CABGAR: An AR Glasses System for Enhanced Visualization during Coronary Artery Bypass Grafting (CABG)

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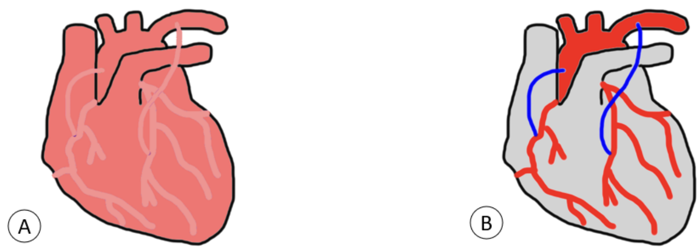

Fig. 1. (A) View of a patient's heart without aid. (B) Enhanced visualization of a patient's heart using CABGAR.

Coronary Artery Bypass Grafting (CABG) is a surgical procedure that reroutes blood flow around obstructed or constricted sections of the coronary arteries. Clear visualization of the patient's organs and blood vessels is essential for surgeons to perform the procedure accurately. In this paper, we envision an AR glasses system that could be developed within the next 10-20 years, designed to improve visualization during CABG. This AR system would superimpose a 3D model onto the surgeon's field of view, highlighting organs and blood vessels and offering a detailed, dynamic representation of the patient's anatomy throughout the surgery. Moreover, the AR glasses would facilitate remote collaboration and mentorship, enabling surgeons with varying backgrounds and expertise to learn from one another and conduct complex procedures with expert guidance. While the creation of such a system is currently in its infancy, we believe it holds the potential to transform cardiac surgery by making CABG procedures safer, quicker, and more precise.

CCS Concepts: • **Human-centered computing → Mixed / augmented reality**.

Additional Key Words and Phrases: augmented reality, 3D visualization, Coronary artery bypass grafting

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1 INTRODUCTION

CABG is a surgical procedure utilized to treat Coronary Artery Disease, a condition that arises when the coronary arteries become blocked due to plaque buildup, which can result in heart attacks [19]. The objective of CABG involves taking a healthy blood vessel from the patient and attaching it to a coronary artery beyond the obstructed area, creating a new route for blood to reach the heart [1].

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CABG presents significant challenges due to the high level of precision required from the surgeon to ensure proper blood flow and long-term success. One of the main difficulties of performing CABG is achieving good visibility of the surgical site. Blood can obscure the surgical field, making it difficult for the surgeon to see the area where the bypass is being created. [10].

This paper presents CABGAR, a wearable device in the form of glasses for the surgeon performing the procedure. Using AR and 3D Visualization Technology, the glasses is able to create a visual overlay by highlighting important organs of the patient in real time. This enables the surgeon to have a clearer view of the patient during the procedure and should help improve surgical precision and reduce the risk of inadvertent damage to vital structures of the patient. Another feature of CABGAR is the remote assistance capability, which allows for seamless collaboration and mentorship between surgeons, irrespective of their geographical location. This feature not only enables experienced surgeons to provide guidance and support to their less-experienced counterparts during complex procedures but also facilitates knowledge sharing among medical professionals.

2 RELATED WORK

This future interface builds on existing systems and technologies that are related to this concept:

2.1 Real time Organ Recognition

Several studies have explored the use of neural networks to identify various objects and anatomical features in surgical videos [2, 21]. However, these studies primarily focused on endoscope-recorded footage and did not specifically target the detection of the heart or coronary arteries. Moreover, the endoscope was connected to a computer for video streaming and analysis, which may not be viable in the context of a portable smart glasses system. One notable study achieved 91.3% precision in recognizing the GI tract [4], suggesting promising results, but there is room for improvement. Future research should explore the potential of adapting these neural network approaches for CABG procedures using portable smart glasses systems to enhance detection accuracy.

2.2 Smart Glasses for surgical video streaming

Hiranaka et al. demonstrated the potential of Smart Glasses in live video streaming of knee arthroplasty surgeries. The glasses allowed surgeons to stream procedures to multiple locations with internet access, fostering learning and collaboration among medical professionals. While there were limitations in image quality and stability [8], this study underscores the value of remote surgical observation using Smart Glasses and highlights the benefits of increased collaboration among surgeons. Adapting this idea to CABG procedures could yield similar benefits, and future advancements in camera and video streaming technology are expected to make this method even more viable and effective.

2.3 3D Visualization and AR for Orthopedics

Orthopedics is a branch of medicine focused on musculoskeletal disorders and injuries [20]. It has recently seen the application of AR in surgical procedures. One technique, Integral Videography, generates a 3D image of the surgical scene that can be viewed from different angles. This enables surgeons to have better insight into the surgical area [12].

