

Temporal Shift - Multi-Objective Loss Function for Improved Anomaly Fall Detection

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Abstract

Falls are a major cause of injuries and deaths among older adults worldwide. Accurate fall detection can help reduce potential injuries and additional health complications. Different types of video modalities can be used in a home setting to detect falls, including RGB, Infrared, and Thermal cameras. Anomaly detection frameworks using autoencoders and their variants can be used for fall detection due to the data imbalance that arises from the rarity and diversity of falls. However, the use of reconstruction error in autoencoders can limit the application of networks' structures that propagate information. In this paper, we propose a new multi-objective loss function called Temporal Shift, which aims to predict both future and reconstructed frames within a window of sequential frames. The proposed loss function is evaluated on a semi-naturalistic fall detection dataset containing multiple camera modalities. The autoencoders were trained on normal activities of daily living (ADL) performed by older adults and tested on ADLs and falls performed by young adults. Temporal shift shows significant improvement to a baseline 3D Convolutional autoencoder, an attention U-Net CAE, and a multi-modal neural network. The greatest improvement was observed in an attention U-Net model improving by 0.20 AUC ROC for a single camera when compared to reconstruction alone. With significant improvement across different models, this approach has the potential to be widely adopted and improve anomaly detection capabilities in other settings besides fall detection.

Keywords: Fall Detection; Computer Vision; Video Anomaly Detection; Machine Learning; Deep Learning;

1. Introduction

The number of older adults is growing, as both a ratio and absolute numbers in populations, creating a tremendous challenge for health care systems Fuster (2017). Falls are a leading cause of injury and death in older adults Kramarow (2015). To reduce the risk of complications, fall detection is important as it allows for early intervention and reduce additional health complications Stinchcombe et al. (2014); Rubenstein and Josephson (2002). It also enables older adults to live independently by ensuring that they receive assistance when needed. Video or computer vision detection systems are preferred for fall detection, as they require no user input, are non-invasive, and can work in a variety of environments, including the home Igual et al. (2013). However, fall detection is a challenging problem,

both from a predictive modeling perspective and practical considerations, such as privacy and false alarm rates Khan and Madden (2014); Khan and Hoey (2017).

Predictive modeling for fall detection is challenging due to the rarity and diversity of fall events, making it difficult to create a well-defined class for falls or to capture all possible variations of falls in a dataset Khan and Hoey (2017). Previous research shows that natural falls occur only on 0.3% to 1.6% of days Stone and Skubic (2014); Debard et al. (2012), and even then, each fall may last only a few seconds, resulting in very highly skewed datasets Khan and Hoey (2017). Therefore, even long-term studies may not contain enough fall data to build a robust supervised classifier Khan (2016). Additionally, each rare fall event can vary greatly from one another, making it even difficult to capture possible variations Khan (2016); Charfi et al. (2012). Finally, practical considerations, such as low false alarm rates and privacy, need to be taken into account when developing fall detection systems, as they can significantly affect the system’s usefulness and adoption.

This paper introduces a novel multi-objective loss function, Temporal Shift, which significantly enhances the optimization of video anomaly detection frameworks. Temporal Shift is comprised of reconstruction loss and prediction loss and is applied to various convolutional autoencoder network structures. The networks are evaluated on the Multi-Visual Modality Fall Detection Dataset (MUVIM) Denkovski et al. (2022), demonstrating that Temporal Shift enables:

- Improved performance of 3D Convolutional autoencoder (3DCAE) for fall detection.
- Improved optimization of skip connections and attention units within an autoencoder framework.
- Effective multi-visual fusion, enabling better detection of anomalies with multiple camera modalities.

The paper’s contribution of developing Temporal Shift to the field of video anomaly detection is a significant advancement that has the potential to be applied beyond fall detection to other anomaly detection applications.

2. Literature Review

Video anomaly detection has a wide range of applications and methods outside of fall detection. Following the success of deep learning in image classification Krizhevsky et al. (2017); He et al. (2016), many researchers have started focusing on the anomaly detection problem in videos by applying different types of deep learning methods, such as 3D Convolutional Autoencoders (CAEs) Hu et al. (2022); Mishra et al. (2023), Long Short-Term Memory Networks (LSTMs) Abbas and Al-Ani (2022) and Temporal Convolutional Networks Abedi and Khan (2023). These approaches typically involve training the model on normal data and then detecting deviations in the reconstruction error or output to identify anomalies.

