interpretation and advice provided by the AI will be pretty reliable, as the lowest accuracy was 69% for one of the sinus bradycardia reports, and the highest was 84% accuracy for atrial fibrillation. This amounts to the AI's accuracy for one interpretation being around 75%, compared to other interpretations and advice by the AI on the same disease, showing that it has high consistency and accuracy.

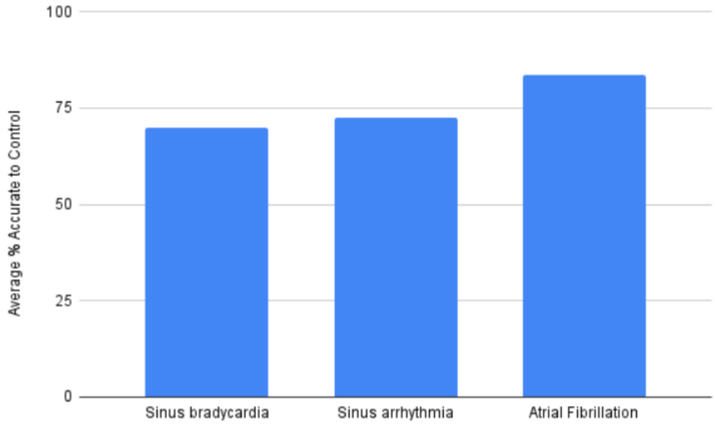

Figure 9. Figure of experiment 1

Another potential blind spot is the fact that the AI could be less accurate when a graph has more than 1 diagnosis. As proven before, AI's ability to provide interpretation and advice for a specific diagnosis is pretty well, but it could change for multiple reasons, as it will have more to explain, and will be less consistent.

To test for the AI's accuracy on multiple diagnoses at once, we could test multiple ECG graphs with the same diagnoses, and check its interpretation and advice accuracy and consistency using a control group.

The graph in Figure 10 shows the percentage of similarity of interpretation and advice given by the AI compared for one attempt with each attempt containing multiple diseases, matching the control group, vs said control group. This suggests that even with multiple diseases, the interpretation and advice given by the AI is still around the same accuracy as with only one disease tested at a time, as the average similarity for all these attempts averages around 75%. With this information, we can safely say that the AI model used in our algorithm is accurate and consistent in the information it provides.

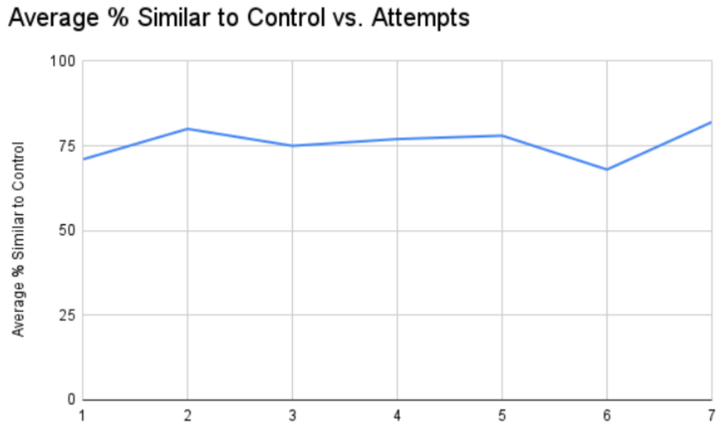

Figure 10. Figure of experiment 2

5. RELATED WORK

Fu et al. (2021) proposed an AI-enhanced mobile system to help patients manage and learn about cardiovascular health outside of hospitals in China [5]. Their proposal utilizes a hardware device that can acquire ECG data and send it to their mobile system, and then onto a cloud service that will be sent to both AI and doctors to provide analysis. Their method provides users with the full experience of collecting data and then receiving information, allowing for further effectiveness. However, this is inefficient, as doctors will have to use a lot of time and resources to manually help patients. Instead, ECGSmart just uses AI to provide analysis and feedback. It could be argued that the AI can be unreliable, but the AI is checked for accuracy and is very specific to meet the app's purpose.

Rafie et al. (2021) argue that AI and machine learning are vital to future ECG interpretation [6]. They emphasize its importance in the field as AI develops, and discuss limitations and accuracy. ECGSmart helps build on this importance by using AI to help in the medical care field. Rafie et al. (2021) also propose a potential incorporation of AI into ECG interpretation, first combining an AI diagnosis and a cardiologist's interpretation, and then using AI again to enhance care for patients. ECGSmart fits this, as itt goes down the path of using AI to enhance patient care and further develops this idea by also providing a library with common ECG-related terms.

Sun et al. (2023) provide a variety of ideas on how AI can be implemented in the cardiology world, providing countless opportunities for doctors and patients [7]. They emphasized the usage of AI and how it would optimize treatment and educate patients. ECGSmart accomplishes this point and specializes in it. This would help AI expand into patient care.

6. CONCLUSIONS

Overall, ECGSmart, as an AI-based ECG interpretation tool, aims to help users better understand their heart health by providing intuitive and user-friendly features. Its design fully considers user needs, from a simple interface to rich educational resources, striving to enhance user experience while delivering accurate and reliable medical information.

In this study, we conducted two experiments to ensure the accuracy of our AI model and our prompt. The first experiment focused on the overall accuracy of the AI. The results showed that the AI provided decently accurate and largely consistent results, as expected by the specific parameters of its prompt. By showing accuracy and consistency, the experiment proves that the AI model is a good fit for our app and can correctly provide what it offers. The second experiment focuses on the accuracy and consistency of the AI when presented with multiple ECG diagnoses. This effectively finds if the AI can handle multiple cases at once, and figure out its capabilities. The experiment gave accurate and consistent results again, proving that it can handle multiple diagnoses.

We also compared methodologies that proposed the integration of AI systems in ECG interpretation to the patient care and user education field. Methodology A proposed using both AI and live experts to provide feedback on patients' diagnoses (Fu et al. 2021) [5]. This method provides users with the full experience but is limited by the focus on live expert analysis and confirmation, which will take extra time. Methodology B emphasizes the usage of AI in the ECG field and points out how AI can be useful in the patient care field (Rafie et al. 2021) [6]. ECGSmart contributes to this, as AI in the patient care field is exactly what our app was made for. Methodology C also discusses AI in the patient care field and expands on treatment optimization and patient learning (Sun et al. 2023) [7]. ECGSmart fits into this description and has a library specifically for patient learning.

Considering this, in the future, as technology advances and user demands evolve, ECGSmart will continue to adapt to meet a broader range of needs in cardiovascular health management. The development shall prioritize user feedback and continuously improve interpretation algorithms and feature designs. By regularly updating the knowledge base and introducing new educational content, ECGSmart can become an essential tool for users to learn about heart health and play an active role in promoting public health education. Additionally, strengthening collaborations with medical institutions will provide users with more authoritative interpretations and recommendations, further solidifying the application's place in the field of cardiovascular health.

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