Research on Image and Video Coding Algorithms for Compressive Imaging

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博士学位論文
論文内容の要旨および審査結果の要旨

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１．論文内容の要旨

Driven by the advances in artificial intelligence technologies, smart environments (or “pervasive computing”) already penetrate our daily lives. The image/video acquisition system is one of the most important components in many smart environments, including mage sensing and image compression. Compared to other undergoing research that is mostly focused on the development of image sensing and pixel compression separately, this dissertation focuses on the whole system, and proposes to integrate the compressive sensing (CS) based image sensing techniques and the corresponding measurement domain data compression. 1) This research develops a novel sensing matrix to increase the efficiency of the CS based sensor. 2) This work applies the measurement domain compression for the output of CS sensors. Compared with pixel domain compression, the power of compression can be significantly reduced with a little loss of compression ratio. 3) Compared to the direct output of CS based sensors, this research further reduces the size of measurement, which can be significantly save the transmission bandwidth. The dissertation includes the following chapters.

Chapter 1 [Introduction] introduces the background of image sensing and compression systems. After that, the motivation and main contributions are presented.

Chapter 2 [Compressed Sensing] describes the theoretical basis of this dissertation.

Chapter 3 [Novel structured Sensing Matrix by Scrambling Orthogonal Walsh Matrix for Compressive Sensing] presents a novel structured sensing matrix called Continuously ordering Walsh matrix (CoW). This sensing matrix allows faster convergence due to the short distance of data clusters in the non-polynomial hard problem of non-deterministic computation when it comes to optimization. As s a result, comparing existing measurement matrices, the proposed CoW can

significantly improve the sensing quality in terms of PSNR and SSIM by 10%.

Chapter 4 [A Measurement Coding System for Block-based Compressive Sensing Images by Using Pixel-Domain Feature] explores the relationship between sensing matrix the following measurement coding. The pixel features are embedded in the sensing matrix. An efficient measurement coding component is applied by efficiently using the pixel features. Compared to previous works, the experimental results show that the proposed system can significantly improve coding efficiency, increasing PSNR by 1.94dB - 2.3dB and lowering bitrate by 42% - 65% in terms of bit-per-pixel.

Chapter 5 [Intra Prediction Based Measurement Coding Algorithm for Block-Based Compressive Sensing Images] employs an intra-prediction algorithm to compress the measurement. The algorithm encodes prediction error between target and predicted measurement, resulting in smaller data size. Consequently, this work can significantly reduce the data size in terms of bit-per-pixel by 10.90% and simultaneously increase 3.95 dB in PSNR compared to the state-of-the-art works. Moreover, the proposal is implemented on FPGA. It gave 10 times higher throughput than software. The core power consumption is at 50 mW and working at 88 MHz when processing 3840 × 2160 pixels with the sampling rate of 1/4.

Chapter 6 [Temporal Redundancy Reduction in Compressive Video Sensing by using Moving Detection and Inter-Coding] describes an inter prediction-based measurement coding algorithms. Only the moving part in the current frame is encoded to reduce the data size. This algorithm is suitable for the video composed of large non-moving area. The experimental results show that the proposal can greatly reduce bandwidth usage in terms of bit-per-pixel by 63.15%, improve PSNR by 1.56dB, and SSIM by 14.81% on average when compared to the state-of-the-art.

Chapter 7 [Multiple Candidates Based Hybrid Hierarchical Search for Compacting Compressively Sensed Video] presents hybrid hierarchical search for the inter-prediction based measurement coding. The moving direction and the residual are encoded. This algorithm is suitable for various videos. The experimental results show that the proposal can greatly reduce bandwidth usage in terms of bit-per-pixel by 64.15%, improve PSNR by 0.48dB, and SSIM by 1.16% on average compared to the state-of-the-art works.

Chapter 8 [Measurement Coding Framework for High-Resolution Compressive Imaging] integrates the whole system with intra-inter prediction, quantization, and entropy coding. The performance on a variety of 4K datasets is evaluated. The proposed system improves image quality

in PNSR and SSIM by 8.5 and 5.5 %, respectively. Furthermore, data size in terms of bit-per-pixel is reduced by 40% compared to previous works.

Chapter 9 [Cube-based Video Coding Framework for Block-based Compressive Imaging] proposes to reorder the measurement to a cube shaped image. And then, the existing pixel domain coding algorithms can be reused for the measurement domain coding. It can greatly save the time for developing new compression algorithms.

Chapter 10 [Discussion] summarizes the proposal and discusses the future works.

As mentioned above, this research proposes new techniques for image/video acquisition system. A new sensing matrix, vector-based and cube-based measurement coding algorithms are introduced. The proposed system can increase the compression ratio while keeping the image/video quality.

２．審査結果の要旨

This dissertation proposes image sensing and compression techniques for the compressive imaging system. These techniques can increase the compression ratio while keeping the image/video quality. The novelty and effectiveness were confirmed in the following points.

1. A new structured sensing matrix to improve the image quality

To reduce the size of spectral data, compressive imaging systems are developed to sample fewer measurements than the Nyquist-rate ones. Most existing compressed sensing approaches suffer from low image quality. This thesis proposes a novel structured sensing matrix named CoW, constructed by scrambling orthogonal Walsh matrix. It can keep the image quality under a low sampling rate. This sensing approach is expected to be widely used in image sensors.

2. Measurement coding algorithms to increase the compression ratio

To further compress measurements, the output of compressed sensing and image sensor, this thesis presents a measurement coding framework using measurement-domain prediction. By compressing the difference between the predicted measurement and current measurement, the compression ratio is further improved. Compared to the mainstream systems that directly output the measurement, integrating the proposed measurement coding algorithms achieve higher compression ratio while keeping the high image/video quality. These proposals are likely to inspire a new research topic in improving the compression ratio.

3. A new framework of image acquisition

This thesis proposes a new framework that integrates image sensing and measurement coding as a whole system. The sensing matrix is designed to compress the data and embed the pixel features.

And then, by utilizing the pixel features embedded in the sensing matrix, efficient intra and inter prediction algorithms are developed for the measurement coding. This novel contribution opens a new research direction for the compressive imaging systems.

As mentioned above, this thesis proposes a new framework for compressive imaging systems by combining sensing and coding techniques. New sensing and coding algorithms are implemented and verified for a wide range of videos. These novel contributions open a new research direction for image/video acquisition systems in developing a high compression ratio with high image/video quality in the future. Accordingly, this examination committee unanimously concluded that the submitted doctoral thesis is fully qualified for the Doctor of Philosophy (Engineering).

（報告様式Ⅲ）