2.1. Video Anomaly Detection for Falls

Traditional handcrafted features for fall detection rely on changes in bounding box proportions or joint/skeletal positional information to extract features characterizing the body’s

geometry, motion, and position [Ramachandran and Karuppiah \(2020\)](#); [Gutiérrez et al. \(2021\)](#). However, certain limitations, such as occlusions or camera positioning within homes [Baldewijns et al. \(2016\)](#), can hinder the robustness and accuracy of these methods in fall detection. Deep learning methods that can extract a broader range of features might offer improved performance.

Nogas et al. [Nogas et al. \(2020\)](#) introduced a 3D Convolutional Autoencoder (3DCAE) for fall detection within an anomaly detection framework. The reconstruction error from the 3DCAE was used directly to detect falls. This method was found to outperform convolutional LSTMs [Nogas et al. \(2018\)](#). Khan et al. [Khan et al. \(2021\)](#) extended this work by incorporating the autoencoder into an adversarial learning system, demonstrating similar performance using thermal and depth cameras. Mehta et al. [Mehta et al. \(2021\)](#) added a secondary stream that encodes optical flow images, placing more emphasis on the temporal component. Moreover, a region-aware mechanism was used to isolate the image regions where the body is located, creating a region of interest.

Ronneberger et al. proposed a U-Net architecture for biomedical image segmentation [Ronneberger et al. \(2015\)](#). This method has been extrapolated for use with 3D images through a V-Net [Milletari et al. \(2016\)](#). Recently, a U-Net has also been used in a video anomaly detection framework [Kim et al. \(2022\)](#). Oktay et al. [Oktay et al. \(2018\)](#) introduced an Attention U-Net to improve upon existing U-Net structures. Attention Gates (AGs) enable a model to focus on specific structures within the image without additional supervision. Attention mechanisms form the backbone of state-of-the-art models such as transformers and have been widely used in predictive tasks, including natural language processing [Vaswani et al. \(2017\)](#); [Devlin et al. \(2018\)](#). Since skip connections in a U-Net structure convey abundant direct spatial and temporal information, AGs provide a way to isolate important aspects of the image. However, in the context of reconstruction error, all parts of an image are equally important for reducing error.

Applying certain techniques proven effective in other deep learning computer vision tasks, such as U-Net structures, Residual connections, or Attention Gates, to video anomaly detection can be challenging. These techniques, which modify the information flow through the network, were developed primarily for classification or segmentation tasks. When reconstruction error is used as the loss function, it prompts these network structures to propagate as much information as possible, bypassing much of the learning process. As such, a modified loss function, such as proposed by Liu et al. [Liu et al. \(2018\)](#), can help incorporate these methods within a video anomaly detection framework.

2.2. Future Frame Prediction

Several researchers have used the prediction of a single or multiple future frames (or images in a video sequence) for video anomaly detection tasks. Liu et al. [Liu et al. \(2018\)](#) used a stack of four frames to predict the fifth frame. The adversarial loss is found by discriminating between the predicted optical flow frames and the true frame. This means that only the predicted frame is used to find the loss, and none of the reconstructed frames. However, this still allows for optimization of the U-Net skip connections introduced in the Generative Adversarial Network (GAN). The authors normalized all of the reconstruction errors between 0 and 1. This introduces temporal leakage, as future values were used to

normalize past ones. The approach of using four frames and then predicting the following frame was also used by Nguyen et al. [Nguyen and Meunier \(2019\)](#) in a two-stream network. Jamadandi et al., [Jamadandi et al. \(2018\)](#) use a GAN to take a series of four frames and predicts the subsequent four (future) frames. Wu et al. [Wu et al. \(2019\)](#) also used four frames to predict the fifth in their latent space restriction approach. Tang et al., [Tang et al. \(2020\)](#) introduced a method that also seeks to use reconstruction in addition to the prediction error of frames to detect anomalies. Their approach also used optical flow images and the four-part loss function introduced by Liu et al. [Liu et al. \(2018\)](#). However, they use two U-Net autoencoders in series. The first autoencoder takes an input of four frames $I_t, I_{t+1}, I_{t+2}, I_{t+3}$ and seeks to predict the 5th frame, or I_m . The second autoencoder then takes this predicted and tries to reconstruct the ground truth or I_{t+4} . However, this method only tries to predict a single frame. We expand on this work by introducing temporal shift, a multi-objective loss function that uses both the reconstruction and prediction of frames. This is accomplished by predicting an overlapping window of frames, of which a portion of frames are reconstructed and the rest is predicted.

