Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [IG DEP dependable wireless feedback controlling schemes considering errors and delay in sensing data and controlling command packets]

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Abstract: [As a use case of dependable wireless networks, an adaptive feedback control schme to remote sensing and controlling wireless capsule endoscope is introduced. The proposed scheme is applicable for all wireless feedback controlling loop systems]

Purpose: [information]

Dependable wireless feedback controlling schemes considering errors and delay in sensing data and controlling command packets

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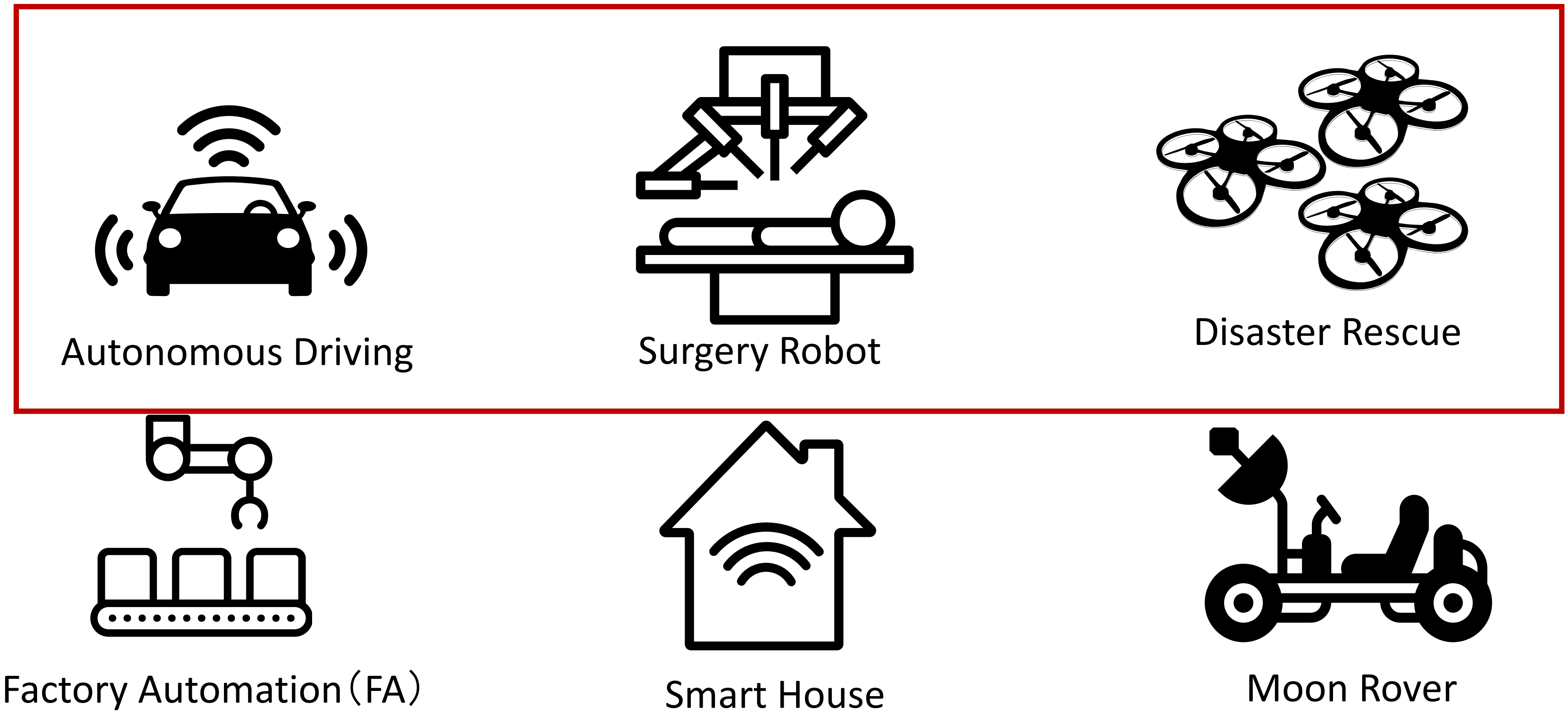
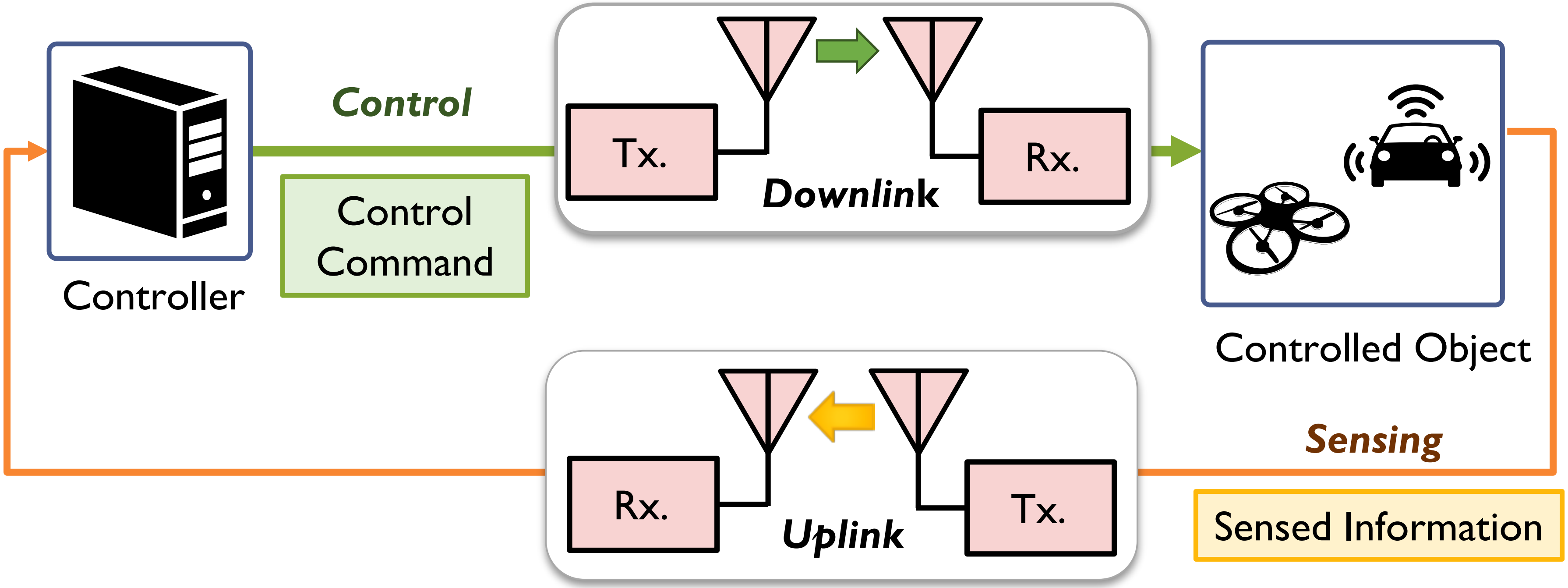
Control × Wireless Communication



[Source of Images] https://thenounproject.com/

・How to guarantee the safety is important
⇒ Optimizing the conventional wireless communicaton system with Control Theory（=*'Reliable Communication and Control:**RCC**'*）

Keyword in RCC: Wireless Feedback Control(WFC)



※Closed Feedback Control Loop

Error and Delay in WFC

【Error】

- Comm. Error…(∵Multipath Fading, Shadowing, …etc.)
- Control Error…(∵Comm. Error, Comm. Delay, …etc.)

