Action Plan

*Classifying Arrhythmia in Fighter Pilots*

Students and Student numbers:

* Bianca Burlacu - 705366
* Wojciech Kolasa - 695344
* Codrin Calin - 696627
* Salman Kanj - 689581

Email address:

* [705366@student.inholland.nl](mailto:705366@student.inholland.nl)
* 695344@student.inholland.nl
* [696627@student.inholland.nl](mailto:696627@student.inholland.nl)
* [689581@student.inholland.nl](mailto:689581@student.inholland.nl)

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1. Introduction

This action plan outlines the research assignment undertaken by Project Group 3, which consists of the following students: Bianca Burlacu, Wojciech Kolasa, Codrin Calin and Salman Kanj. Project Group 3 is working on Classifying Arrhythmia in Fighter Pilots for TNO.

F-35 pilots sometimes experience unexplained physiological events (UPEs) during high-G maneuvers, raising concerns about potential physiological anomalies. Accurately distinguishing between genuine arrhythmic events and false alarms is critical for pilot safety and operational effectiveness. To address this, TNO seeks to develop an advanced ECG-based arrhythmia classifier.

This project focuses on improving the reliability of an arrhythmia classification system designed to detect irregular heartbeats in pilots. A key challenge is ensuring the classifier performs well across different domains and sensor types, as ECG measurement conditions may vary.

The goal is to enhance the classifier’s ability to generalize across datasets, ensuring reliable performance even when trained on controlled experiments but applied in real flight conditions. This will be achieved by exploring innovative machine learning approaches that improve domain transfer adaptability.

This document follows a structured approach to outline the research assignment, its background, methodology, and expected outcomes. The introduction presents the purpose of the project and its significance. The second chapter provides details on the assignment itself, including the problem statement and its broader context. Chapter three explores the assignment in depth through analysis and theoretical research, examining relevant literature and prior studies. The fourth chapter focuses on the research design, outlining the definitive assignment, objectives, research questions, scope, and methodology. It also specifies the deliverables and project timeline. Chapter five addresses communication strategies, while chapter six discusses the professional competencies relevant to the project. The document concludes with a list of sources and appendices, providing additional reference material.

2. Assignment and background

This section provides an overview of the research assignment, including the problem it seeks to address and its broader context. The objective is to gain insight into the significance of the project and the environment in which it is conducted. The section outlines the assignment issued by the client, as well as the sector, company, and department relevant to the research.

2.1. The assignment issued

The assignment, issued by TNO (Netherlands Organisation for Applied Scientific Research), focuses on classifying arrhythmia in F-35 fighter pilots. Pilots sometimes experience unexplained physiological events (UPEs) during high-G maneuvers, raising concerns about potential physiological anomalies. The goal of this research is to develop an advanced ECG-based arrhythmia classifier that can reliably distinguish between actual arrhythmias and false alarms.

The primary challenge is ensuring that the classifier is reliable enough to perform well across different sensor types and measurement conditions. Given that there is limited real-world flight data involving arrhythmic events, the classifier must be trained on controlled experimental data while maintaining high accuracy when applied in real flight conditions. Initial research has shown that traditional machine learning models, such as Random Forests, fail to generalize effectively to new datasets, whereas Support Vector Classifiers (SVCs) show better cross-domain adaptability. This project aims to enhance the classifier’s domain transfer stability through innovative machine learning techniques.

2.2. Context of the assignment

**Sector**

This research falls within the defense and aerospace sector, specifically focusing on physiological monitoring and aviation safety. Fighter pilots are subjected to extreme physical conditions, particularly during high-G maneuvers, where physiological stress can lead to performance degradation or medical incidents. Ensuring pilot safety is a priority for defense organizations worldwide, making real-time health monitoring a crucial area of research.

A key challenge in this sector is the reliability of physiological monitoring systems. Current ECG-based classifiers often struggle with cross-domain performance due to variations in sensor types, signal noise, and environmental conditions. The ability to create a stable and adaptable classifier will contribute to improved in-flight health monitoring and potentially set new standards for pilot safety protocols.

**Company: TNO**

TNO is an independent research organization in the Netherlands dedicated to applied scientific research. It collaborates with government bodies, private enterprises, and academic institutions to drive innovation in fields such as defense, energy, health, and ICT. TNO’s mission is to apply knowledge to enhance societal well-being and economic competitiveness.

