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Methods and Analytical Tools To Assist Medical Personnel During The Evacuation of The Wounded From The Battlefield*

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Abstract

In modern combat operations, the quick and effective management of evacuating wounded soldiers is crucial for reducing battlefield mortality. Medical evacuation (MEDEVAC) ensures that casualties receive timely medical care, which is vital for survival in high-risk environments. The complexities of contemporary warfare, characterized by asymmetric threats and multinational operations, require advanced solutions that integrate situational awareness, real-time decision-making, and seamless coordination across diverse units. A key component of battlefield medical support is Tactical Combat Casualty Care (TCCC), which provides best practices for delivering life-saving interventions at the point of injury.

This paper introduces the Esculap platform, which provides a solution for pharmaceutical interoperability. It allows international partners with different reference systems (formularies) to operate under a unified classification system. The platform goes beyond simple translation and facilitates drug substitutions when needed. It integrates advanced technologies such as Optical Character Recognition (OCR), facial recognition, and a graph database to enhance both efficiency and accuracy in critical medical operations.

Keywords: medevac, tactical combat casualty care, optical character recognition, battlefield medical support, decision support system

Introduction and research motivation

In today's combat environments, providing quick and effective medical care can mean the difference between life and death. Battlefield injuries often occur in fast-paced, complex situations where immediate medical attention and evacuation are crucial. Tactical Combat Casualty Care (TCCC) is the foundation of military medical response and is divided into three phases: Care Under Fire (CUF), Tactical Field Care (TFC), and Tactical Evacuation Care (TEC) [1], [2]. These phases guide medics in delivering life-saving interventions, stabilizing patients, and preparing them for evacuation under hostile conditions. However, modern warfare, particularly in multinational and coalition operations, introduces new challenges that traditional medical protocols and systems struggle to address [3], [4], [5], [6].

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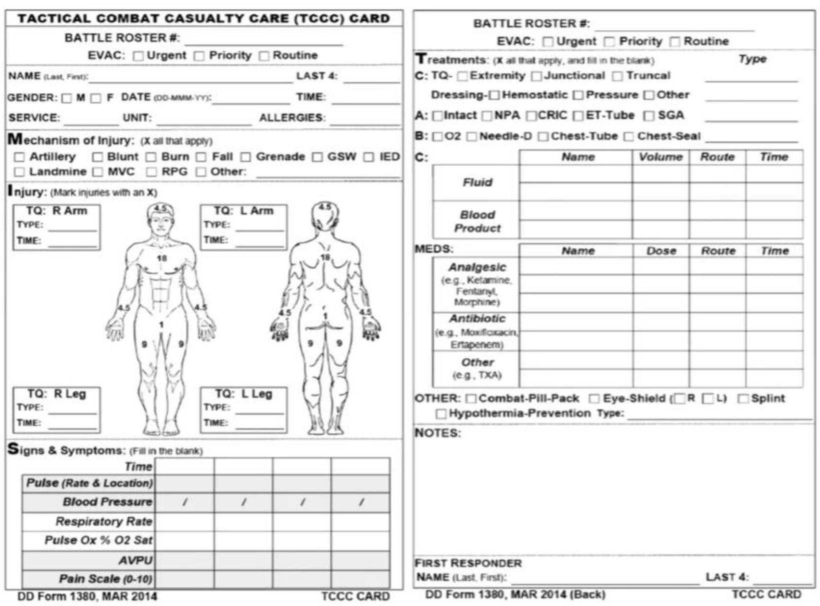
The changing nature of warfare, characterized by uneven threats, quick movement, and international alliances, requires advanced solutions such as artificial intelligence (AI), data analytics, and real-time health monitoring. AI-powered decision support systems (DSS) can aid medics by offering real-time data analysis, automated triage recommendations, and access to crucial medical information [7], [8]. Moreover, remote health monitoring systems can continuously monitor soldiers' vital signs, providing medics with an up-to-date view of a patient's condition even before they reach the site of injury. This integration with Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems enhances battlefield coordination, enabling quicker, more informed decisions on medical evacuations (MEDEVAC).

