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A Smart Helmet Framework Based on Visual-Inertial SLAM and Multi-Sensor Fusion to Improve Situational Awareness and Reduce Hazards in Mountaineering

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ABSTRACT

Sensitivity to surrounding circumstances is essential for the safety of mountain scrambling. In this paper, the authors present a smart helmet prototype equipped with visual SLAM (simultaneous localization and mapping) and barometer multi-sensor fusion (MSF), IMU (inertial measurement unit), omnidirectional camera, and global navigation satellite system (GNSS). They equipped the helmet framework with SLAM to produce 3D semi-dense pointcloud environment maps, which are then discretized into grids. Then, the novel danger metrics they proposed were calculated for each grid based on surface normal analysis. The A* algorithm was applied to generate safe and reliable paths based on minimizing the danger score. This proposed helmet system demonstrated robust performance in mapping mountain environments and planning safe, efficient traversal paths for climbers navigating treacherous mountain landscapes.

KEYWORDS

Head, Mountaineering, Multi-Sensor Fusion (MSF), Pointclouds, Route Planning, Simultaneous Localization and Mapping (SLAM)

INTRODUCTION

Mountain scrambling, often called alpine scrambling, is a recreational sport that entails ascending mountain peaks and ridges while sometimes employing one's hands to scale rock walls and navigate challenging terrain (Whymper, 1871). While less technical than rock climbing, scrambling can still be quite dangerous, given the exposure to heights and objective hazards. Some of the potential dangers of mountain scrambling include falling from narrow ledges and cliffs; rockfall when climbing steep rock faces, with loose rocks potentially dislodged onto climbers below; rapid weather changes like rain, wind, and lightning (which can lead to slippery conditions, loss of visibility and hypothermia); getting lost due to lack of distinctive landmarks in mountainous terrain; and exposure to altitude sickness, sunburn, dehydration, and cold weather injuries due to the high altitude environment.

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The underlying mountaineering severity can lead to tragic consequences. Analysis of The International Alpine Trauma Registry (IATR) data reveals that out of 306 recorded mountain accidents resulting in multisystem trauma, the majority were due to falls onto solid ground (51.4%), followed by falls in snowfields (10.8%), falls into crevasses (8.1%), and being struck by stones (5.4%). In 24.3% of cases, the cause was unknown (Rauch et al., 2019). These examples remind us of the dangers climbers who venture onto precipitous terrain face. The field would benefit from continued efforts to improve safety protocols and leverage technological innovations to mitigate the risks inherent to these physically and mentally demanding sports.

In this regard, a novel helmet prototype has been invented that presents a viable solution by alerting individuals through a loudspeaker about potential hazards and suggesting the safest route while minimizing travel time. The equipped SLAM technology offers a revolutionary approach to managing the objective risks inherent in mountaineering through the collaborative integration of multiple sensors. At the same time, the Multi-Sensor Fusion (MSF) has great promise to address the limitations of SLAM systems alone for enhanced precision and reliability. This helmet showcases the ability to use real-time data from the surrounding environment to show the best route to the destination.

RELATED WORK

Throughout human history, helmets have played a crucial role in safeguarding the lives of individuals facing dangerous environments and challenges. From ancient civilizations to the present day, the evolution of helmet technology has been driven by a relentless pursuit of safety and protection. In the early days, helmets were forged from basic materials such as leather and bronze. Warriors and adventurers wore them to guard against head injuries in combat and dangerous terrain. As the centuries passed, helmet design and materials advanced, incorporating iron, steel, and carbon fiber. These improvements significantly enhanced protective capabilities, but the helmet is still primarily focused on protecting against physical impacts.

The rise in amateur mountaineers has increased the risk of fatal accidents, necessitating advanced safety equipment. In the 21st century, mountaineers face numerous environmental and navigational hazards, requiring protection beyond physical impacts. Helmets equipped with computer vision and guidance capabilities are essential, aiding in decision-making under extreme conditions and ensuring safer, less strenuous routes, especially in altitude sickness and hypothermia cases.

A principal method used in our helmet framework is Simultaneous Localization and Mapping (Durrant-Whyte & Bailey, 2006; Engel et al., 2018), which is widely used to enable a robot or autonomous vehicle to construct a map of an unfamiliar environment while simultaneously recognizing its position in that environment. The recent advancement in 3D map reconstruction (Grisetti et al., 2010) and SLAM (Ebadi et al., 2022b) not enable robots to precisely positioning and make autonomous decisions in a scalable approach (Kohlbrecher et al., 2011) that can be applied to extreme environments.

This technique facilitates the helmet system in navigating through intricate and unexplored areas by continuously updating its spatial awareness. By utilizing Simultaneous Localization and Mapping for generating detailed 3D terrain mapping and recognizing cliffs, edges, and overhangs, scramblers could more effectively evaluate potential risks of falling or rockfall and choose paths that are less exposed.

Moreover, another primary function of SLAM systems is to map surroundings while locating oneself, which makes this technology highly suitable for mitigating disorientation. Since the lack of noticeable reference points within rugged mountainous settings can frequently result in hikers becoming disoriented, the utilization of precise, up-to-date positioning technology within a constantly evolving diagram of the mountains could significantly enhance understanding of the current situation and lower the incidence of unintentional deviations from the intended path. A few Simultaneous Localization and Mapping (SLAM) algorithms have integrated supplementary

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