TNO operates across multiple sectors, with a strong presence in defense and national security. It provides technological solutions that support the Dutch military, including research on human performance in extreme environments. Within this context, the arrhythmia classification project aligns with TNO’s broader goal of enhancing safety and operational effectiveness in high-risk scenarios.

**Department**

The research is conducted within TNO’s Human Performance and Biomedical Monitoring division. This department focuses on understanding physiological responses to extreme conditions and developing technologies to optimize human performance. Key activities include:

* Developing physiological monitoring systems for military and aerospace applications
* Conducting biomedical research on human adaptation to stress and fatigue
* Designing AI-driven solutions for real-time health monitoring

The research team consists of data scientists, biomedical engineers, and defense specialists working together to enhance the resilience of physiological monitoring technologies. This project contributes to ongoing efforts in optimizing ECG signal processing and improving the practical deployment of machine learning models in operational environments.

3. Analysis and Theoretical Exploration

This section will provide a detailed examination of the problem presented in the project, analyze the requirements and context surrounding the task, and explore theoretical sources and research on the relevant topic. This will include understanding the key problem, its stakeholders, and the broader context, as well as reviewing existing literature and research to offer deeper insights into the challenge.

### 3.1. Analysis of the Assignment

The task at hand involves developing an arrhythmia classifier capable of detecting irregular heartbeats in F-35 pilots during high-stress, high-G manoeuvres. The pilots sometimes report feeling unwell during these manoeuvres, and it is crucial to determine whether this is due to genuine physiological anomalies or is a false alarm caused by sensor or environmental factors. This challenge is compounded by the fact that the classifier must generalize well to different sensors and sensor types, which may change in the future, making it necessary for the algorithm to perform effectively across different datasets.

**Problem Description**:  
The main problem is the inability of current machine learning models to generalize across different domains, sensor types, and activity conditions. The classifier must be able to detect arrhythmic events reliably from ECG data, which is recorded in varying conditions (resting, running, or high-stress flight situations). A significant hurdle is that real-world flight data showing arrhythmias does not exist, so the classifier must be trained and validated using controlled datasets, which may differ from actual flight conditions. Ensuring the classifier’s reliability when moving between different data sources is crucial.

**Stakeholders**:

* **F-35 Pilots**: They are the most directly affected group. Their safety is the highest priority, as a misdiagnosed arrhythmia could jeopardize their health and mission success.
* **Dutch Government**: Through TNO, the Dutch government has a vested interest in ensuring the safety and performance of its armed forces.
* **TNO**: The organization responsible for addressing this issue through the development of a reliable arrhythmia detection system that can be integrated into the cockpit systems of fighter jets.
* **ECG Sensor Manufacturers**: These companies provide the technology used to collect the physiological data needed for classification, and their devices must be reliable enough to handle the extreme conditions of high-G maneuvers.
* **Medical Professionals and Flight Medics**: They must accurately interpret the data, ensuring that pilots receive appropriate medical attention if a genuine arrhythmic event occurs.

**The Client**: The client for this project is TNO, who has commissioned the research to develop an arrhythmia classifier that can be used for F-35 pilots. They are looking for solutions that can be implemented in a real-world context, ensuring pilots' safety and maximizing the generalizability of the model.

**Other Affected Groups**:

* **Aircraft manufacturers**: Manufacturers of the F-35 jet and the cockpit systems will be indirectly affected as they may need to integrate the arrhythmia detection system into the aircraft's operational systems.
* **Air Force Operations**: The operational procedures and health monitoring protocols used during flight may need to adapt if new detection systems are implemented.

**Who Will Benefit**:

* **Pilots**: They will benefit directly from the improved safety and health monitoring, potentially preventing health incidents during flight.
* **TNO**: Successfully addressing this challenge would reinforce TNO's reputation as a leader in developing innovative and impactful solutions for the defense sector.
* **Dutch Defense Forces**: The safety of pilots during missions will be improved, contributing to the overall effectiveness and safety of the military operations.
* **ECG Sensor Manufacturers**: The demand for more stable and adaptable ECG sensors would rise, prompting innovation in the sensor technology.

**Who Might Be Negatively Affected**:

* **Overly Cautious Monitoring Systems**: If the classifier is too sensitive, it may lead to false alarms, causing unnecessary panic, interruptions, or even causing pilots to abandon critical missions due to erroneous readings. A poorly optimized system could negatively affect performance in the cockpit.
* **Manufacturers of Older or Less Reliable ECG Sensors**: Manufacturers whose devices do not meet the evolving demands of high-stress environments might lose out on opportunities for integration into defense systems.