The Continuum of Care is crucial for managing health and providing support on the battlefield. It involves a continuous process of care, from identifying and assessing injuries to treatment, evacuation, and rehabilitation. However, multinational operations present unique challenges. For instance, medical teams from different nations may use drugs labeled in their native languages, confusing, especially without internet access for translation or shared databases [3], [9], [10]. Additionally, the TCCC card – sample visible in **Figure 1**, which contains vital casualty information, is often lost in the chaos of combat, particularly during the transport of wounded soldiers under enemy fire. Furthermore, maintaining operational security during MEDEVAC complicates the sharing of vital medical data, as digital communication could leave a footprint that jeopardizes the mission. These challenges highlight the need for innovative solutions to streamline medical care, ensure seamless information sharing, and improve overall battlefield readiness.


TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

BATTLE ROSTER #: ____

EVAC: ☐ Urgent ☐ Priority ☐ Routine

NAME (Last, First): ____ LAST 4: ____

GENDER: ☐ M ☐ F DATE (DD-MMM-YY): ____ TIME: ____

SERVICE: ____ UNIT: ____ ALLERGIES: ____

Mechanism of Injury: (X all that apply)

☐ Artillery ☐ Blunt ☐ Burn ☐ Fall ☐ Grenade ☐ GSW ☐ IED
☐ Landmine ☐ MVC ☐ RPG ☐ Other: ____

Injury: (Mark injuries with an X)

TQ: R Arm TYPE: ____ TIME: ____

TQ: L Arm TYPE: ____ TIME: ____

TQ: R Leg TYPE: ____ TIME: ____

TQ: L Leg TYPE: ____ TIME: ____

4.5 18 4.5 4.5 1 9 9 4.5 18 4.5 4.5 1 9 9

Signs & Symptoms: (Fill in the blank)

Time				
Pulse (Rate & Location)				
Blood Pressure	/	/	/	/
Respiratory Rate				
Pulse Ox % O2 Sat				
AVPU				
Pain Scale (0-10)				

DD Form 1380, MAR 2014 TCCC CARD

BATTLE ROSTER #: ____

EVAC: ☐ Urgent ☐ Priority ☐ Routine

Treatments: (X all that apply, and fill in the blank) Type

C: TQ- ☐ Extremity ☐ Junctional ☐ Truncal ____

Dressing-☐ Hemostatic ☐ Pressure ☐ Other ____

A: ☐ Intact ☐ NPA ☐ CRIC ☐ ET-Tube ☐ SGA ____

B: ☐ O2 ☐ Needle-D ☐ Chest-Tube ☐ Chest-Seal ____

C:

	Name	Volume	Route	Time
Fluid				
Blood Product				

MEDS:

	Name	Dose	Route	Time
Analgesic (e.g., Ketamine, Fentanyl, Morphine)				
Antibiotic (e.g., Moxifloxacin, Ertapenem)				
Other (e.g., TXA)				

OTHER: ☐ Combat-Pill-Pack ☐ Eye-Shield (☐ R ☐ L) ☐ Splint
☐ Hypothermia-Prevention Type: ____

NOTES:

FIRST RESPONDER
NAME (Last, First): ____ LAST 4: ____

DD Form 1380, MAR 2014 (Back) TCCC CARD

Figure 1 Tactical Combat Casualty Care (TCCC) card

Expanding on the challenges and research motivations, we suggest an integrated solution that utilizes advanced AI and IT technologies to aid medical personnel during battlefield evacuations. This solution includes various functions that aim to improve the speed, accuracy, and efficiency of TCCC processes and MEDEVAC operations. The system is designed to smoothly integrate into current military infrastructures and includes the following key capabilities:

- Drug Search by Name, Active Substance, or Disease: The system provides an intelligent search function that allows medical personnel to quickly identify medications based on their name, active ingredient, or associated disease. This feature is particularly useful in multinational operations where drug names and standards may vary.