3. Methods

The methods section will cover three primary aspects: the dataset utilized, the proposed loss function, and the evaluation methods employed for the loss function. The evaluation will involve three main models. The first model is a baseline 3D convolutional autoencoder (3DCAE). Next, the 3DCAE architecture is adapted into an Attention U-Net. Lastly, the 3DCAE is modified into a multi-modal network to handle multiple camera modalities for fall detection. The objective is to assess how the loss function, Temporal Shift, enhances the optimization of different network types within an anomaly detection framework for the purpose of fall detection with single and multiple camera modalities.

3.1. Dataset

The Multi Visual Modality Fall Detection Dataset (MUVIM) was used for anomaly detection of falls [Denkovski et al. \(2022\)](#). It contains (6) vision-based sensors of different modalities including thermal, depth, infra-red (IR) and RGB cameras (See Figure 1 for example images). Pre-processing steps included converting images to grey scale, re-sizing to 64 by 64, normalizing image values and reducing frame rate to 8 frames per second. In the case of the thermal camera, the frame rate was significantly lower. As such, frames were duplicated as needed in order interpolate the dataset to 8 frames per second. The dataset contains videos of older adults performing activities of daily living (ADL) activities and is used as the normal dataset for training. Videos containing both normal activities and falls are performed by younger adults in the test set. The dataset consisted of 200,000 frames, with 160,000 frames used for testing and 40,000 frames used for training. The dataset collected contains both older adults (with normal activities and no falls) and younger adults (with both normal activities and falls). Only video's without falls were used for training to define the normal class, thus only older adults' data was used for training and younger adults' data for testing. This division ensures the model differentiates between fall and non-fall events without being influenced by age-related differences, preventing model bias. In an anomaly detection approach, the data for “anomalous” class (fall in this case) is

not available; therefore, no validation set is explicitly created to avoid information leakage during testing.

The combination of multiple modalities was of interest as it has been observed that the addition of visual modalities such as RGB and depth can improve performance [Song et al. \(2015\)](#); [Eitel et al. \(2015\)](#). Modalities selected for combination were limited to those captured by the same camera system - such as the Orbbecc Depth and Infra-red images. This allows for the highest degree of similarities across modalities.

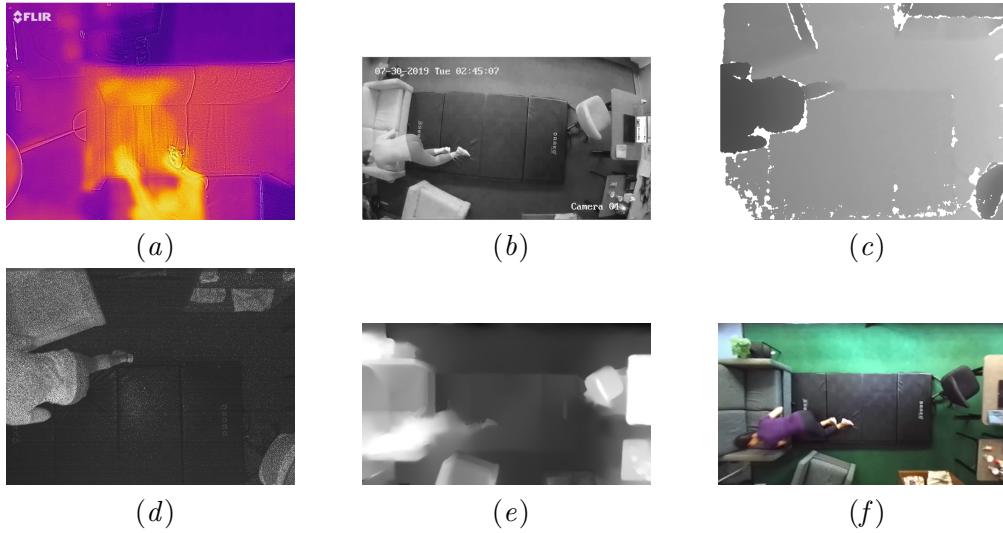


Figure 1: Start of the fall as indicated by manually produced labels for each camera. (a) Center FLIR Thermal, (b) Hikvision IP, (c) Orbbec Depth, (d) Orbbec IR, (e) - Stereolabs ZED Depth, and (f) Stereolabs ZED RGB

3.2. Temporal Shift Loss

In the context of an autoencoder, temporal shift is a multi-objective problem comprised of reconstruction loss and prediction loss. The first part, reconstructive loss, is found by comparing the reconstruction error of frames that were input into the autoencoder with reconstructions of those same frames. Prediction loss is found by the autoencoder generating frames that were not input into the autoencoder and are instead only used to find the error. See Figure 2 for details.