✓ Depending on the Targeting Application

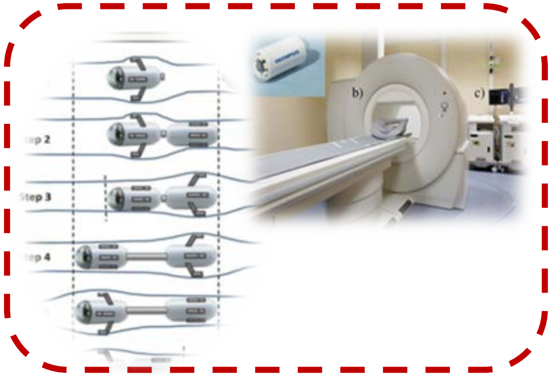
【Delay】

- Comm. Delay…(∵Limited Bandwidth, Retransmissions, …etc.)
- Control Delay…(∵Processing time, Comm. Delay)

Research Strategy

- Aiming at the Medical ICT Applications, we have tried to suppose specific WFC system
- Deriving the channel capacity & Estimating the allowable sampling interval
- Proposing and Evaluating the adaptive error control and delay control

Capsule Endoscopy: Now and in the Future



In Mechanical Engineering and Control Engineering

Next Generation

(Ex.) Micro robot

http://www.kohnolab.dnj.ynu.ac.jp/intro/introduction-j.html

Near Future

Diagnosis･Surgery

Present

Diagnosis

(Ex.) ENDOCAPSULE 10

http://www.nikkei.com/article/DGXNASFK0402R_U3A200C1000000/

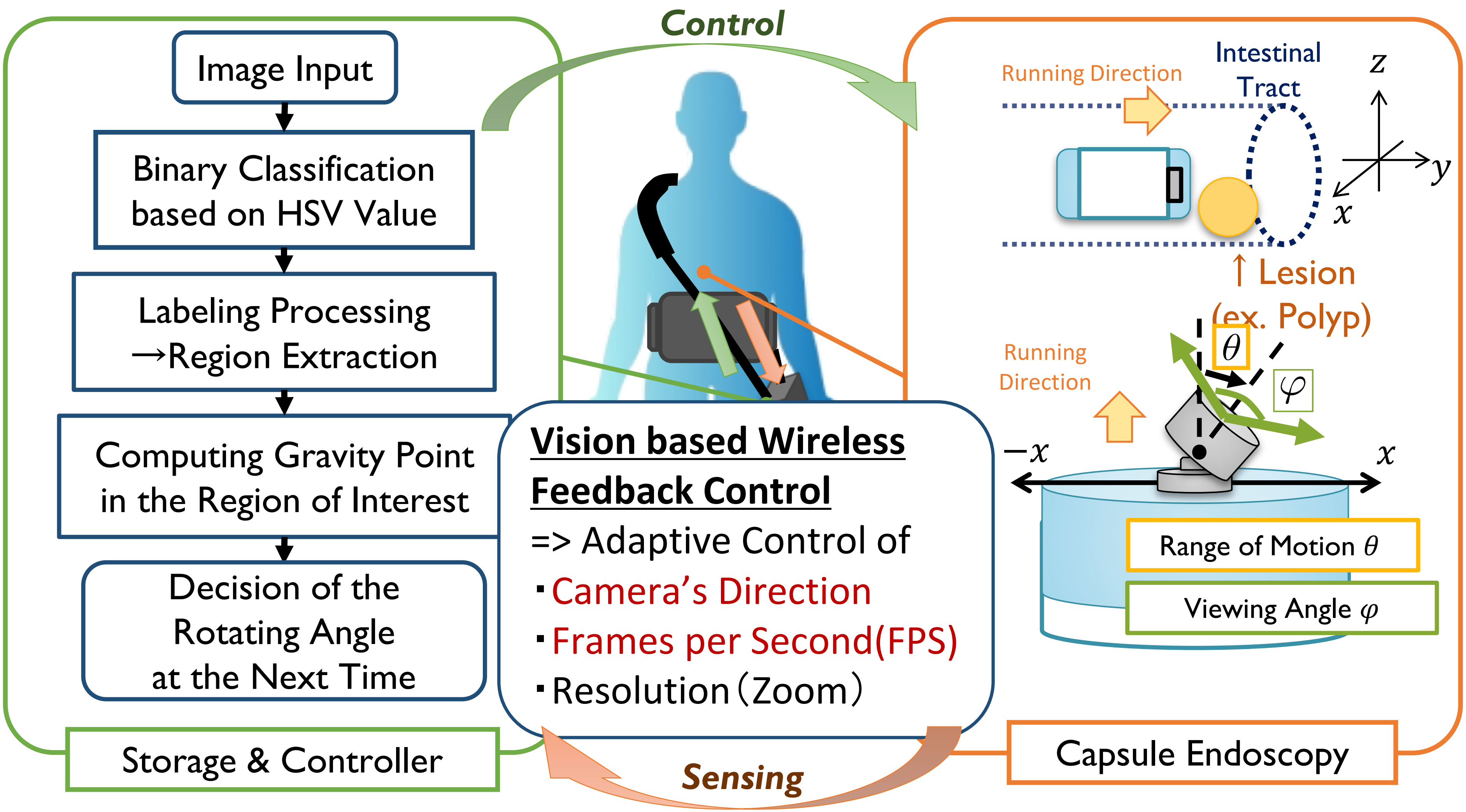
Vision of Our Research

【※Assumption】
Bi-directional Comm. is available.

How to gather the medical information considering battery life, safely and efficiently ?

Topics
- Channel Modeling for Implant BAN
- QoS-based Control
- Channel Environment Based Error Control

Expected Capsule Endoscopy System



Definition of Dependability in This Study

Q.1: What's the index of dependability in the proposed system?

A.1 : Tracking Ability to the Featured Point on Target(= gravity point of Region of Interest)

Q.2: How to improve the tracking ability?

