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Adaptive Neural Compression of Biometric Data in Health Game – Experimental Compression Using AI on Real-Time Vitals

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ABSTRACT

In this case we present a variable adaptive neural solution which reduces the bandwidth and storage requirements for continuous health related data like heart rate, respiration and galvanic skin responses in games. We have put a fourth a deep learning model which is trained on dynamic biometric signals to make the compressions to change according to the signals activity level and what is going on in the game. A simple neural encoder decoder architecture we present also meets the very low latency requirements of health related in game apps. We report that the results of our study support the that which we put forth as it reports real time health feedback parameters of the game environment.

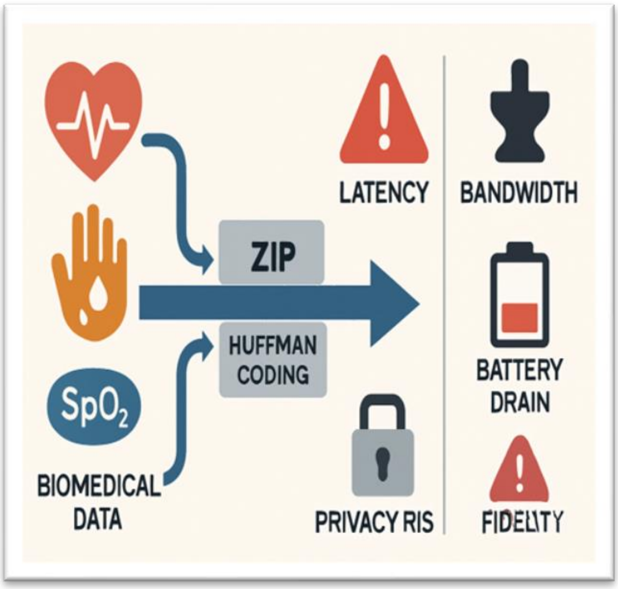
INTRODUCTION

Health focused gaming platforms has created new opportunities for personalized health, rehabilitation and wellness. This "health games" utilize real time physiological measures e.g. heart rate, oxygen saturation, and electrodermal activity to adjust game mechanics and provide therapeutic or training effects. Yet, streaming high frequency biometric data continously poses a formidable challenge effective storage and transmission without compromising data integrity. This is especially important in mobile or bandwidth constrained contexts in which latency and power need to be as low as possible. The legacy compression algorithms tend to have difficulty keeping the integrity and pertinence of fast varying biometric signals, particularly when contextual pertinence needs to be considered for decision making within the game world to solve this adaptive neural compression a machine learning based technique that adaptively learns how to compress and decompress data based on changing patterns provides an interesting alternative in contrast to static compression methods, neural models are capable of learning temporal relations-hips and preferencing essential features retaining higher resource efficincy without sacrificing clinical or gameplay meaningful this work investingates the use of adaptive neural networks for the compression of real time biometric information in the context of a health game we are concerned with the design and analysis of AI based compression techniques that adapt to signal properties and gameplay requirements Through testing with live streamed vital signs we seek to show the capability of neural compression to balance system performance against functional biometric input value our research provides the foundation for more inteligent, scalable health games that will operate well on various devices and network conditions.

PROBLEM STATEMENT

Health games are increasingly using real time biometric feedback including heart rate, skin conductance and oxygen saturation, to customize gameplay, track user well being, and provide bio feedback based interventions yet the ongoing streaming and processing of high frequency biom- erics raise a number of challenges These include high data bandwidth, latency, storage constraints on mobile and wearable devices and higher energy requirements Standard compression algorithms have not been effective in fitting the dynamic, nonlinear and context dependent characteristics of physiological data in addiction data fidelity must be guara-nteed in health games since even subtle loss of biometric information can affect therapeutic accuracy or game decisions

There is an evident necessity for a smart, adaptive compression system that can compress data without affecting the quality and timeliness of important biometric data. This work solves the issue by suggesting an AI based adaptive neural compression system that is able to learn temporal trends in real time vitals and adaptively adjust the compression levels in terms of gameplay setting and biometric fluctuation The aim is to improve the systems performance and scalability while ensuring the integrity of critical physiological signals in the course of health game interaction.