For a given window of length L , it is divided into two overlapping sub-windows. The first sub-window is comprised of frames 0 to W . The second sub-window is temporally shifted by an amount equal to S . This means the second sub-window contains frames S to $W + S$, where $L = W + S$. In essence, we are generating a window of frames (with length W) that has been shifted by a temporal offset of S . For example, if we want an input window of 6 frames ($W = 6$) and a temporal shift S of 2, we will need a total window size of $W + S$ or 8. Then we input the first sub-window (frames 0 to 5) into the autoencoder and use the

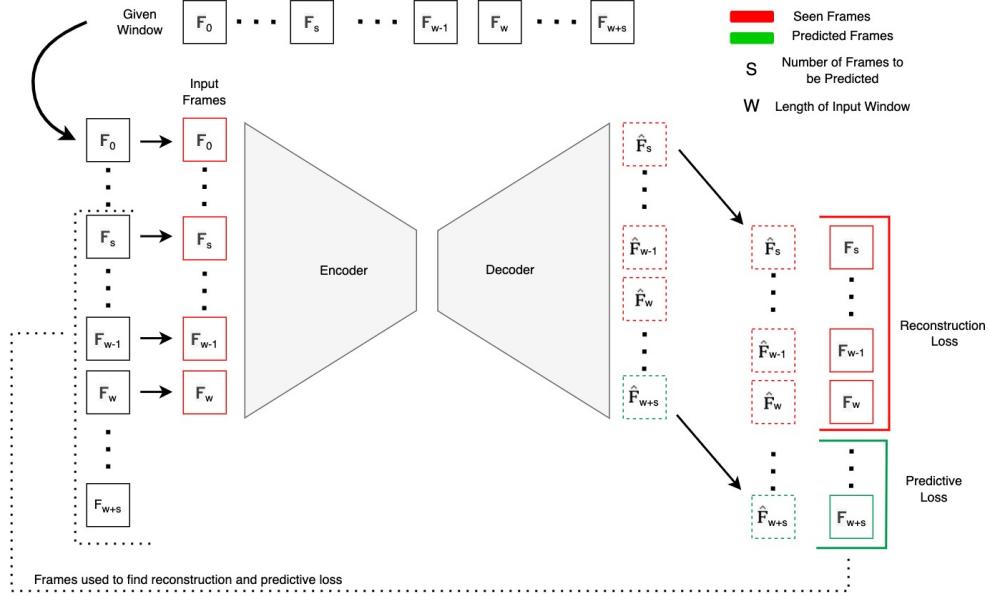


Figure 2: The six input frames (F) and six output frames (P) for a window length of eight, and a temporal shift of two.

second sub-window to find reconstruction error (frames 2 to 7). This will result in having 4 frames that are reconstructed (2 to 5) and 2 that are predicted (6 and 7). See Figure 3

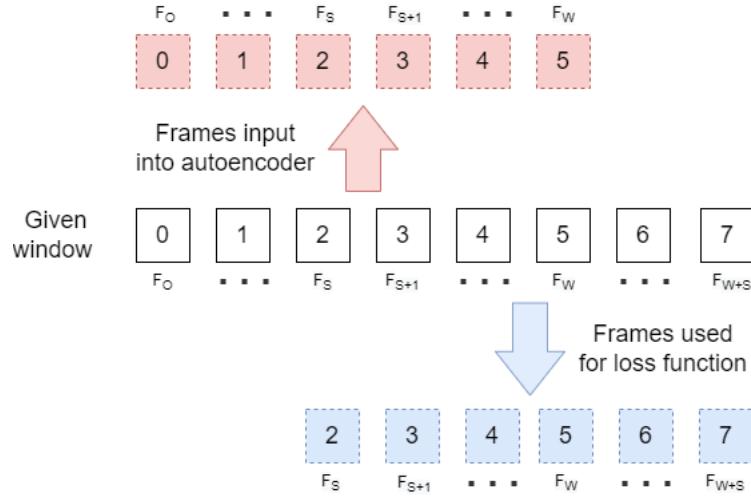


Figure 3: Example of frame selection for a window of 8 frames, and an input window of $W = 6$ and a temporal shift of $S = 2$

3.2.1. TEMPORAL SHIFT - HYPER PARAMETER TUNING

Hyper parameter tuning on an anomaly detection dataset is very challenging. This is because in an anomaly detection framework, it is assumed that one does not have the anomalous class data. As such, the use of a validation set cannot be used. However, tuning the hyperparameter on the test set is problematic due to the model adapting to fit (or over-fit) test set and also due to leakage of information. Recognizing this, several methods were tried to identify the best performance on the test set.

