AI-Driven Applications for Diagnostic, Clinical Decision Support and Prevention in Cardiology, Orthopedics, and Oncology

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Abstract

Artificial Intelligence (AI) is rapidly transforming the healthcare landscape, enabling smarter diagnostics, continuous monitoring, prevention and advanced clinical decision support. This paper presents a unified overview of several AI-driven research initiatives carried out within the SoWide/Ibis Lab targeting critical areas in medicine, including cardiology, orthopedics, and oncology. We describe lightweight machine learning and deep learning models for real-time noise filtering in ECG signals, enhancing the diagnostic capabilities of wearable devices. We then present a novel pipeline for detecting and classifying periprosthetic fractures in hip arthroplasty using automated Gruen zone classification. Ongoing efforts include the development of an AI-powered chatbot for interpreting lung cancer screening results and a computer vision-based approach for assessing lymphadenectomy performance via anatomical landmark detection. These projects exemplify practical, efficient, and scalable AI solutions tailored for both clinical environments and real-world settings, contributing to improved patient outcomes and reduced healthcare workload.

Keywords

Signal processing, Object detection, Computer vision, Machine Learning

1. Introduction

The global health landscape is undergoing rapid transformation, driven by evolving patient needs, an aging population, the increased burden of chronic diseases, and the integration of advanced technologies into clinical practice. In this context, artificial intelligence (AI) has emerged as a cornerstone in reimagining and enhancing healthcare delivery [1]. From diagnostics, prevention and clinical decision support to personalized medicine and operational optimization, AI systems are increasingly demonstrating the ability to tackle complex healthcare challenges with speed, accuracy, and scalability [1].

The COVID-19 pandemic underscored the fragility of existing healthcare infrastructures while simultaneously accelerating the adoption of digital health tools, including AI-based solutions. As a result, national and international initiatives are now focused on strengthening public health systems and embedding resilience into medical workflows. Within this broader momentum, Italy's healthcare system is poised for transformation, and the integration of AI technologies into diagnostic, preventive, and operational processes is a critical strategic opportunity [2]. The Italian AI community, spanning universities, research centers, hospitals, and industry, has a key role to play in developing and deploying innovative solutions that are both scientifically rigorous and practically impactful [2].

This paper contributes to this ongoing effort by presenting a set of applied AI projects developed within interdisciplinary collaborations part of the Spoke 1 of the DARE project in which we are involved. More specifically, these collaborations include computer scientists from our lab (SoWide/Ibis Lab), clinicians from Parma University Hospital, and engineers from different entities. These projects span three major areas of healthcare where intelligent systems can offer substantial value: (1) cardiovascular diagnostics through wearable technologies, (2) orthopedic imaging and surgery support, and (3) oncology-driven

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decision support. Although distinct in their clinical applications, these projects share a common methodological foundation: the use of machine learning (ML) and deep learning (DL) techniques to extract meaningful information from complex biomedical signals and images, often under the constraints of real-time inference, limited memory, and high-stakes decision contexts.

The first contribution addresses the challenge of real-time noise detection in electrocardiogram (ECG) signals acquired through wearable devices. As wearable cardiac monitoring becomes more prevalent, especially in out-of-clinic environments, the ability to filter out motion artifacts and avoid false arrhythmia classifications is essential for accurate diagnosis and data reliability. Our work proposes a lightweight and memory-efficient classification approach suitable for embedded systems, showing how Random Forest models paired with heart rate variability (HRV) features strike a balance between performance and computational feasibility.

The second contribution introduces an end-to-end AI pipeline for the automatic detection and classification of periprosthetic fractures (PPFs) after total hip arthroplasty, using radiographic imaging. This pipeline is the first of its kind to automate classification based on Gruen zones, which are critical for orthopedic decision-making but traditionally require expert interpretation. Our approach combines object detection and segmentation techniques to locate the prosthesis and fracture sites, demonstrating high performance in both detection and classification tasks and paving the way for clinical integration.

