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AI-Driven Drowning Prevention: A Transformer-Based Approach for Pool Monitoring

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ABSTRACT

Drowning deaths are the third leading cause of accidental fatalities worldwide, with indoor swimming pool drownings, especially among children, becoming an increasing concern. Traditional methods of monitoring swimmers in large pools are often inadequate, leading to growing incidents of drowning accidents. To address this issue, this project proposes an innovative drowning detection system for swimming pools using Video Vision Transformer (ViViT). The proposed system employs a novel embedding scheme and Transformer variants to model video clips, extracting spatio-temporal tokens from the input video. These tokens are then encoded through a series of transformer layers to capture the spatio-temporal information of drowning events. By leveraging a pre-trained ViViT model, the system calculates the similarity between query and candidate scenes using cosine similarity, enabling accurate detection of drowning incidents. The system is designed to be lightweight, using Temporal Transformer and Feature Pyramid Networks to efficiently detect drowning events, especially in infants, without the need for large, resource-intensive models. This approach ensures real-time performance while maintaining high detection accuracy. The proposed system aims to provide automated, accurate alerts in case of drowning incidents, which is crucial for reducing swimming pool-related accidents and enhancing overall safety. Experimental results indicate that the proposed method delivers a balance of high accuracy and fast detection speed, demonstrating its potential for effective use in real-world applications.

OVERVIEW

Drowning is a leading cause of death in children and teens. Among young children, most drownings happen in home pools or hot tubs. In teens, drowning is more likely to happen in oceans, lakes, and rivers. It happens fast and is usually silent. Drowning is a type of suffocation induced by the submersion of the mouth and nose in a liquid. Drowning is a respiratory impairment caused by being submerged or immersed in water.
Childhood drowning commonly occurs when a child is left unattended or during a brief lapse in attention (World Health Organization, 2023). Most instances of fatal drowning occur alone or in situations where others present are either unaware of the victim's situation or unable to offer assistance.Drowning is defined by the World Health Organization Opens a new window(WHO) and other medical groups as respiratory impairment (i.e. being unable to breathe) as a result of being underwater. Though the term "drowning" has traditionally only been used to refer to fatal events in the water, WHO's definition includes both fatal drowning and nonfatal drowning. An average of 3,957 Indian infants die from drowning each year, with children ages 1 to 4 at the highest risk. In fact, drowning is one of the leading causes of unintentional deaths among children ages 1 to 14, second only to car crashes. Children under 15 also experienced a high rate of fatal drownings and nonfatal drowning injuries, with an average of 371 fatalities per year between 2018 and 2023 and 8,300 injuries that needed hospitalization between 2020 and 2023. drowning in children can be very devastating and have profound effects on the family. There might not be enough time to save the drowning child, as such, all efforts should be directed toward prevention.

FUTURE ENHANCEMENT

The future scope of the Infant Drowning Prevention and Alert System holds immense potential for expansion and refinement. Several avenues for development and enhancement can be explored to further strengthen the system's capabilities:

- **Global Scalability:** Extend the system's reach to a broader audience by making it adaptable to various cultural and geographical contexts. Consider language localization, cultural sensitivity, and compliance with international safety standards to ensure global applicability.
- **Mobile Application Development:** Develop dedicated mobile applications for caregivers, pool managers, and administrators to provide a more user-friendly and accessible experience. Mobile apps can offer additional functionalities, such as real-time alerts, remote monitoring, and easy configuration.
- **Integration with Smart Home Devices:** Explore integration possibilities with smart home devices and platforms to enhance the system's connectivity. This could involve compatibility with voice-activated assistants, smart speakers, or other IoT devices to provide a seamless and integrated user experience.

• **Research on Infant Behaviour Patterns:** Invest in ongoing research to understand and incorporate more nuanced infant behaviour patterns near water. This could involve collaboration with child development experts, paediatricians, and psychologists to refine the system's behavioural recognition capabilities.

By exploring these avenues, the Infant Drowning Prevention and Alert System can evolve into a holistic solution, continually adapting to emerging technologies and user needs while maintaining its core objective of preventing infant drowning incidents.

SYSTEM ARCHITECTURE

The proposed system is structured into several interlinked modules that collectively work to detect and prevent infant drowning incidents in real-time.

1. User Interface Layer

Web Admin Panel: For configuring system settings, training the DrownNet model, and monitoring alerts.

Pool Manager Dashboard: For camera setup, emergency contact management, and live monitoring.

Caregiver Interface: Receives notifications and alerts, ensuring prompt response.

2. Surveillance & Input Layer

Camera Network: Continuous video streaming from strategically placed surveillance cameras near water bodies.

3. Processing & Detection Layer

DrownNet Model: Built using CNN, RPN, and feature fusion networks, trained on diverse infant activity datasets.

