Efficient Video Data Structure and Compression Scheme for Fabric Wicking Phenomenon Studies

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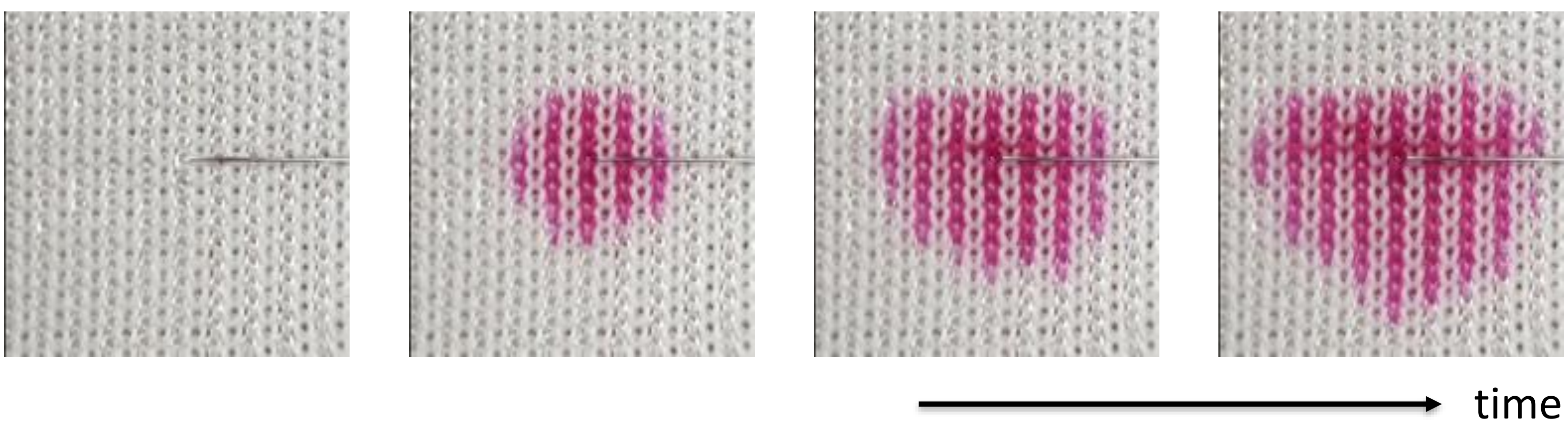
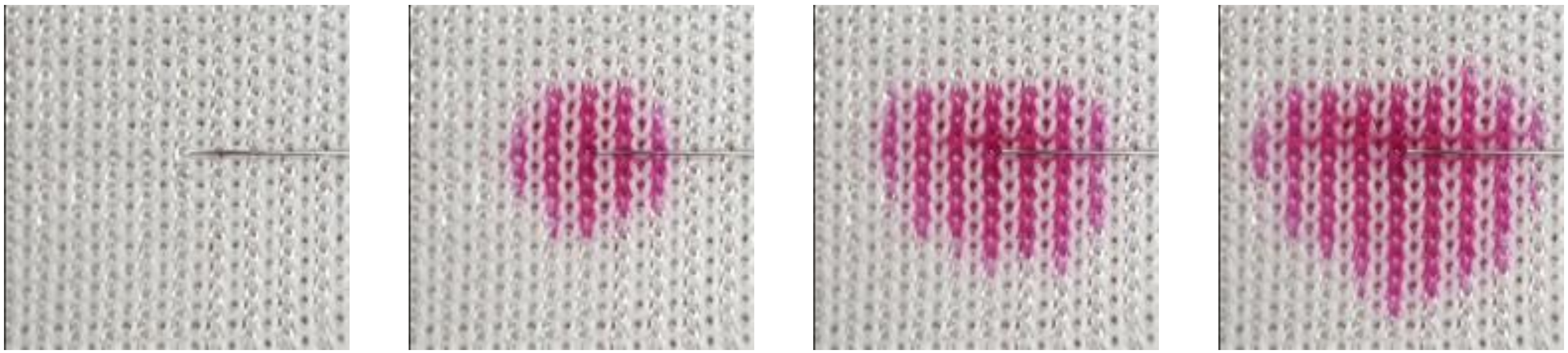
Wicking Phenomenon of Fabrics