- Electronic TCCC Card: The traditional TCCC card, which is crucial for documenting a soldier's injuries and treatment, is digitized in this solution. The electronic TCCC card ensures that vital medical information is always available, even in chaotic combat scenarios, reducing the risk of data loss and ensuring continuity of care throughout the evacuation process.
- Substitute Medicine Finder: In situations where the required medication is unavailable, the system can automatically suggest alternatives based on the active substance or drug class. This feature ensures that appropriate treatments are administered even in resource-limited environments, improving patient outcomes.
- Drug Recognition with OCR (Optical Character Recognition): The system integrates OCR technology to recognize and identify medications from packaging or labels. This is especially useful in multinational settings where drug packaging may differ, enabling medics to accurately identify the right medication even under time constraints.
- Patient Identification via Face Recognition: To ensure that medical records are correctly matched to the right individual, the system includes facial recognition technology to identify patients on the battlefield. This functionality helps avoid medical errors and ensures that treatment is tailored to the correct individual, even in mass casualty events.
- Data Sharing via QR Code: The system enables quick and efficient sharing of medical data through QR codes, allowing medics to transfer patient information securely and rapidly to other personnel or medical facilities. This feature is crucial when communication networks are compromised or unavailable, ensuring that vital data reaches the necessary parties.

These capabilities form the core of the proposed system, which was initially presented as a Proof of Concept (PoC) during the NATO TIDE Hackathon [11]. The solution demonstrated its potential to significantly enhance battlefield medical operations by streamlining the collection, management, and sharing of critical medical data under challenging conditions. By integrating these advanced functionalities, the system offers a robust framework for improving situational awareness, decision-making, and patient care throughout the entire Continuum of Care.

Related work

Several advanced solutions for medical evacuation on the battlefield have been developed to address the complexities of modern warfare, especially in scenarios involving mass casualties and tactical challenges. A short review of the available solutions is presented further in this chapter.

The DSS-MEDEVAC [9], [10] is an AI-driven decision support system designed for military medical evacuations, integrating health monitoring sensors and command systems to assist in critical decision-making. It automates triage based on real-time vital signs and seamlessly connects with C4ISR for communication with higher command. The system also updates the Tactical Combat Casualty Care (TCCC) card electronically, ensuring accurate data during evacuation.

The NFR (NATO First Responder) [12] is a system developed by the U.S. Defense Health Agency for documenting battlefield injuries and transmitting this information to medical facilities. It integrates with NATO standards and uses near-field communication (NFC) when cellular networks are unavailable.

The BATDOK [13], [14] (Battlefield Assisted Trauma Distributed Observation Kit) is a point-of-injury software tool developed by the Air Force Research Laboratory. The system allows medical professionals to wirelessly monitor the vital signs of multiple patients at the same time. It captures a complete medical history from the time of injury through evacuation and subsequent care. BATDOK is designed with an easy-to-use interface and customizable alerts. It can integrate with different wireless sensors and operate as an open architecture system, allowing it to adapt to new medical technologies and communication protocols.

In the Moment (ITM) [15] program developed by DARPA aims to develop AI systems capable of making medical decisions autonomously in battlefield conditions. These systems are designed to support small military units during triage and mass casualty management. ITM algorithms are created to autonomously assess the health of soldiers and prioritize medical evacuation.

ATRACT (A Trustworthy Robotic Autonomous System to Support Casualty Triage) [16], [17] aims to deploy autonomous drones to assist in assessing injuries and facilitating evacuation shortly after an injury. These drones are equipped with advanced sensors and AI, enabling them to quickly provide medical information to emergency personnel, thus improving response times and survival chances.

In modern battlefield operations, Command and Control systems such as Common Operational Picture (COP) platforms are crucial for situational awareness and can support monitoring soldier status, coordinating medical evacuations, and maintaining communication with personnel in real-time. These systems integrate geospatial data, communication tools, and real-time updates to enhance decision-making during operations. One well-known system is the Tactical Assault Kit (TAK) [18], which improves situational awareness by providing real-time geospatial information and collaborative tools. TAK is widely used in military, law enforcement, and emergency response because it delivers timely and accurate data. Blueforce [19] offers a range of products similar to the TAK family, but they are commercial and require payment. Other products from this class of systems are tCOP (tactical common operational picture) and mCOP (mobile common operational picture) [4], [20], [21], [22]. These products offer functionality for all battlespace dimensions and crisis management, specifically designed for territorial defense units and land forces.

