RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

Content Adaptive Encoding Method for High Frame Rate Screen-Camera Communication

M.S. Defense Presentation

Yaqin Tang

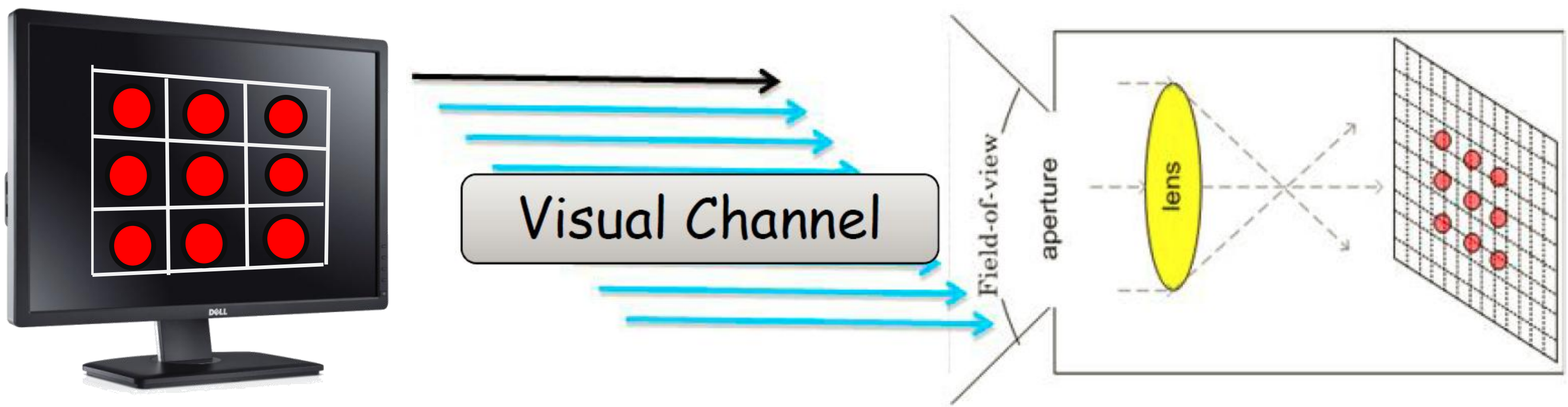
yaqin.tang@rutgers.edu

Advisor(s): Prof. Marco Gruteser,
Prof. Kristin Dana, Prof. Narayan Mandayam

January 13^{th} 2016

WINLAB, Rutgers University

Screen-camera Communication



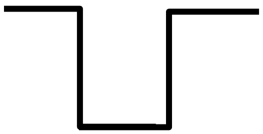
Transmitter (screen)

Receiver (camera)

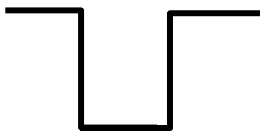
Signal modulation

Image analysis
Signal demodulation

1 0 1 …



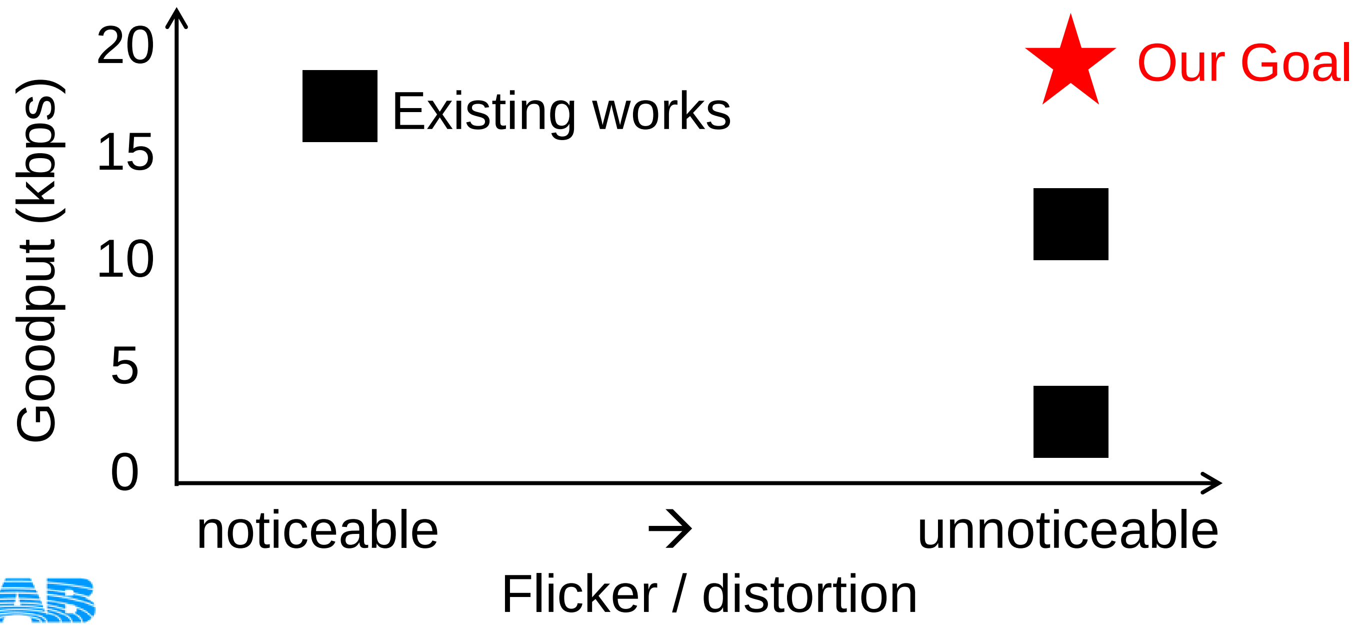
1 0 1 …



Motivations and Objectives

Key considerations:

User experience	Communication performance
Invisibility	Goodput (accurate bits per unit time)



Outline

- User experience: flicker perception factors
- System design
  - content-adaptive encoding method;
  - signal amplitude tracking decoding method;
- Prototype implementation
- System performance evaluation
- Conclusion and future work

Outline

- User experience: flicker perception factors
- System design
  - content-adaptive encoding method;
  - signal amplitude tracking decoding method;
- Prototype implementation
- System performance evaluation
- Conclusion and future work