**When the Problem Arose**: The problem has existed as long as fighter pilots have been subject to high-stress, high-G environments. The specific focus on ECG-based arrhythmia detection has become more critical with the increasing complexity and performance demands placed on pilots. The need for real-time health monitoring is amplified as the aircraft systems grow more sophisticated and as pilot safety becomes a top priority in military operations.

**What Prompted the Problem**: The problem arose from reports by F-35 pilots who sometimes experience unexplained physiological events during high-stress maneuvers. These experiences raised concerns about the pilots' safety and led to the need for a reliable system to monitor heart health during such critical operations.

**Why It’s a Problem**: This problem is critical because any misdiagnosis could lead to serious health risks for the pilots and potential loss of life. Moreover, if the arrhythmia classifier fails to perform reliably across various scenarios, it might undermine confidence in using ECG-based health monitoring systems in future missions.

**Where the Problem Occurs**: This problem occurs primarily during high-G maneuvers in F-35 jets, where pilots are subjected to intense physical stress. The data used for training and validating the classifier must come from controlled conditions (e.g., resting or activity-based ECG data) but needs to generalize well to real-world flight conditions, which have higher variability.

**Tools to Sharpen the Problem**:

* **Fishbone Diagram**: A fishbone diagram can help identify potential causes of the problem, including factors like sensor quality, environmental conditions, pilot stress levels, and data quality. This will give insights into the root causes that affect model performance.
* **5xWhy**: The 5xWhy technique will help drill down to the core issues by repeatedly asking “why” to understand why current models do not generalize well, why pilot health monitoring is critical, and why current solutions are insufficient.

### 3.2. Theoretical Exploration: Source Research

To deepen our understanding of the problem, a comprehensive literature review is essential. The theoretical exploration will look at relevant existing research, explore possible methodologies for developing the classifier, and examine previous studies and current technological trends in arrhythmia detection.

**Action Plan for Finding Sources**:

* **Exploring Similar Problems**: There are several studies that have explored arrhythmia detection from ECG signals. Many of these focus on detecting arrhythmias in resting or semi-active states, but very few focus on high-stress or high-G environments, which is a key gap.
* **Use of PhysioNet**: The MIT-BIH Arrhythmia Database on PhysioNet offers an excellent starting point for developing a classifier in a controlled environment. From there, we can explore research on transferring models to new environments, like exercise or flight scenarios.
* **Searching for Key Sources**: We will search for articles, books, and white papers on:
  + Arrhythmia detection techniques in medical diagnostics.
  + The use of machine learning and signal processing in ECG classification.
  + Techniques for improving cross-domain generalization in machine learning.
  + Studies on the effects of high-G forces on human health, particularly on cardiac function.

**Important Concepts and Insights**:

* **ECG Signal Processing**: Filtering, feature extraction, and noise reduction are key aspects that can significantly improve classification performance.
* **Machine Learning Techniques**: SVMs, Random Forests, and newer deep learning models like convolutional neural networks (CNNs) have been used for arrhythmia detection. However, techniques for ensuring generalization across sensor types, noise conditions, and environments are under-researched.
* **Domain Transfer in Machine Learning**: Techniques like transfer learning and domain adaptation are important when applying models trained on controlled data to real-world flight conditions.
* **Current Trends in Pilot Health Monitoring**: As aviation technology advances, so does the need for more reliable and unobtrusive health monitoring systems for pilots, which is driving research into real-time monitoring solutions.

**Previous Research and Existing Solutions**:

* **Existing Solutions**: Current methods for arrhythmia detection in medical settings largely rely on supervised machine learning algorithms. However, adapting these models to work in dynamic, high-risk environments like fighter jets has not been sufficiently explored.
* **Previous Research**: Much of the research into ECG-based arrhythmia detection has focused on the medical domain and has been trained using data from patients at rest. Limited research has been done on detecting arrhythmias in physically demanding environments, which directly applies to this project.

**Existing Methods and Techniques**:

* **Feature Extraction**: Several methods for ECG feature extraction are well established, including the use of time-domain features (like heart rate variability) and frequency-domain features (such as power spectral density).
* **Unsupervised Learning**: As part of the evaluation of models on datasets with unknown arrhythmia labels, unsupervised learning techniques such as clustering and anomaly detection could be applied.

