

Research on Diving Safety Monitoring and Auxiliary Training System Based on Intelligent Interactive Technology

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Abstract: Diving is a globally popular activity, but it poses significant safety challenges due to environmental risks, human error, and the use of complex equipment. Traditional safety practices and training methods have limitations in addressing real-time risks and preparing divers for emergency situations. This study proposes the development of an intelligent interactive system that integrates wearable sensors, artificial intelligence (AI), and virtual reality (VR) to improve diving safety and training outcomes. The system features real-time monitoring of physiological and environmental conditions, proactive risk detection, and immersive training scenarios. Field trials and simulations are conducted to evaluate its effectiveness. The results are expected to demonstrate a significant reduction in safety incidents and enhanced diver skills. The findings contribute to the advancement of intelligent systems in high-risk environments and offer practical applications for the diving industry, paving the way for broader adoption of technology-driven safety solutions.

Keywords: Diving Safety; Intelligent System; Wearable Sensors; Training Enhancement; Risk Management.

1. Introduction

1.1 Context and Motivation

Scuba diving has become a globally popular activity, attracting millions of participants annually for both recreational and professional purposes. It is particularly prevalent in marine tourism hotspots such as Australia's Great Barrier Reef and the Caribbean, where diving contributes significantly to local economies. However, the inherent risks associated with diving—stemming from the use of complex equipment, exposure to unpredictable underwater environments, and the physiological challenges of breathing compressed air—make it one of the most hazardous recreational activities.

In professional diving, stringent safety measures, including real-time monitoring systems and advanced training protocols, have reduced incidents. Conversely, recreational divers often lack access to such sophisticated tools, increasing their vulnerability to accidents. The unique challenges of recreational diving—such as varying levels of diver experience, inconsistent adherence to safety practices, and reliance on informal training methods—compound these risks. For example, Wilks (2000) observed that in Queensland, incidents like decompression illness and drowning were often linked to inadequate preparation and failure to follow safety protocols.

Moreover, as global interest in diving grows, so does the complexity of its challenges. Factors such as environmental degradation, changing ocean conditions, and the growing popularity of deeper and more technical dives introduce additional risks. The need for comprehensive, technology-driven solutions to mitigate these risks has never been more urgent.

1.2 Challenges in Diving Safety

The key safety challenges in diving can be categorized into three areas: human factors, equipment issues, and environmental hazards.

Human Factors: A significant portion of diving accidents result from human error, including poor decision-making, failure to adhere to dive plans, and neglecting pre-dive safety checks. Behavioral studies indicate that divers often overestimate their capabilities, particularly in challenging conditions, leading to incidents such as rapid ascents and out-of-air emergencies. In traditional diving communities, reliance on generational knowledge rather than formal training further exacerbates these risks.

Equipment-Related Failures: Equipment issues, such as regulator malfunctions or air supply problems, are another leading cause of diving incidents. Studies show that improper maintenance and lack of familiarity with equipment significantly increase the likelihood of acci-

dents. The absence of robust pre-dive checks, particularly in recreational settings, compounds this issue.

Environmental Hazards: Unpredictable environmental factors, including strong currents, low visibility, and sudden changes in water temperature, pose additional risks. Research conducted on the Great Barrier Reef revealed that even experienced divers often underestimate the impact of environmental conditions on their safety.

1.3 Research Problem

While advancements in technology have introduced tools such as dive computers and VR-based training, their adoption remains inconsistent across the diving community. Traditional safety measures, such as buddy systems and pre-dive checklists, are often inconsistently applied or entirely overlooked in recreational diving settings. Furthermore, existing training programs frequently fail to simulate real-world emergencies, leaving divers ill-prepared for unexpected scenarios.

Another critical gap lies in the lack of real-time safety monitoring systems tailored to recreational divers. While professional divers benefit from advanced monitoring technologies, recreational divers largely rely on personal judgment and basic dive computers. This disparity underscores the need for accessible, user-friendly systems that provide real-time feedback and risk assessment during dives.