Although this study is not directly related to CABG, it shares similar goals and concepts with CABGAR, demonstrating the potential benefits of AR and 3D visualization techniques in orthopedic surgery that could be applied to CABG. However, rendering high-resolution 3D visualizations in real-time remains challenging with current technology [12]. Additionally, the study relies on multiple trackers, screen displays, and powerful computers, which require a significant amount of space, making it potentially unsuitable for smaller operating rooms. Future research could explore ways to address these limitations and apply the advancements in AR to CABG procedures.

3 SPECULATIVE DESIGN

Applying a speculative design lens to CABGAR involves exploring various scenarios and reflecting on the implications of this technology [3]. We will examine the possible, plausible, probable, and preferable futures of CABGAR, accounting for the complexity of future developments and societal complexities.

3.1 Possible futures

Given the conservative nature of the medical field, the adoption of CABGAR will likely face initial resistance from practitioners [27]. Surgeons and medical professionals may be skeptical of the technology's safety, reliability, and efficacy. To overcome this resistance, the technology will need to undergo rigorous testing and validation, where CABGAR should demonstrate improved outcomes and reduced complications for patients. As more professionals begin to trust and rely on CABGAR, the technology will gain broader acceptance, becoming an integral part of CABG and other surgical procedures. Early adopters will play a crucial role in shaping the technology's reputation and encouraging its widespread use.

3.2 Plausible futures

In this scenario, CABGAR is primarily adopted as an educational tool. The ability to record surgical footage with 3D visualization and sharing it with students and other medical professionals provides a valuable resource for learning and skill development [17]. The 3D visualization helps deepen understanding of complex anatomical structures, while remote collaboration features allow surgical teams to learn from experts around the world [26]. However, privacy concerns arise due to the recording and sharing of patient data, leading to the need for strict regulatory measures and ethical guidelines to ensure patient consent and data protection [13].

3.3 Probable futures

In this scenario, CABGAR becomes widely adopted in cardiac surgery, transforming the way CABG procedures are performed. The technology allows for improved visualization, quicker and more precise surgeries, and reduced patient risk. The remote collaboration feature of CABGAR also becomes an essential part of surgical practice, leading to a global network of interconnected medical professionals sharing knowledge and expertise [26]. This widespread adoption leads to a overall decrease in complications and improved patient outcomes, although disparities in access persist due to cost and availability.

3.4 Preferable futures

In an ideal future, CABGAR would be accessible and affordable to healthcare professionals globally [15], helping to bridge the gap between well-resourced and under-resourced medical communities. The remote collaboration feature of CABGAR would enable surgeons in rural or low-income areas to access expertise and resources otherwise unavailable to them [26]. This technology would also prioritize patient privacy and data security, ensuring that sensitive information is protected while still enabling personalized care. Ultimately, the widespread adoption of CABGAR would lead to a more equitable and effective healthcare system, improving patient outcomes and surgical care worldwide.

4 CABGAR

We apply the Speculative Design Approach along with the Principles of Universal Design [24] and the 10 Usability Heuristics [18] in mind when designing CABGAR.

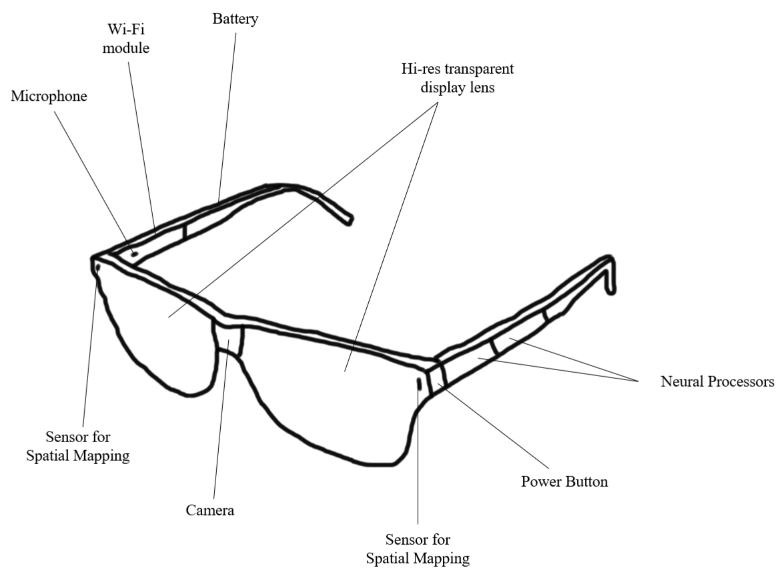

Fig. 2. A Low-fidelity mockup of CABGAR and its components.