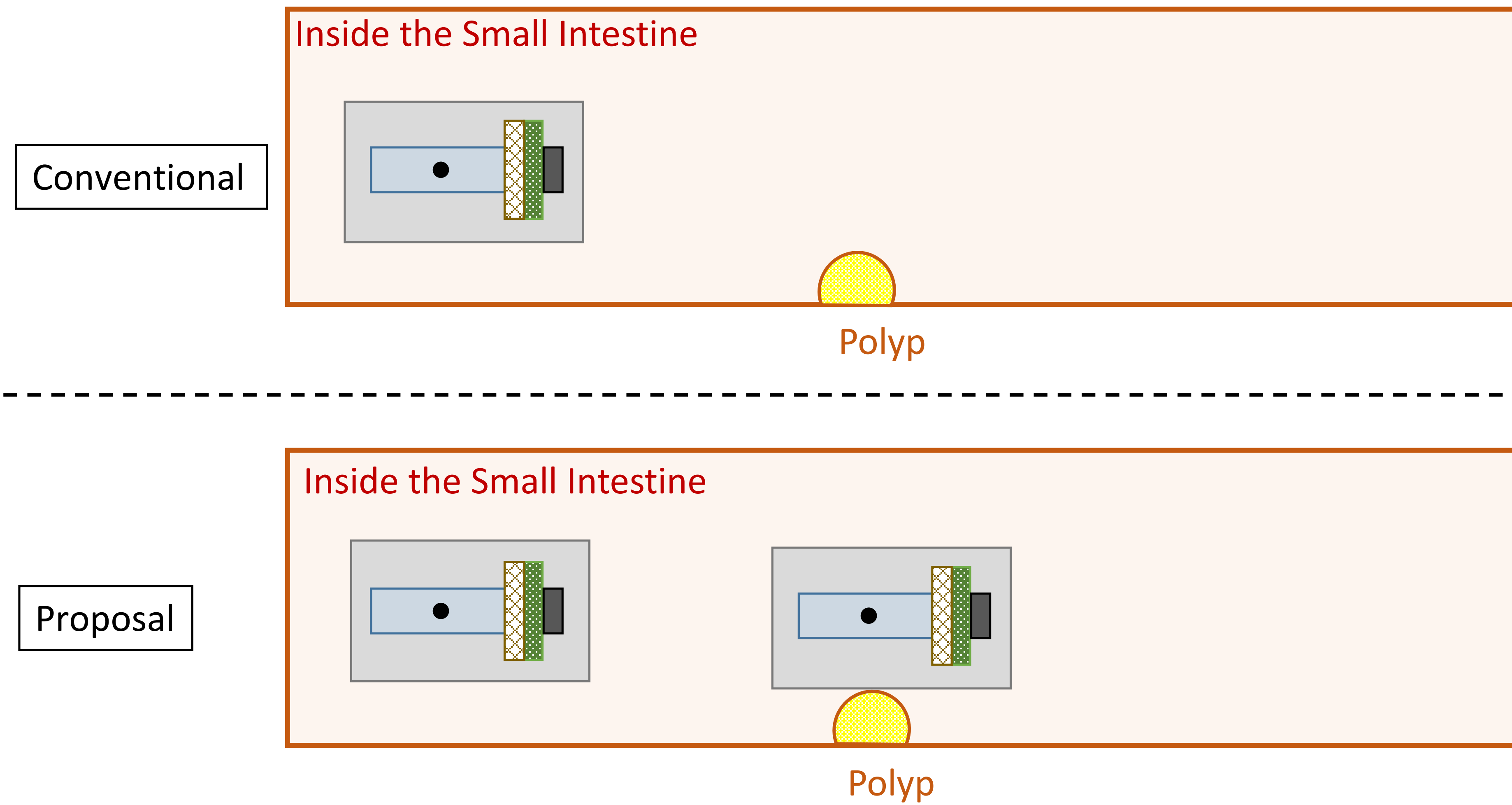
✓ Travel time by the target is limited

◎ By deriving the maximum FPS(=aFPS) theoretically, under aFPS, the system can change the FPS without error and retransmission

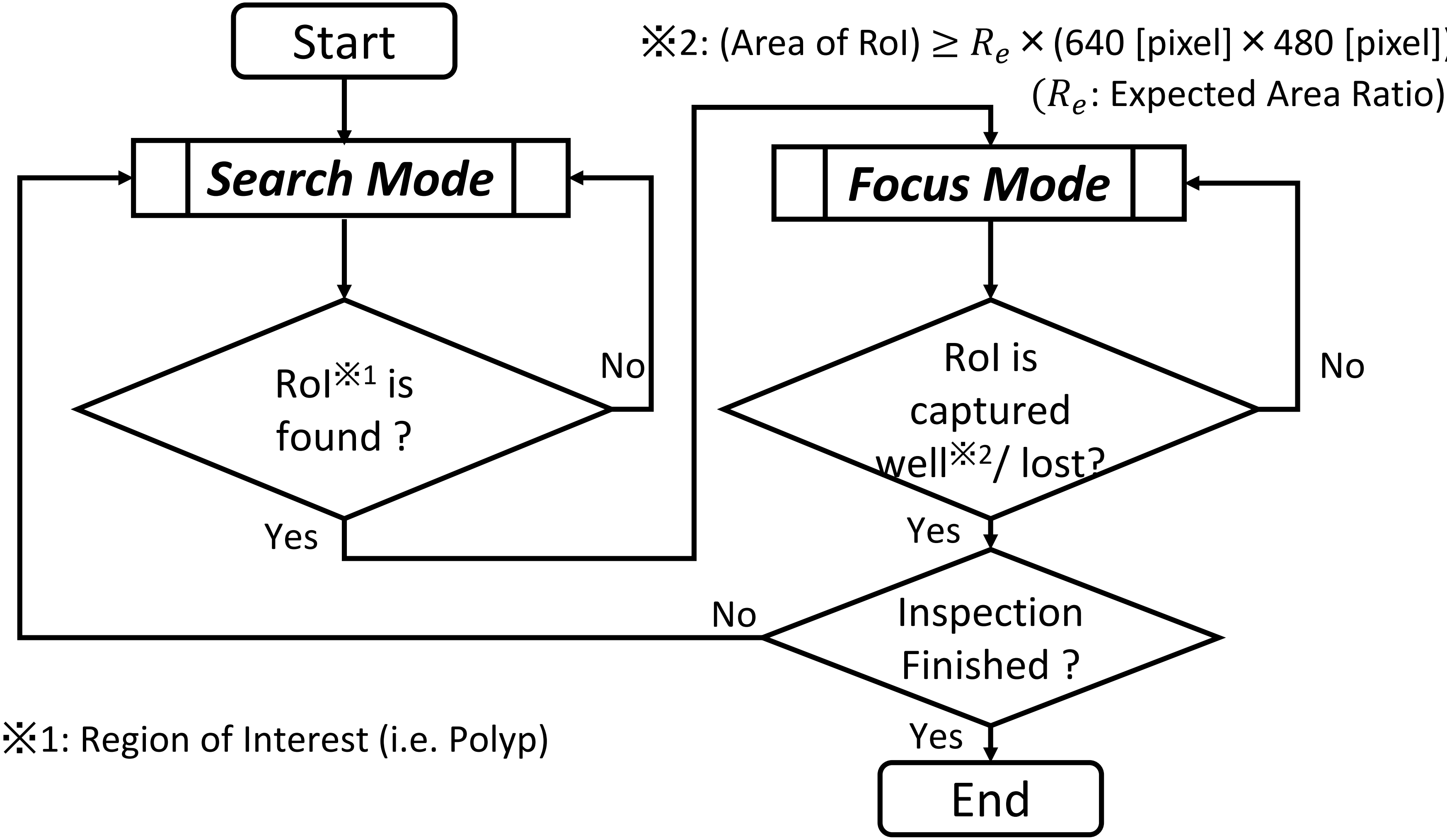
✓ Environment is changed dynamically

◎ By using the feedback information(=captured image), the system can realize adaptive capturing