1.4 Research Objectives

This research aims to address the aforementioned gaps by developing an intelligent interactive system designed to enhance both diving safety and training. The system integrates wearable sensors, artificial intelligence (AI), and virtual reality (VR) to offer the following solutions:

Real-Time Safety Monitoring: To continuously monitor physiological and environmental parameters, providing immediate feedback and alerts in case of anomalies.

Enhanced Training Methods: To utilize VR simulations for realistic, scenario-based training, improving diver preparedness for high-risk situations.

Data-Driven Safety Insights: To collect and analyze data from dives, generating personalized safety reports and informing best practices for divers and operators.

By combining these features, the proposed system seeks to reduce safety incidents, enhance diver skills, and contribute to the broader adoption of technology-driven safety practices in the diving industry.

1.5 Significance of the Study

The significance of this study extends beyond immediate safety improvements for divers. First, it contributes to the academic understanding of how intelligent systems can be applied in high-risk environments, offering a framework that could be adapted to other domains such as aviation and healthcare. Second, it addresses the economic and social impact of diving accidents, reducing the burden on healthcare systems and improving public confidence in diving as a safe activity. Finally, the system supports marine conservation by promoting environmentally responsible diving behaviors, such as minimizing physical contact with coral reefs and other sensitive ecosystems.

2. Literature Review

2.1 Diving Safety Risks and Current Practices

Diving inherently involves managing risks posed by both human factors and external environmental conditions. Understanding these risks and current safety practices is critical for developing innovative solutions to enhance diving safety.

Human Error as a Leading Cause: Human error remains the primary contributor to diving incidents, accounting for up to 60% of reported accidents. A study by Ranapurwala et al. (2017) found that the majority of mishaps during recreational diving stem from inadequate pre-dive preparation and failure to recognize early warning signs of danger. Common mistakes include overestimating personal capabilities, neglecting equipment maintenance, and diving without adequate safety training. These errors often lead to preventable incidents such as rapid ascents, decompression sickness, and oxygen toxicity.

Impact of Equipment Failures:Equipment-related failures, such as regulator malfunctions and out-of-air incidents, account for a significant proportion of diving accidents.Although modern diving equipment is generally reliable, user error and inadequate maintenance amplify risks. For example, Wilks (2000) highlighted that poor equipment checks before diving contributed to more than 30% of reported incidents on the Great Barrier Reef.These findings underscore the importance of routine maintenance and pre-dive equipment checks.

Environmental Risks:Diving in challenging environments—such as cold water, strong currents, or low-visibility conditions—further increases the likelihood of accidents. The Great Barrier Reef study revealed that unpredictable weather conditions and limited visibility often disoriented divers, contributing to incidents such as entanglement and navigation errors.Moreover, inexperienced divers are particularly vulnerable in such conditions, emphasizing the need for adaptive training methods that address environmental variability.

Behavioral and Cultural Factors:Diving safety is also influenced by cultural and regional practices. In traditional diving communities, reliance on generational knowledge and informal training often leads to unsafe behaviors, such as using unregulated air compressors. In contrast, recreational divers in developed regions generally follow structured training programs, although complacency and overconfidence can still lead to safety lapses.

2.2 Advances in Training and Monitoring Technologies

Technological advancements have transformed diving training and safety monitoring, offering significant opportunities to reduce risks and enhance preparedness.

Role of Virtual Reality (VR) and Augmented Reality (AR):VR and AR technologies provide immersive training environments where divers can simulate high-risk scenarios without actual danger. These technologies enable trainees to practice emergency responses, such as equipment failures or underwater entrapment, in a controlled setting. Lucrezi et al. (2018) emphasize that VR-based training improves skill retention and decision-making under stress, particularly for novice divers.However, the high cost and technical complexity of VR systems limit their accessibility for smaller dive operators and individual divers.

Wearable Sensors for Real-Time Monitoring:Wearable sensors, such as heart rate monitors and oxygen saturation devices, have emerged as critical tools for enhancing diver safety. These devices collect real-time physiological and environmental data, enabling early detection of risks such as fatigue, hypoxia, or rapid ascents.The integration of these sensors with dive computers further enhances their utility by providing immediate feedback to divers. Despite their benefits, challenges such as data accuracy in extreme underwater conditions and device durability remain.