Standard triage methods such as START (Simple Triage and Rapid Treatment) [23] and SALT (Sort, Assess, Lifesaving Interventions, and Treatment/Transport) are still widely used for battlefield medical support. These methods rely on basic observations, such as respiration rate and mental status, to classify patients. While effective in traditional scenarios, these methods lack the precision of AI-enhanced systems that can incorporate multiple vital signs and provide dynamic, real-time triage updates.

Solution Description

Esculap is a mobile application designed to provide a comprehensive toolkit for use during medical evacuations. The solution was developed using a technology stack that included Java with Spring Boot for the backend, Neo4j as the graph database [24], and Spring Data Neo4j for managing the database. For the front end, TypeScript and React Native were used, while Tesseract handled OCR-related tasks. Additionally, during the analysis phase, Python and Jupyter Notebook were employed for data research. Specialized tools such as NetworkX [25], NetCenLib [26], RPaSDT[27] and NSDLib [28] were also used for dedicated graph-based solutions, which enabled efficient handling and analysis of graph structures throughout the project. Mobile platforms were chosen due to their cost-effectiveness compared to specialized devices, as well as their ability to contain all necessary components [29], [30].

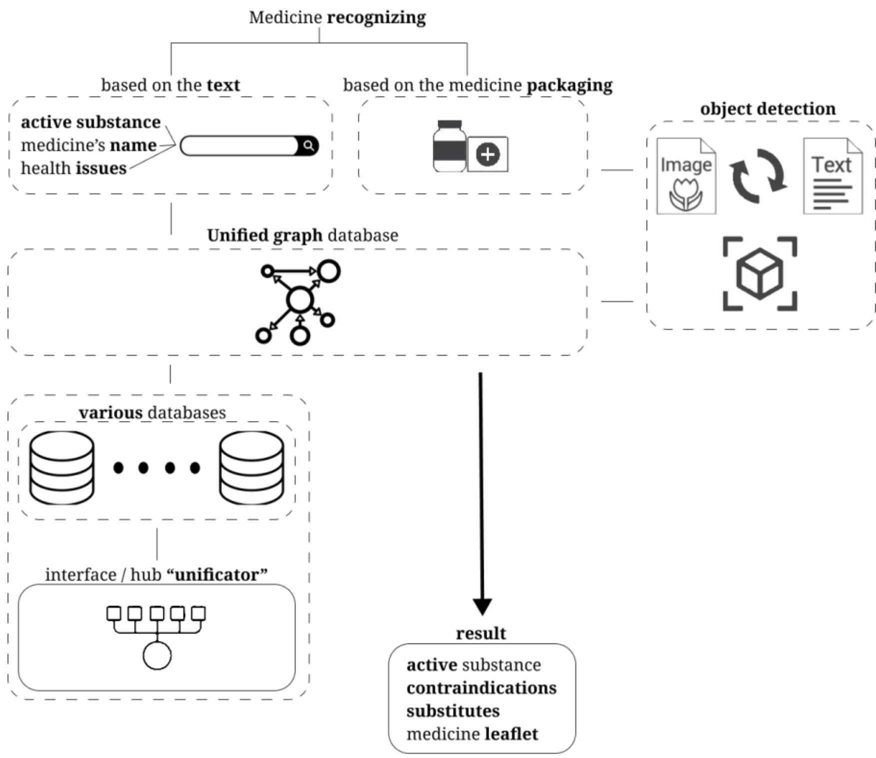


Figure 2 Medicine recognition flow

There are two ways to identify medicines. One way is to use a text search engine where you can enter the name of the drug, the active substance, or the ailment it treats. Another option is to use a graphical search engine, which recognizes drugs based on their packaging. Both search engines use a graph database that contains comprehensive data from various countries and organizations [31]. The search results provide information about the drug's contraindications, substitutes, leaflet, active ingredient, and amount. The medicine recognition process is presented in **Figure 2**.