**Possible Limitations and Risks**:

* **Data Availability**: There is limited real-world data from F-35 pilots experiencing arrhythmias, which makes model validation difficult.
* **Sensor Variability**: The different sensors used in ECG recording could introduce noise or variability, which could affect model accuracy.

4. Research design

***Introduction***

This section outlines the research design for the project Classifying Arrhythmia in Fighter Pilots, undertaken for TNO. The research design details the refinement of the research problem, objectives, and research questions. It also defines the scope and methodology of the study, ensuring a structured and reproducible approach. Additionally, this section describes the deliverables and the project schedule*.*

4.1. Definitive assignment

Based on the initial analysis and exploration, the assignment is refined as follows: The project aims to develop an arrhythmia classification system capable of detecting irregular heartbeats in F-35 fighter pilots during high-G manoeuvres. Given the challenges in obtaining real in-flight arrhythmia data, the classifier must generalize well across different datasets and sensor types. The research will focus on improving domain transfer resilience to ensure the model performs reliably in various operational environments.

4.2. Objectives and desired results

#### **Research Objective**

The primary research objective is:

* To develop a reliable machine-learning-based arrhythmia classifier that can generalize across different sensor types and datasets, ensuring high accuracy in real-world flight conditions.

This research aims to enhance domain adaptation techniques to improve classifier performance across varied ECG signal characteristics.

#### **Client's Objective**

TNO seeks to develop a classification system that:

* Accurately detects arrhythmia events in fighter pilots.
* Demonstrates effectiveness across multiple ECG sensor types.
* Can be integrated into future monitoring systems used in military aviation.
* Provides actionable insights to improve pilot safety during high-G maneuvers.

#### **Desired Results (SMART Goals)**

* **Specific**: Deliver an arrhythmia classification model optimized for adaptability across ECG sensor domains.
* **Measurable**: The model should achieve accuracy in detecting arrhythmic events on unseen datasets.
* **Achievable**: Utilize machine learning techniques like domain adaptation and transfer learning.
* **Relevant**: Address the challenge of ECG signal variability and generalization to real-world flight conditions.
* **Time-bound**: Complete the research and deliver a functional prototype within the project timeframe.

4.3. Main research question and sub-questions

#### **Introduction**

The following research questions align with the objectives and define the research's analytical scope.

### 4.3.1. The main research question

How can a machine-learning-based arrhythmia classifier be designed to ensure stable and reliable performance across multiple ECG sensor domains in fighter pilots

### 4.3.2. The sub-questions

* What are the key ECG features associated with arrhythmia detection in fighter pilots?
* Which machine learning techniques improve generalization across different ECG datasets?
* How can domain adaptation methods enhance classifier performance across different ECG sensor types?
* What is the optimal evaluation framework for assessing classifier effectiveness in real-world conditions?
* To what extent does the final classifier meet the performance requirements set by TNO?

4.4. Scope and delineation

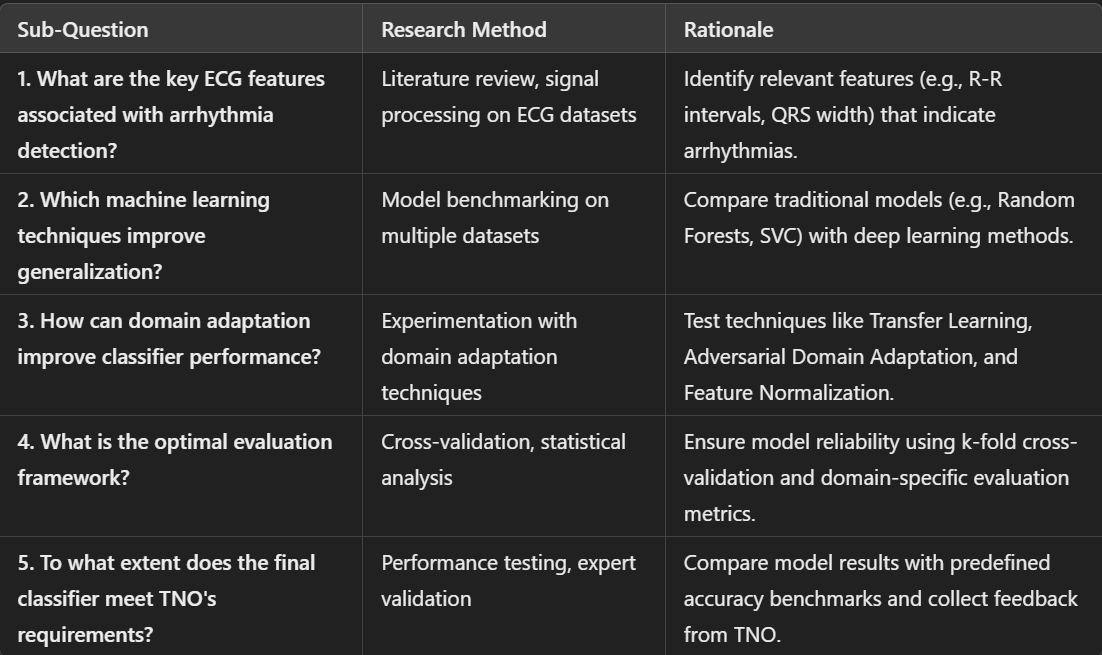
The project will focus on:

* Developing a machine learning model for ECG-based arrhythmia classification.
* Exploring domain adaptation techniques for improved cross-sensor stability.
* Evaluating model performance using publicly available and simulated ECG datasets.
* Validating the classifier against predefined TNO performance criteria.

The following aspects are not included in the scope of this project:

* Real-time implementation on flight hardware.
* Latency of the model
* Medical certification for clinical use.
* Investigating pilot-specific physiological variations outside ECG signals.

4.5. Research method per sub-question



4.6. Products to be delivered

The final deliverables include:

1. **Arrhythmia Classification Model** (Python-based)
   1. Machine learning model trained on diverse ECG datasets.
   2. Optimized for domain stability.
2. **Technical Report**
   1. Description of methodology, model development, and findings.
   2. Evaluation results and recommendations for deployment.
3. **Prototype Implementation**
   1. Functional codebase for testing and demonstration.
4. **Supporting Documentation**
   1. Data preprocessing pipeline.
   2. Model training and evaluation framework.
5. **Presentation for TNO**
   1. Summary of results and recommendations.

4.7. Overview of activities and schedule

#### **Project Phases**

1. **Phase 1: Research & Literature Review (Weeks 1-4)**
   1. Study existing ECG classification techniques.
   2. Identify relevant machine learning approaches.
2. **Phase 2: Data Collection & Preprocessing (Weeks 5-8)**
   1. Gather ECG datasets.
   2. Implement feature extraction and normalization.
3. **Phase 3: Model Development (Weeks 9-12)**
   1. Train baseline models.
   2. Experiment with domain adaptation techniques.
4. **Phase 4: Model Evaluation & Optimization (Weeks 13-16)**
   1. Perform cross-validation.
   2. Compare results across multiple datasets.
5. **Phase 5: Documentation & Finalization (Weeks 17-20)**
   1. Compile technical report.
   2. Deliver final presentation.

A detailed Trello board will be used to track dependencies and milestones.

5. Communication

The parties involved in the assignment are the client, Maarten Schadd, who works for TNO, and Project Group 3, consisting of Bianca Burlacu, Wojciech Kolasa, Codrin Calin, and Salman Kanj.

As agreed, Project Group 3 will take the lead in managing the project, ensuring smooth progress and timely decision-making. This includes coordinating tasks, maintaining clear communication, and proactively addressing challenges to meet project goals effectively.

We have established that meetings with TNO will take place online via Microsoft Teams. These meetings will be scheduled upon reaching significant project milestones, allowing us to update the client on progress, gather feedback, and align on next steps.

Within our group, we maintain bi-weekly communication to discuss progress, address challenges, and plan upcoming tasks. This frequency will increase as deadlines approach, particularly when assignments need to be submitted. We use a combination of in-person discussions and online collaboration tools to stay aligned.

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| --- | --- | --- | --- | --- |
| Name | Job title | Organisation/department | Email address | Telephone numbers |
| Maarten Schadd |  | TNO | maarten.schadd@tno.nl |  |
|  |  |  |  |  |

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Appendices

*<Additional texts, charts, results and so on will be included in the appendices. Each appendix should be numbered. When writing the body text of the action plan, be sure that you adequately refer the reader to the appendices.>*