Mission Clock for Intuitive Drone Control Interface for Search and Rescue (SAR)

By

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Declaration of own work

I declare that the work in this MSc dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

Harsha vardhan - 5th december, 2024

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Abstract

This project presents the development of an interactive Mission Clock, designed specifically for Search and Rescue (SAR) operations to provide a visual representation of critical mission parameters. Built using Python with the Tkinter library, the Mission Clock offers a user-friendly interface that allows SAR teams to effectively manage mission duration, track battery levels, monitor elapsed time, and identify critical time markers such as sunrise and sunset. These features are crucial for ensuring the mission's safety and success, particularly in remote or challenging environments [1], [2].

The interface integrates several user-oriented functionalities, such as visual alerts for low battery levels and elapsed mission time, along with manual overrides for adjusting current mission parameters. Additionally, the Mission Clock is designed to allow users to mark waypoints dynamically, providing intuitive visual feedback that helps improve mission navigation [3] and [4].

A critical aspect of the project involved the application of heuristic evaluation, a usability inspection method, to refine the Mission Clock interface. This evaluation was conducted by usability experts based on Nielsen's 10 Usability Heuristics, which focus on principles such as visibility of system status, error prevention, consistency and standards, and aesthetic and minimalist design. The evaluation identified usability issues, including the need for clearer visual hierarchy and improved feedback mechanisms[5].

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1 Introduction

1.1 Motivation

The term Search and Rescue (SAR) is described as "the task of searching for missing persons or locating and recovering persons in distress and delivering them to a place of safety" by [6]. SAR operations are missions that are critical of response time and precision which determine the difference between life and death. The increase in the reliance on Unmanned Aerial Vehicles(UAVs) for SAR missions highlights the importance of UAVs for critical applications and the immediate need for effective control interfaces which are pivotal in enabling situational awareness, efficient controlling of drones and real-time data visualisation. This project is built on these principles, aiming to create a user-friendly interface that enhances mission tracking and decision-making during sensitive scenarios.

A well designed control interface acts as a lifeline for SAR operators by guiding them through chaotic environments and enabling them to save live effectively.[7] emphasises that such an interface would improve real-time situational awareness, streamlines operational processes and reduce the cognitive load on the operators. By integrating visualisation of mission critical metrics such as elapsed time, waypoint tracking and battery level monitoring, this project aligns with their inputs for user-centered designs in UAV based SAR operations. The practical challenges of UAV integration into SAR operations as discussed by [2], further heightens the significance of this project. They highlight that while UAVs provide unparalleled advantages in covering large areas quickly, their effectiveness is often hindered by limitations in interface, particularly in real-time control, adapting to the environment and visualisation of mission critical data. This project addresses the need for synthesizing critical data into an intuitive and actionable format through a robust interface solution.

The motivation for this project also grew from the need to bridge technological and operational gaps identified in SAR research by [8]. For instance, [2] push for advancements in optimized flight paths, enhanced image acquisition and real-time feedback mechanisms. This project contributes to these advancements by incorporating features such as sunrise-sunset time indicators for improved mission planning, dynamic waypoint visualization for better navigation and battery level monitoring to manage UAV endurance, which contributes towards effective and efficient SAR operations.

Moreover, the integration of SAR specific data visualisation tools within a single interface in the project aims to address the limitations of the current UAV interfaces. By displaying mission progress and environmental factors in a concise and accessible manner, the interface reduces the operator workload and improves decision making. This aligns with [2] recommendation for software solutions that tailor UAV functionality to the unique demands of SAR missions.

In summary, this project is motivated by the need to improve SAR efficiency through an advanced interface design which is suitable for SAR operators who have limited experience in UAV operations. By leveraging insights from UAV research and challenges faced during real-world SAR operations, this project seeks to provide a practical user-focused solution that enhances mission outcomes while addressing critical operational limitations.

1.2 Aim

The aim of the project is to develop an advanced drone control interface for SAR operation, the mission clock, which enhances real-time situational awareness and facilitate rapid decision-making for SAR operators. This tool integrates visualisation of UAV and mission data, adaptive to the environment and aligns with user-centered design principles to improve operational efficiency and safety in SAR operations.

1.3 Objectives

1. To Provide SAR operators with real-time visualisations of key metrics, including elapsed mission time, UAV battery levels, waypoint tracking and sunrise and sunset time to support real-time decision making for SAR operators [9].
2. To incorporate user-centered design principles to create an intuitive interface, reducing cognitive load and operational errors for SAR operators [10].
3. To address dynamic mission requirements for changing environmental conditions through adaptive visual elements and real-time feedback[11].
4. To integrate UAVs and mission specific data such as waypoint visualisation, elapsed time and environmental factors effectively with SAR operators (Sophie Hart).
5. To develop a system that integrates scalability, efficiency and responsiveness to strike a balance between computational complexity and real-time performance.(Douer Meyer, 2020)
6. To do a heuristic evaluation to test the usability of the interface.

2 Key contributions

This project integrates with several concepts highlighted by previous researches:

2.1 Decision Support Systems(DSS)

The project is built on the framework outlined in [8], which highlights the importance of DSS in aiding SAR operators particularly in automating features that assist operators in decision making. This project integrates DSS elements to assist operators with real time data visualisation and decision making.

2.2 Situational awareness

[8] identifies degradation of situational awareness as a key challenge for UAV operators which is addressed in this project by providing real-time mission metrics in a centralized interface and data prioritization to ensure operators have a clear understanding of the mission environment at all times[9].

2.3 User-centric interface design

[8] stresses that the importance of designing interfaces that align with the needs of the payload operators. This project incorporates these by virtue of Heuristic evaluation to ensure the interface meets the practical requirements of SAR operators.