Flicker Perception

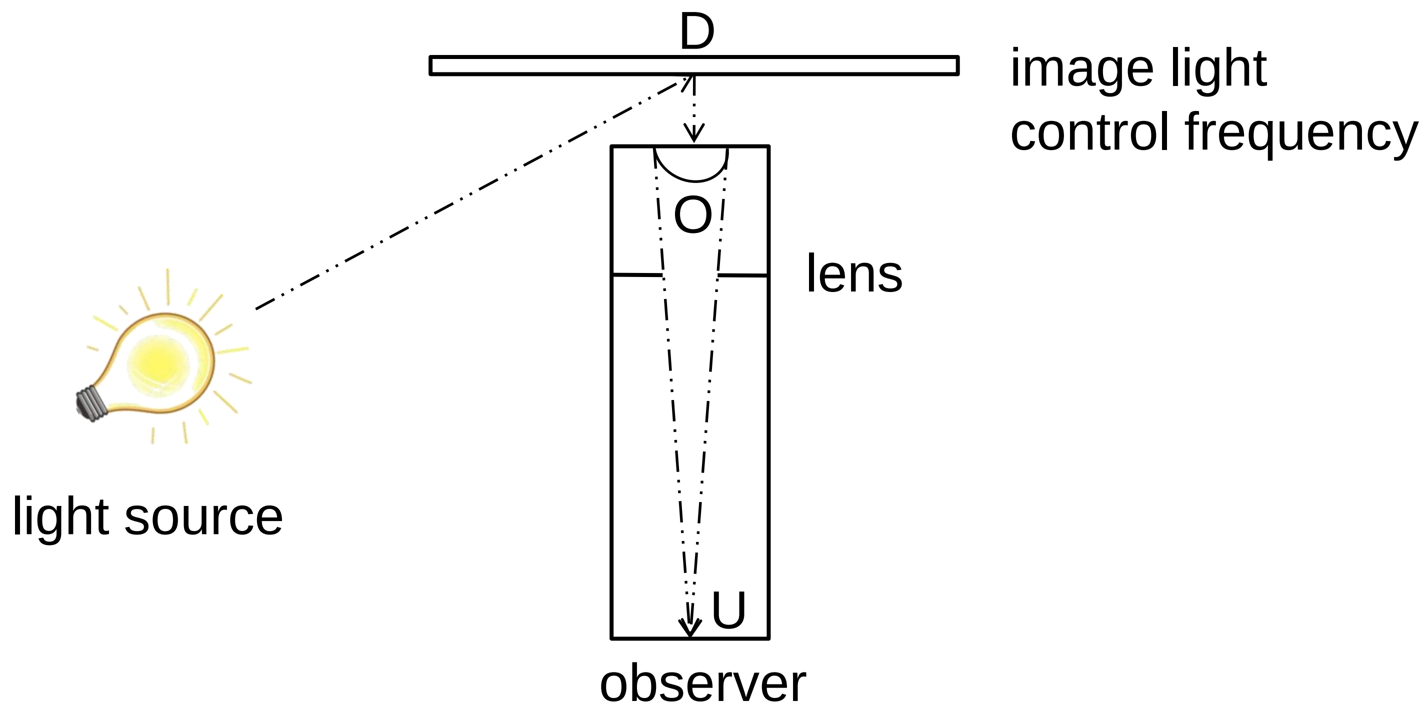
Definition: apparent fluctuation and change in the brightness of the displaying surface.

Affecting factors:

- Frame rate
- Modulation amplitude
- Edge effect
- Viewer's field of view
- Image content

Flicker Perception – frame rate

No obvious flicker if:
Brightness change frequency > 100 Hz.

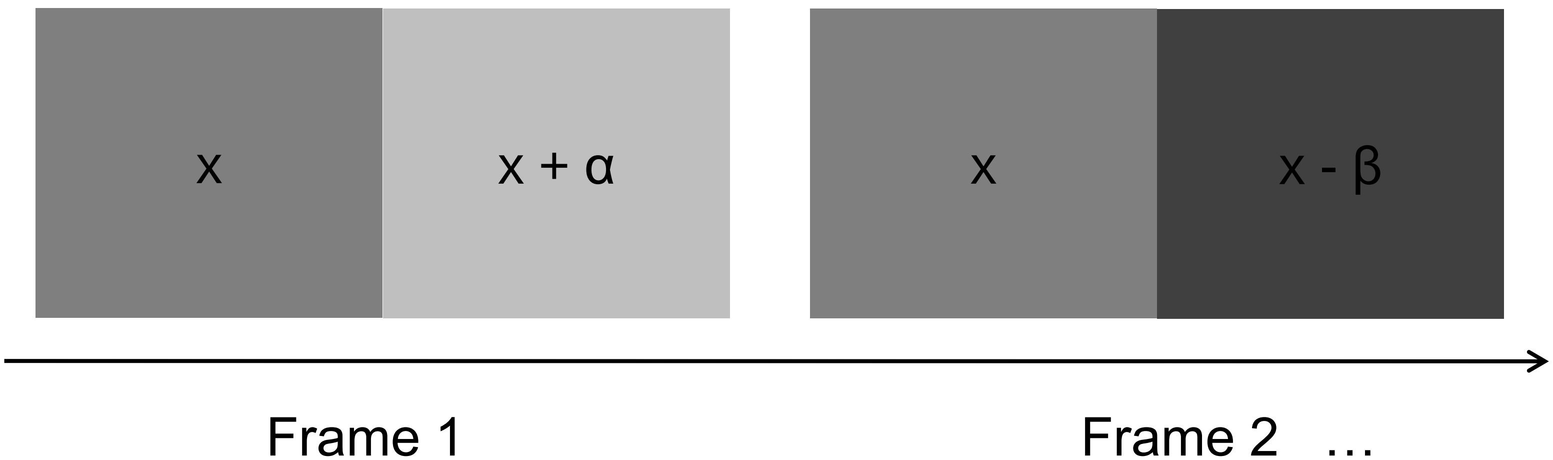


* Note: this is a simplified experiment setup from D.H. Kelly, “Sine wave and flicker fusion”.

Flicker Perception – modulation amplitude

Signal amplitude experiment:

- x: original brightness;
- α, β: alteration amplitude.



Flicker Perception – modulation amplitude

Brute force method:

- check brightness from (0~255) ± (1~10).

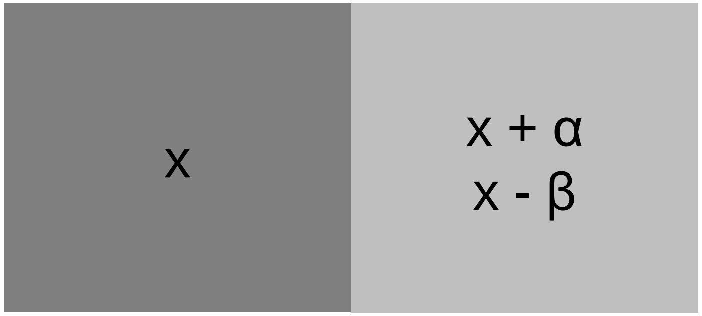
x ~ (0, 255)							
α, β	1	2	3	4	…	9	10
1							
2			★				
3							
…							
10							

- (+2 / -3) win for flicker perception and camera detection.

Flicker Perception – edge effect
viewer's field of view

Observation:

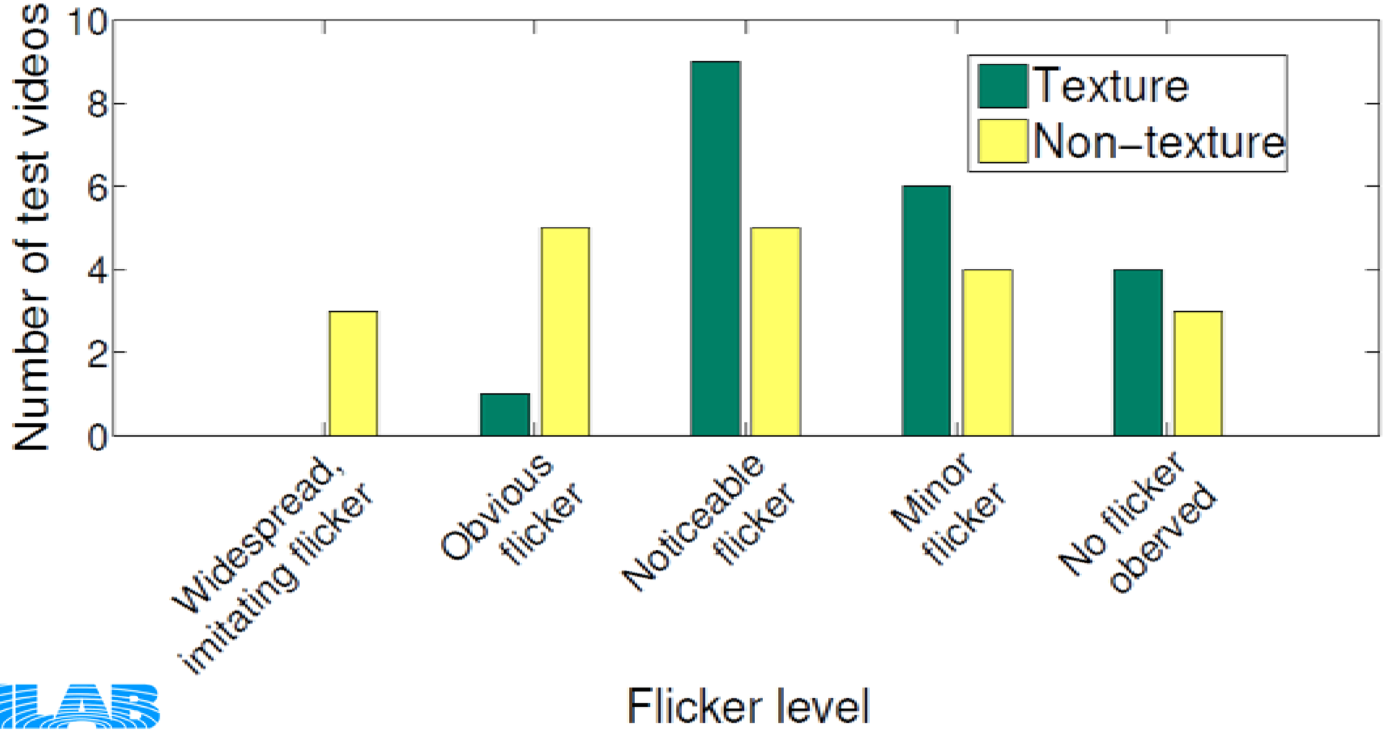
- Along the edges → more obvious flicker.
- Smaller field of view in retina → less flicker.
  (combine viewing distance and display block size)