In parallel with these studies, we are also actively developing two additional AI applications with high potential for patient-centered care. The first is a conversational AI system, designed as a clinical chatbot, that interacts with patients undergoing lung cancer screening. This tool provides explanations and personalized guidance about screening results, bridging the communication gap between patients and healthcare providers in high-risk cohorts. The second is an AI-based pipeline to evaluate the adequacy of lymphadenectomy, a critical step in many oncologic surgeries. Specifically, it identifies key anatomical structures automatically, which allows to extract objective metrics for surgical quality assessment, with implications for both intraoperative support and postoperative auditing.

Collectively, these projects illustrate the multidimensional impact of AI in healthcare: enhancing diagnostic accuracy, enabling personalized patient interaction, contributing to the prevention of diseases, and supporting clinicians in both routine and high-complexity settings. They also reflect the essential role of interdisciplinary collaboration and the importance of balancing scientific innovation with real-world applicability. Our contributions align with the goals of this workshop, which seeks to bring together actors from academia, industry, and the healthcare sector to accelerate the development and deployment of impactful AI solutions for medicine and health.

2. Projects

2.1. Noise Filtering in ECG for Wearables

In recent years, wearable devices for continuous heart monitoring have garnered significant attention due to their ability to facilitate the early detection of arrhythmias [3], including atrial fibrillation, which is crucial in preventing severe cardiovascular events [4]. ECG recordings from wearable devices rank particularly vulnerable to noise and interference, such as baseline drift, motion artifacts, and power-line interference [5]. These noise sources degrade the signal quality and complicate the detection of arrhythmias, which depends on accurate signal morphology [6]. Therefore, the classification and subsequent automatic filtering of noisy signals are essential to enhance diagnostic specificity for arrhythmia detection and to maintain high overall diagnostic accuracy while minimizing computational load.

This project aims to develop a novel interference classification method to enable selective filtering to enhance the signal quality prior to arrhythmia analysis (See Figure 1). Specifically, we evaluated:

1. Various feature sets to identify those most effective for noise detection: (1) the original complete ECG signal, (2) time-domain features of HRV, extracted using NeuroKit [25], a Python package that automatically identifies ECG R-peaks and computes the HRV characteristics, and (3) both frequency- and time-domain features of HRV.

2. The performances of four distinct algorithms in classifying ECG signals: (1) Random Forest (RF), (2) Support Vector Machine (SVM), (3) Multilayer Perceptron (MLP), and (4) Convolutional Neural Network (CNN) with batch normalisation and binary cross-entropy as the loss function.

The performance of the algorithms demonstrated significant variation across the three approaches, with the HRV time-domain features proving to be the most balanced and effective [7]. Utilising these features, the RF algorithm achieved the highest accuracy (0.9726), specificity (0.9625), and sensitivity (0.9853). Meanwhile, both the SVM and CNN exhibited commendable performance, each demonstrating high specificity and sensitivity.

Using the whole signal samples as features identifies CNN as the most effective algorithm, albeit with lower overall accuracy and sensitivity. In contrast, the SVM struggles with sensitivity and fails to identify any true positives. When both HRV-related time- and frequency-domain features are employed, the RF algorithm maintains its efficacy demonstrating high accuracy and balanced metrics. However, SVM and MLP perform suboptimally using both time- and frequency-domain features compared to only using time-domain ones. Overall, HRV-related time-domain features yielded the most robust results across all the metrics and considered algorithms.