2.4 Cognitive load management

Drawing on [8], the mission clock reduces the cognitive load by using clear visual indicators such as arcs and markers for concise and effective presentation of mission critical information.

2.5 Waypoints management

Concepts from [2] on UAV flight path optimization and area coverage efficiency were utilized to design the dynamic waypoint visualisation system which ensures UAVs are effectively deployed across large search areas.

3 Literature Review

Use your literature review to help the reader to understand the value and the interest in your project. You should look for related works already published that either support the merit of your project, or provide the background understanding/information to make your new claims. Try to avoid writing a "catalogue" of related works (e.g this would have little of your own insight added). Instead, describe to the reader why the related work is interesting or relevant to your own work. What did they achieve? What did they overlook? It is highly recommend you finish your Literature Review with a final subsection "Summary", where you may wish to formulate highly specified research questions or hypotheses, or assert the need for your Research Methodology (next chapter).

3.1 Search and Rescue (SAR)

Search and Rescue(SAR) missions play a pivotal role in safeguarding communities by locating and assisting individuals in distress which are often under challenging and hazardous conditions. These operations are critical in mitigating the adverse effects of natural disasters, accidents, lost during expeditions and other emergencies, thereby preserving lives and enhancing societal resilience.

3.1.1 Challenges faced during SAR missions

There are multiple challenges associated with SAR missions, which are,

Time constraints

Of the numerous problems faced during SAR missions, time is the most critical challenge as prolonged operations can diminish survival chances and can endanger rescue personnel. It is often referred to as the "golden hour" in disaster response contexts [2]. Rapid action plays an essential role in saving lives and preventing further harm. However, multiple factors impede timely response including inaccessible terrains, environmental changes and communication discrepancies.
Natural disasters such as earthquakes and floods often leave infrastructure in disarray which delays the arrival rescue teams at affected as noted by [2] . This lost time needs to be compensated with the help of technologies such as UAVs which can be rapidly deployed to search for survivors. The main reasons for the constrain in time during SAR missions are as follows,

1. Inefficient communication systems, delay in reading and processing the data from instruments lead to delays in SAR missions as emphasised by [12] . They also highlight the need for better coordination

tools. They argue that many SAR operations lack integrated systems for real-time data sharing which leads to delay in decision making.

2. The role of situational awareness in addressing time constraints is discussed by [9]. The lack of tools that provide integrated, real-time situational data forces rescuers to rely on incomplete or outdated information which prolongs decision-making.

3. While UAVs and Decision support systems (DSS) are highlighted as promising solutions, current implementations lack scalability. Existing DSS tools are not universally interoperable which complicates multiagency SAR efforts [10].

4. Additionally, the cognitive load of managing multiple inputs can paradoxically slow decision making during critical phases[10].

Rescuer fatigue

SAR missions are often physically and mentally exhausting for rescuers. Prolonged efforts in hazardous environments lead to fatigue, impaired decision making, situational awareness and overall performance[13]. This fatique impacts the following processess,

1. Fatigue reduces cognitive performance which makes it difficult for rescuers to assess risks accurately or adapt to changing conditions [10]. As per [13] This fatigue accumulates rapidly when rescuers are required to process large amounts of data, especially in high stress scenarios involving multiple UAVs.

2. As per [14] physical fatigue especially in extreme weather conditions, increases the likelihood of accidents among the rescuers. For instance, in cold climates, prolonged exposure leads to hypothermia which further diminishing operational effectiveness. This emphasises the need to reduce to burden on the rescuers by reducing their operation time along with reducing their cognitive work load.

3. Prolonged SAR missions also take a toll on mental health and constant exposure to distressing scenes coupled with the pressure of life and death decisions contributes to stress related disorders [15].

Moreover, SAR operations also face issues like resource limitations, environmental hazards which are not part of this project and are therefore disregarded.

The mission clock project needs to address both time constraints and fatigue, two of the most significant challenges in SAR missions. Proposed solutions like integrating DSS into UAVs for real-time data visualisation and automated drone tasking could be useful in mitigating the above challenges and lead to significant advancements in reliability and adaptability to varying field conditions. The mission clock overcomes these limitations by offering a scalable, user-centered solution that integrates seamlessly into existing SAR workflows.

3.2 The role of UAV in SAR

Unmanned Aerial vehicles (UAV), commonly known as drones have become integral to SAR operations due to their flexibility, mobility and accessibility. UAVs have enhanced SAR missions significantly due to their ability to access hazardous or inaccessible areas, perform complex tasks and provide real-time monitoring.

3.2.1 Advantages of UAVs in SAR operations

1. UAVs can be deployed rapidly and offers immediate situational awareness by capturing aerial imagery and generating detailed maps of disaster stricken areas. For instance, during the 2015 Nepal earthquake, drones were instrumental in creating 3D maps that facilitated efficient resource allocation and planning [12].

2. Equipped with advanced sensors such as LiDAR, thermal imaging cameras, UAVs can detect heat signatures of suvivors even in low- visibility conditions, thereby expediting rescue efforts[7].

3. UAVs can excecute predefined flight paths to systematically cover search areas optimizing coverage and reducing the time requried to locate missing people.[16]

3.2.2 Challenges faced by UAVs in SAR operations

Despite their advantages, UAVs face several operational and environmental challenges during SAR missions:

1. UAVs typically have limited battery life, which limits their operational time and range. This limitation is critical in extensive search areas, where longer flight times are necessary to cover the area thoroughly. The Mission Clock project attempts to address this by incorporating a real-time mission duration tracker and battery level indicator, providing precise updates to manage and optimize flight operations effectively.