Expected Movement in the Proposed System

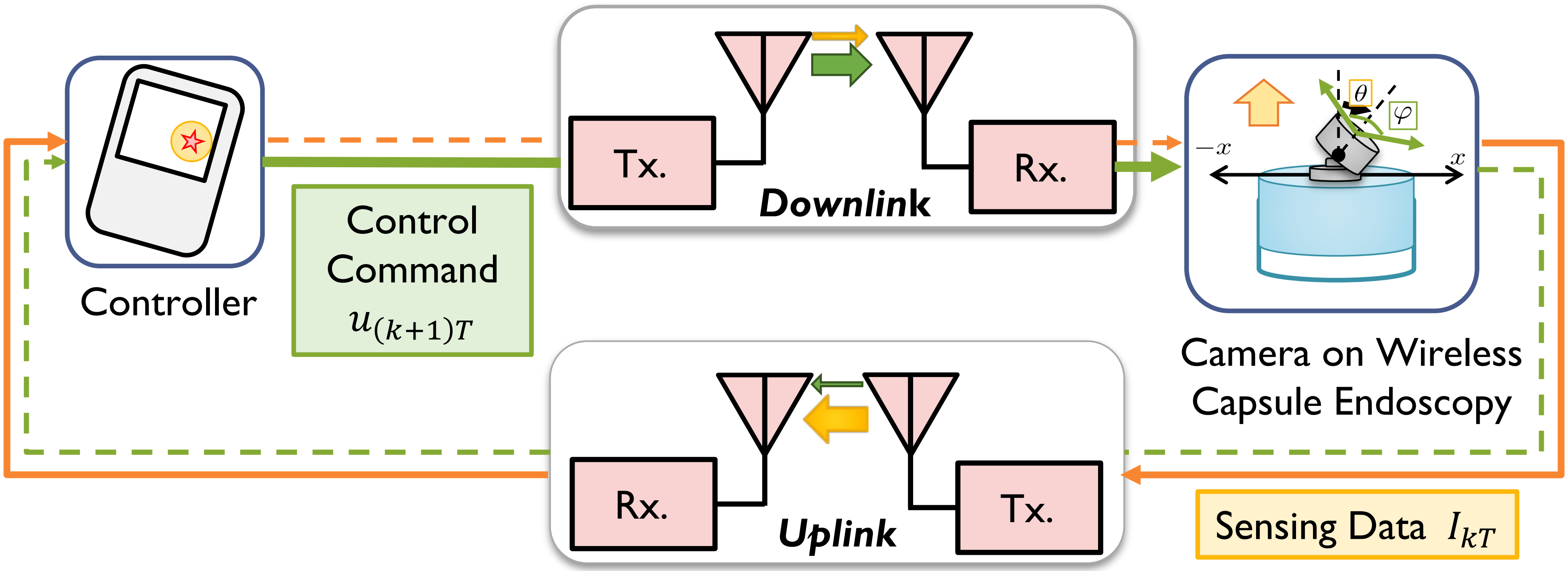


Flowchart of the Proposed System



※1: Region of Interest (i.e. Polyp)

Block Diagram of Proposed System



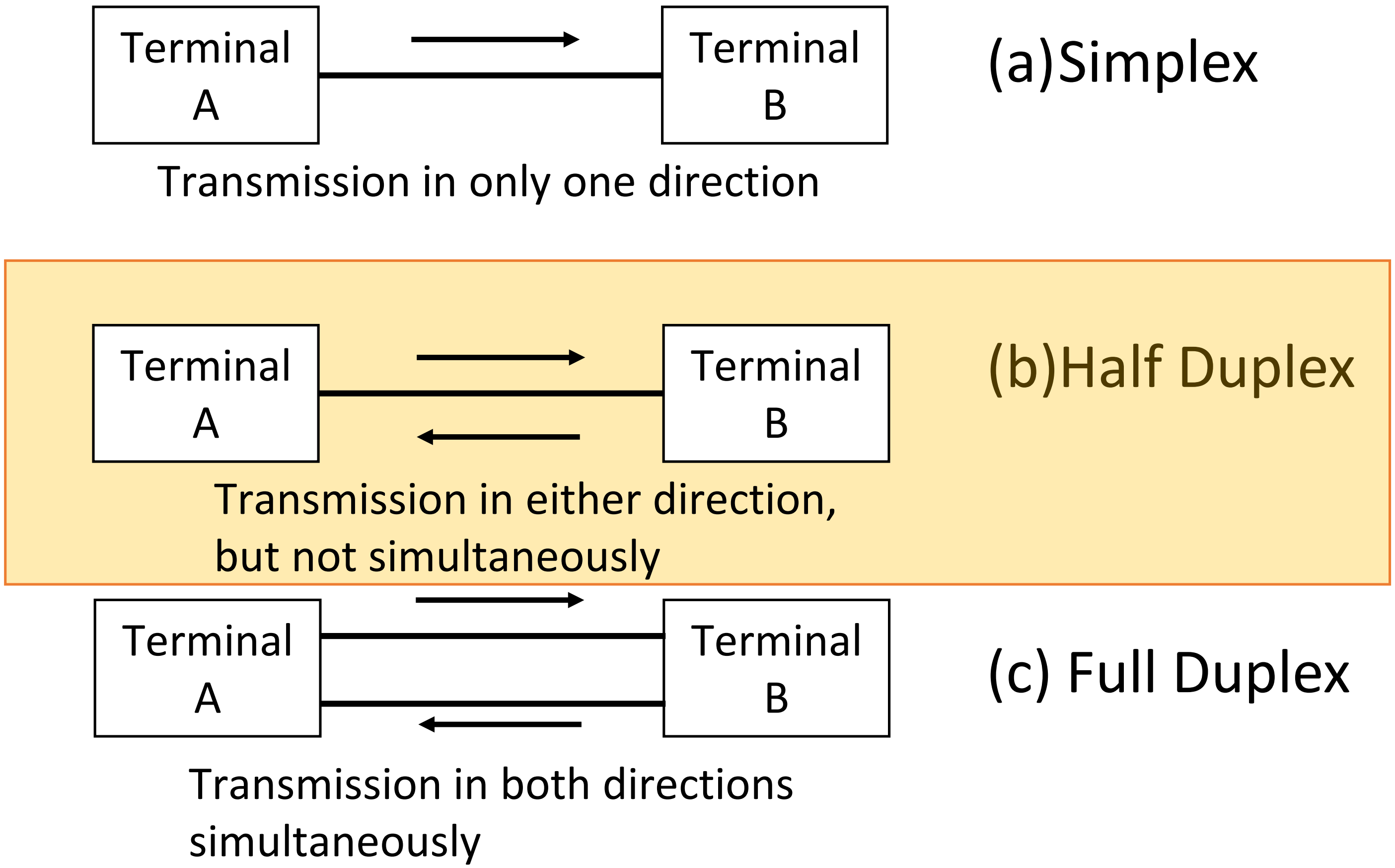
- Transmitted signals are as follows:

(1)Image (= 640 × 480 RGB Images) (2)Control Command

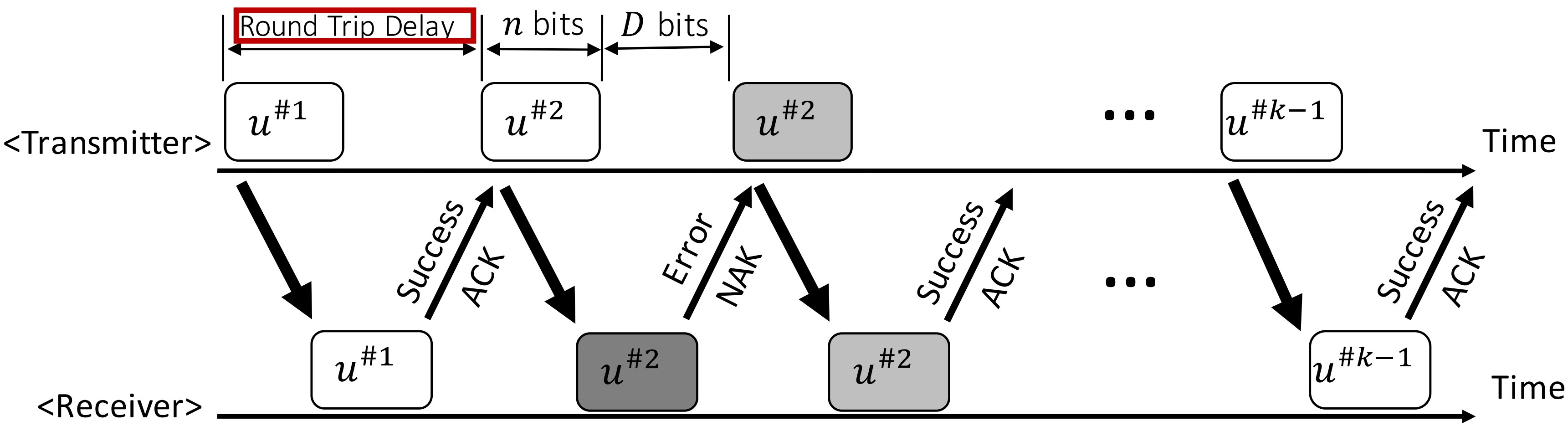
(3)ACK/NAK of Image (4)ACK/NAK of Control Command

Communication Systems

- Size of the capsule is limited, so usually, the half duplex system is used.
  ===>> In this research, we also use it.



Stop and Wait ARQ



$$T_{SW} = \left(1+\frac{D}{n}\right)(1-P_d) + 2\left(1+\frac{D}{n}\right)P_d(1-P_d) + 3\left(1+\frac{D}{n}\right)P_d^2(1-P_d) + \cdots = \frac{1+D/n}{1-P_d}$$