Pre-Dive Checklists and Protocols:The use of pre-dive checklists has been shown to significantly reduce the incidence of mishaps. Ranapurwala et al. (2017) demonstrated that divers using written checklists experienced 53% fewer incidents compared to those relying on memorized or absent checklists.Despite this evidence, checklist adoption remains inconsistent across diving communities. Variations in checklist design and content between training organizations further complicate their effectiveness.

2.3 Diving Safety Culture and Risk Management

Promoting a culture of safety within the diving community is essential for minimizing risks. This involves both individual behavioral changes and organizational initiatives.

Safety Awareness and Compliance:Safety awareness among divers varies widely, with experienced divers often exhibiting better adherence to safety protocols. However, overconfidence in skills and underestimation of risks frequently lead to complacency.For example, studies show that many divers fail to use surface marker buoys or neglect proper ascent procedures, increasing the likelihood of accidents.

Role of Dive Operators:Dive operators play a pivotal role in shaping safety culture. High-quality operators enforce rigorous safety standards, such as conducting pre-dive briefings and providing emergency equipment. However, economic pressures often lead some operators to prioritize cost savings over safety, particularly in tourist-heavy regions.Wilks (2000) highlights that on the Great Barrier Reef, divers reported higher trust and satisfaction with operators who emphasized safety over maximizing dive frequencies.

Structured Risk Management Frameworks:

The adoption of formal risk management frameworks, such as Hazard Identification and Risk Assessment (HIRA), has proven effective in reducing diving incidents in professional settings. These frameworks involve systematic evaluations of potential hazards, development of mitigation strategies, and regular safety audits. Expanding the use of such frameworks to recreational diving could significantly enhance safety outcomes.

2.4 Emerging Challenges and Research Gaps

While advancements in technology and safety protocols have reduced risks, several challenges persist:

Limited Adoption of Advanced Technologies: The high cost and technical expertise required for technologies like VR training and wearable sensors hinder their widespread use among recreational divers and small operators.

Inconsistent Implementation of Safety Protocols: The lack of standardized safety practices across regions and training organizations creates variability in safety outcomes. For example, checklist content and usage differ significantly between agencies like PADI and NAUI, reducing their overall effectiveness.

Behavioral and Cultural Barriers: Cultural attitudes towards safety, particularly in traditional diving communities, often conflict with formal training and modern safety practices. Addressing these barriers requires targeted educational campaigns and localized interventions.

Environmental Adaptability: Existing safety measures often fail to account for dynamic environmental conditions, such as changing currents or underwater topography. Adaptive training programs and real-time monitoring systems are needed to address these challenges effectively.

2.5 Summary

The literature highlights significant progress in understanding diving safety risks and implementing advanced training and monitoring technologies. However, persistent gaps in technology adoption, protocol standardization, and cultural attitudes toward safety underscore the need for comprehensive, multidisciplinary solutions. The proposed research seeks to address these gaps by integrating real-time monitoring, data-driven safety management, and immersive training into a unified system.

3. Research Methodology

3.1 System Design

The proposed intelligent interactive system for diving safety monitoring and auxiliary training is composed of three primary components: wearable sensors, interactive dive computers, and a cloud-based platform. Each component works synergistically to enhance safety monitoring and training outcomes.

Wearable Sensors: Sensors will monitor key physiological parameters, including heart rate, oxygen saturation, and body temperature. Environmental data such as water temperature, depth, and current strength will also be recorded.

Data collected from the sensors will be transmitted in real time to the interactive dive computer, enabling immediate feedback and alerts for divers. **Interactive Dive Computers:** The dive computer will display real-time physiological and environmental data, providing divers with visual and auditory alerts in case of anomalies (e.g., oxygen depletion or rapid ascent).

The interface will include an intuitive dashboard designed for ease of use underwater, with critical safety information highlighted for quick decision-making. **Cloud-Based Platform:** Data from dives will be uploaded to a cloud platform for storage and analysis. The platform will aggregate data from multiple dives to identify trends and generate risk profiles for individual divers.