2. Performance of UAvs can be significantly affected by adverse weather conditions such as high winds, rain, or extreme temperatures, which can impede flight stability and the functionality of onboard sensors. Research by [17] emphasizes the need for UAVs to have robust systems that are capable of adapting to changing environmental conditions to maintain operational effectiveness [17].

3. Accurate navigation is essential for an effective SAR operation. For this UAVs rely heavily on GPS for location tracking and waypoint navigation. However, GPS signals can be unreliable in certain environments like dense forests or urban areas with high-rise buildings, potentially leading to decreased accuracy in location tracking and operational inefficiency [11]. The Mission Clock's waypoint management feature, which involves real-time updating and tracking of waypoints on an interactive display, is a strategic enhancement that could mitigate these navigation challenges.

4. Data Management and Real-Time Communication: Efficiently managing the vast amounts of data collected during UAV flights is crucial for timely decision-making. Bandwidth limitations for transmitting high-resolution images and videos in real time can delay the relay of critical information. The integration of UAV operations with advanced ground-based software systems like the Mission Clock can streamline data handling and improve communication channels between the UAV and the control center.

5. UAVs operating in SAR missions must navigate complex airspace regulations and privacy concerns. Ensuring compliance with these regulations while maintaining operational flexibility is a significant challenge [18].

The integration of UAVs into SAR operations represents a significant advancement which offers enhanced situational awareness and operational efficiency. However, their effectiveness is dependent upon overcoming technical and regulatory challenges. The mission clock project aims to enhance SAR operations by providing a unified mission tracking interface that integrates critical mission data such as UAV battery levels, waypoint tracking and environmental conditions into an intuitive interface, the mission clock which facilitates rapid decision making and reduces cognitive load for the SAR operator. This integration directly addresses the challenges of time constraints and situational awareness in SAR missions which enhances the effectiveness of UAVs.

3.3 UAV Ground Control Stations (GCS) and Human-computer Interaction (HCI)

Ground control Stations (GCS) and flight data interfaces are integral to UAV missions, especially in time sensitive SAR operations. GCS provides the command infrastructure for UAV operations, integrating real-time telemetry and decision support tools.

1. They facilicate real-time data integration by combining UAV telemetry and environmental data.

2. Visualisation tools provide graphical representations of flight paths, timelines and resource usage data.

3. The Decision Support Systems(DSS) assist in prioritising tasks and optimising mission parameters.

The importance of integrating multiple data streams into GCS to enhance situational awareness in UAV mission is highlighted by [12].

3.3.1 Real-time visualisation

Real-time visualisation addresses rapid decision making, which is one of the most critical aspects of SAR missions. By allowing operators to dynamically analyse UAV movements and environmental changes tools like DSTVis reduces cognitive burden on operators[1].

Interactive visual tool help operators quickly identify patterns and outliers in flight data which is especially useful in large scale SAR operations involving multiple UAVs. However, the interface relies heavily on operator interpretation, which might vary based on skill levels [1].

3.3.2 Timeline integration in GCS

Timeline integration is crucial for both operational training and live mission support, while the framework is primarily designed for post-mission evaluation, its timeline visualisation approach can be adapted for real-time operations. However, its limited emphasis on real-time application renders it less effective in active SAR missions where immediate decisions are required [9].

3.3.3 Multimodal interfaces

Multimodal tools such as visual, auditory and haptic feedback can enhance decision-making by providing operators with diverse sensory inputs for time-critical alerts. These interfaces significantly improves the usability of GCS by reducing cognitive overload and enabling faster reaction times for the operator[3]. However, they can become overwhelming for the operator, leading to a cluttered experience where multiple inputs can compete for attention of the operator if not designed carefully. Their adoption is also constrained by the need for specialised hardware, which may not be readliy available during all SAR opertions [15].

3.3.4 Adaptive time domain features

Adaptive features such as preprocessed timelines and event markers, reduce the cognitive burden on operators by presenting actionable insights rather than raw data . By prioritizing critical events such as waypoint completion or battery depletion, these features ensures operators to focus on urgent or important tasks without being overwhelmed. However, over reliance on pre-processing algorithms might lead to critical data being filtered out particularly in scenarios with unpredictable changes [2].

The mission clock project can incorporate timeline visualisation as a central feature, which integrates real-time event tracking and predictive analytics for active missions. A multimodal feedback can also be implemented selectively using high contrast visual cues to alert the operator for time critical updates along with the option to customise filters and priorities which would ensure adaptibility to varied mission requirements [19].

3.4 Research gaps

Despite advancements in Unmanned Aerial Vehicle (UAV) technologies, current Ground Control Station (GCS) interfaces exhibit significant limitations, particularly in time-sensitive Search and Rescue (SAR) operations. Identifying these gaps underscores the necessity for this project, which aims to enhance GCS interfaces for improved efficiency and effectiveness.

Cognitive overload in Multi-UAV Operations

Operators managing multiple UAVs often face cognitive overload due to complex interfaces and high data influx. [20] highlights that the current mission planning systems lack user-centric designs, leading to increased operator workload and potential errors .

Inadequate real-time data integration

Existing GCS interfaces frequently fail to provide seamless real-time data integration, crucial for dynamic decision-making in SAR missions. The absence of synchronized timelines and predictive analytics hampers situational awareness and timely responses[7].

Limited multimodal interaction capabilities

Many GCS interfaces do not support multimodal interactions, such as visual, auditory, and haptic feedback, which are essential for effective communication in high-stress environments. This limitation can lead to misinterpretation of critical information during SAR operations[21].