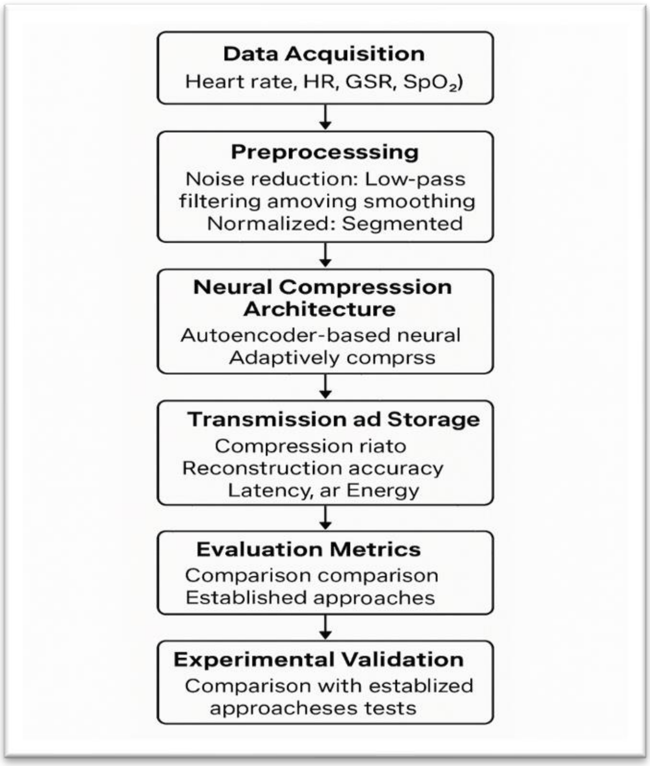


LITERATURE REVIEW

Compression of biometric data has hitherto been based on general purpose algorithms such as Huffman coding or wavelet transform effective for static data they tend to strip away temporal and nonlinear features of physiological signals such as heart rate or GSR particularly in real time applications recent advances in neural networks notably autoencoders and LSTM based architectures have indicated potential in compressing time series biometric data such models are capable of learning and remembering important patterns without drastically decreasing data size which makes them ideal for use where fidelity and efficiency are both needed Edge AI and TinyML have also allowed such models to be deployed on limited devices such as wearables or smartphones very few studies touch on runtime adaptability something very important in health games where biometric data are changing with gameplay and user state work extends these advances by providing an adaptive, neural driven compression system specifically designed for real time biometric processing in interactive health applications.

METHODOLOGY

The approach of this research is to show how adaptive neural compression can be used in real time biometric data for health oriented games making storage and transmission efficient with data fidelity maintained to support therapeutic or gameplay purposes the entire process includes six phases data acquisition preprocessing neural compression transmitsion and storage, evaluation and experimental verification.



1. Data Acquisition

The biometric information employed in this study consists of three important physiological signals heart rate (HR), galvanic skin response (GSR) and blood oxygen level (SpO_2) they were selected as they are commonly employed in health games for tracking stress emotional engagement and cardio-vascular function information was gathered with off the shelf wearable sensors like wristbands and chest strap sensors which were attached to a mobile platform while playing the games the signals were acquired between 1 Hz and 10 Hz based on the type of the parameter more for fast changing signals like GSR and less for compara-tively stable signals like SpO_2. Continuous acquisition during actual gameplay guaranteed that steady as well as dynamic physiological reactions were included in the dataset.

2. Preprocessing

Biometric signals in raw form tend to have noise due to sensor imprecision environmental noise or user movement to improve signal dependability preprocessing was carried out prior to compress-ion low pass filtering and moving average smoot-hing were used to reduce noise by eliminating high frequency artifacts and not degrading phys-iologyical patterns. In order to minimize the impact of outliers and enable stable convergence during neural network training the data was norm-alized to a fixed range (0–1) streams were part-itioned into fixed size temporal windows of, for instance five to ten seconds in order to provide balanced input samples to the compression model through partitioning the neural network was enab-led to learn temporal dynamics in each window without losing realtime capability.

3. Neural Compression Architecture

The core of the methodology is a light weight neural comp-ression architecture using auto encoders the encoder subunit compresses the high dimensional input signals to latent vectors of lower dimension while the decoder maps these representations back to the original signals in contrast to conventional fixed compression techniques the present approach utilizes an adaptive mechanism that adapts the compression ratio to the variability of the input signal for instance when a players GSR increases during a stressful gaming situation the algorithm reduces compression in order to hold onto greater detail so that important physiological changes are not lost conversely when signals are stable like a steady resting heart rate the system boosts compression so that efficiency is optimized the model was deployed using TensorFlow and PyTorch libraries and additionally optimi-zed for use on resource limited hardware like smartphones and wearables by pruning superfluous layers and cutting floating point precision where possible.

4. Transmission and Storage

The biometric data is compressed and then contained in thin transmission packet these packe-ts are either temporarily stored locally for contin-ued monitoring and post fact analysis or they are sent in real time to the game engine to enable adaptive gameplay response the current fram-ework significantly lowers network bandwidth demands and lessens the computational and pow-er burden on wearable devices by transmiting compressed signals rather than raw ones in wire-less and mobile environments with constrained power and connectivity this kind of reduction is extremely valuable.