Gray block experiment

Flicker Perception – image texture

- Attribute representing spatial arrangement of gray levels of the pixels in a region of image.
- Texture regions give less flicker.



Flicker Perception – brightness and contrast

Image brightness:

- Visual perspective, color in R, G, B space or gray scale from 0 to 255 pixel intensity value.

Image contrast:

- Visual concept defined by the difference in the color and brightness of the object.

Both are minor factors!

Flicker Perception Factors

Frame rate -> greater than 100 Hz.

Modulation amplitude -> (+2 / -3) brightness alternation.

Edge effect -> more flicker along edges.

Viewer's field of view -> smaller area in retina, less flicker

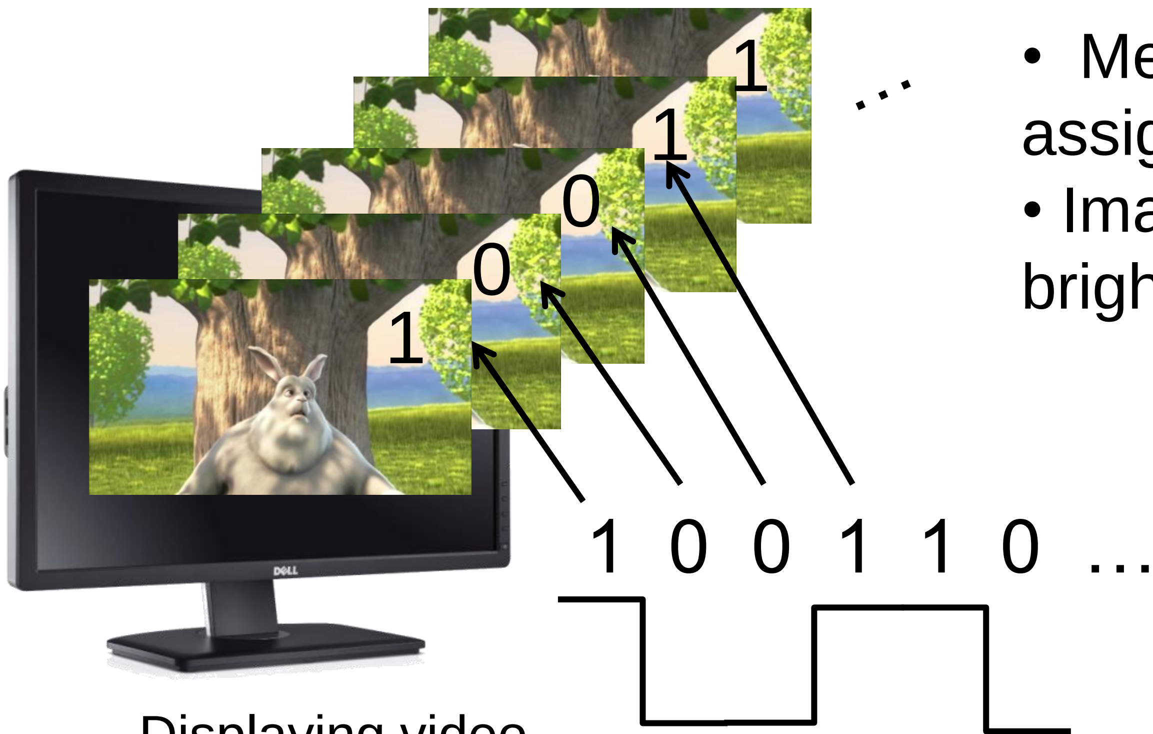
Image content -> image texture (major factor)
image brightness / contrast (minor)

Outline

- User experience: flicker perception factors
- System design
  - content-adaptive encoding method;
  - signal amplitude tracking decoding method;
- Prototype implementation
- System performance evaluation
- Conclusion and future work

Content Adaptive Encoding Method

Temporal domain encoding:



Displaying video

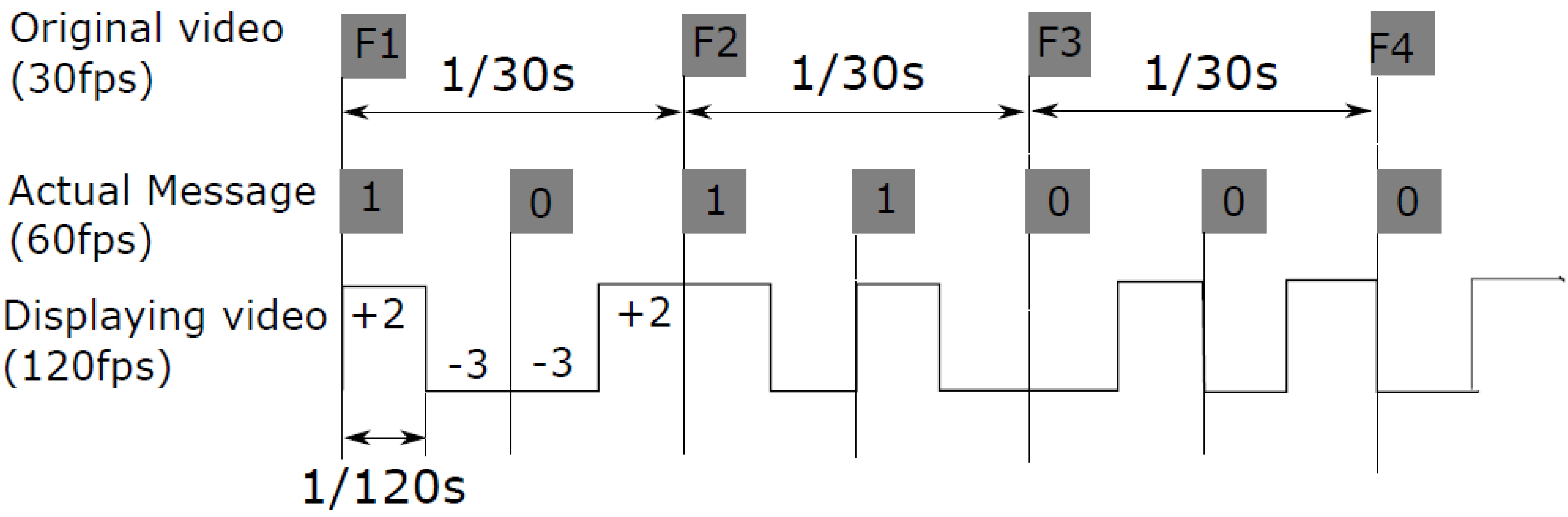
- Message bit-stream assigned to each frame;
- Image modulated as brightness change.