3.4.1 Justification for this project

The Mission Clock project address these gaps by developing a GCS interface that:

1. Incorporate user-friendly designs and features to alleviate operator burden.
2. Provide synchronized timelines and predictive analytics for improved situational awareness.
3. Integrate various feedback mechanisms to ensure clear communication.
4. Offer tools that enable effective teamwork and coordinated decision-making.

By addressing these critical areas which are in line with the objectives discussed previously, the project aims to improve the efficiency and effectiveness of SAR operations, ultimately contributing to better mission outcomes.

4 Research Methodology

In order to address the challenges discussed previously, this project employs a comprehensive research methodology that integrates user-centered design principles, evaluation process and metrics and robust data analysis.

4.1 Research design

This project adopts a User-Centered Design (UCD) methodology, in order to ensure that the interface meets the specific needs of SAR operators. Firstly, the problems in existing UAV interfaces used for SAR were identified and defined through literature from reputed journals. Secondly, the core functionalities such as real-time visualisation of time specific data and multimodal feedback were defined. And then, low-fidelity prototypes were developed and refined using heuristic evaluation [5].

This project is guided by three primary questions which address usability, efficiency and cognitive demands for SAR mission interfaces:

1. How does the visual elements in drone control interfaces enhance situational awareness and decision making for SAR operators?
2. What will be the impact of multimodal feedback mechanisms such as visual, auditory or haptic on operator perfromance and error rates in time-sensitive scenarios?
3. How will real-time data integration improve the efficiency and adptability of SAR mission controls?

4.1.1 Hypothesis

As per [3] and [2] and the comprehension of the limitations made through the previous literature review, this project hypothesise that:

> *H1: Multimodal feedback mechnisms reduce reaction times and error rates compared to visual based interfaces.*
> *H2: Real-time data visualisation enhances situational awareness and leads to faster mission completion times.*
> *H3: User-centered Design principles improve usability metrics and reduce cognitive load of the operator.*

These hypothesis were followed by the implementation process were the software and hardware used were mentioned explicitly along with documentation of the technical aspects of this project.

4.2 Implementation

This section explains the technology platform, software and hardware, system architecture and the modules to describe the implementation of the solutions discussed in earlier studies.

4.2.1 Technology platform

The Mission clock for SAR is implemented using the following technologies.

- **Programming language:**
  This project is implemented using **Python** which is a widely used high-level programming language. It is also known for its readability and ease of use. Python 3.13 which is the latest stable version of Python and was chosen due to its versatility and rich collection of libraries that are ideal for rapid prototyping and Graphical User Interface (GUI) development [22].

- **GUI framework:**
  The Graphical User Interface was created using **Tkinter** which is a built-in Python library was used for creating graphical applications. Tkinter is highly suitable for the project due its ease of integration into python and straightforward structure for creating interactive applications.

4.2.2 System architecture and modules

The System architecture uses a modular approach in order for easy organisation and maintenance of the code.

Modules:

1. **Initialization ("init" method):**
   The `init` method initialises the Tkinter root window, mission duration and geographical coordinates. It also defines graphical attributes such as clock dimensions which serve as the visual representation of the mission. This step is important for setting up the main frame of the interface [23]. Refer algorithm 1 for GUI Initialisation module.

2. **Manual override controls:**
   This module provides manual override to allow the developer to override the mission elapsed time and current time which helps for user training and to simulate different mission scenarios. This feature is implemented using **Entry** widget of Tkinter for text input and **Button** widget for triggering the override after starting the mission. Algorithm 2 represents Override function module.

Algorithm 1 GUI initialization module

Input: None

Output: Initialized GUI with visual elements

Initialize root canvas dimensions: width = 600, height = 600

Add clock components: rings, markers, and battery indicators

Define clock center coordinates:

$$(x_c, y_c) = \left(\frac{\text{canvas width}}{2}, \frac{\text{canvas height}}{2} \right)$$

Draw static elements using radii r_{outer}, r_{inner}, r_{minute}, and r_{hour}

Algorithm 2 Override Functionality Module

Input: User inputs for time or elapsed time

Output: Updated clock state

Override time:

$$t_{\text{override}} = \text{User Input: } HH : MM$$

if Valid format **then**

  Update current time: $t_{\text{current}} = t_{\text{override}}$

end if

Override elapsed time:

$$t_{\text{elapsed override}} = \text{User Input: Minutes}$$

if $0 \leq t_{\text{elapsed override}} \leq 60$ **then**

  Update elapsed time: $t_{\text{elapsed}} = t_{\text{elapsed override}}$

end if

3. **Clock parameters:**

   The key parameters of the clock are defined through this module which includes radii for different rings(hour, minute, waypoint) and the positioning of the clock face. The modularity of these parameters allows easy customisation and adjustments which ensures adaptability.

4. **Static clock elements**

   This module draws static elements on the clock face, including the hour and minute rings, waypoints, battery markers, and time indicators such as sunrise and sunset. The canvas object (tk.Canvas) of Tkinter is used to draw these elements and the trigonometric functions from the mathematics module are used to determine their placement [24]. These elements serves as the basis for the dynamic representation of mission time, battery consumption and other key factors in SAR missions. Algorithm 3 highlights the mission duration module and algorithm 4 represents sunrise and sunset updation.

Algorithm 3 Mission Duration Highlighting Module

Input: Start time t_{start}, Duration dur

Output: Highlighted mission arc

Compute start and end angles:

$$\theta_{\text{start}} = 90 - t_{\text{start}} \cdot 6$$

$$\theta_{\text{extent}} = -\text{dur} \cdot 6$$

Draw mission arc with parameters $(\theta_{\text{start}}, \theta_{\text{extent}})$

5. **Sunrise/sunset time calculation:**

   The **Suntime** library was used to determine the times of sunrise and sunset based on latitude and longitude of the application location. This feature is useful for SAR operations, as it helps in mission plan optimisation in terms of available daylight [25]. Refer algorithm 4 for Sunrise/sunset time calculation.