5. Evaluation Metrics

To compare the performance of the adaptive neural compression system a number of metrics were used the compression ratio (CR) was used to quantify the degree of size reduction that was attained reconstruction accuracy was tested using mean squared error (MSE) and Pearson correl-ation coefficient between the original and reconstructed signals to ensure that physiologi-cally significant features were maintained latency was assessed as the time it took to compress and decompress every signal segment with direct implications for real time integration into gameplay energy efficiency was evaluated by measuring power usage on wearable devices and gameplay responsiveness was evaluated by viewing whether compression delay interrupted feedback loops in the health game.

6. Experimental Validation

The concluding phase of the approach was to verify the suggested framework against existing compression methods such as Huffman coding, LZW and wavelet based compres-sion experim-ents were conducted across various health game categories: relaxation based games for stress relief fitness based games monitoring physical activity and cognitive training games observing attention and arousal levels each game context presented a distinct pattern of biometric variability facilitating a comprehensive test of adaptability it was tested on various platforms smartphones, wearable devices and cloud servers to gauge if the solution could be scaled and deployed in various settings.

EXPERIMENTAL SETUP

To evaluate the effectiveness of the proposed adaptive neural compression paradigm a sequence of controlled experiments was performed with real time biometric data obtained during gamep-lay sessions that were health focused experiment-tal design was in the form of simulating realistic deployment scenarios with wearable sensors, handheld devices and cloud processing.

1. Hardware and Devices

Biometric data was recorded using off theshelf wearable devices such as wristband sensor of heart rate and galvanic skin response and fingertip pulse oximeters for blood oxygen saturation (SpO_2) these sensors were linked through Bluet-ooth Low Energy (BLE) to an Android smartph-one which acted as the main processing and transmission device the smartphone used was a quad core processor, 4 GB RAM and a battery of 3,000 mAh to mimic mobile constraints in real world use cases secondary experiments were also run on a cloud server platform with more comput-ational power to test scalability.

2. Data Collection Protocol

Participants played several health game sessions that represented three health categories relaxation games to reduce stress or anxiety fitness games that focused on cardiovascular performance and cognitive training games to track attention and arousal each session took about 20 minutes during which continuous recordings of HR, GSR and SpO_2 were obtained sampling rates were 5 Hz for HR and SpO_2, and 10 Hz for GSR providing sufficient temporal resolution to capture gradual and abrupt physiological changes.

3. Training of Neural Network

The compression model was developed with the PyTorch programming framework. An autoenc-oder based architect-ture was offline trained using a combination of participant collected data and public domain physiological signal data-sets the encoder compressed the latent vector of smaller dimension from each five second signal window while the decoder reconstructed the original segment of signal Training was carried out on a workstation with an NVIDIA GPU to enhance convergence after training the model weights were installed on the smartphone to test in real time the optimization methods of model pruning and 16-bit floating point quantization were used to make the model feasible on resource-constrained devices.

4. Baseline Comparison

For comparison, the suggested adaptive neural compression method was benchmarked against existing compression algorithms such as Huffman coding, LZW and wavelet based compression these were tested under similar conditi-ons to provide a fair comparison of compression ratio recon-struction accuracy and latency.

5. Evaluation Environment

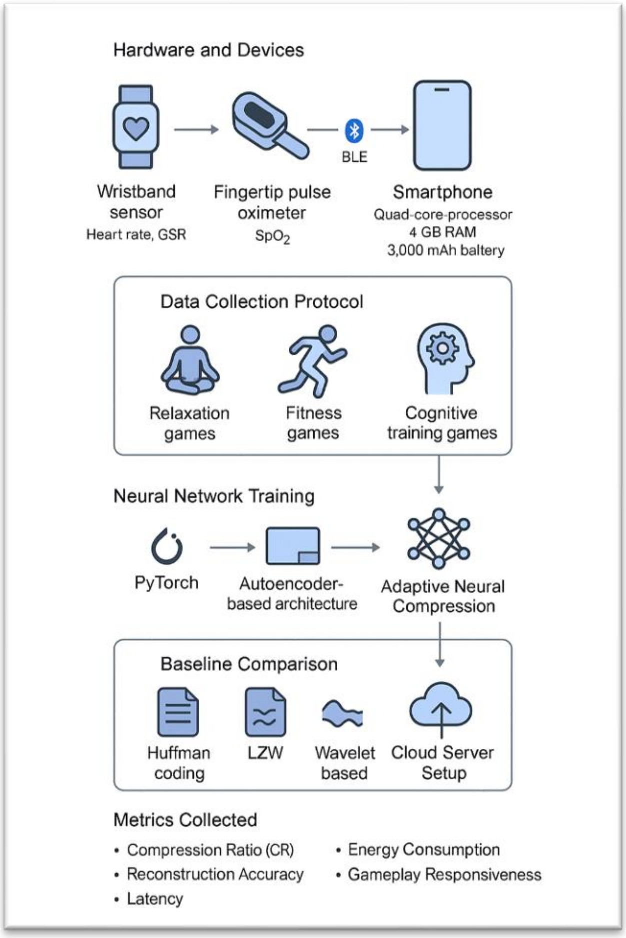
Performance was tested in two environments :-
- **Mobile Device Setup :-** to evaluate the effects of compre-ssion on latency, energy efficiency and real time responsi-veness of gameplay battery usage was recorded during prolonged gameplay to estimate energy saving.