Consecutive same bits reduce displaying frequency!

Content Adaptive Encoding Method

Temporal domain encoding:

- Manchester code ensures minimum frequency at 60 fps.
- Bit 1, brightness increase 2; bit 0, decrease 3.



Content Adaptive Encoding Method

Spatial domain encoding:

- ***Checkerboard*** on top of each frame.
  - improve throughput;
  - decease field of view in retina.
- Texture and edges analysis.

Content Adaptive Encoding Method

Image texture analysis:

- Texture range filter.

2	3 Min	4	5
7	8	9	10
12	13	14	15 Max
17	18	19	20

Original image matrix sample

Texture range value:
15 – 3 = 12

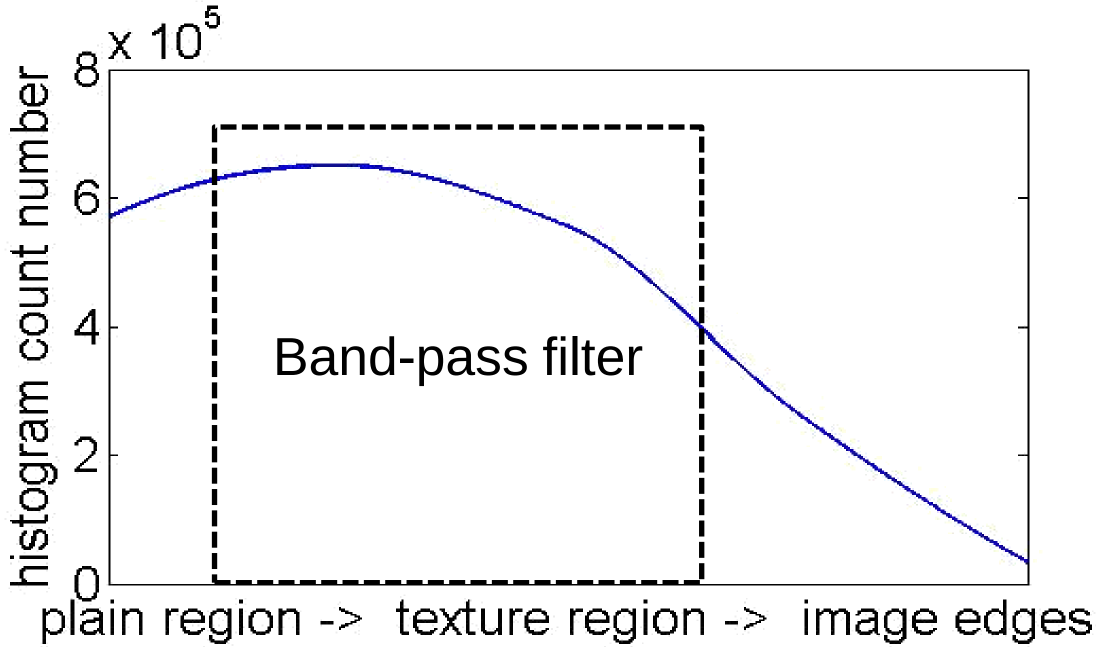
5	7	7	6
11	12	12	11
11	12	12	11
6	7	7	5

Corresponding texture range value

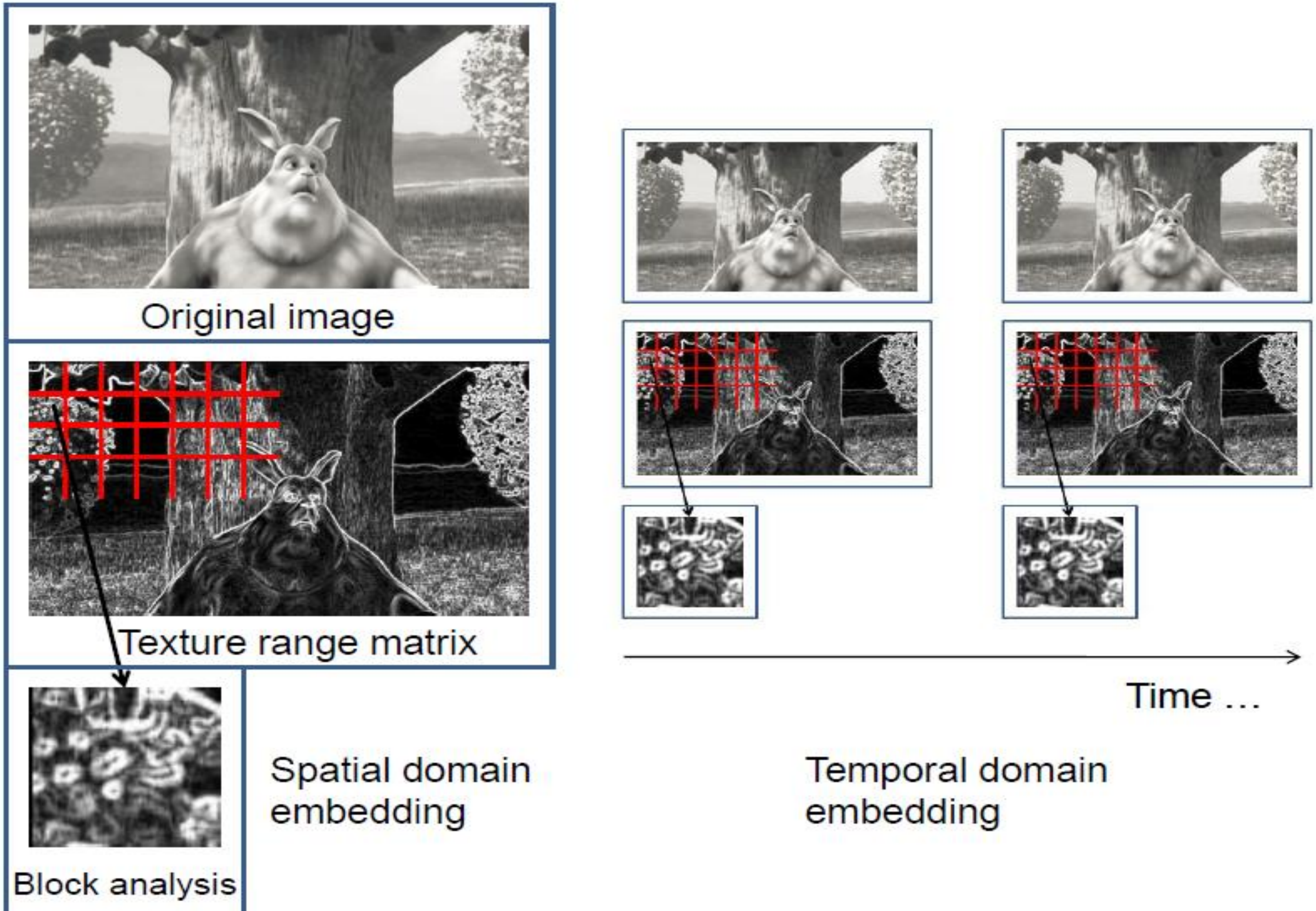
Content Adaptive Encoding Method

Image texture analysis:

- Texture range filter.
- Choose a band pass filter to:
  - get texture region & avoid edges