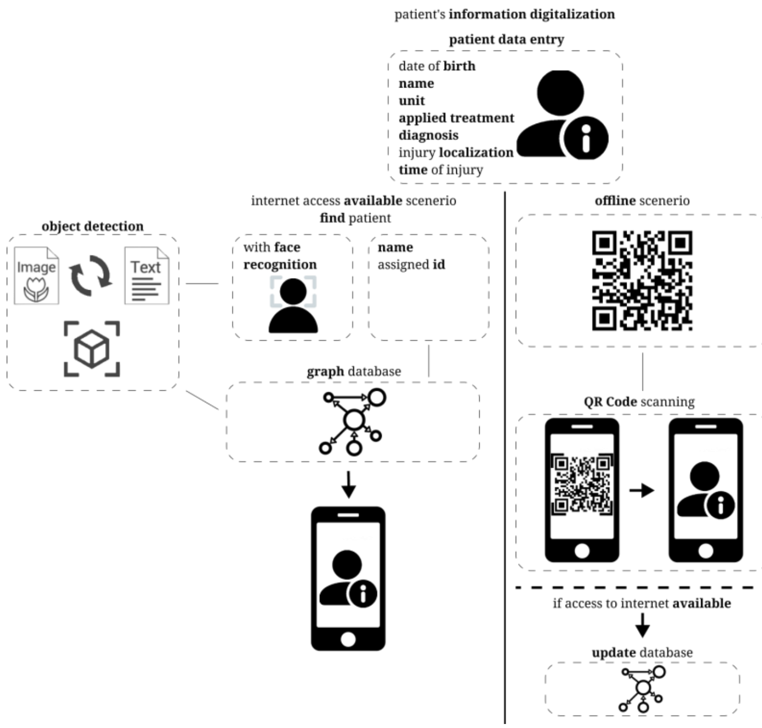


Figure 3 Online and offline mode application flow

The *search function for drugs* allows users to search by name, active substance, and disease. This feature utilizes a graph database to categorize multiple medications into structured groups. This enables the application to find similar medications based on active substances, diseases, similar actions, and other factors. The system supports multiple languages for drug names, conditions, and active substances. Figure 4 presents a portion of the graph database and the application interface, whereas
Figure **5** depicts application search view usage.

The electronic version of the Tactical Combat Casualty Care (TCCC) card provides significant advantages over traditional paper-based systems. By digitizing this critical medical information, military units can maintain a centralized database of all soldiers' health records and treatment histories. This consolidation allows for quick access and seamless sharing of vital data among medical personnel, especially in high-stress combat situations as presented in
Figure **6**.