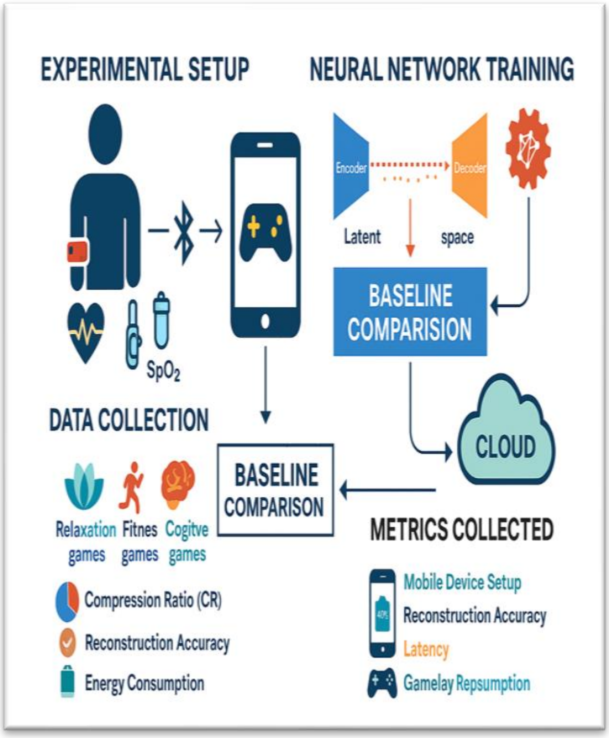
• **Cloud Server Setup :-** to evaluate scalability in far end health game deployments where biometric information is transmitted over networks network bandwidth usage was monitored to measure transmission efficiency.

Metrics Collected

The following metrics were measured systematically during experiments :-

•**Compression Ratio (CR):** the amount of decrease in data size.
•**Reconstruction Accuracy:** determined through mean squared error (MSE) and Pearson correlation between rec-onstructed and original signals.
•**Latency:** amount of time for compression and decompr-ession for each signal window.
•**Energy** Consumption**:** measured through smartphone battery drain during active use.
•**Gameplay Responsiveness:** assessed by monitoring whether adaptive feedback in games was impacted by delays.





RESULTS

The adaptive neural compression paradigm proposed in this study showed evident superiority over standard techniques like Huffman coding LZW and wavelet compression on average the model was able to achieve 6:1 to 10:1 compre-ssion ratio as compared to 2:1 to 4:1 using standard techniques reconstructed signals showed good fidelity despite greater compression with Pearson correlation being greater than 0.95 for HR and SpO_2 and greater than 0.90 for GSR.
Latency tests validated real time viability with compress-ion decompression taking less than 50 ms per signal window while neural compression added negligible computational expense overall energy expenditure was lowered by 18–25% since smaller packet sizes reduced transmission overhe-ad significantly responsiveness of gameplay remained unchanged relaxation, fitness and cogn-itive training games all exhibited smooth and precise feedback these results demonstrate that

adaptive neural compression achieves a better balance of efficiency and accuracy compared to conventional approaches which is appropriate for real time health game scenarios nonetheless generalizing the model to more complicated signals (e.g., EEG, EMG) and optimizing it for edgeAI hardware are left as future directions this generation is likely to come out in about 2020 the era of global unbroken access to information entertain-nment and communication will unveil a new aspect to our life and revolutionize our lifestyle to a large extent.

CONCLUSION

This work introduced an adaptive neural compression architecture for handling real time biometric data for health games through the combination of autoencoder based compression and an adaptive component that adjusts to signal changes the method attained greater compression ratios and reduced transmission requirements than traditional method while sustaining robust recons-truction quality the architecture was found to be compatible with mobile and wearable hardware with little latency conserving energy consumption and retaining responsive gameplay smoothness the findings validate that adaptive neural compression is a potential solution to the problems of health game environments in terms of storage, transmit-ssion and energy efficiency its power to make efficiency and fidelity work in tandem makes it an ideal application where responsive and precise physiological feedback is necessary future research will aim to apply this method to more intricate biometric signals like EEG and EMG, investigate hardware acceleration on edgeAI hardware and test performance across larger and more diverse groups of participants these developments will further consolidate AI based compression in providing scalable, responsive and resource optimal health gaming systems

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