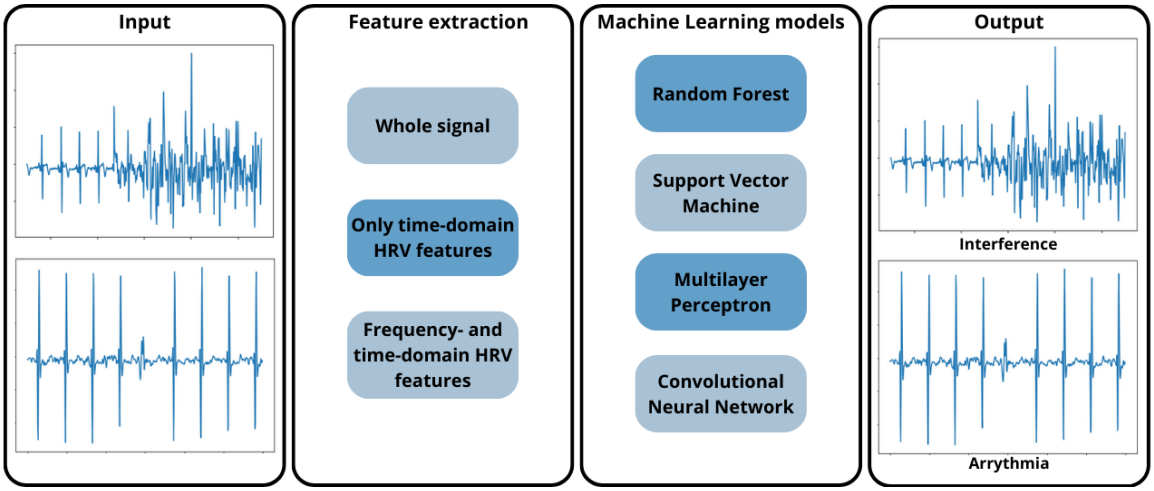

Figure 1: Pipeline followed in the research

2.2. AI for Gruen Zone Classification in Orthopedics

Periprosthetic fractures represent a critical challenge in orthopedic surgery, particularly for patients undergoing total hip arthroplasty (THA) [8]. These fractures, occurring around the prosthetic prothesis, are complex to diagnose and manage due to variability in fracture types, their location, and the biomechanical interactions with the prothesis [9]. Among the classification frameworks, the Gruen zones, which delineate the femoral regions surrounding the prosthetic stem into seven distinct zones, serve as a pivotal guide for localizing and categorizing these fractures [10]. Accurate identification of these zones during diagnostic imaging is crucial for tailoring effective treatment strategies, which may range from non-operative management to complex surgical interventions such as revision surgery [10].

Despite advances in imaging technology and surgical techniques, the manual detection and classification of PPFs remain fraught with challenges [9]. Human error, variability in interpretation, and increasing workloads for radiologists and surgeons contribute to diagnostic delays and inconsistencies [9]. The growing complexity and frequency of PPFs, driven by an aging population and the rising number of THA procedures, underscore the urgent need for innovative diagnostic solutions [9].

In this project we introduce the first automated AI pipeline for classifying PPFs according to Gruen zones. The pipeline incorporates prosthesis detection, image rotation, fracture localization, and zone classification, using VGG and EfficientNet-based object detection models, and the Segment Anything Model (SAM) for image processing (see Figure 2). Trained on annotated X-ray datasets, the pipeline

achieved high accuracy: prosthesis detection (mAP 99.56%), fracture detection (mAP 86.20%), and Gruen zone classification (96.72%). This system improves diagnostic precision and supports clinical workflows in orthopedic imaging [11].