There are two main hyper-parameters that need to be set. The first is the length of the window. It was found that eight frames per window worked best. However, this may be dependent on video frame rate and the specifics of anomaly (fall in our case). The second parameter is the length of time shift and thus the number of frames to be predicted. Results for various window lengths are shown in Table 1 in the results section. To compare to related work by [Liu et al. \(2018\)](#); [Nguyen and Meunier \(2019\)](#), the window length was set to five and the temporal shift to one. This meant that four frames would be used to predict one frame. Additionally, window lengths 6, 8 and 10 were explored with various temporal shifts of 1 through 4. Even numbers were only used to eliminate rounding scenarios. Experimentally, it was found that the best performance was achieved with an input window of 6 and a temporal shift of 2, so these were used for further experiments. This means a total window length of 8 was used.

3.3. Modeling

Three main variations of modeling approaches were employed in this study. The first two variations focus on a single modality at a time. These include the baseline 3D convolutional autoencoder (3DCAE) and the Attention U-Net networks. The 3DCAE serves as a baseline model structure, allowing us to evaluate the impact of the Temporal Shift Loss on a network without skip connections. The Attention U-Net, on the other hand, incorporates attention mechanisms and skip connections in order to evaluate if temporal shift loss can effectively optimize the networks. The third variation involves a multi-modal network that examines whether combining two video modalities can enhance performance compared to using a single modality. This approach simultaneously incorporates two modalities and combines them in the latent space. While the combination of multiple modalities, such as RGB and Depth, has been explored in classification tasks, it remains to be seen whether incorporating multiple modalities can provide a better definition of reconstruction error-based loss in the context of anomaly detection.

3.3.1. 3DCAE

The 3DCAE has demonstrated superior performance in fall detection within an anomaly detection framework [Nogas et al. \(2020\)](#). It was found to outperform other methods, including convolutional LSTMs [Nogas et al. \(2018\)](#). The 3DCAE has also shown to be adaptable to other frameworks, such as adversarial learning [Khan et al. \(2021\)](#). We chose to use a 3DCAE as our reference baseline. Compared to other deep learning methods, this approach offers high performance while maintaining relative simplicity. Its adaptability enables the integration of other network structures, such as skip connections or attention gates relatively easily. This adaptability facilitates the assessment of the impact of these network structures

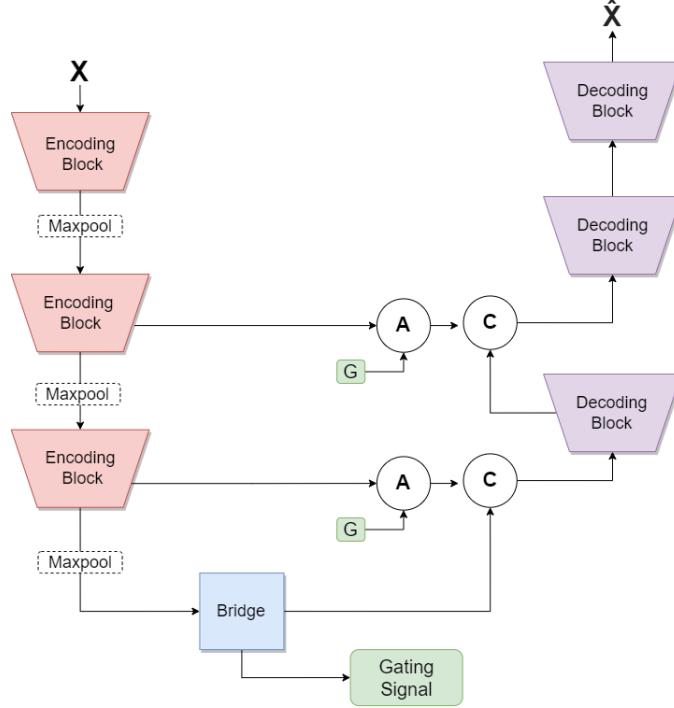


Figure 4: Attention U-Net Structure used. Circle A; The modified attention gate mechanism. Gating signals from the lowest (coarsest) dimensionality were up-scaled in order to be applied to various feature maps.

when coupled with and without Temporal Shift. The MUVIM dataset was introduced by Denkovski et al. (2022), who conducted extensive experiments on window sizes and network hyper-parameters. Given our utilization of the same dataset and baseline autoencoder model, we adopted their model parameters.