Content Adaptive Encoding Method



Content Adaptive Encoding Method

Flicker and goodput oriented:

Our encoding method	Reasons
Temporal encoding • Display at 120fps; • Brightness change +2, -3 with Manchester code;	Frame rate Modulation amplitude
Spatial encoding • Checkerboard size 32*32 $pixel^2$; • Texture range analysis and bandpass filter.	Viewer's field of view Edge effect Image texture

Outline

- User experience: flicker perception factors
- System design
  - content-adaptive encoding method;
  - signal amplitude tracking decoding method;
- Prototype implementation
- System performance evaluation
- Conclusion and future work

Decoding Method

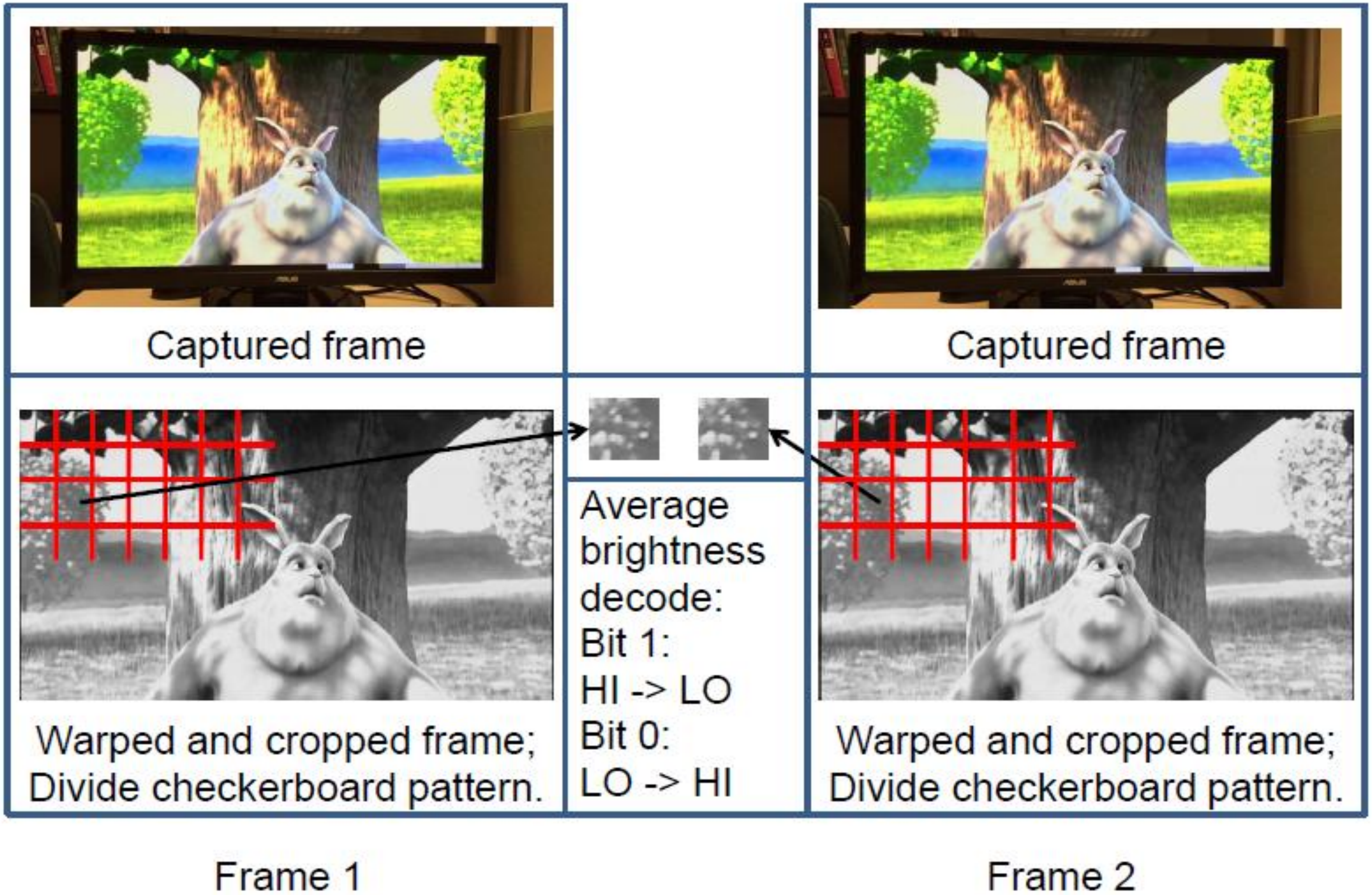
Assumption, receiver knows:

- Starting frame of the message;
- Original video resolution;
- Checkerboard size.
- Encoded checkerboard patterns;

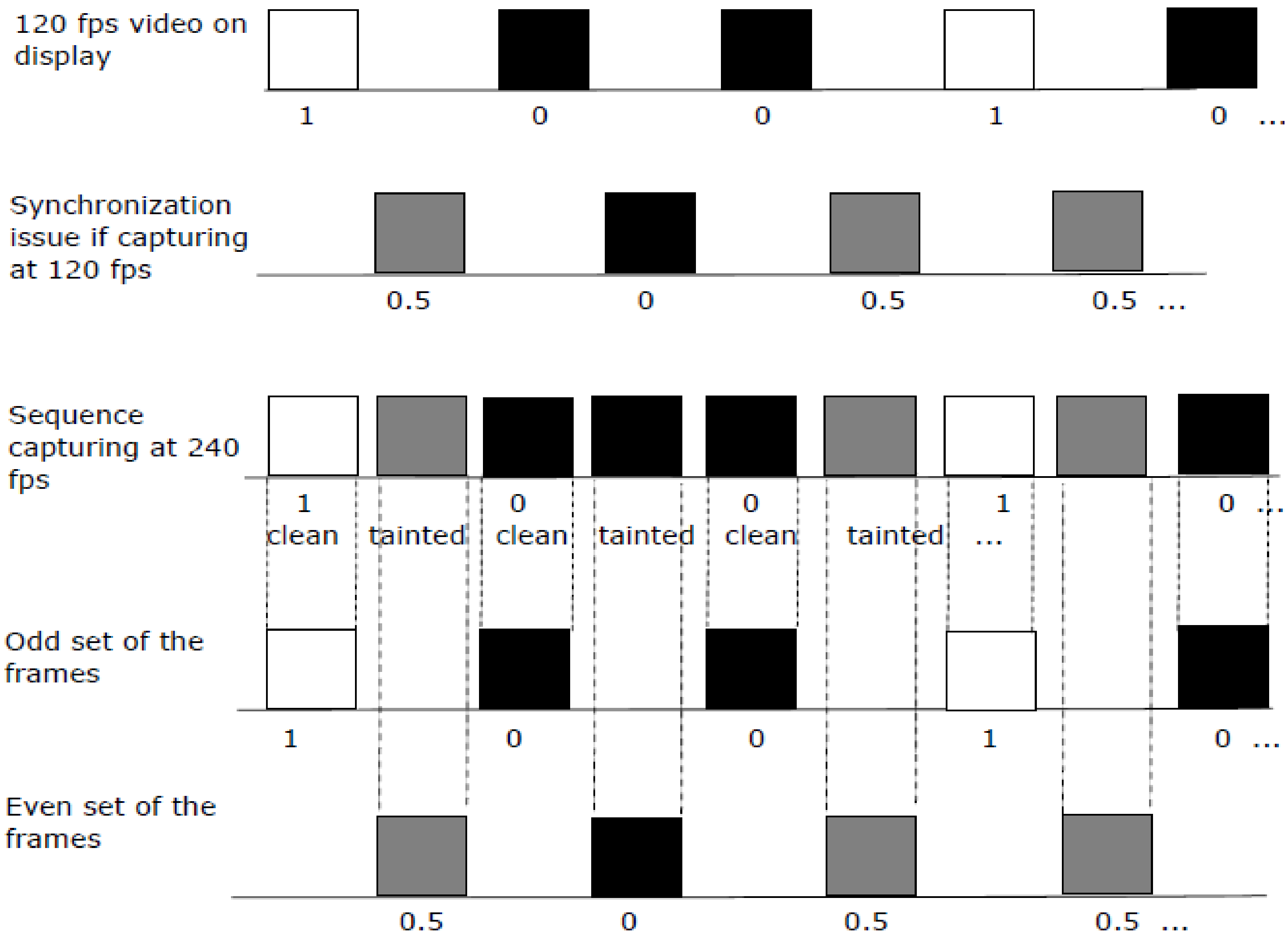
Algorithm:

- Track temporal brightness change, if
  - High to low → “bit 1”
  - Low to high → “bit 0”

Decoding Method



Frame Alignment Issue

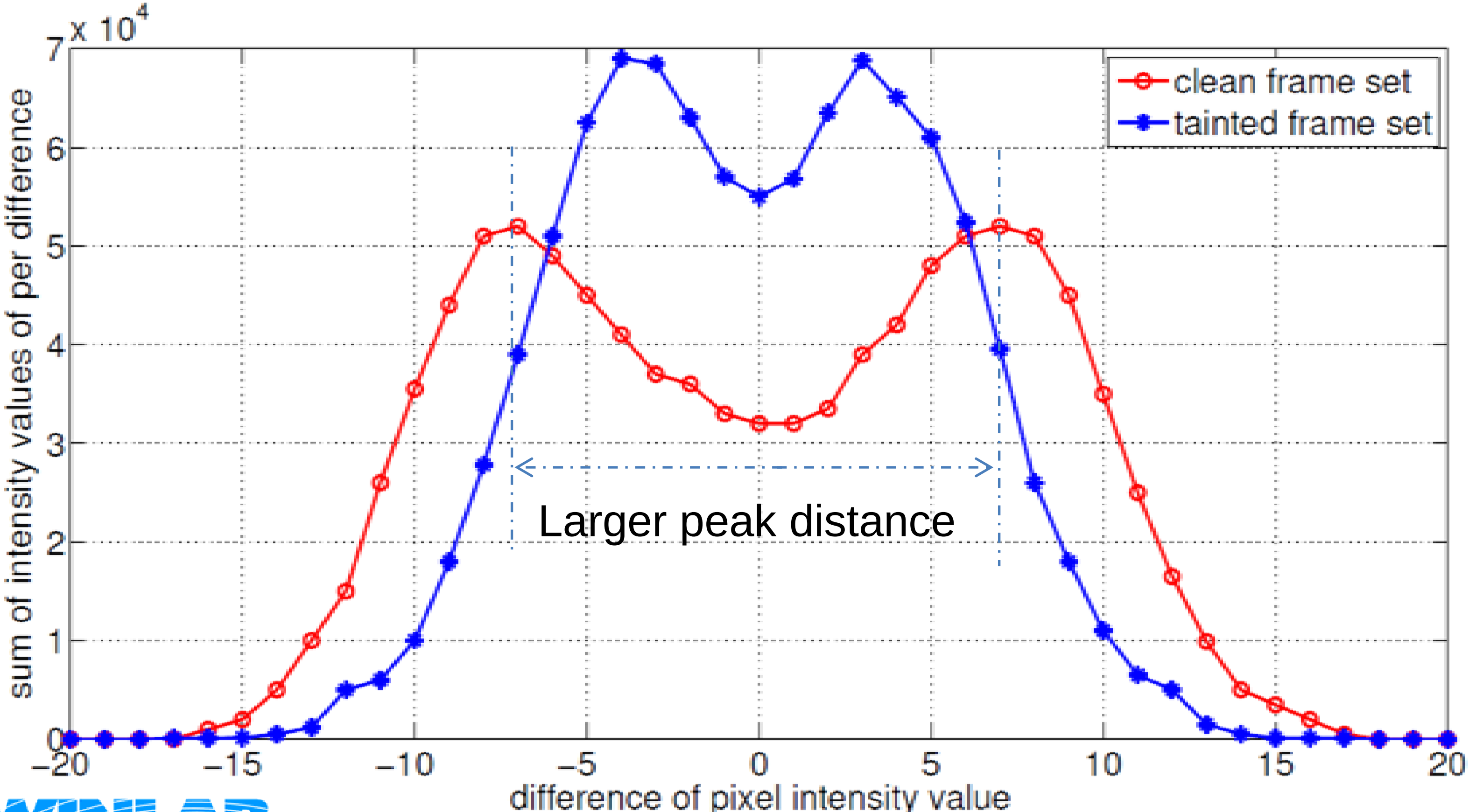


Clean frames!

RUTGERS

Frame Alignment Issue

Histogram method to extract clean frames.



WINLAB
WIRELESS INFORMATION NETWORK LABORATORY

Encode Pattern Detection

Recap: - content-adaptive encoding

- selected blocks encoded message.

Algorithm: find large brightness change blocks.

Frame 1

-1	0	0	1	0
1	0	-1	-1	1
0	-1	1	1	0
1	0	0	1	0
1	0	0	-1	-1

\- (subtract)

frame 2

-1	1	1	0	1
0	1	-1	-1	0
1	-1	0	0	1
0	1	1	0	1
0	1	1	-1	-1

= (equals)

difference matrix (in absolute value)

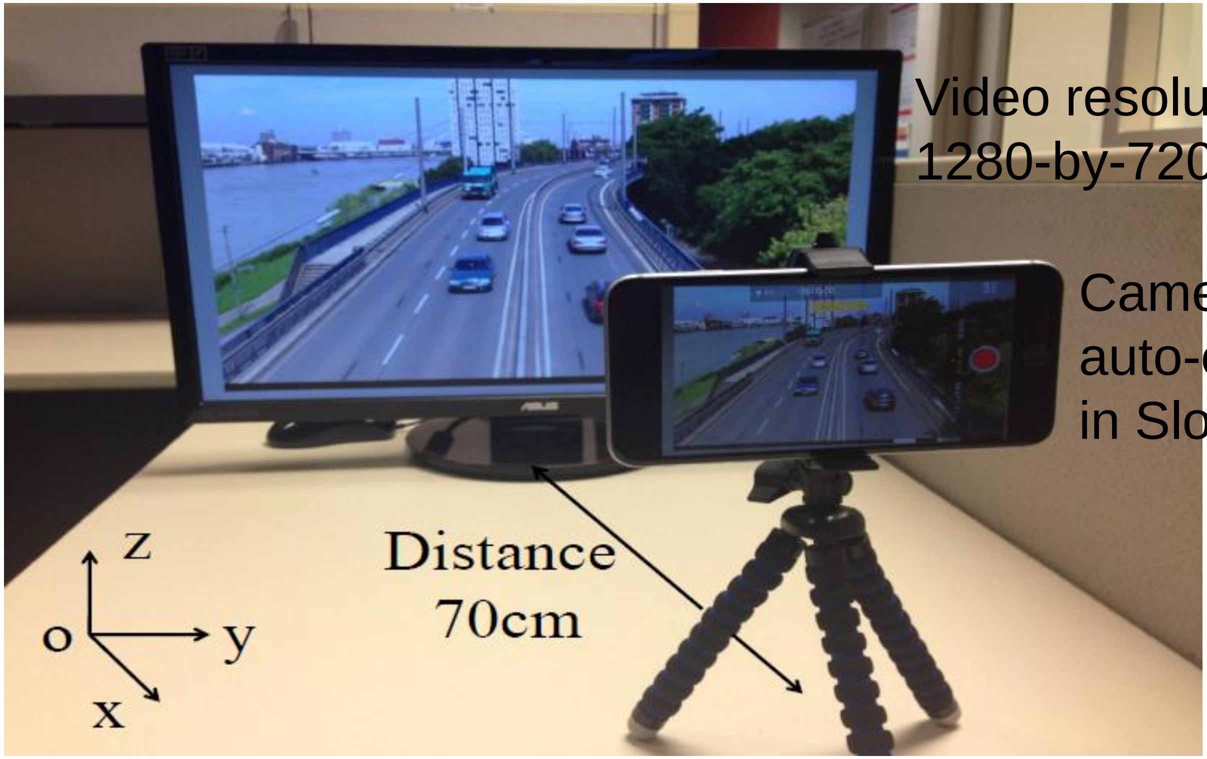
0	1	1	1	1
1	1	0	0	1
1	0	1	1	1
1	1	1	1	1
1	1	1	0	0