- Wicking phenomenon of fabrics dominates physiological comfortableness of clothes:
  - How fast does sweat/liquid transfers within fabrics?
  - In what pattern?
- Video frames recorded for studying wicking for a blended fabric made up of hydrophobic and hydrophilic yarns:



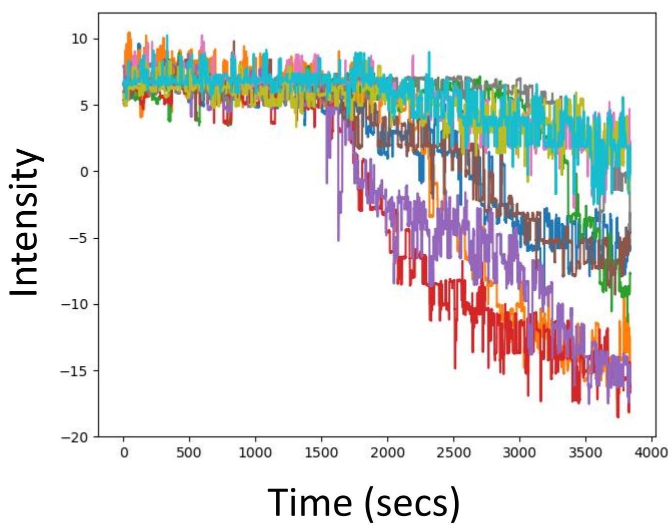
Wicking-Performance Video

Frames:

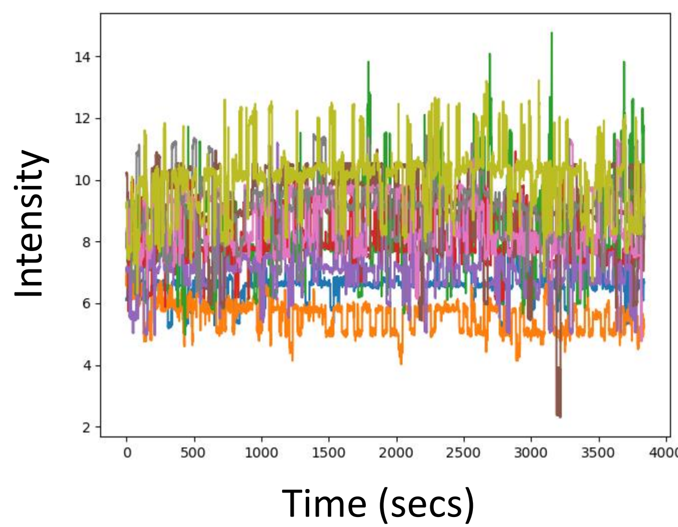


Intensity at selected pixel locations:

Locations that become wet



Locations that keep dry



Low SNR!

Problem Statement

- Textile scientists want to understand yarn-level wicking behaviors, e.g., what's the wetting time of a yarn?
- Need an efficient video data structure to allow ***retrieving color information along the time*** for each pixel.
- Overhead for a video encoded using H.265/HEVC can be 2 million (= 1920 × 1080) to 1.
- Loading a 3-min video requires 31 GBytes. Nonscalable!
- ***Solution***: Change the basic storage unit from the frame → the volume of blocks.
- Also need to compress the new data structure for storage: manage file size while maintaining visual quality.

Strategies for Time Series Extraction

- 1st approach: Keep only the RGB values at the required location and discard those of other locations. **Overhead in time = 2M to 1.**
- 2nd approach: Do not discard info for other locations but appending the info to the file indexed by spatial location. **Requires I/O operations > 2M * num of frames**
- 3rd approach: Improves 1 & 2 by loading the whole video into memory and then saving a time series for every pixel location. **Prohibitive memory usage: 31 GBytes.**

➢ We propose an **efficient data structure** by combining the advantages of all three approaches.

Complexity Comparison

Table 1: Complexity for different approaches for dumping time series for every pixel location. Complexity for decoder excluded.