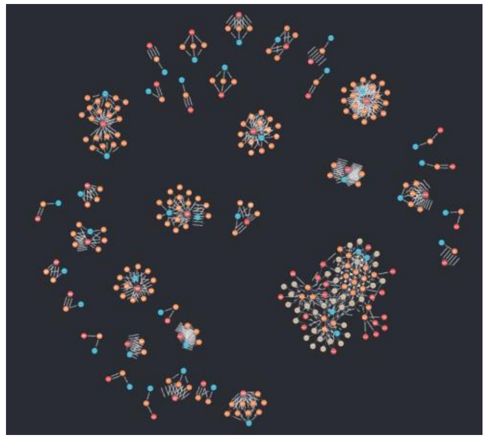


Figure 4 Portion of data extracted from a graph database

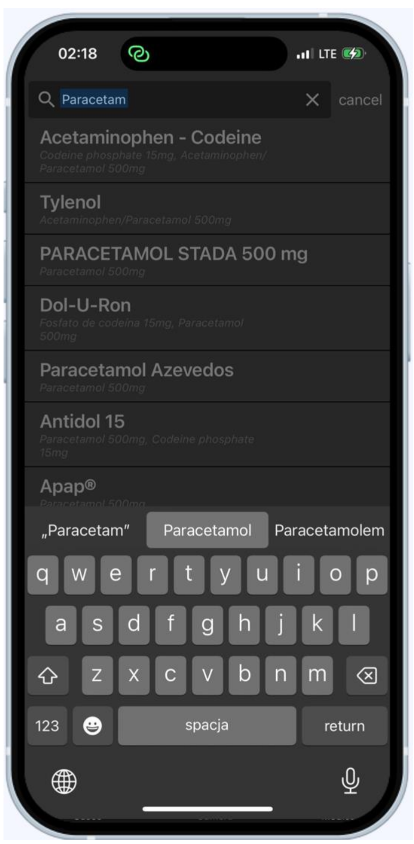


Figure 5 Esculap - search drug view

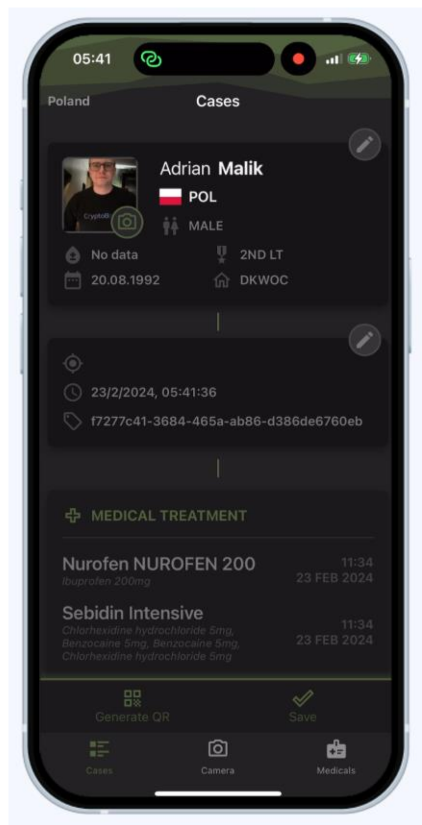


Figure 6 Escluap – the electronic version of the Tactical Combat Casualty Care (TCCC) card view

The *Find Substitute feature* is closely related to the previous one. Each medication is linked to others through active ingredients, similar effects, and more. With this app, users can change the country and see all similar medications available in the selected location. This helps them find a drug based on the ones they are already familiar with. Additionally, each drug includes pictograms that provide clear information to the app users [32]. Sample usage of this feature can be observed in Figure 7.

An *OCR-based drug recognition feature* was developed to address interoperability issues. For instance, if a Greek soldier visits a German doctor and requests a prescription for a medication they have been taking, the doctor may not be familiar with the drug. Additionally, the German doctor may encounter difficulty in prescribing the Greek-named drug due to a lack of a Greek alphabet keyboard. In such a scenario, the doctor can activate the OCR module to recognize the drug by taking a picture of it [33] as presented in Figure 8. The application utilizes learned text recognition models to recognize the drug, decipher the active substance and dosage, and suggest alternative drugs from a list familiar to the German doctor.

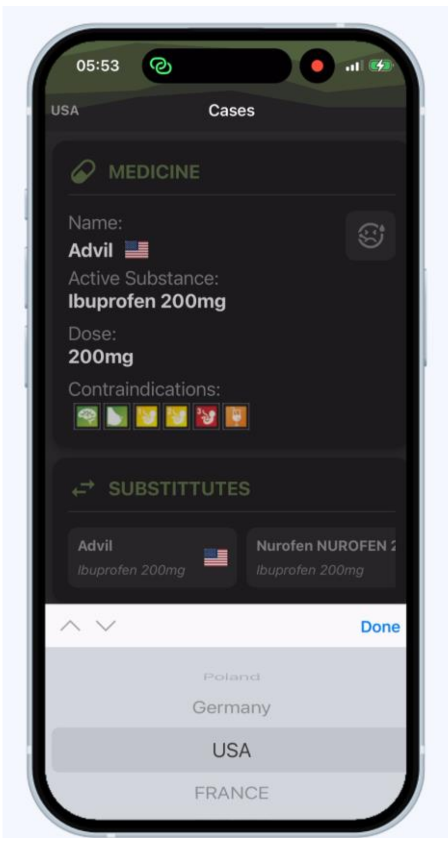


Figure 7 Esculap - Update country settings view

Figure 8 Esculap - Camera in module drugs recognition

The face recognition module for patient identification is especially helpful when a patient's card is missing, for example, in cases of confusion on the battlefield. If a soldier cannot be identified, medical personnel can use this module to take a photo of the patient's face (assuming it is undamaged). The application saves the photo and, using highly effective machine learning algorithms [34], compares it with the database of stored photos. If the face is successfully recognized, the patient will be added to the system, and their current data, including their last known location, prescribed medications, and existing medical conditions, will be updated and synchronized.