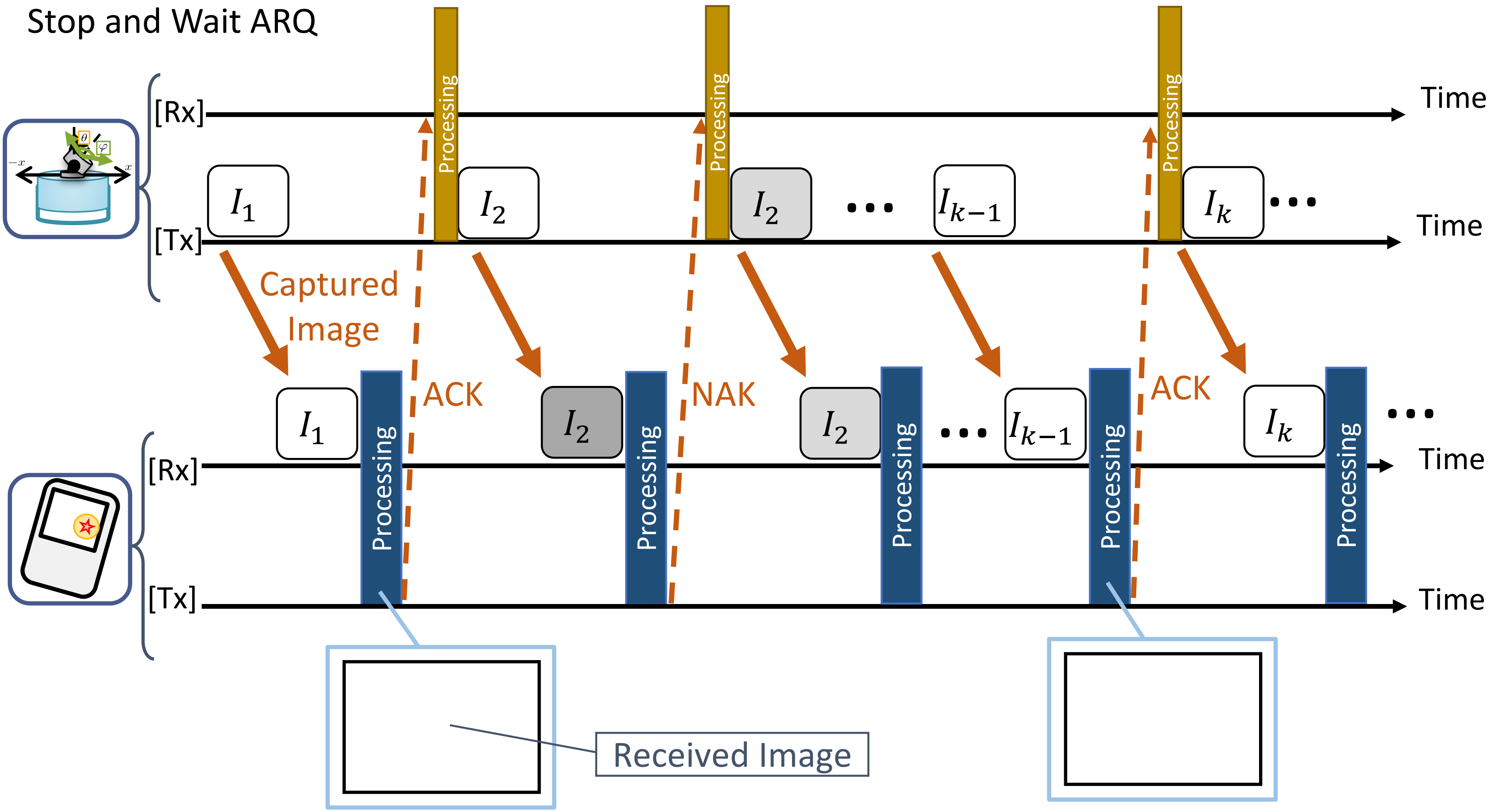
「Round Trip Delay (≈1/FPS)」

$$\eta_{SW} = \frac{1}{T_{SW}} = \frac{1-P_d}{1+D/n}$$

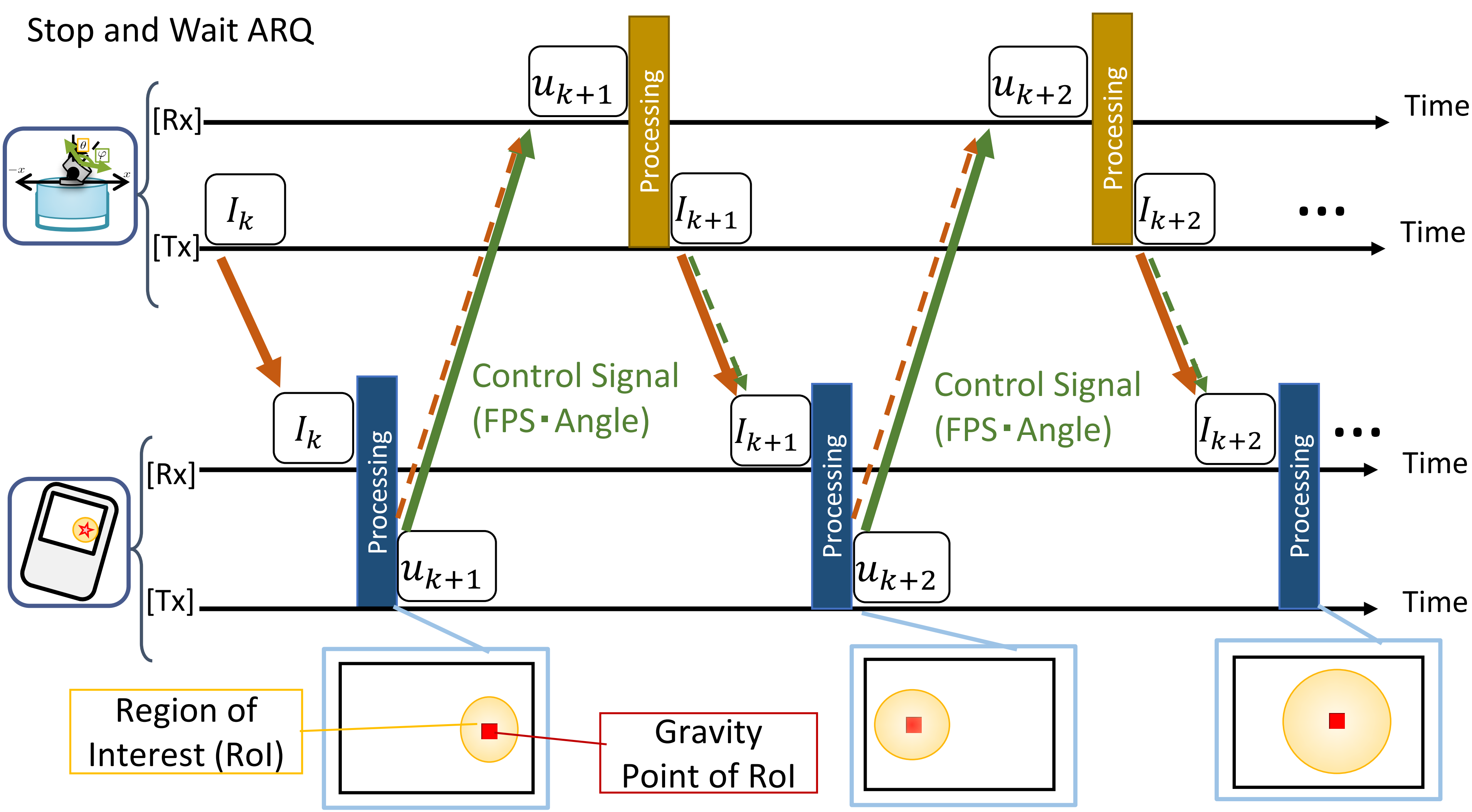
→【Proposal B.1】
Adaptive FPS Control based on sensing data

Search Mode

Stop and Wait ARQ



Focus Mode


Stop and Wait ARQ
[Rx]
[Tx]
u_{k+1}
Processing
I_k
I_{k+1}
u_{k+2}
I_{k+2}
Time
Time
Control Signal
(FPS・Angle)
Processing
Time
Time
Region of Interest (RoI)
Gravity Point of RoI

Channel Capacity in the Supposed System

- The antenna of WCE sends out the signal with a frequency 434.1 MHz and with a bandwidth at 1.6 MHz

Eq.(1) : Shannon-Hartley Theorem

$$C = B \log_2 \left(1 + \frac{S}{N}\right)$$

C : Channel Capacity[bits/sec]

B : Bandwidth of the Channel

Eq.(2) : Derivation of Signal to Noise Power Ratio

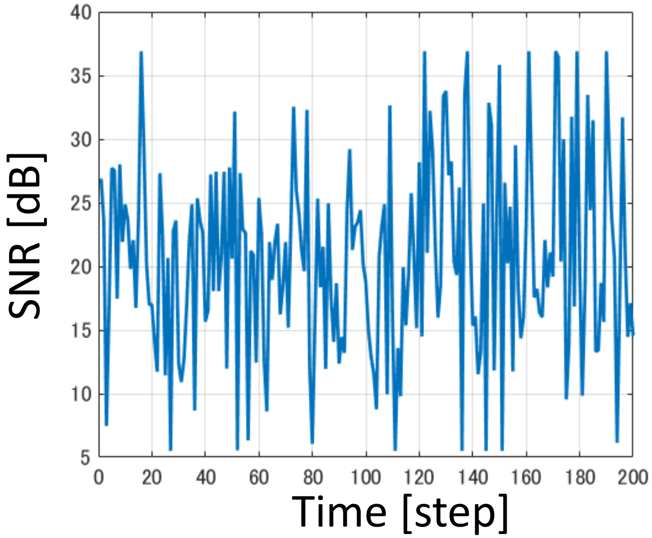
$$\left(\frac{S}{N}\right)_{dB} = P_t - PL(d) - P_n$$

P_t : Tx Power[dBm]

P_n : Noise Power[dBm]

$PL(d)$: Path-loss [dB]