The models are only trained on normal data. Consequently, when a fall event occurs, the reconstruction is expected to be high in majority of the cases. During the testing phase, the reconstruction error is calculated for a given window. However, as a frame may appear in multiple windows, the frame’s reconstruction error is determined by averaging the reconstruction errors from all windows it appears in. The reconstruction error from all videos are then concatenated into a large vector. Now to determine when a fall has happened, a threshold for the reconstruction error would have to be established. However, this creates an inherent trade-off between sensitivity and specificity (i.e. can choose a lower false positive rate but higher true positive rate). To circumvent this trade-off, the performance evaluation utilizes the area under the curve metrics, specifically the receiver operating characteristic curve and the precision-recall curve. By employing these metrics, the performance assessment encompasses all possible thresholds without the necessity of setting a specific threshold.

3.3.2. ATTENTION U-NET

The overall structure for the Attention U-Net is shown in Figure 4. As outlined earlier, skip connections and attention structures usually don't perform well in networks that focus on reconstruction. In such cases, learning can be bypassed and all information is important to minimizing reconstruction loss. A few key modifications to the original U-Net structure were implemented to help prevent direct propagation of information. Firstly, the last U-Net skip connection was removed, preventing access to information from the lowest levels. Second, the sigmoid layer used in the attention gate was replaced with a sequential softmax activation across each dimension. This was done as it causes the weighting of the features to become sparser as they must sum to 1. This would prevent a heavy weighting on all features, which may occur if a sigmoid activation layer was used in a reconstruction framework. The encoder consisted of three encoding blocks connected to a bridge. The decoder was comprised of three decoding blocks; two of which have attention gated skip connections directly connecting them to encoding blocks. As done in the original Attention U-Net paper Schlemper et al. (2019), the gating signal was taken from the coarsest layer and up-scaled to fit various feature maps.

3.3.3. MULTI-MODAL NETWORK

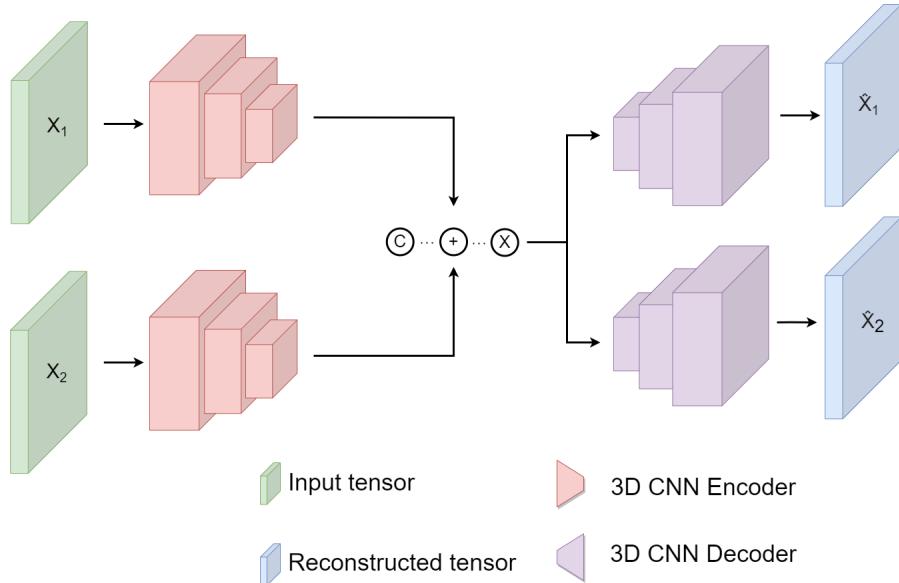


Figure 5: Multi-modal network framework used. Fusion occurred by one of three operations (multiplication, addition, or concatenation) at the bottleneck layer.

The multi-modal framework is outlined in Figure 5. It is comprised of individual encoders and decoders. The baseline 3DCAE network structure is used. The modalities are combined in the latent space through one of three operations, addition, multiplication, or concatenation. The addition or multiplication of feature maps amplifies the contribution of shared features that are heavily weighted, which increases their importance in the final

output. This can improve the performance of the model by allowing it to focus on the most important features and make more accurate predictions. However, with an anomaly detection framework sharing of features may be difficult as decoding is focused on reconstructing individual modalities. In addition the low-level features such as shapes, edges, are shared between the modalities with only high-level features being different. Models are only trained on normal or ADL data consisting of older adults. Test data contains a mixture of ADL data and falls from younger adults. As a single frame appears multiple times across overlapping windows, the mean reconstruction error for a frame is used.