The Esculap uses a face recognition module created by Adam Geitgey [35]. This module serves as an interface to the dlib tool, which is a state-of-the-art facial recognition tool built using deep learning. The model has an impressive accuracy of 99.38% in the Labeled Faces in the Wild comparison test. The first step in the pipeline is face detection, which is performed using the Histogram of Oriented Gradients (HOG) algorithm. The key idea behind the HOG descriptor [36] is that the local appearance and shape of an object in an image can be represented by the distribution of intensity gradients or edge directions.

The image is divided into small connected regions called cells, and for the pixels within each cell, a histogram of gradient directions is generated. The descriptor is then formed by concatenating these histograms. Once a face is detected, it must be compared with others to distinguish the unique features of the person it belongs to. Deep neural networks [37] are used for this task. By comparing a person's photo with photos of others, the network learns to differentiate between them through the use of specialized algorithms. The network employed is pre-trained on millions of photos, allowing it to quickly and effectively capture 128 unique parameters for each individual. After the final training of the face images, each person in the database occupies a unique position in a 128-dimensional space. The final step is to compare these parameters using well-known classifiers, such as a Support Vector Machine (SVM) [37]. The classifier identifies the most closely matching person and provides their label, which in this case is an ID but could also be the person's first and last name. Figure 9 presents the result of the detected face in the Esculap application.

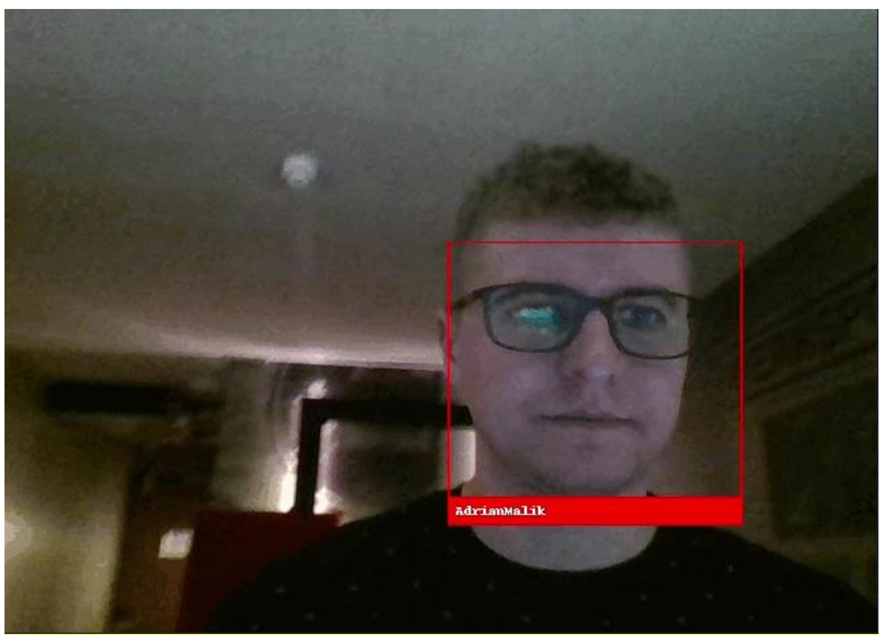


Figure 9 Esculap - Patient face recognition

When soldiers lack internet access, *sharing data via the QR code feature* becomes crucial. They can easily share data between mobile devices by using QR codes. The process is uncomplicated - one soldier who wants to share data simply clicks the share button, while the other soldier uses the app to take a picture of the QR code and receives the data. This method ensures that no digital footprint in the form of radio waves is left behind. It is particularly useful during the critical initial phase of combat medical evacuation, where maintaining operational safety is of utmost importance. Figure 10 presents the usage of this feature.