IEEE802.15.6 CM2



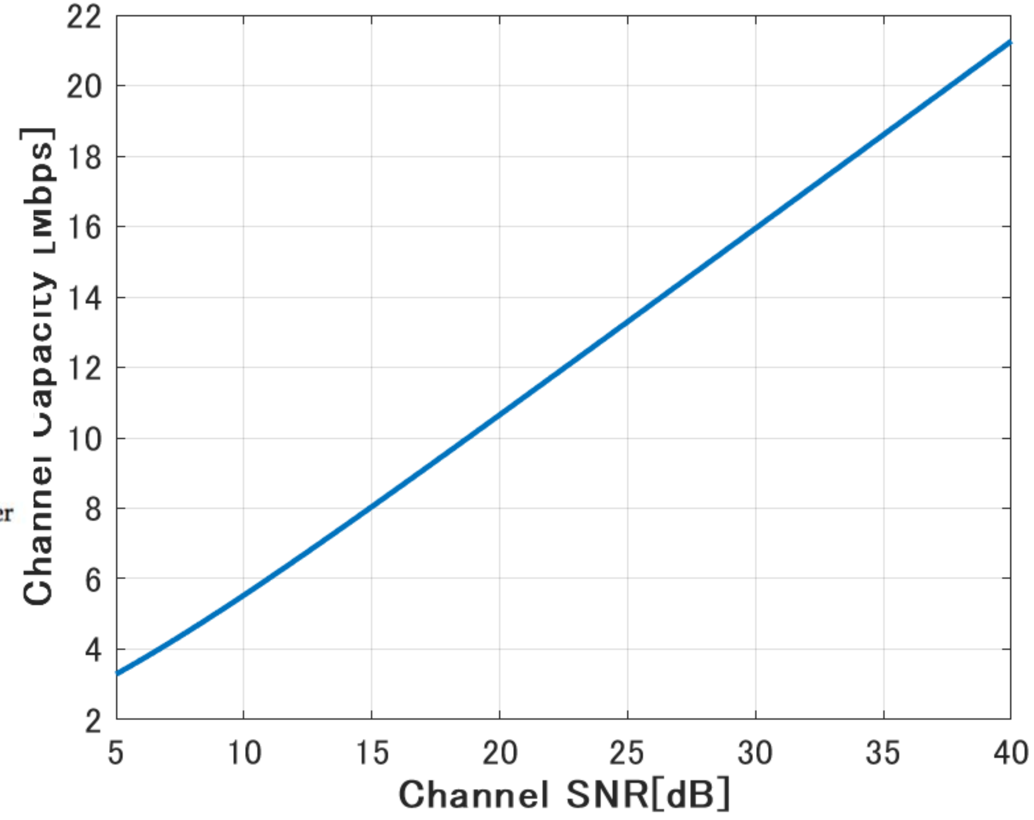
Derived Channel Capacity in Each SNR

By applying Eq(2) to Eq(1), the channel capacity in each SNR can be derived.

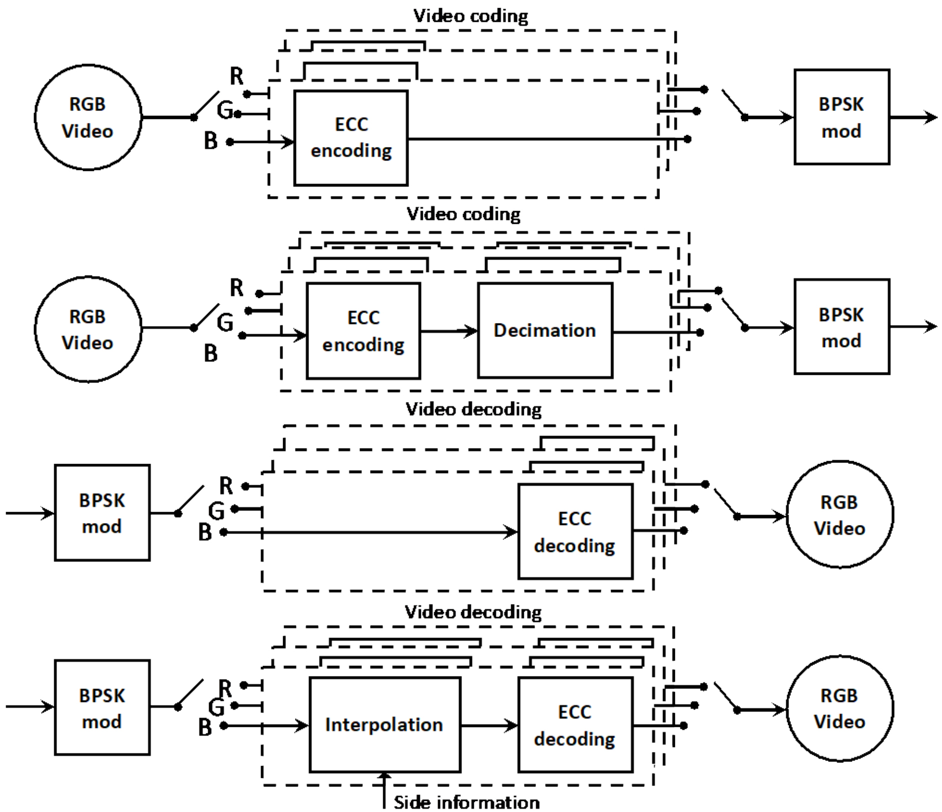
Table 3.1 Parameters to Derive the SNR for Implant BAN

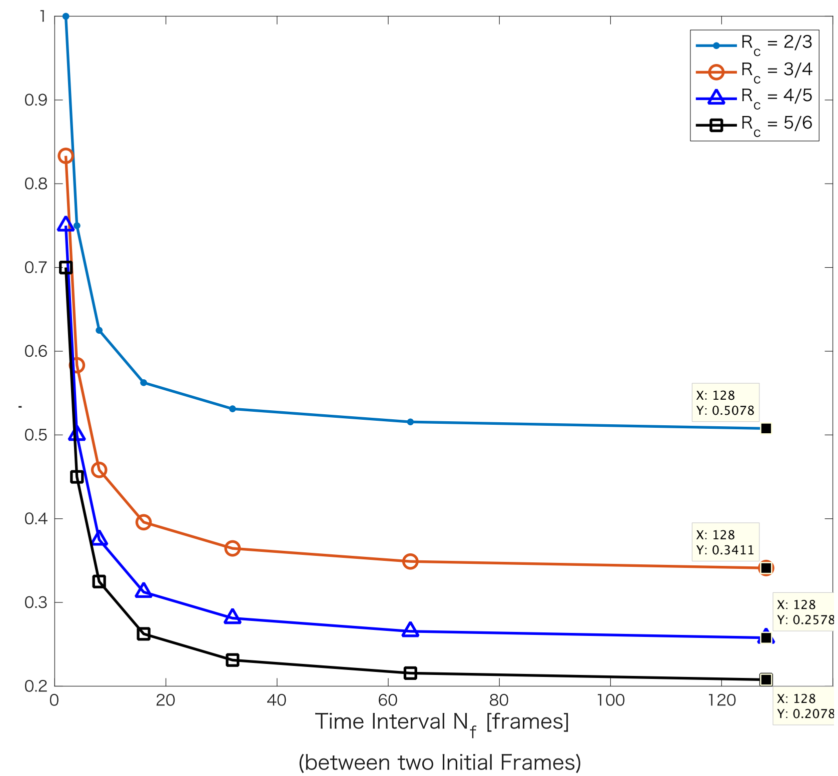
Transmitted Power P_t	1 [μW]
Propagation Distance d	10 [cm]
Boltzmann Constant k	1.38×10^{-23}
Reference Source Temperature T_0 [24]	290 [K]
Antenna Temperature T_{InBody}	310.15 [K]
Signal Bandwidth B	300 [kHz]
Noise Figure of the Receiver NF	$8(= 10 \log_{10} F)$ [dB]