Algorithm 4 Sunrise and Sunset Calculation Module

Input: Latitude lat, Longitude lon

Output: Sunrise (t_{sunrise}) and Sunset (t_{sunset}) times

Define today's date: $d =$ current date

Compute sunrise and sunset using Sun library:

$$t_{\text{sunrise}} = \text{Sun.get\_local\_sunrise}(\text{lat}, \text{lon}, d)$$

$$t_{\text{sunset}} = \text{Sun.get\_local\_sunset}(\text{lat}, \text{lon}, d)$$

if Sunrise or sunset computation fails **then**

    Set defaults: $t_{\text{sunrise}} = 06:00$, $t_{\text{sunset}} = 18:00$

end if

6. **Elapsed time arc:**

   This module draws an arc to represent elapsed mission time which increases in the clockwise direction as the mission progresses. The arc also changes colour to orange at 20 minutes and red at 30 minutes for the 40 minutes mission. This 40-minutes is the average estimate for the battery life. The **"blink arc"** component ensures high visibility for the visual feedback and alerts the operator during critical mission phase i.e., battery depletion period. This visual feedback helps the SAR operators track mission time more effectively and adds layer of urgency when needed [26]. Algorithm 5 represents Mission clock updatation..

Algorithm 5 Mission Clock Update Module

Input: Elapsed time t_{elapsed}

Output: Updated clock arcs and pointers

Compute elapsed time arc angle:

$$\theta_{\text{elapsed}} = -\left(\frac{t_{\text{elapsed}}}{\text{max duration}}\right) \cdot 360^\circ + 270^\circ$$

Update battery indicator:

$$\theta_{\text{battery}} = \left(1 - \frac{t_{\text{elapsed}}}{\text{max duration}}\right) \cdot 360^\circ$$

if $t_{\text{elapsed}} \geq 20$ minutes **then**

    Blink elapsed time arc in **orange**

else if $t_{\text{elapsed}} \geq 30$ minutes **then**

    Blink elapsed time arc in **red**

end if

Update digital clock:

$$t_{\text{digital}} = t_{\text{current}} \quad \text{or overridden time}$$

7. **Battery Indicator and Waypoint tracker:**

   The **Battery indicator** is represented by an arc, which decreases over elapsed mission time, providing a clear and visual indication of battery status.The battery indicator ensures the mission can be monitored within safe power limits and the operator to determine the return of the UAV back to home.

   The **waypoints** are added when the user clicks on the interface or loads itself from a waypoint file. They are represented by small triangles on the waypoint ring which indicates the estimated travel time towards each waypoint. This helps in visualisation of mission checkpoints which aids in navigation and clarity in mission progress through the relation between battery depletion time and the waypoints. Refer algorithm 6 for Waypoint management.

8. **Pointers for Hour and Minute:**

   The hour and minute pointers are calculated using trigonometric functions. The **"update pointer"**

Algorithm 6 Waypoint Management Module

Input: User click at (x, y)

Output: Added waypoint to clock

Compute distance from center:

$$d = \sqrt{(x - x_c)^2 + (y - y_c)^2}$$

if $|d - r_{\text{waypoints}}| \leq 15$ **then**

    Compute angle:

$$\theta_{\text{waypoint}} = \arctan\left(\frac{y - y_c}{x - x_c}\right)$$

    Plot waypoint at:

$$(x_{\text{wp}}, y_{\text{wp}}) = \big(x_c + r_{\text{waypoints}} \cdot \cos(\theta_{\text{waypoint}}), y_c + r_{\text{waypoints}} \cdot \sin(\theta_{\text{waypoint}})\big)$$

end if

method uses the current or the overridden time to draw the pointers on the clock. The current angle is calculated based on the position of the hour/minute hand in a standard 12-hour clock format and the minute timer dial [23] [24].

9. **Digital clock update:** This module displays the current time at the center of the clock and updates every second. It uses the **Canvas.itemconfig()** method of Tkinter to update the time text dynamically.This is because, having both analog pointers) and digital displays makes the mission clock more accessible to individuals who may prefer different ways of representing time, thereby improving usability [23]. Algorithm 5 represents digital clock update feature.

The figures 4.1, 4.2 and 4.3 show the developed interface at the said interval of elapsed mission time.

4.3 Evaluation methodology

4.3.1 Heuristic evaluation

Heuristic evaluation is a usability inspection method where evaluators assess an interface against predefined usability principles known as heuristics. This method is proposed by **Jakob Nielsen** to identify usability issues quickly and cost effectively without requiring actual user testing [27].

Advantages of Heuristic evaluation

1. The developer can evaluate the system using established heuristics [27]
2. Quick feedback can be obtained which provides a structured approach to uncover usability issues efficiently [27].