4.1 Design

CABGAR is conceived as lightweight, ergonomic glasses that offer comfort for extended periods of use. For example, CABGAR mainly incorporates voice command functionality via its built-in microphone, minimizing the need for manual input and reducing physical effort. This design choice aligns with both the Low Physical Effort principle from Universal Design and the Aesthetic and Minimalist Design heuristic from the 10 Usability Heuristics, ensuring a user-friendly experience for surgeons during CABG procedures. Moreover, users can customize the display of anatomical structures by adjusting brightness, color, or even disabling the feature entirely based on their preferences. This adaptability aligns with the Flexibility in Use principle of Universal Design and the 10 Usability Heuristics [18, 24], further enhancing the system's usability for various users and situations.

4.2 Technology Overview

CABGAR is equipped with a camera and sensors that continuously capture the surgeon's field of view. When the camera is pointed at the patient during CABG, CABGAR's built in Neural Processors helps identify and track the patient's organs, blood vessels, and other relevant anatomical structures in real-time. CABGAR then superimposes the digital 3D model onto the surgeon's field of view in real-time, providing the surgeon with a dynamic representation of the patient's anatomy.

CABGAR is also equipped with a built-in microphone and camera, serving as a video recorder, although it is essential to obtain consent before using this feature [16]. The integrated Wi-Fi module allows for live streaming or uploading recorded sessions to hospital data servers. A compact, long-lasting battery powers CABGAR, ensuring ample energy for extended surgical procedures without frequent recharging or interruptions. The device charges wirelessly via an induction charger, eliminating the need for cumbersome wires and enhancing its overall usability.

5 SCENARIOS

5.1 Scenario 1

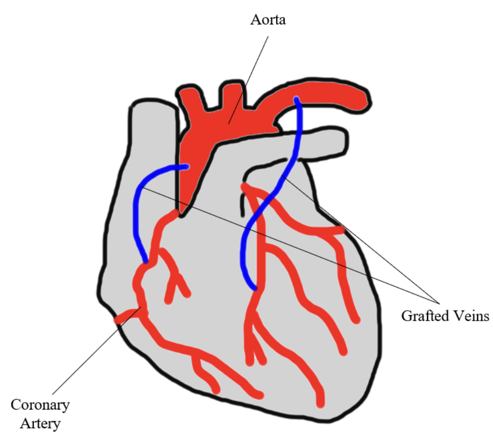

Fig. 3. Visualizing a patient's heart through CABGAR: distinct colors highlight various heart structures for enhanced surgical guidance.

Dr. JC, a an experienced cardiac surgeon, is performing a CABG procedure on a patient with severe coronary artery disease. Dr. JC wears CABGAR throughout the surgery, and they highlight critical structures of blood vessels and organs, as shown in Fig 3. Through voice commands, Dr. JC tells CABGAR to change the brightness of how it highlights Coronary Arteries. This allows Dr. JC to perform the procedure with a higher level of precision, reducing the risk of complications, and resulting in an overall better patient outcome.

5.2 Scenario 2

Dr. ZF, a less experienced cardiac surgeon in a rural hospital, is preparing for a complex CABG procedure. She connects with Dr. KW, a renowned cardiac surgeon, using CABGAR's remote collaboration feature. During the surgery, Dr. KW observes the procedure through Dr. ZF's AR Glasses and offers real-time guidance and feedback, ensuring a successful operation and allowing Dr. ZF to learn from an expert in the field.

5.3 Scenario 3

A hospital has recently decided to record a CABG procedure to create an educational resource for medical students. They let Dr. PJ, an experienced cardiac surgeon, perform this task while wearing CABGAR. After obtaining consent

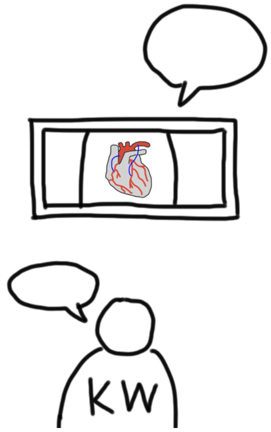

Fig. 4. Dr. KW observes the CABG procedure on a TV screen and advises Dr. ZF in real-time.

from the patient and other staff present in the operating room, Dr. PJ uses a voice command to start the recording. Throughout the surgery, Dr. PJ narrates his actions, providing insights into his decision-making process. He also occasionally enables and disables the 3D overlay of organ highlighting to emphasize the locations of organs and blood vessels in the patient. Once the surgery is completed, CABGAR uploads the recording to the hospital's secure server. The hospital can then retrieve the recording for educational use.