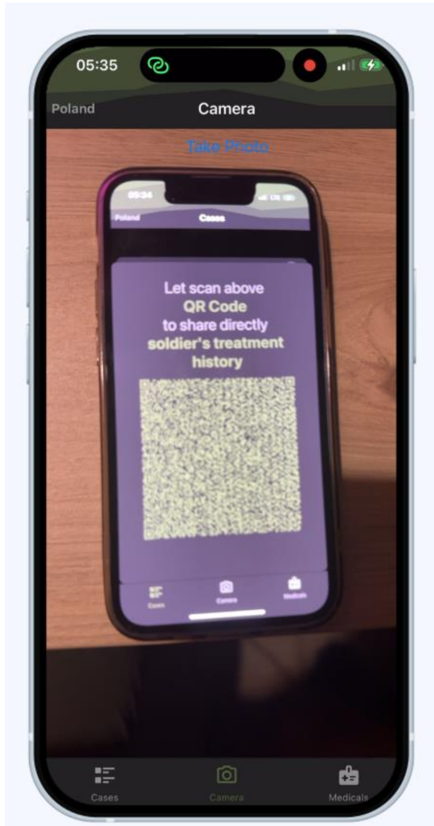


Figure 10 Esclulap - Sharing data via QR Code

Solution usage

To better illustrate the practical applications of the solution, a detailed use case scenario can be examined to highlight how the application can be used effectively in real-life situations.

- Step 1 - First Aid

A soldier was injured on the battlefield, and a combat medic provided assistance and evacuated the soldier. The injured soldier received the necessary medical care before being transported to the nearest hospital. During the aid, the medic used an electronic TCCC card to document treatments and injuries in the application.

- Step 2 – Medevac

In the next step, the other team from another country took the injured soldiers from the first medic. They received a QR code (with no digital footprint) and continued treatments. In the application, every single record had a translation to their own country's language (or another language set in the application). Thanks to this, they understood all the drugs that were given to the patient. They also took a photo of the injured soldier to provide data to the facial recognition module. Upon reaching the hospital (a safe place to use the internet), the app connected to the internet and sent the data to the server. After that, every medic can receive data about this patient through the application by scanning the soldier’s face, as well as by name, surname, or ID.

- Step 3 – Hospitalization

Upon the soldier's arrival at the hospital, a team of medical professionals is ready to provide advanced care. The hospital staff uses an app to access the soldier's medical records quickly. When the hospital team conducts an assessment, they can update the soldier's status in real-time on the app. Since the medical response is international, the app also provides translations of medical terms and treatments into the hospital staff's preferred language

Conclusions

Esculap is a versatile smartphone app that addresses the critical need for efficient medical evacuation (MEDEVAC) operations in modern combat scenarios. By leveraging advanced technologies such as a graph database, facial recognition, and Optical Character Recognition (OCR), it enhances the coordination and accuracy of battlefield medical support, particularly in high-risk environments. Esculap provides a cost-effective solution, enabling soldiers to operate with just a smartphone and reducing the need for expensive dedicated hardware and software.

This platform also solves the challenge of pharmaceutical interoperability, allowing international forces with differing medical systems to work under a unified framework. Facilitating drug substitutions when necessary ensures that soldiers receive the care they need, even in multinational operations.

Moving forward, Esculap could be further developed by incorporating more advanced machine learning algorithms for predictive analytics in medical scenarios and expanding its capabilities for broader use in non-military settings, such as disaster response or civilian medical evacuations. This continued development will strengthen its role as an essential tool for critical medical operations, both on and off the battlefield.

Statements and Declarations

Ethics Approval and Consent to Participate: The study did not involve human subjects, animals, or sensitive data, and therefore ethics approval was not required. However, since the image contains a human face, it is important to clarify that the detected face belongs to one of the authors of the publication, and consent for its use and publication has been obtained.

Consent for Publication: All the authors declare their consent for publication.
Competing Interests: None declared.

Data Availability: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Acknowledgements: Not applicable

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