Outline

- User experience: flicker perception factors
- System design
  - content-adaptive encoding method;
  - signal amplitude tracking decoding method;
- **Prototype implementation**
- System performance evaluation
- Conclusion and future work

Prototype Implementation

- 120fps video displayed using *glvideoplayer*.
- Iphone6 recording at 240 fps.



Video resolution
1280-by-720

Camera fixed
auto-exposure;
in Slo-Mo mode

Experiment Videos


bigbuckbunny


Bosphorus


ReadySetGo


ShakeNDry


football


highway


walking


YachtRide


Jockey

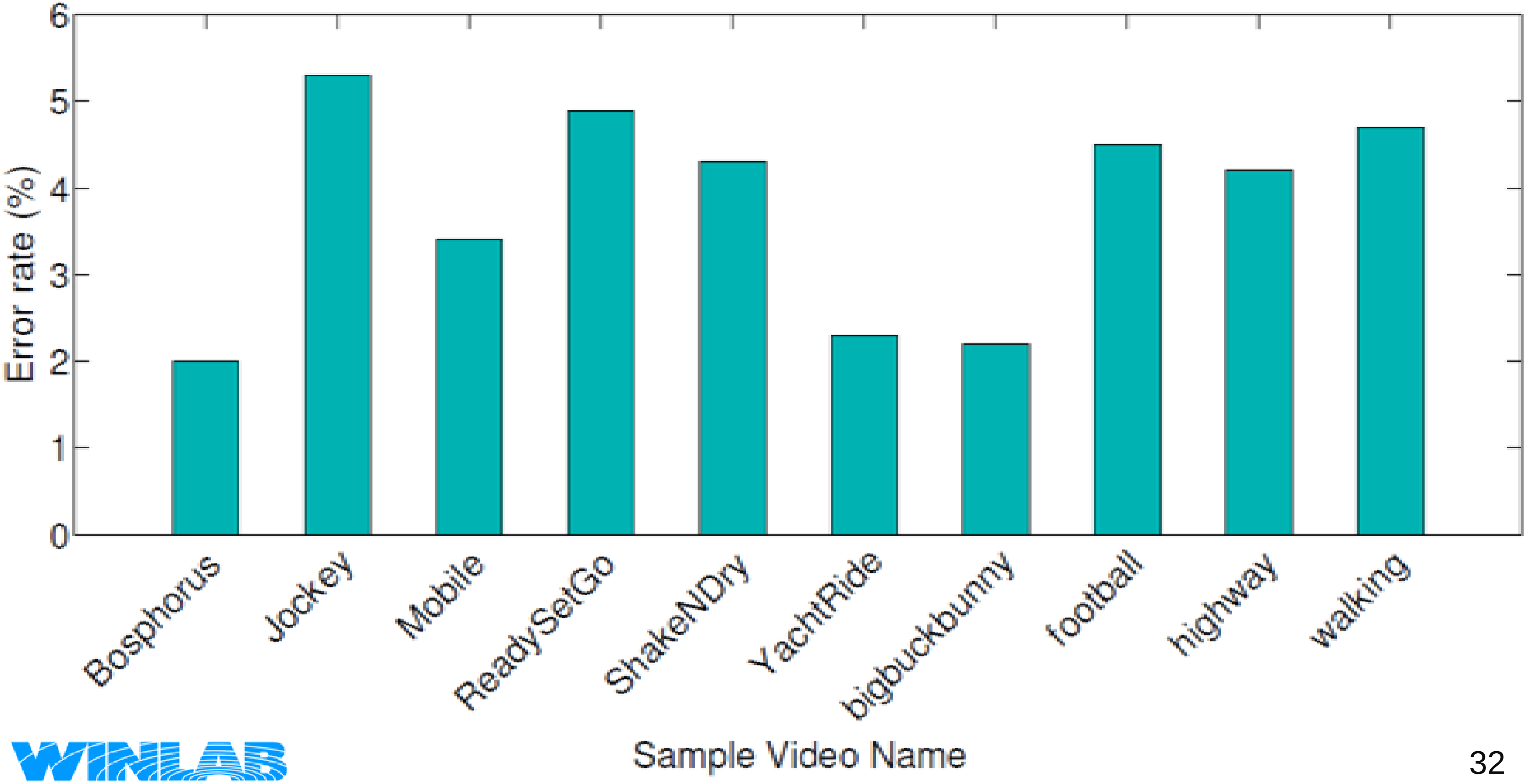

Mobile

Outline

- User experience: flicker perception factors
- System design
  - content-adaptive encoding method;
  - signal amplitude tracking decoding method;
- Prototype implementation
- **System performance evaluation**
- Conclusion and future work

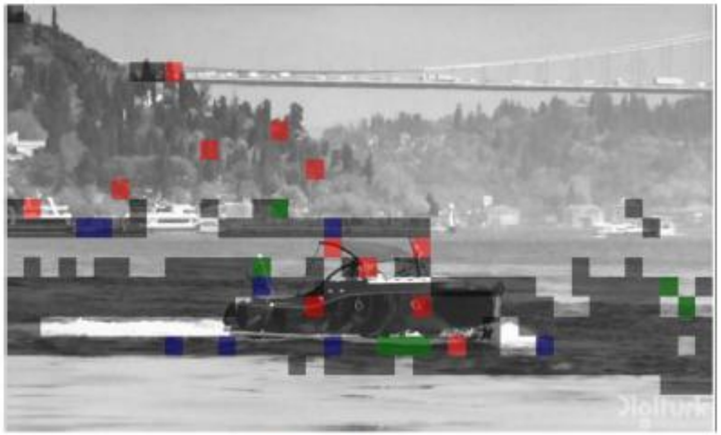
Pattern Detection Evaluation

- Static scene, color videos



Sample Error Markers

bigbuckbunny



Bosphorus

highway

Jockey

Red
not encoded blocks as encoded;

Green
bit 0 blocks as not encoded;