6 PLAN FOR EVALUATION

Evaluating user satisfaction and interaction with CABGAR can be approached through a combination of qualitative and quantitative methods:

(1) **Surveys and Questionnaires** - Distribute surveys and questionnaires to users such as surgeons and medical students who have used CABGAR. These surveys can assess users' overall satisfaction, perceived ease of use, usefulness, and any challenges faced during the experience [25].
(2) **Usability Testing** - Observe users interacting with CABGAR. This can provide valuable insights into the intuitiveness and practicality of the technology, as well as any potential issues that may arise during use [6].
(3) **Performance Metrics** Collect and analyze performance metrics from CABG procedures that utilized CABGAR, such as operation time, complication rates, and patient outcomes. Improved performance may be indicative of user satisfaction and enjoyment of the technology [23].
(4) **Adoption and Retention Rates** - Track the rate at which users adopt CABGAR and continue to use them over time. For example, having high adoption and retention rates may suggest that users find the technology enjoyable and valuable.
(5) **Feedback Channels** - Establish feedback channels, such as online forums or chat groups, where users can discuss their experiences and offer suggestions for improvements. This can help gauge user enjoyment and identify areas for further development [14].

7 BENEFITS, CONTRIBUTION AND LIMITATIONS

7.1 Benefits

- **Enhanced Precision** - By highlighting critical structures such as organs and blood vessels, CABGAR can help surgeons perform the procedure with increased accuracy, reducing the risk of complications.
- **Remote Collaboration** - CABGAR enables remote collaboration and mentorship, allowing surgeons to consult with experts worldwide and learn from their expertise, particularly in complex cases.
- **Scalability** - The technology has the potential to be adapted for other surgical procedures, making it a versatile and transformative tool in healthcare [5].

7.2 Contributions

- **Encourages Innovation** - The possible widespread adoption of CABGAR could spur innovation in other medical fields, leading to a more connected and collaborative healthcare ecosystem.
- **Democratizing Access** - CABGAR can help bridge the gap between well-resourced and under-resourced medical settings by enabling remote collaboration, training, and mentorship.
- **Global Knowledge Sharing** - CABGAR can facilitate global knowledge sharing, promoting the exchange of best practices and surgical techniques among healthcare professionals worldwide.

7.3 Limitations

- **Current technology** - As CABGAR is a proposed idea of a future interface, current technology may be unable to build such a system to work exactly as described, such as accurate 3D mapping of organs.
- **Cost and Accessibility** - The cost of developing and implementing CABGAR could be a barrier to widespread adoption, particularly in under-resourced settings [7].
- **Initial Resistance** - The medical community may be skeptical of new technology [11, 27], leading to resistance in adopting CABGAR until proven safe, reliable, and effective.

8 ETHICAL CONSIDERATIONS

The use of CABGAR may involve the collection and storage of sensitive patient data such as recordings or real-time physiological information. It is crucial to ensure that this information is handled securely and in compliance with relevant data protection regulations to protect patient privacy. As a result, patients should be made aware of the use of CABGAR during their surgery and informed about the potential benefits and risks associated with the technology. Obtaining informed consent ensures that patients understand and agree to the use of CABGAR during their procedure [9].

There is a also risk that healthcare professionals may become overly reliant on CABGAR, potentially losing the ability to perform surgeries without them. It is essential to ensure that healthcare professionals are adequately trained in using the technology and maintain their surgical skills even without the assistance of the glasses, particularly if there are technical failures or other unforeseen issues [22].

9 FUTURE WORK

Future developments for CABGAR could incorporate additional functionalities to make the CABG procedure even safer and effective. Specifically, CABGAR may integrate real-time guidance and data analysis of the patient during

CABG, providing surgeons with valuable insights and support during the procedure. Moreover, the system could feature immersive virtual simulations, offering medical students and trainees invaluable hands-on experience, complete with real-time feedback and performance analysis. These enhancements would contribute to the continued evolution and utility of CABGAR in the field of cardiac surgery.

10 CONCLUSIONS

In this paper, we proposed CABGAR, a future interface that aims to provide surgeons with improved accuracy in performing CABG, and the ability to collaborate and learn from experts in real-time. Overall, CABGAR could pave the way for a safer, more efficient, and innovative future in cardiac surgery, ultimately benefiting both patients and medical professionals alike.

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