4. Results

Table 1: Results achieved by various temporal windows with the baseline 3D CNN model. W represents the length of the input window and S represents the amount of temporal shift. The total window length is the sum of these two.

| W | S | AUC | Hikvision IR | Orbbec IR | Orbbec Depth | ZED Depth | ZED RGB | Thermal |
|---|---|-----|--------------|--------------|--------------|--------------|--------------|--------------|
| 8 | 0 | ROC | 0.904 | 0.905 | 0.820 | 0.795 | 0.703 | 0.831 |
| | | PR | 0.074 | 0.068 | 0.031 | 0.028 | 0.018 | 0.061 |
| 6 | 2 | ROC | 0.912 | 0.902 | 0.824 | 0.834 | 0.729 | 0.814 |
| | | PR | 0.075 | 0.076 | 0.033 | 0.034 | 0.021 | 0.062 |
| 4 | 4 | ROC | 0.912 | 0.900 | 0.775 | 0.776 | 0.684 | 0.806 |
| | | PR | 0.091 | 0.069 | 0.026 | 0.029 | 0.021 | 0.057 |
| 4 | 1 | ROC | 0.826 | 0.872 | 0.744 | 0.649 | 0.612 | 0.643 |
| | | PR | 0.058 | 0.053 | 0.044 | 0.015 | 0.016 | 0.014 |

Area under the curve of receiver operating characteristics (AUC ROC) and precision recall curve (AUC PR) are reported per modality in Table 2. The results of hybrid fusion are reported in Table 3.

Table 1 shows the comparison of results with various choices of W and S. It can be observed that W=6 and S=2 works best for most of the camera modalities for detecting falls. We keep this configuration for the rest of the experiments. From Table 2, we observe that temporal shift or the use of both reconstruction and prediction loss can improve fall detection results, with the highest AUC ROC and AUC PR scores achieved by models that incorporate both loss functions in temporal shift. The highest AUC ROC was achieved with the Orbbec IR camera with Attention U-Net with an AUC ROC of 0.920 and also achieved the highest AUC PR of 0.105. This has improved on baseline results by 0.02 AUC ROC and 0.03 AUC PR. Larger performance increases are seen in a multi-modal framework as seen in Table 3. Two of the three combinations of modality saw large performance increases, with multiplication bottleneck fusion performing the best. The performance increased from 0.893 AUC ROC to 0.929 AUC ROC for the combination of both Orbbec Infrared and Depth cameras. The combination of Hikvision IR and ZED Depth cameras saw a performance improvement of 0.855 to 0.901 AUC ROC. AUC PR also increased with the combination of Orbbec cameras, achieving the highest AUC PR score of 0.126.

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Table 2: AUC ROC and PR values for various loss functions. No Skill shows the performance achieved by a random chance classifier. All results are found with a window of eight frames and a temporal shift of two. Bold values indicate the highest results for that modality. Italic script indicates the loss function used for training and testing.

| Visual Modality | AUC | No Skill | 3D CNN <i>Reconstruction</i> | 3D CNN <i>Prediction</i> | 3D CNN <i>Temporal Shift</i> | Attention U-Net <i>Reconstruction</i> | Attention U-Net <i>Temporal Shift</i> |
|-----------------|-----|----------|---------------------------------|-----------------------------|---------------------------------|--|--|
| Orbbec IR | ROC | 0.5 | 0.905 | 0.866 | 0.902 | 0.816 | 0.920 |
| | PR | 0.010 | 0.068 | 0.048 | 0.076 | 0.074 | 0.105 |
| Orbbec Depth | ROC | 0.5 | 0.820 | 0.659 | 0.824 | 0.700 | 0.829 |
| | PR | 0.010 | 0.031 | 0.014 | 0.033 | 0.033 | 0.039 |
| ZED Depth | ROC | 0.5 | 0.795 | 0.590 | 0.834 | 0.616 | 0.724 |
| | PR | 0.017 | 0.028 | 0.012 | 0.034 | 0.012 | 0.029 |
| ZED RGB | ROC | 0.5 | 0.703 | 0.651 | 0.729 | 0.612 | 0.726 |
| | PR | 0.017 | 0.018 | 0.014 | 0.021 | 0.017 | 0.022 |
| Thermal | ROC | 0.5 | 0.831 | 0.769 | 0.814 | 0.612 | 0.786 |
| | PR | 0.009 | 0.061 | 0.047 | 0.062 | 0.045 | 0.058 |
| Hikvision IR | ROC | 0.5 | 0.904 | 0.784 | 0.912 | 0.895 | 0.912 |
| | PR | 0.010 | 0.068 | 0.048 | 0.076 | 0.074 | 0.105 |

Table 3: Performance of various multi-modal fusion methods. Columns indicate the modalities/cameras used, and each models respective performance with different loss functions. Best performance per input modality combination is bolded.

