CoNaviMap: Collective Navigation in Wilderness Search and Rescue Using Collaborative 3D Sketch Mapping

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Wilderness Search and Rescue (WSAR) is a complex and time-sensitive operation that requires efficient spatial communication and navigation. Existing mapping technologies, including paper and digital maps, play a critical role in WSAR but face limitations in collaborative and real-time updates. This position paper introduces CoNaviMap, a collaborative 3D sketch mapping tool leveraging Augmented Reality (AR) to enhance the navigation performance of WSAR. By enabling distributed teams—such as search teams and commanders—to share and modify a sketch map intuitively, CoNaviMap integrates the benefits of digital maps (editable, transferable, collaborative) and sketch maps ((intuitive, familiar, instant). The research raises key research questions about the performance of collaborative 3D sketch mapping in WSAR and aims to inform the future development of interactive sketch mapping technologies for WSAR.

CCS Concepts: • **Human-centered computing** → **Empirical studies in interaction design**; **Mixed / augmented reality**; **Open source software**.

Additional Key Words and Phrases: Collaborative 3D sketch mapping, wildness search and rescue, extended reality, spatial interaction, spatial cognition

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1 INTRODUCTION

Wilderness Search and Rescue (WSAR) is a critical, time-sensitive operation that involves locating victims, navigating complex environments, and coordinating among multiple responders through spatial communication and collective sense-making [1]. WSAR comprises three phases: search, rescue, and recovery [4]. This research focuses on the search phase, as searching for a missing target is the first and often most challenging phase of WSAR [6].

Mapping technology and navigation play a crucial role in the search phase. Search teams use maps to determine the probable area in which a missing target is most likely to be found from its last known position [2], and then identify routes to search these areas systematically. "Navigation is coordinated and goal-directed movement through the environment[9]" that "involves both planning and execution of movements [9]". It encompasses cognitive and

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behavioral actions such as recognizing landmarks, remembering routes, and orienting within the environment [3], which is crucial in WSAR. As a result, search team training includes map reading and land navigation based on a combination of paper maps and electronic methods [2].

2 BACKGROUND

2.1 Maps in wilderness search and rescue

Both electronic geospatial information such as digital maps and geographic information systems (GIS), as well as paper maps, are universally used as navigational aids in the WSAR community. Electronic geospatial information has visualization, spatial analysis, and information management capabilities [14]. For instance, the Norwegian voluntary organization uses a location tracker to monitor and display real-time updates of search team locations on a digital map and enable historical analysis of missions [7]. However, electronic geospatial information presents challenges. First, WSAR teams often consist of volunteers and professionals with varying levels of geographic expertise, leading to difficulties in effectively utilizing these technologies [11]. Second, additional constraints, such as limited money, training, and compatibility, further hinder the adoption of advanced mapping tools. Third, these technologies primarily contain pre-incident data, whereas dynamic data from field teams are often unarchived or stored in an unstructured manner [5].

In contrast, paper maps provide a more intuitive cartographic interaction through annotations or other manual manipulation methods, as people feel more familiar with paper maps [11]. For instance, sketch mapping—drawing maps with pen and paper—offers an intuitive and accessible way to represent field information [15]. By externalizing spatial knowledge, getting thoughts, and planning strategies, sketch maps help to understand the situation, build a common operating picture, and communicate among responders [11, 13]. Acetate sheets or tracing paper have traditionally been used to record search areas by overlaying sketched information on topographic maps to see which areas have not been searched and which need to be researched [2]. The "quick and dirty" characteristics of sketch maps complement digital maps in specific scenarios, particularly in the early stages of a search when updated digital maps are unavailable due to the incidents. However, traditional paper-based (PB) sketch maps have limitations, including static representations, difficulties in remote collaboration, and challenges in accurately depicting complex 3D information. Digitizing and sharing PB sketch maps also introduces potential errors and delays.

2.2 3D sketch mapping via augmented reality and virtual reality

Augmented Reality and Virtual Reality (AR/VR) advances offer new opportunities to overcome the limitations of digital and sketch maps and combine their benefits. Mid-air sketching interfaces, e.g., Gravity Sketch [12], enable users to draw directly in three dimensions (3D). Building on this idea, Kim et al. [8] introduced 3D sketch mapping, allowing users to express spatial knowledge through mid-air drawing. As an implementation of 3D sketch mapping, Xiao et al. [16] developed a layered sketching system in VR, which is similar to the aforementioned acetate sheets and tracing paper methods and is demonstrated to better align with cognitive maps and improves spatial understanding in 3D contexts [16]. More recently, Xiao et al. [15] extended the concept of 3D sketch mapping by developing an AI-driven sketch-to-terrain interface in augmented reality, enabling non-experts to externalize their cognitive maps of terrain with minimal training.

The limitation in the current practice of using digital maps and sketch maps in WSAR practices, as well as the innovation of AR/VR technologies motivated and inspired the current research to develop a 3D sketch mapping tool for

WSAR in AR/VR. Teamwork is a fundamental strategy in WSAR operations, and the success of a mission often depends on the coordinated efforts of the team. We introduce the conceptual development of collaborative 3D sketch mapping and select a common action in WSAR, navigation, as our use cases to demonstrate this concept.

3 CONAVIMAP: COLLABORATIVE 3D SKETCH MAPPING FOR COLLECTIVE NAVIGATION

The main features of collaborative 3D sketch mapping are that distributed users, such as the commander and search team, can communicate with each other remotely through intuitive sketching coupled with other communication methods. This concept is particularly useful for distributed users who have asymmetric information. On the one hand, the commander gathers information from a wide variety of disparate sources (e.g., topographic maps, tourist maps, drones, weather forecasts, and social media) [10] while the field team explores the site and may find traces or objects of the missing target. Collaborative 3D sketch mapping provides a VR/AR-based platform to combine information and create a sketch map, which may facilitate the generation of a common operating picture and promote efficiency in the implementation of tasks.

Based on this concept, we plan to develop a tool, CoNaviMap, in VR/AR that allows the commander to plan routes and guide the field team to find the victims faster. Our hypothesis is that it will leverage the complementary affordances of digital (editable, transferable, collaborative) and sketch (intuitive, familiar, instant) maps for more efficient collective navigation in terms of distance and time.

4 RESEARCH QUESTIONS

Limited prior research investigates how navigation may work for pairs or groups of people in WSAR, so it is crucial to carefully consider the implications of collaboration. The main research questions for this concept that need to be addressed are as follows:

(1) Does collaborative 3D sketch mapping enhance WSAR navigation performance over verbal communication and 2D sketch mapping in success rate, time, and distance?
(2) How do dyads communicate in navigation to reach a destination?
(3) How does the communication behavior of users using 3D collaborative sketch mapping inform the design of future sketch mapping tools for WSAR?

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