Post-dive reports will provide divers with detailed feedback, highlighting areas for improvement and reinforcing safe diving practices.

Artificial Intelligence (AI) Integration: AI algorithms will be used to detect potential risks and predict incidents based on historical and real-time data. For example, patterns associated with decompression sickness or fatigue can be identified and addressed proactively.

3.2 Evaluation Framework

The evaluation of the proposed system will involve both simulation studies and field trials to ensure its effectiveness and reliability.

Simulation Studies: Virtual simulations will be conducted to test the system's performance under various scenarios, including equipment failure, rapid ascents, and physiological stress.

These simulations will help refine the system's algorithms and interface design before deployment in real-world environments.

Field Trials: The system will be deployed in controlled diving environments, such as training pools and shallow open-water sites, to collect real-world data on its performance. Participants will include both novice and experienced divers, allowing for an assessment of the system's adaptability to different skill levels and scenarios.

Metrics for Evaluation: Safety Improvements: Reduction in the incidence of safety-related incidents, such as rapid ascents or out-of-air situations, will be a key metric.

Training Effectiveness: Improvements in diver skills, such as reaction times and adherence to safety protocols, will be measured through pre- and post-training assessments. **System Usability:** User feedback on the system's interface, responsiveness, and ease of use will be collected through surveys and interviews.

3.3 Experimental Design

Participants:

Divers with varying levels of experience (e.g., beginner, intermediate, advanced) will be recruited to ensure the system's generalizability. Ethical considerations, including informed consent and safety precautions, will be strictly adhered to during all experiments. **Data Collection:** Physiological and environmental data will be continuously recorded during dives, and post-dive surveys will capture subjective feedback on the system's usability and effectiveness.

Statistical Analysis: Data collected from the trials will be analyzed using statistical methods to evaluate the system's impact on safety and training outcomes. Comparisons will be made between dives conducted with and without the system to quantify its effectiveness.

3.4 Limitations and Challenges

The system's performance may be influenced by environmental factors such as water temperature and visibility, which could impact sensor accuracy and data transmission. Adoption of the system may face resistance from divers accustomed to traditional practices. Comprehensive training on system use will be essential to address this challenge. Integration with existing diving equipment and standards will require collaboration with industry stakeholders to ensure compatibility and compliance.

4. Expected Outcomes

This research proposes an intelligent interactive system aimed at revolutionizing diving safety and training by integrating technological innovation with practical application. The system is expected to deliver quantifiable benefits, create a safer diving culture, and influence broader industries. Below are the detailed anticipated outcomes:

4.1 Development of an Intelligent Accident Prevention System

4.1.1 Real-Time Risk Identification and Alerts

The system leverages cutting-edge sensor technology and AI to provide real-time feedback, enabling divers to proactively address potential dangers. Additional functionalities include: **Predictive Alerts:** The system predicts potential hazards based on historical and real-time data patterns. For example, divers exhibiting signs of elevated stress (e.g., irregular breathing or heart rate) will receive early warnings to prevent panic or fatigue-induced incidents. **Multi-Modal Alerts:** In addition to visual and auditory alerts, the system supports tactile feedback, such as vibrations through wearable devices, to ensure divers remain alert even in noisy or low-visibility conditions.

4.1.2 Data-Driven Safety Management

Post-Dive Risk Assessment: The system analyzes and categorizes each dive's risk level, providing detailed feedback on diver performance and environmental conditions. High-risk behaviors (e.g., rapid ascents or insufficient safety stops) are flagged for review.

Collaborative Safety Optimization: Dive operators can use aggregated data to enhance group safety protocols, such as pre-dive brief-

ings focused on common risk factors identified through the system. **Benchmarking:** Operators can compare safety metrics across dives and diver groups, fostering accountability and continuous improvement in safety practices.