Video Vision Transformer (VVT): Processes frames to extract spatial-temporal patterns, enabling behavioral analysis.

Prediction Engine: Integrates outputs from DrownNet and VVT to identify potential drowning behaviors.

4. Alerting & Notification Layer

Anomaly Detection Module: Compares real-time behavior to learned patterns to detect anomalies.

Notification System: Delivers alerts through SMS, email, in-app notifications, and audible alarms.

5. Data Management Layer

Database (MySQL): Stores user data, system settings, and historical monitoring records.

LITERATURE REVIEW

Several recent studies have explored methods for detecting drowning and similar critical events using advanced technologies. He et al. (2023) proposed an automatic real-time infant drowning detection system using YOLOv5 and Faster R-CNN, leveraging video surveillance. Their approach demonstrated strong performance but struggled in densely populated or toy-disturbed environments, leading to missed or false detections.Zhang (2023) introduced CA-U2-Net for infrared dim and small target detection by enhancing U2-Net with attention mechanisms and a contour detection branch. Although effective in challenging infrared scenarios, it is not tailored for drowning detection.Endo (2022) developed a bathing accident monitoring system using a depth sensor to prevent drowning incidents. While promising, this approach is limited to environments where depth sensing is feasible.Together, these studies show significant progress in surveillance and detection technologies, with room for improvement in complex and cluttered environments.

METHODOLOGY

- Step 1: Data Collection

Gather video footage of infants around pools, bathtubs, and lakes.

Annotate clips with labels for normal and dangerous behavior scenarios.

- Step 2: Data Preprocessing

Convert videos into frames.

Apply grayscale conversion, noise filtering, binarization, and segmentation.

- Step 3: Model Training (DrownNet)

Region Proposal Network (RPN): Detects regions of interest in video frames.

CNN: Classifies behavior patterns as safe or unsafe.

Feature Fusion: Enhances accuracy by combining visual and behavioral features.

- Step 4: Real-Time Monitoring

Integrate DrownNet and VVT into the web app for live video analysis.

Continuously analyze video feeds to monitor infant behavior.

- Step 5: Anomaly Detection & Alerts

Detect deviations from normal behavior using learned models.

Generate and dispatch alerts when risky behavior is detected.

- Step 6: Caregiver Intervention

Real-time notifications prompt caregivers to take immediate action.

Alerts include context (time, camera ID, behavior pattern) for clarity.

RESULT

The proposed Infant Drowning Detection System was successfully developed and deployed using Video Vision Transformer (VVT) and the DrownNet Model. The system was tested in a simulated pool environment with real-time video input and demonstrated high efficiency in identifying potentially dangerous behaviors among infants near water bodies.

Key results observed:

- High Detection Accuracy The combined use of DrownNet and VVT led to improved recognition of infant movements and distress behaviors, reducing false positives compared to traditional CNN-based approaches.
- Real-Time Monitoring The system effectively processed live video streams, ensuring timely detection of drowning risks.
- Prompt Alert Generation The alert module successfully generated immediate notifications through multiple channels (SMS, email, in-app, and audible alarms), enabling quick caregiver response.
- User Interface Feedback Users including pool managers and caregivers were able to easily navigate and operate the web-based interface for monitoring and responding to alerts.
- System Responsiveness The latency between behavior detection and alert generation was minimal, ensuring effective intervention opportunities.
- Overall, the system achieved its goal of delivering a reliable, automated solution for preventing infant drowning incidents, showcasing strong potential for real-world deployment in homes, pools, and public aquatic

CONCLUSION

In conclusion, this project stands at the forefront of technological innovation in ensuring the safety of infants around water bodies. By harnessing the capabilities of the Video Vision Transformer (VVT) and the trained DrownNet Model, the system demonstrates remarkable accuracy in the real-time detection of potential drowning risks. Its proactive alerting mechanism serves as a crucial lifeline, delivering immediate notifications to caregivers and facilitating prompt intervention in critical situations. The user interfaces, including the Web Admin, Pool Manager, Pool Camera, and DrownNet Model interfaces, collectively contribute to a comprehensive and user-friendly system. Administrators benefit from secure access and flexible configuration options, while pool managers gain oversight and control over camera setups and emergency contacts. Caregivers receive real-time alerts through multiple channels, ensuring they stay informed and can respond swiftly to any potential threats. The system's adaptability to diverse environments, coupled with the Historical Data and Reporting Module, fosters a culture of continuous improvement. The insights gained from historical data allow for refinements in the model and system configuration, ensuring ongoing efficacy and responsiveness to emerging challenges. In essence, the Infant Drowning Prevention and Alert System not only represents a technological milestone but also a compassionate and practical approach to safeguarding the well-being of infants. Its multifaceted design, proactive features, and commitment to ongoing enhancement position it as a valuable tool in creating safer aquatic environments and preventing tragic incidents of infant drowning.

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