



# A robust transmission system for astronomical images over error-prone links

Paul Thienphrapa and Jane Dong

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*A proposed transmission system adopts content-based error correction to maximize the quality of astronomical images transmitted over the Internet to educators and researchers.*

The James Webb Space Telescope (JWST) is expected to produce a vast number of images that will be valuable for astronomical research and education. To support research activities related to the mission, the National Aeronautical and Space Administration (NASA) has provided funds to establish the Structures Pointing and Control Engineering (SPACE) Laboratory at California State University, Los Angeles (CSULA). One of the SPACE Laboratory's research activities involves designing an efficient image transmission system that is optimized for astronomical images. Due to the great optical range, sensitivity, and volume of images that the JWST will generate, as well as the scientific community's marked interest in studying these images, such a system is essential in enabling productive Origins-related investigations throughout the world. (NASA's Origins program addresses fundamental questions about the origin and evolution of the universe.) By balancing the constraints of network bandwidth, time delay, and image quality, and by capitalizing on the properties of astronomical images, a novel image transmission system would allow audiences, including scholars, educators, and the general public, to maximize their respective efforts in studying the images.

Many research programs exist for improving the quality of transmitted images. However, the unique characteristics of astronomical images impose great challenges. Due to the noiselike nature of many astronomical images, the error control mechanism that works for general images and video does not yield desirable results. Based on a thorough investigation of different types of astronomical images, zerotree-based wavelet compression is selected to reduce the data size, and content-based error correction is used to maximize the quality of received images in error-prone networks.

The proposed robust transmission system consists of three major components: a smart image sending module, a robust transmission module, and an image receiving and display module. The sending module performs wavelet-based image compression and robust packetization. The transmission module conducts cross-layer optimization to maximize the quality of the received image over lossy channels. The receiver performs loss detection, feeds back channel statistics, repairs the received image with error concealment, and displays the image in a real-time fashion.

The core of the proposed system is content-based retransmission, which ensures that the most important packets are received. To quantify the significance of an astronomical image packet, a novel metric (index) is defined for each packet by jointly considering its information weight, the characteristics of its image content (content index), and its impact in the error concealment step (concealment profit). During transmission, the sender first estimates the channel packet loss rate based on transmission statistics, and calculates the content index and concealment profit for each input packet. Based on the sign of the concealment profit, the smart streaming system determines whether error concealment is suitable for the input image, and chooses the most appropriate error control mechanism. Additionally, using an importance metric, the sender selects the optimal transmission policy to maximize the quality of the received image under the selected error control mechanism and network constraints.

The responsibilities of the receiver include loss detection, error concealment, and image reconstruction. As the receiver accepts incoming packets, it extracts the sequence identifier from each packet to reconstruct the data stream. The receiver also uses the sequence identifiers to detect packet loss. It notifies the sender of the packet loss via a feedback channel if the packet can be retransmitted in time. To ensure real-time display, late packets are

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dropped and error concealment is applied to repair the image quality during reconstruction. Error concealment is a prediction-based error control method using the received contents in the surrounding locale. This technique can be used for some astronomical images when the transform coefficients vary gradually across the transform domain. Error concealment is a desirable error correction approach because it does not require additional bandwidth and consumes negligible computation time.

The proposed transmission system is being implemented with a user-friendly graphical interface, which allows users with various backgrounds to conveniently view, process, and transmit FITS (Flexible Image Transport System) images. Many experiments have been conducted to evaluate the performance of the developed transmission system. Experimental results show that the proposed approach consistently outperforms protocol-based error correction for various types of astronomical images.

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#### Author Information

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##### Paul Thienphrapa and Jane Dong

SPACE Laboratory

Department of Electrical and Computer Engineering

California State University, Los Angeles

Los Angeles, CA

<http://www.calstatela.edu/space>

<http://www.calstatela.edu/faculty/jdong2>

Paul Thienphrapa was a research assistant in the SPACE Laboratory while he pursued a master's degree in electrical engineering at California State University, Los Angeles. He is now a PhD candidate at Johns Hopkins University.

Jane Dong is an assistant professor in the Department of Electrical and Computer Engineering at California State University, Los Angeles, and a research advisor for the SPACE Laboratory. She received a PhD degree in electrical engineering from Ohio State University, specializing in real-time 3D multimedia communication.

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