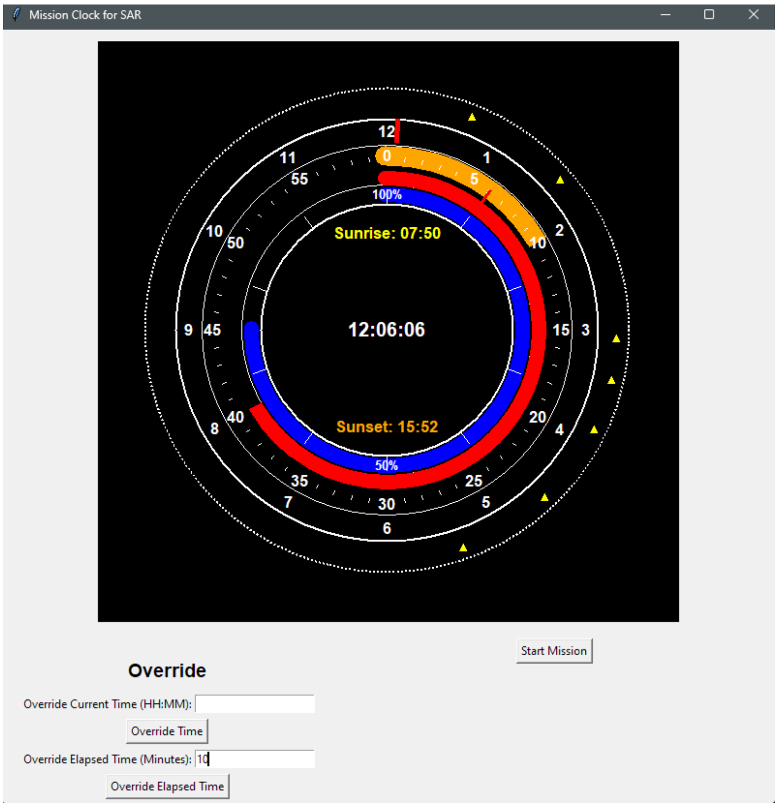

Figure 4.1: Shows the interface when the elapsed time is 10mins

3. Heuristics uses principles liek visibility of system status, error prevention and aesthetic design [27].

Why Heuristic evaluation is apt for this project?

The mission clock for SAR system aims to provide an intuitive, real-time interface for critical SAR operations. Since this system involves high-stake usability requirements, heuristic evaluation is appropriate due to the following reasons:

1. SAR systems require interfaces that are reliable, error-tolerant and easy to understand, even for resuers with very limited knowledge on UAV operations.

2. Heuristic evaluation allows for rapid identification of usability issues which is crucial during the prototyping stage.

3. By addressing usability heuristics like error preevention and system status, the evaluation aligns with the needs of SAR operators.

4. Heuristic evaluation requires less resources when compared to field testing with actual SAR personnel.

Implementation of Heuristic evaluation

As per [27] implementation of heuristic evaluation for this project is as follows:

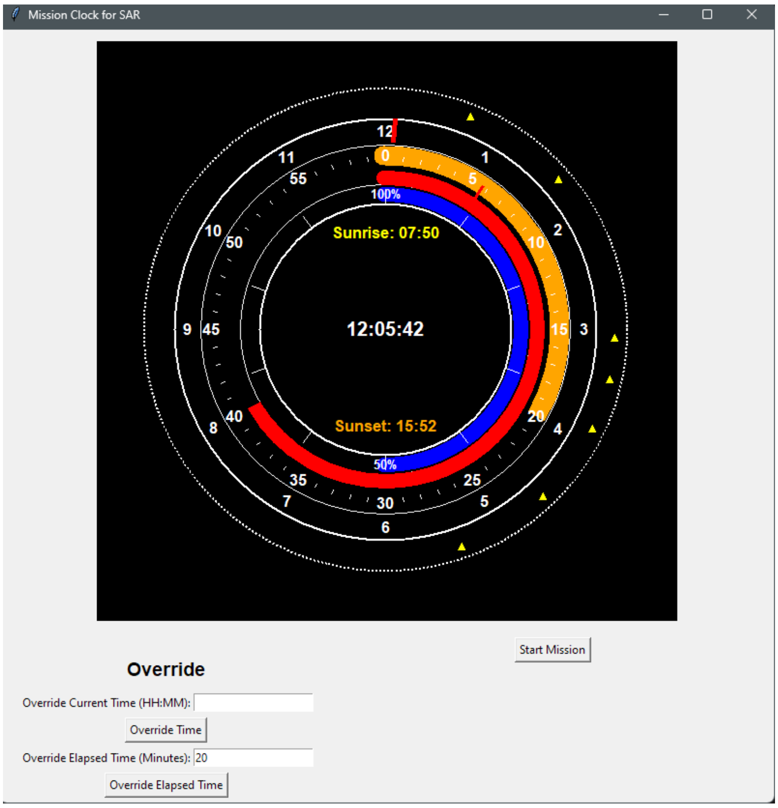

Figure 4.2: Shows the interface when the elapsed time is 20 mins

1. **Define objectives:**

   Evaluate the Mission Clock interface for usability which focuses on SAR-specific needs such as real-time updates, minimal errors, and quick recovery options.

2. **Choose Heuristics:**

   By using Nielsen's 10 Usability Heuristics [27]:

   (a) Visibility of system status.

   (b) Match between system and real world.

   (c) User control and freedom.

   (d) Consistency and standards.

   (e) Error prevention.

   (f) Recognition over recall.

   (g) Flexibility and efficiency of use.

   (h) Aesthetic and minimalist design.

   (i) Help operators recognize, diagnose, and recover from errors.

   (j) Help and documentation.