Approach	**Peak memory usage ($\times 3$ bytes)**	**Pixel loading overhead**	**I/O for output**
#1	WH	$WH^{\triangledown}$	Low
#2	WH	1	High$^{\triangledown}$
#3	$WHL^{\triangledown}$	1	Low
Proposed	$WH\ell$	1 to N^2	Low

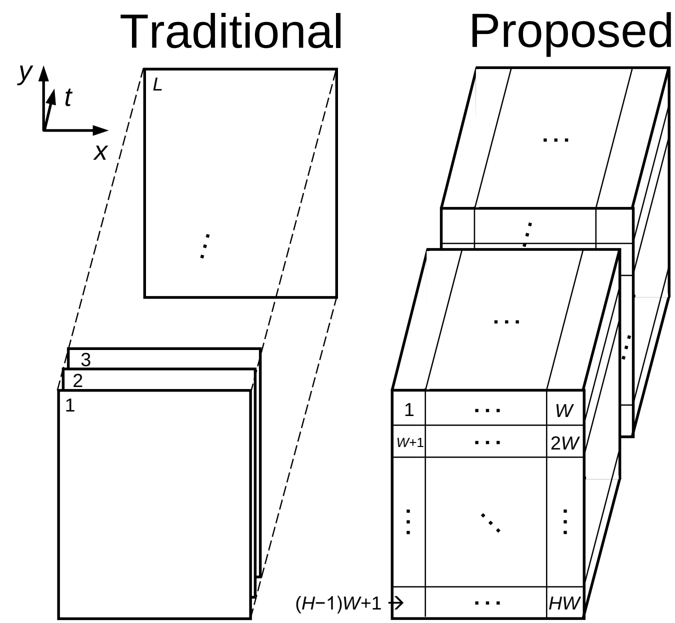
$\triangledown$ indicates that the approach is extremely inefficient in this aspect.

Frame size, W-by-H; the total number of frames, L; segment length, ℓ; block size, N.

Proposed Efficient Data Structure

Key features:

- Hold data in memory but use short segments $\ell = 120$ frames and small block size $N \ll \min(W, H)$. **Low memory usage (712 MB).**
- Save the pixels the first time they are decoded. **Low or no pixel loading overhead.**
- Low I/O requirement for file system.



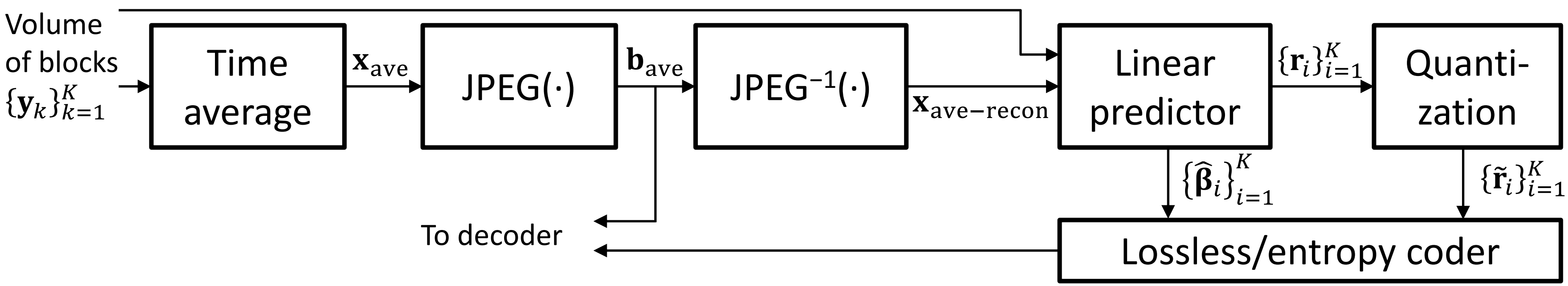
Comparison video data structures

Compression for Proposed Data Structure

- **Motivation**: Generally purpose lossless compression for video data, no matter arranged in what form, is likely to be inefficient.
- Off-the-shelf video codecs such as H.265/HEVC may be an overkill, even when royalty fee factored in.
- Wicking videos has very specific properties that can be easily exploited for reducing the redundancy: frame-level intensity change, and minor spatial motion.