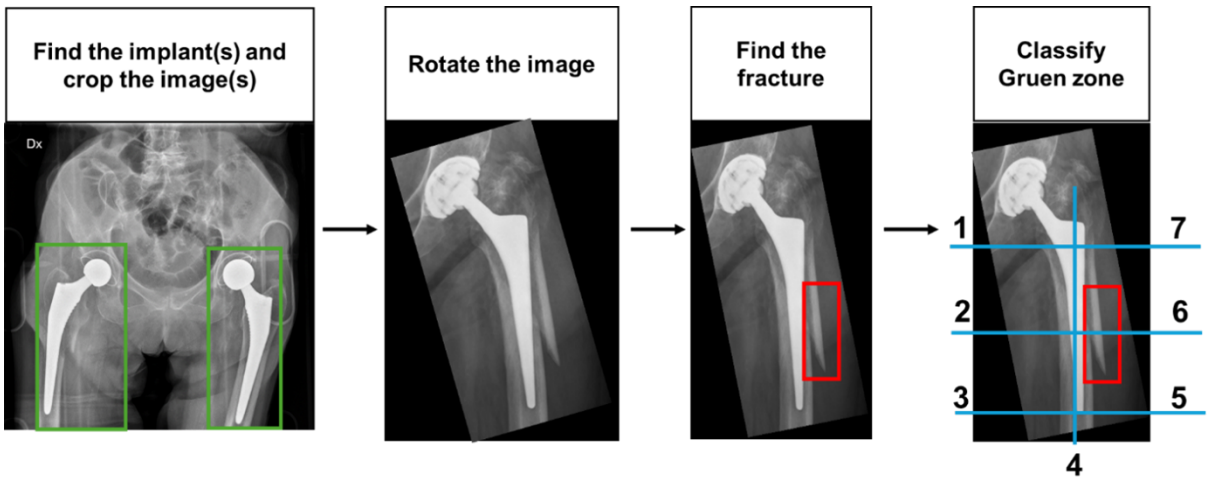

Figure 2: Architecture of the model

2.3. Chatbot for Lung Cancer Screening Interpretation

Conversational chatbots are AI-powered digital tools designed to interact with users through natural language, providing real-time support, information, and guidance. In medicine, these chatbots have emerged as valuable companions for patients, especially those managing complex and serious conditions like lung cancer [12].

For lung cancer patients, conversational chatbots can serve multiple roles—offering personalized education about the disease and treatments, helping monitor symptoms, reminding patients about medications and appointments, and providing emotional support [13]. These chatbots enhance patient engagement and can improve adherence to care plans by delivering accessible, timely, and tailored information.

By leveraging natural language processing and machine learning, conversational chatbots offer a scalable way to extend healthcare beyond clinical settings, supporting lung cancer patients in managing their health more effectively and reducing the burden on healthcare providers [13].

In this project we are currently developing a conversational AI assistant designed to interact with patients undergoing lung cancer screening in the context of the DARE pilot project "Data mining, artificial intelligence, and machine learning approaches to identify subnetworks of cancer associated with early prediction, survival, metastasis or phenotypes in cancer subtypes focusing on lung ". The chatbot provides personalized explanations of screening results and addresses patient concerns, particularly for individuals who need follow-up appointments. The system integrates medical ontologies, a set of frequently asked questions, natural language understanding, and empathetic dialogue generation, aiming to enhance patient engagement, reduce anxiety, and improve health literacy.

2.4. Anatomical Landmark Detection for Surgical Assessment

Lymphadenectomy is a surgical procedure often performed in cancer treatment, to remove lymph nodes that may contain cancer cells. It plays a key role in accurate cancer staging, guiding treatment decisions, and improving patient outcomes by helping to determine the extent of disease spread.

Performance assessment in lymphadenectomy refers to the systematic monitoring and evaluation of how effectively and thoroughly the procedure is performed. This is vital because incomplete or inadequate lymph node removal can lead to inaccurate staging, potentially resulting in suboptimal

treatment plans [14]. Moreover, consistent performance control helps ensure surgical quality, minimizes complications, and improves prognostic accuracy. By implementing robust performance control measures healthcare providers can optimize lymphadenectomy outcomes , ultimately contributing to better management and survival rates for cancer patients [15].

The aim of this project is precisely to build an AI-based pipeline that detects key anatomical landmarks in surgical images to evaluate lymphadenectomy performance automatically. This tool aims to provide objective metrics for surgical quality assessment, aiding both intraoperative decision-making and postoperative review. Currently we are comparing the performance of different object detection models, such as Yolo, Detectron, or EfficientNet-based single-shot detectors. After these objects are found we aim at developing a classifier which searches these areas to find patterns that can effectively discern the performance of the procedure.

3. Conclusion

The described projects collectively represent an integrated effort to embed AI into various stages of patient care, from early diagnosis to surgical evaluation. Each initiative emphasizes clinical relevance, computational efficiency, and applicability in real-world scenarios. These efforts also highlight the importance of interdisciplinary collaboration between computer scientists, clinicians, and industry partners.

Our research contributes to the ongoing transformation of healthcare through practical AI solutions. From ECG signal enhancement in wearables to advanced orthopedic diagnostics and personalized patient communication tools, these projects showcase the potential of AI to address diverse medical challenges. Future work includes expanding dataset diversity, improving model interpretability, and validating these systems in clinical trials.

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Declaration on Generative AI

During the preparation of this work, the author(s) used GPT-4 for Grammar and spelling check. After using these tool(s)/service(s), the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication’s content.

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