4.1.3 Reduction in Common Safety Incidents

The system's automation and early intervention capabilities target frequent issues in diving, such as:

Equipment Malfunctions: Sensors identify anomalies in air pressure or regulator performance, minimizing risks associated with equipment failures. **Panic Situations:** By providing real-time guidance during emergencies, the system can help divers make safer decisions, reducing accidents caused by panic-induced errors.

Environmental Hazards: Alerts regarding dangerous currents, low visibility, or unexpected underwater terrain changes will allow divers to adjust their plans accordingly.

4.2 Enhancing Training Effectiveness

4.2.1 Personalized Training with Intelligent Systems

To address the limitations of traditional training methods, the system offers highly adaptive and immersive training solutions, such as: **Progressive Learning Modules:** Divers begin with basic skills (e.g., buoyancy control) and gradually advance to complex scenarios (e.g., managing equipment failure under time pressure).

Team Training: Group simulations foster collaborative problem-solving, teaching divers how to coordinate during emergencies such as buddy rescues or group ascents. **Virtual Dive Environments:** Simulations replicate unique underwater conditions, such as coral reefs or shipwrecks, allowing divers to gain practical experience before engaging in real-world dives.

4.2.2 Data-Supported Training Feedback

Skill Tracking: Over multiple training sessions, the system tracks individual performance trends, identifying improvements and recurring challenges. **Automated Recommendations:** Based on data insights, the system suggests specific drills or techniques to address weaknesses. For instance, a diver struggling with ascent control may receive customized exercises to refine buoyancy.

Gamification: To increase engagement, the system incorporates gamified elements, such as achievement badges for mastering key skills or completing high-difficulty scenarios.

4.3 Long-Term Impact and Potential Expansion

4.3.1 Building a Comprehensive Safety Culture

Community Engagement: The system enables sharing of anonymized safety data and best practices across the diving community, encouraging widespread adoption of a safety-first mindset. **Safety Incentives:** Dive operators using the system may offer incentives, such as discounted dives or certifications, to divers who demonstrate consistent adherence to safety protocols.

4.3.2 Supporting Industry Standardization

The system has the potential to standardize training and safety practices across the diving industry:

Global Certification Alignment: By integrating the system into certification frameworks, such as PADI or NAUI, training outcomes can be objectively measured and aligned with global safety standards.

Regulatory Integration: Governments and regulatory bodies could use system-generated data to enforce safety regulations, ensuring compliance across dive operations worldwide.

4.3.3 Expansion to Other High-Risk Domains

Beyond diving, the system's design and principles can be adapted to other fields where safety and training are critical:

Space Exploration: Similar real-time monitoring and simulation training could enhance astronaut safety during spacewalks or long-duration missions. **Extreme Sports:** The system can improve safety and training for activities like rock climbing, skiing, and paragliding, where environmental and human factors interact dynamically.

4.4 Quantifiable Impact

4.4.1 Significant Reduction in Safety Incidents

Field trials are expected to yield measurable improvements, such as:

60% reduction in ascent-related incidents.

50% improvement in adherence to safety stops and pre-dive checklists.

30% decrease in panic-induced accidents during simulated emergencies.

4.4.2 Noticeable Improvements in Skills

Compared to traditional training, divers using the system are projected to demonstrate:

Faster mastery of complex skills, such as buoyancy adjustments in challenging conditions.

Higher retention rates for safety protocols, even months after training completion.

Greater situational awareness and decision-making speed during high-pressure scenarios.

4.4.3 User Acceptance and Industry Adoption

Through iterative feedback and design improvements, the system is expected to achieve:

High satisfaction ratings: Divers and operators report ease of use and meaningful impact on safety and training outcomes.

Industry-wide adoption: Operators see the system as a competitive advantage, promoting its use across recreational and professional diving sectors.

4.5 Positive Societal and Environmental Effects

4.5.1 Improved Diver Health and Well-Being

By reducing incidents, the system directly contributes to divers' physical safety and mental well-being.

Divers report increased confidence and reduced anxiety during dives, fostering a more enjoyable and fulfilling experience.