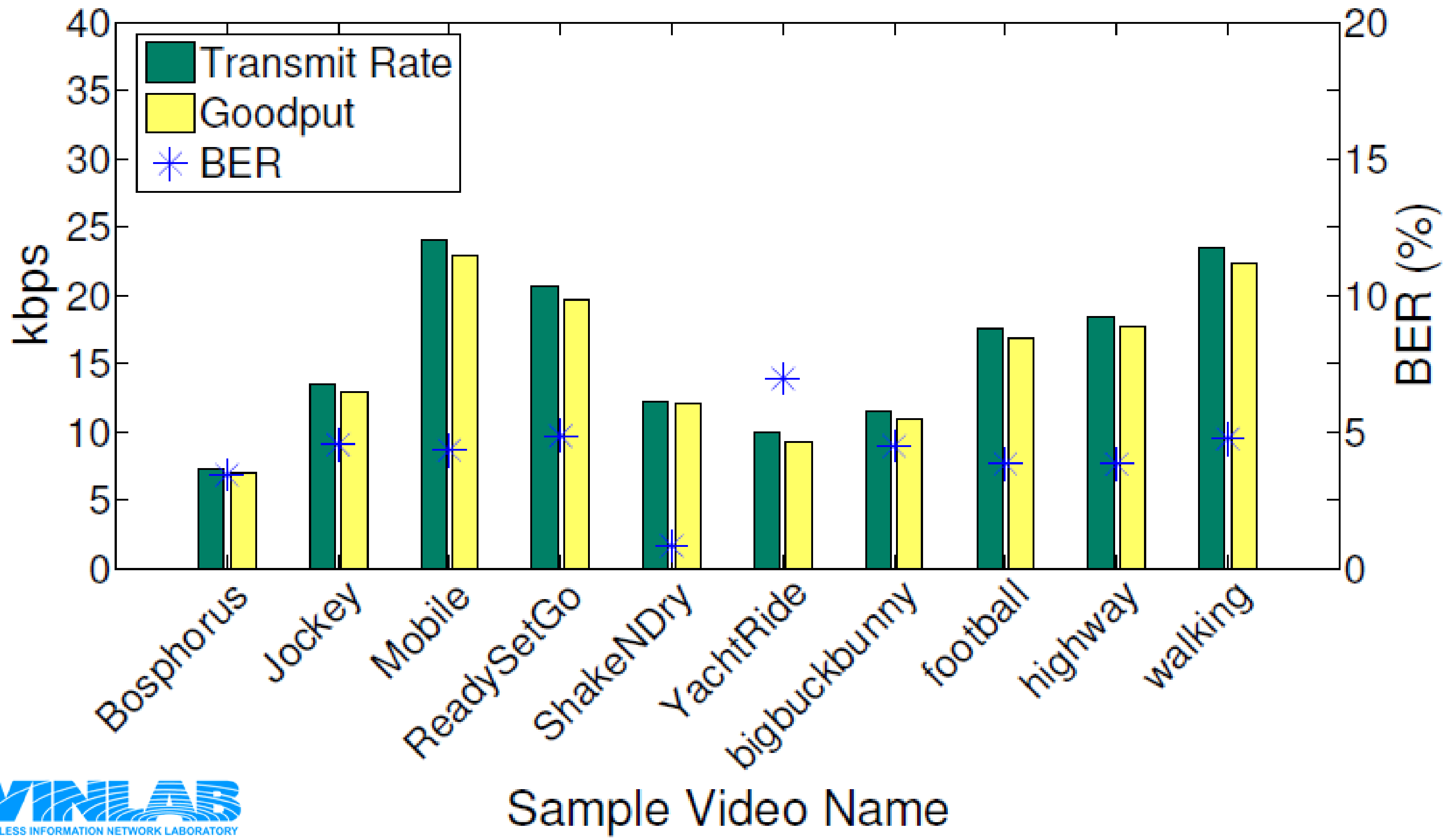
Blue
bit 1 blocks as not encoded;

Gray
original encoded blocks without error.

Basic Decoding Algorithm Evaluation

- Static scene, color videos

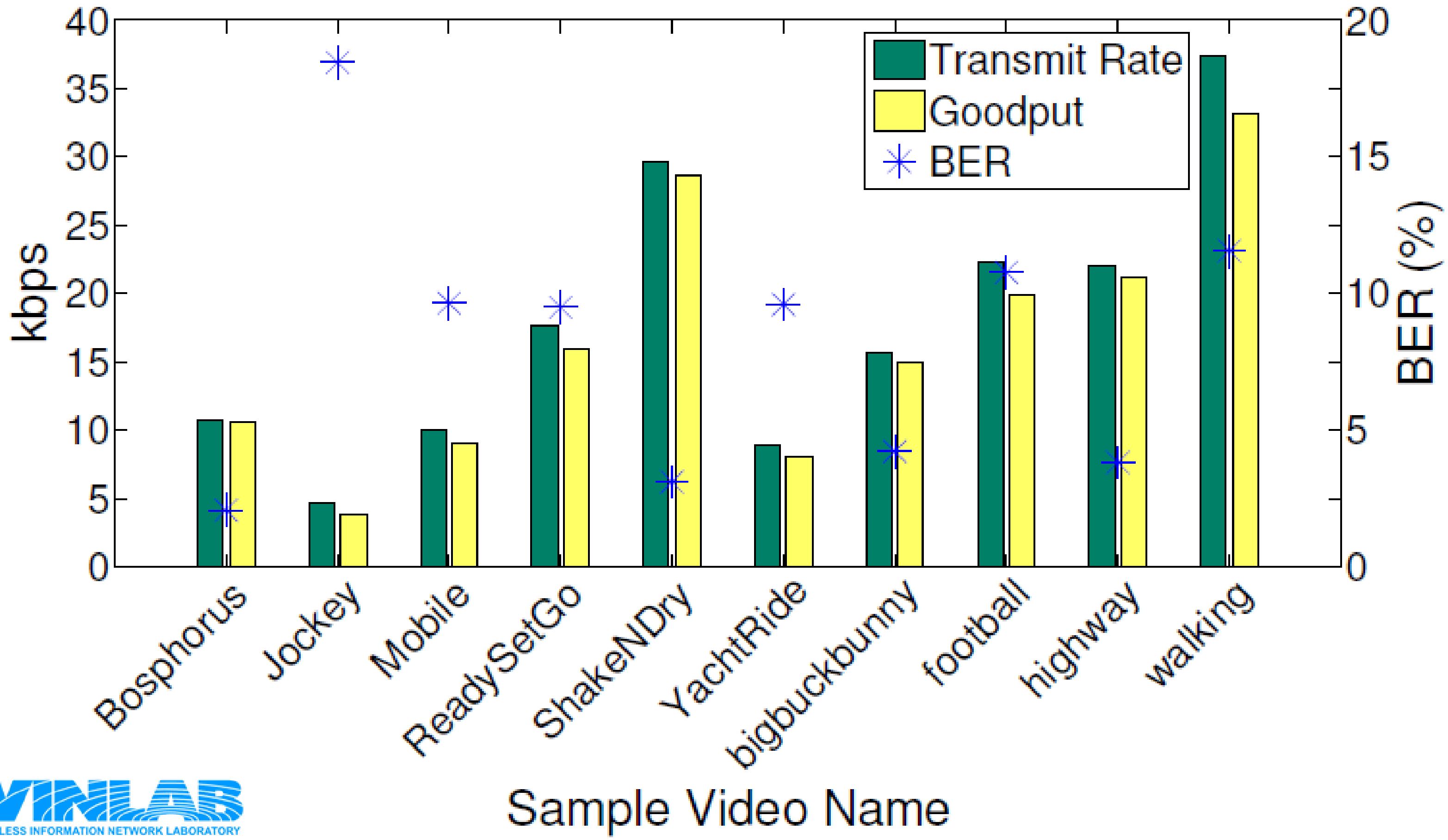
Goodput: correct bits per unit time.



Basic Decoding Algorithm Evaluation

- Dynamic scene, color videos

Goodput: correct bits per unit time.



Conclusions and Future Works

- Explored factors contributing to flicker perception;
- Proposed content-adaptive encoding method to achieve flicker-free screen-camera communication as well as high communication capacity and accuracy;
- Identified reasons causing system error;

- Combine pattern detection to decoding algorithm;
- Applications like screen identification etc.

Thank you!