3. **Evaluate of interface:**

   Static Evaluation: Assess the clock's static elements, such as rings, arcs, and markers, for alignment with

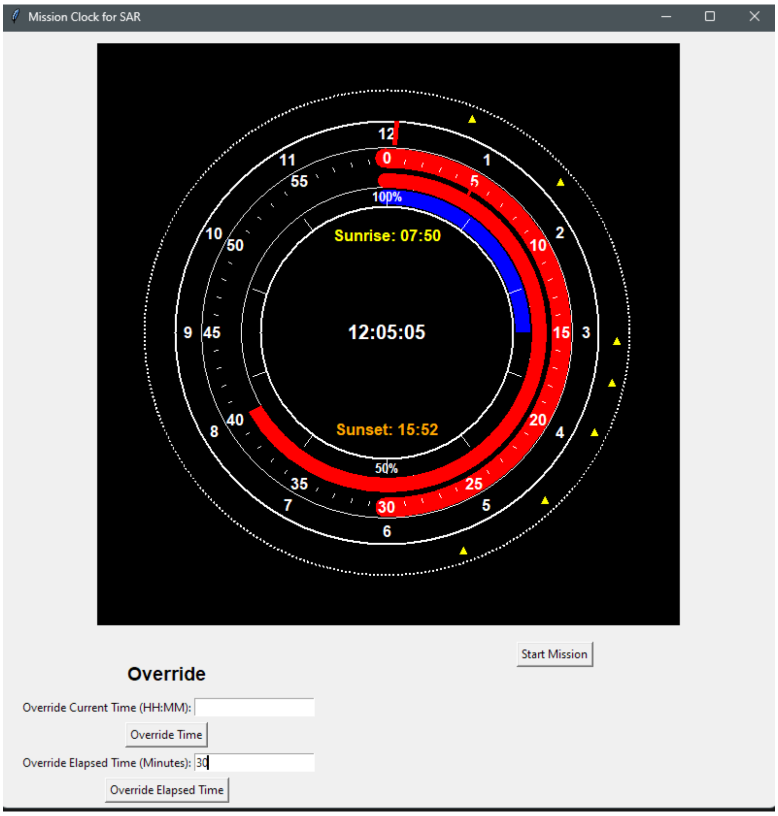

Figure 4.3: Shows the interface when the elapsed time is 30mins

heuristics.

Dynamic Evaluation: Test real-time updates, overrides, and interactions (e.g., adding waypoints).

4. **Document usability issues**

   For each heuristic, evaluators identify the Issues, severity and recommendations for improvement.

5. **Prioritize and refine:**

   Prioritize issues based on their severity and relevance to SAR missions and update the interface iteratively based on feedback.

4.4 Experiment Methodology

You want your reader to agree that you carefully considered your method so that we can trust your results to be both insightful (mean something) and credible (not subject to error):

- If your work is *hypothesis driven*: your method should clearly outline how we expect to gain evidence to address your hypothesis.
- If your work is *solution driven*: your method should clearly outline how and why the measurements you will take are the most important to understand the performance of your system.

- A clear description of the methodology, how it creates a scientific investigation and operates to collect meaningful data.
- A clear justification of why you have chosen this particular approach.
- Information needed for a reader to understand how you did it (can a reader reproduce your work, and collect equally valid results? e.g. hardware/software used, configuration, number of trials, any procedures involving people, the design of any surveys, etc.)
- A description of any approaches taken to process collected data, e.g. metrics are used to combine or post-process data in a meaningful way - you should state any used explicitly, their utility, their suitability to your methodology and their limitations.

5 Results

The heuristic evaluation of the mission clock for intuitive drone control interface for SAR 5.1 and 5.2 highlights both strengths and areas for improvement. The system excels in visibility of system status score of (4) and match between system and real world score of (5), effective use of familiar analog clock interfaces, arcs for elapsed time, and visual metaphors aligns with the user's mental model. Consistent visual elements and logical placement of controls also earned the interface a strong score (5) for consistency and standards.

However, it is noted that certain areas require attention, especially User control and freedom (3) could be improved by adding options to cancel overrides and dynamically pause or restart the mission. Error prevention (3) lacks validation of inputs like override ranges and also recognition rather than recall (4) could utilise better grouping and labeling of override controls. Flexibility and efficiency (3) is limited by the absence of shortcuts or automation, such as waypoint suggestions. The minimalist design (4) is effective but can overwhelm users with visual clutter when too many waypoints are plotted. Furthermore, help and documentation (2) scored the lowest due to the absence of tips, tutorials or help section could hinder new adaptability to new operators. Lastly, error messages (3) need more detail and visual guidance for recovery from mistakes such as incorrect waypoint placement.

Overall, the project performs well in aligning with usability principles while improvements in error handling, user control, and help documentation are necessary to enhance its overall effectiveness. The radar chart visually underscores these strengths and weaknesses, providing actionable insights for refinement.