4.5.2 Promoting Sustainable Diving Practices

Educational Tools: The system provides divers with real-time guidance on minimizing their environmental impact, such as avoiding fragile coral reefs or protected marine life. Scientific Contributions: Environmental data collected during dives can be shared with researchers to support marine conservation initiatives, such as tracking coral bleaching or monitoring endangered species populations. Through these anticipated outcomes, this research delivers significant contributions to diving safety, training methodologies, and broader applications in other high-risk domains. The intelligent interactive system not only addresses current challenges but also sets the stage for future advancements, ensuring that diving remains a safer and more sustainable activity.

5. Conclusion

This study proposes an innovative approach to improving diving safety and training through the development of an intelligent interactive system. By integrating wearable sensors, artificial intelligence (AI), and virtual reality (VR), the system addresses key gaps in current diving practices, offering a comprehensive solution for real-time safety monitoring, immersive training, and data-driven risk management. The findings from this research are anticipated to make significant contributions to both academic and practical domains.

5.1 Academic Contributions

This research advances the theoretical understanding of how intelligent technologies can be applied to high-risk environments like diving. By combining physiological monitoring, AI-based risk detection, and VR-based training, the proposed system represents a novel interdisciplinary framework. It bridges existing gaps between human factors research, environmental risk management, and technological innovation. Furthermore, the insights generated from this study provide a foundation for future research in other high-risk fields, such as aviation, offshore energy, and medical surgery.

The study also contributes to the growing body of knowledge on diving safety by emphasizing the importance of integrating real-time feedback systems with training programs. This holistic approach to safety management moves beyond traditional reactive measures, shifting towards proactive risk prevention.

5.2 Practical Implications

The proposed system has significant practical implications for the diving industry and broader marine tourism sector. For divers, the system enhances personal safety by identifying potential risks in real time and providing actionable feedback during dives. For training agencies, the integration of immersive VR simulations can revolutionize traditional training programs, offering divers the opportunity to practice emergency responses in a controlled and realistic environment.

Dive operators and businesses also stand to benefit from the system's data analytics capabilities, which provide actionable insights for optimizing safety protocols and improving operational efficiency. By reducing the incidence of accidents, the system can enhance customer satisfaction, build trust, and improve the reputation of the diving industry as a whole.

5.3 Social and Environmental Impact

Beyond individual and industry benefits, the study holds broader societal significance. By reducing diving-related injuries and fatalities, the system alleviates the burden on healthcare systems and improves public confidence in diving as a safe and enjoyable activity. The system also promotes environmentally responsible diving practices, helping to protect marine ecosystems from human interference. For example, divers can receive real-time guidance on avoiding fragile coral reefs or minimizing disruption to marine life, contributing to the long-term sustainability of underwater environments.

5.4 Future Directions

While the proposed system offers significant potential, further research is needed to fully realize its capabilities and ensure its widespread adoption. Key areas for future investigation include:

System Adaptability: Expanding the system's functionality to accommodate diverse diving environments, such as deep-sea exploration, cave diving, and ice diving.

Integration with Existing Standards: Collaborating with certification organizations, such as PADI and NAUI, to integrate the system into global diving safety standards and certification programs.

Technological Enhancements: Incorporating advanced AI capabilities, such as machine learning models for personalized risk prediction and adaptive training scenarios.

Field Validation: Conducting extensive field trials across different geographic regions and user demographics to validate the system's effectiveness and usability.

Cost-Effectiveness: Addressing economic barriers to ensure the system's affordability and accessibility for recreational divers and small dive operators.

5.5 Final Remarks

In conclusion, this study demonstrates the transformative potential of intelligent interactive technologies in addressing critical challenges in diving safety and training. By offering an integrated solution that combines real-time monitoring, immersive training, and data analytics, the proposed system not only reduces safety incidents but also enhances the overall diving experience. Its contributions extend beyond the diving community, setting a precedent for the application of intelligent systems in other high-risk industries.

As the diving industry continues to grow, the adoption of such technologies is essential for ensuring the safety, sustainability, and inclusivity of underwater activities. By bridging the gap between technological innovation and practical application, this research paves the way for a safer and more sustainable future in diving and beyond.



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