Proposed Compression Scheme

- Spatial redundancy reduction: Linear prediction / regression for blocks along the time.
- Entropy coding: lossless image/text compression, e.g., PNG, LZMA, Deflate.



$$\mathbf{y}_i = \beta_{i1}\mathbf{x}_{\text{ave-recon}} + \beta_{i0} + \mathbf{e}_i, \quad i = 1, \cdots, K$$

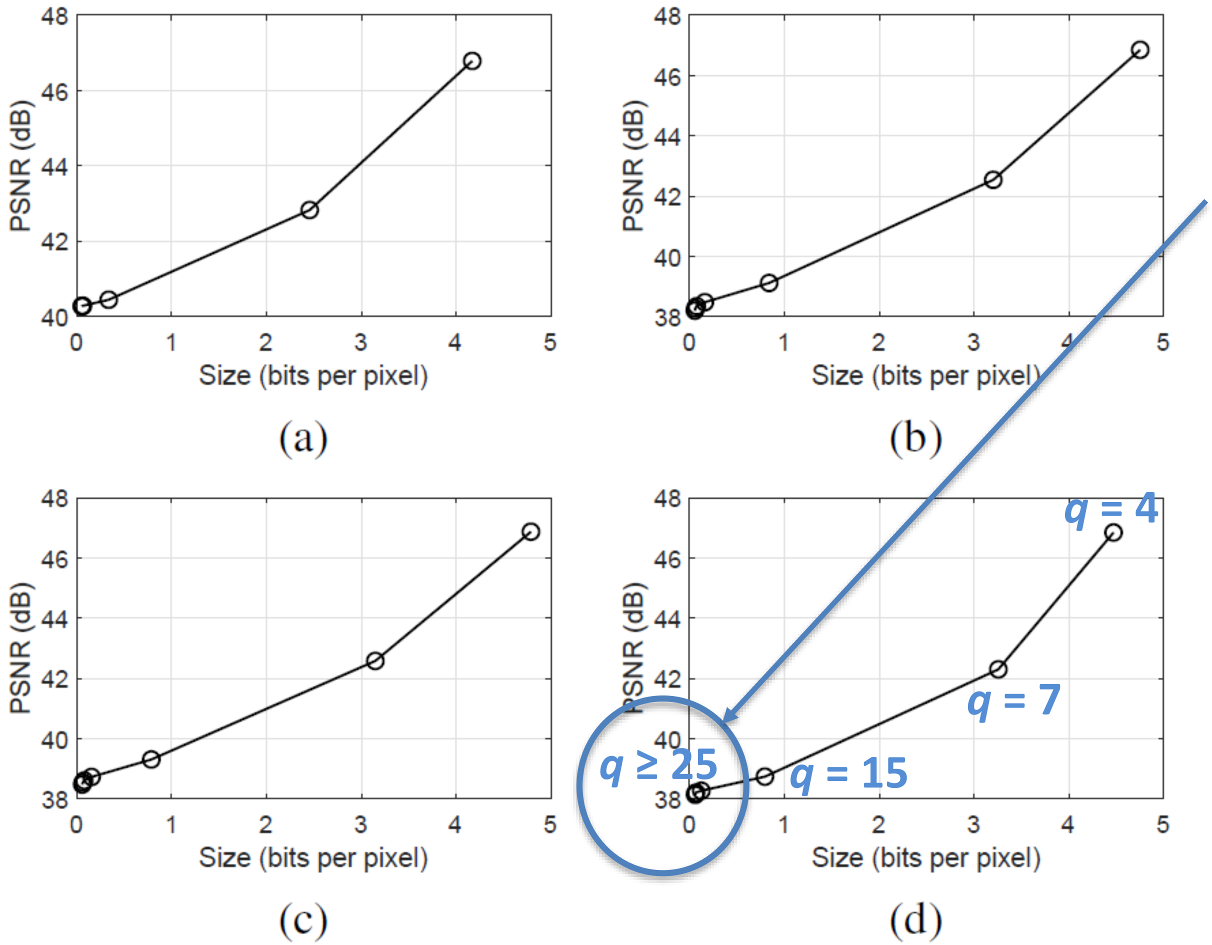
$$\{(\hat{\beta}_{i0}, \hat{\beta}_{i1})^T \; = \; (\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T\mathbf{y}_i\}_{i=1}^K$$

$$\mathbf{r}_i = \mathbf{y}_i - \hat{\beta}_{i1}\mathbf{x}_{\text{ave-recon}} - \hat{\beta}_{i0} = \left(\mathbf{I} - \mathbf{X}(\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T\right)\mathbf{y}_i$$

Experimental Results

- Shoot 4 wicking-performance videos of 315, 127, 142, and 138 secs using iPhone X fixed on a tripod.
- Video content: Needle injecting pink liquid to one yarn, and the liquid subsequently transferred within yarns and between yarns.
- Videos are not completely still:
  - Vibration of injection needle.
  - Nonrigid distortion of fabrics after absorbing liquid.
  - Minor shake, panning, focus blurring for camera.