| Model | AUC | Orbbec IR + Orbbec Depth | | ZED Depth + ZED RGB | | Hikvision IR + ZED Depth | |
|---------------|-----|-----------------------------|-----------------------|------------------------|-----------------------|-----------------------------|-----------------------|
| | | <i>Reconstruction</i> | <i>Temporal Shift</i> | <i>Reconstruction</i> | <i>Temporal Shift</i> | <i>Reconstruction</i> | <i>Temporal Shift</i> |
| Hybrid Concat | ROC | 0.886 | 0.924 | 0.787 | 0.716 | 0.752 | 0.890 |
| | PR | 0.051 | 0.111 | 0.059 | 0.018 | 0.021 | 0.068 |
| Hybrid Add | ROC | 0.858 | 0.927 | 0.760 | 0.733 | 0.833 | 0.896 |
| | PR | 0.039 | 0.125 | 0.019 | 0.021 | 0.046 | 0.092 |
| Hybrid Multi | ROC | 0.893 | 0.929 | 0.758 | 0.746 | 0.855 | 0.901 |
| | PR | 0.080 | 0.126 | 0.020 | 0.022 | 0.055 | 0.103 |

4.1. Discussion

The implementation of temporal shift has been shown to improve the performance of video anomaly detection for falls, specifically for 3DCAE, Attention U-Net, and multi-modal models across different datasets. In particular, Attention U-Nets showed a large increase of almost 0.20 AUC ROC, indicating that temporal shift allows for more effective optimization of techniques used in classification, such as skip connections and attention gates in an anomaly detection framework. The thermal camera may not have improved as much as others, because it had duplicated frames in order to increase the effective frame rate.

Multi-modal models also showed an improvement in performance when temporal shift was applied. Without this method, these models tend to perform worse than single modalities. This may have been due to difficulties in leveraging shared features for reconstruction in multi-modal autoencoders, but the additional information provided by the different modalities may have been beneficial in prediction. Only two modalities were combined at a time due to computational limitations and practical considerations, and these modalities were captured by the same camera to account for frame rate and manual labeling differences. Although improved performance was seen when Depth and IR camera modalities were combined, a decrease in performance was seen with Depth and RGB. This may have been due to the fact the RGB camera was the worst performing modality and may have limited performance benefits.

The overall performance of the model, measured by the AUC ROC metric, is high. The baseline AUC PR performance is dependent on the distribution of labels within the dataset. Despite this, the best performing models demonstrated a significant improvement over random chance, with an approximate ten-fold increase in AUC PR. However, the absolute performance of the model remains low. This may be due to limitations in the dataset for anomaly detection, specifically the lack of diversity in the normal set of data, which indicates moderately higher false positive rates.

Experiments on different window lengths and frames consistently showed that predicting multiple frames outperformed predicting a single frame. The optimal results for fall detection were found with 8 frames (1 second window) and a temporal shift of 2 frames (0.25 seconds). However, if the window size is too long and the temporal length of the prediction is extended too far into the future, the task may become too difficult and less beneficial. The length of input windows and temporal shift used may depend on the type of anomaly and frame rate of the dataset.

5. Conclusions and Future Work

The implementation of temporal shift has been shown to greatly improve the performance of video anomaly detection for falls. Notably, the attention U-Net gave an AUC ROC increase of 20%, indicating better optimization of classification modeling techniques within anomaly detection framework. Both the multi-modal model and baseline 3DCAE model benefited from the implementation of temporal shift, likely because predicting multiple frames requires a better understanding of temporal feature changes over time. The temporal shift approach may work better with anomalies that are sudden in nature, e.g., falls.

In future, we will evaluate the usefulness of slowly evolving anomalies with our approach. The performance of temporal shift could be improved using different network architectures

and attention mechanisms. Additionally, exploring different weightings for the reconstruction loss and prediction loss could provide valuable insights. The temporal shift approach can be applied to many applications, including violence detection in crowded scenes, detecting rare diseases in 3D medical images and responsive behaviors in people with dementia using CCTV footage.

Video anomaly detection frameworks offer help with class imbalance problems like fall detection, but they have limitations. Anything not in the training set is considered anomalous, leading to high false positives and low AUC PR. This study used a semi-naturalistic dataset, which may not fully represent real-world falls. A real world dataset may contain a wider range of activities allowing more efficient model training. Future work will develop privacy-protecting models and establish thresholds for fall detection and alarm triggering.

Temporal shift allowed for the effective training of network structures that use skip connections without a classification based loss function. We hope that this method may be beneficial in many other tasks.

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