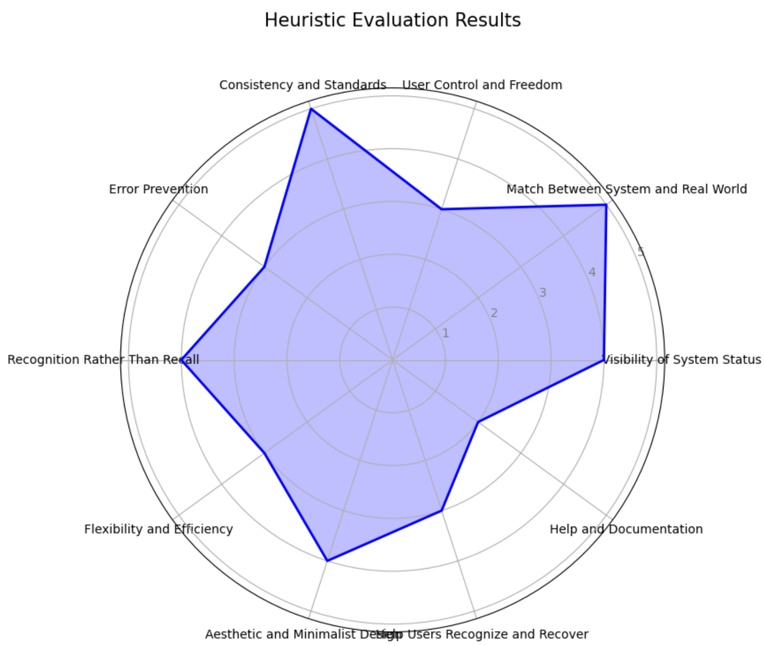

Figure 5.1

Strengths	**Weaknesses**	**Opportunities**	**Threats**
• Intuitive and user-friendly design with familiar clock interface. • Strong visual representation of mission-critical information. • Real-time updates on elapsed time, battery status, and digital/analog clocks. • High consistency in design elements and color codes.	• Lack of robust error prevention mechanisms. • Limited user control (e.g., no pause/restart or cancel override options). • Absence of help and documentation for new users. • Visual clutter when plotting multiple waypoints.	• Potential for integration with advanced AI tools for waypoint prediction. • Use in broader applications like logistics or military operations. • Adding automation and predictive tools to enhance flexibility. • Development of a comprehensive training module or onboarding system.	• User frustration due to lack of error handling and guidance. • Risk of being overshadowed by more feature-rich competitors. • System failures in critical scenarios if weak areas are not addressed. • High user expectations for intuitive operation in high-stakes environments.

Table 5.1: SWOT Analysis

Heuristic	Evaluation Result	Score (1-5)	Recommendations
Visibility of System Status	The system provides real-time feedback on elapsed time, battery status, and digital/analog clock states. Sunrise/sunset markers are visible but static.	4	Enhance real-time updates for sunrise/sunset markers and ensure clear warnings for critical battery levels.
Match Between System and Real World	The circular clock interface, arcs for time, and visual metaphors align well with real-world concepts.	5	Maintain the analog clock structure; no major changes needed.
User Control and Freedom	Override options provide flexibility, but no clear way to cancel an override or restart the mission clock without restarting the app.	3	Add options to cancel overrides and pause/restart the mission clock dynamically.
Consistency and Standards	Visual elements and their meanings are consistent (e.g., red for warnings, yellow for sunrise). No conflicting symbols.	5	Maintain consistency; ensure future updates adhere to the same standards.
Error Prevention	Basic input constraints are present (e.g., override range validation), but invalid inputs could still be submitted without immediate feedback.	3	Disable input fields for out-of-range values and show real-time validation for user inputs.
Recognition Rather Than Recall	Visual elements like elapsed arcs and waypoint markers reduce cognitive load. Override controls are visible but not grouped logically.	4	Group override controls for better usability and label input fields more descriptively.
Flexibility and Efficiency of Use	Override controls cater to advanced users, but there's limited automation for repetitive tasks (e.g., waypoint suggestions).	3	Add shortcuts or predictive tools like automated waypoint suggestions for faster interaction.

Heuristic	Evaluation Result	Score (1-5)	Recommendations
Aesthetic and Minimalist Design	Clean, focused interface; no unnecessary clutter. However, the waypoint ring and mission arcs may overwhelm users visually if too many waypoints are added.	4	Add a "toggle visibility" feature for waypoint rings to simplify visuals during non-navigation tasks.
Help Users Recognize and Recover from Errors	Error messages are basic and not always descriptive. No visual guidance for users recovering from errors like wrong waypoint placement.	3	Add detailed error messages and highlight errors visually (e.g., flash incorrect waypoints).
Help and Documentation	Limited in-app guidance; no tooltips for controls or user tutorials.	2	Provide tooltips for all controls, a brief onboarding tutorial, or a help section accessible from the UI.

Table 5.2: Heuristic evaluation results

6 Discussion and Conclusion

6.1 Discussion

The Mission Clock for SAR project demonstrates a robust alignment with key usability principles, particularly excelling in visibility of system status, match between system and real world, and consistency and standards. These strengths form effective use of visual elements like analog clock interfaces, color-coded arcs for elapsed time, and familiar metaphors that reduce cognitive load (Nielsen, 1994). These features ensure users can intuitively interact with the system, reflecting strong design foundations.

However, the project reveals several areas for improvement. The lack of flexibility in user control and freedom, limits dynamic adjustments during operations, such as canceling overrides or pausing/restarting the mission. Enhanced features in this area could greatly improve user autonomy and satisfaction as per[5]. Similarly, although there are error prevention mechanisms, they are not robust enough to handle out-of-range inputs or guide users through corrective actions, creating potential frustration during critical tasks. Implementing detailed error feedback and real-time validation could address these shortcomings effectively.

The absence of a help system poses a significant barrier for new users. Tooltips, tutorials, and accessible documentation would reduce the learning curve and ensure a smoother onboarding process. This aligns with the principle of recognition rather than recall, where users should not rely heavily on memory to perform tasks. Additionally, automation features like waypoint suggestions and predictive tools could enhance flexibility and efficiency, especially for advanced users managing repetitive tasks.

The radar chart 5.1 highlights these gaps which clearly shows strong performance in usability fundamentals but weaker performance in areas like documentation and error handling. This visual representation provides actionable insights for prioritizing improvements.

6.2 Conclusion

The Mission Clock for SAR is a well-designed system that effectively communicates mission-critical information through its intuitive visual interface and real-time updates. It meets several usability benchmarks, providing a reliable foundation for search and rescue operations. However, addressing deficiencies in automated waypoint marking from a waypoint file, user control,prevention of errors and help systems is essential to fully optimize the user experience. These enhancements will ensure the system not only meets but exceeds usability expectations, enabling efficient and stress-free mission management for both novice and expert users.

6.2.1 Future work

Future iterations should focus on adding dynamic features like pause or restart options, predictive waypoint suggestions and comprehensive help tools. By implementing these changes, the project can establish itself as a highly versatile and user-friendly tool, adhering to key usability principles outlined by [5]. Overall, the Mission Clock for SAR holds great potential to become a operator friendly system for search and rescue operations with continued refinements.

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