Rate-Distortion Performance



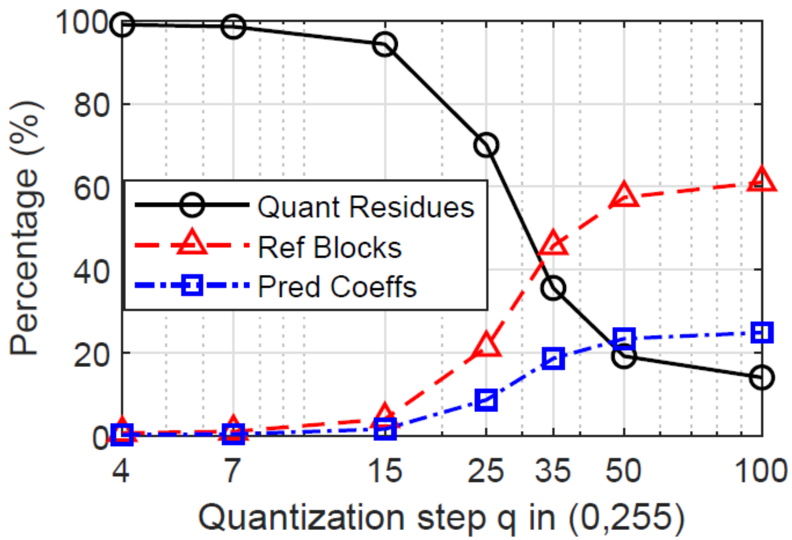
When quantizer becomes coarser, PSNR drops until it reaches a "lower bound".

For q ≥ 25, quality of the reconstructed video is mainly controlled by the quality of reference blocks and the predictor coefficients.

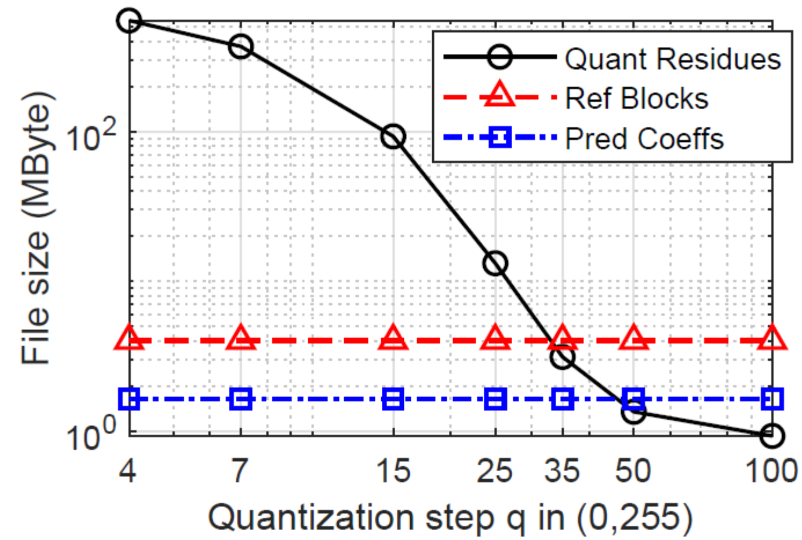
24-bit per pixel videos need << 1 bit per pixel to maintain PSNR > 38 dB.

Size of Compressed Components

Relative



Absolute



File size: < 600 MB @ 46 dB; < 100 MB @ 39 dB → Significant saving than directly storing time series.

Depending on whether textile scientists prefer small or large *q*, future work should improve compression ratio of

- Quantized residues, or
- Reference blocks and prediction coefficients.

Conclusions

- Proposed an efficient video data structure for studying wicking of fabrics.
- Used the volume of blocks as the basic storage unit allowing quick time series retrieval.
- Designed a customized compression scheme that can encode wicking videos in manageable file size while providing satisfactory visual quality.