F :Noise Factor of the Receiver



Compression Ratio in Video Coding





Compression Ratio:

$$R = \frac{1}{N_f}\left\{\frac{1}{R_c} + (N_f - 1)\left(\frac{1}{R_c} - 1\right)\right\}$$

N_f: Initial Frame Period

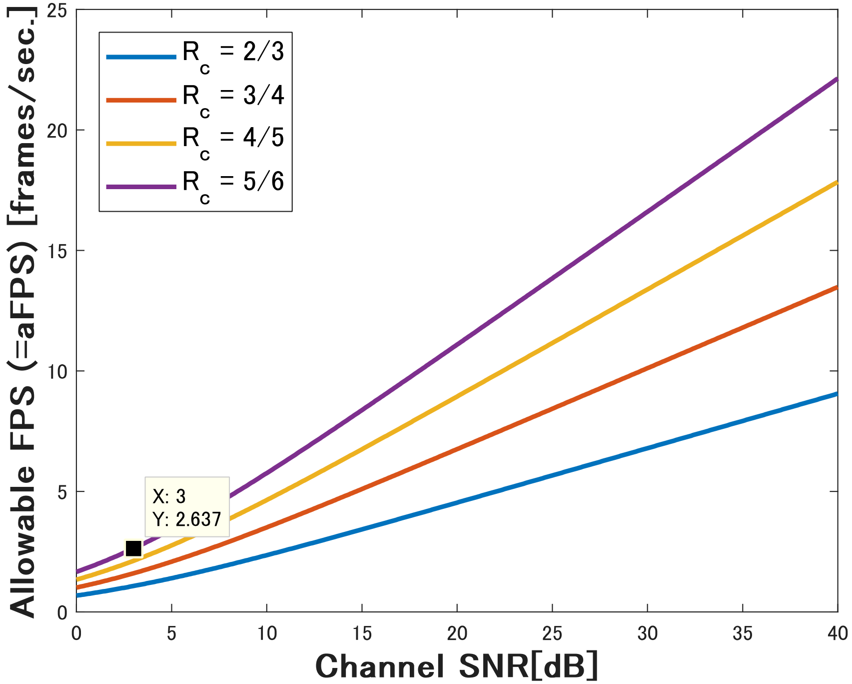
R_c: Code Rate of the Distributed Video Coding

Derivation of the Allowable FPS

Allowable FPS : How many frames can be sent without errors per second in a certain SNR

$$aFPS(R_c, SNR) = \frac{C(SNR)}{M \cdot R(R_c)}$$

$C(SNR)$: Channel Capacity
M : Information Entropy of Raw Image
R : Compression Ratio

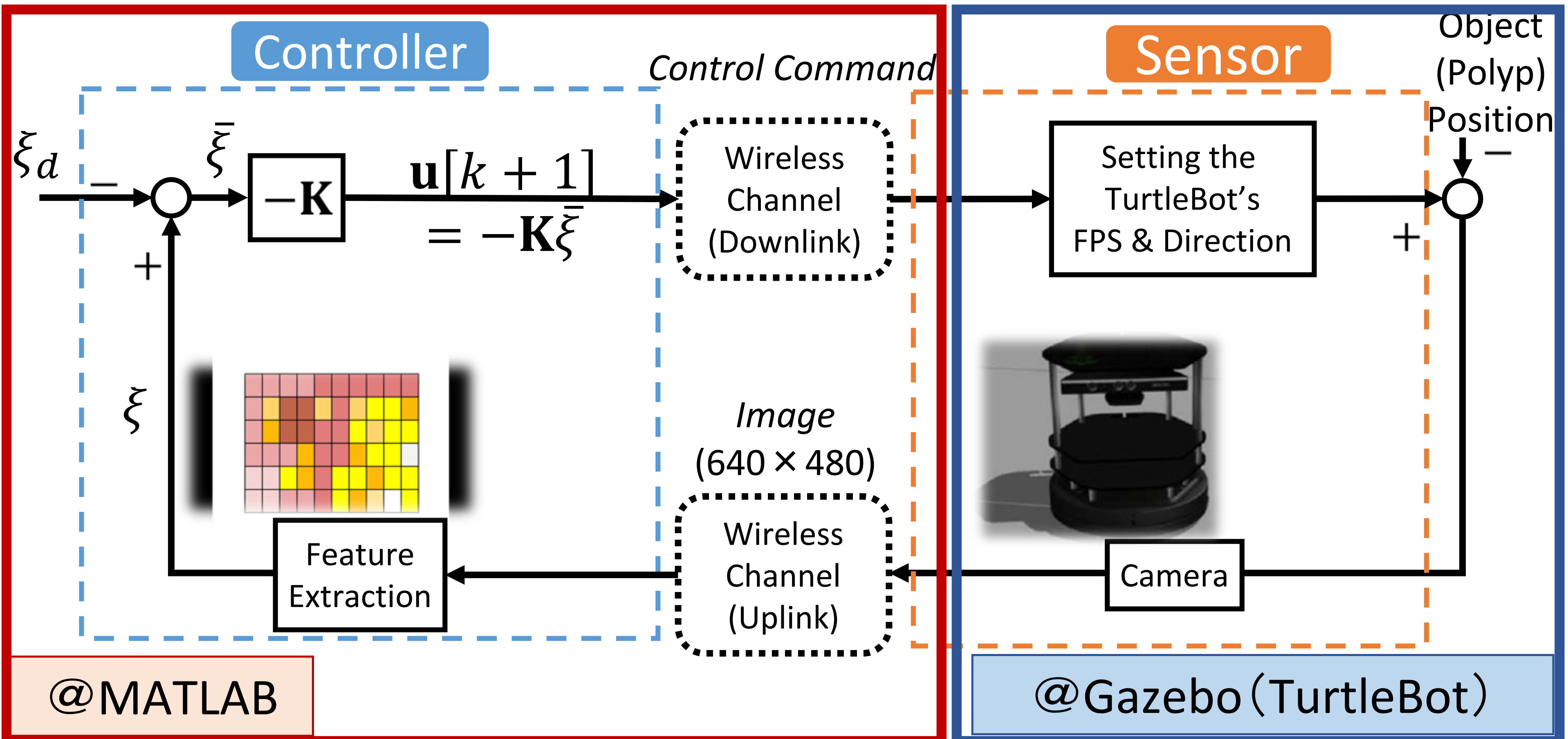


←when transmitting 640 pixel × 480 pixel RGB images

◎Asumption in the Later Parts
"If the images are captured below aFPS, there will be no error and no retransmission"

※**FPS: Frames per Second**

Overview of the Performance Evaluation

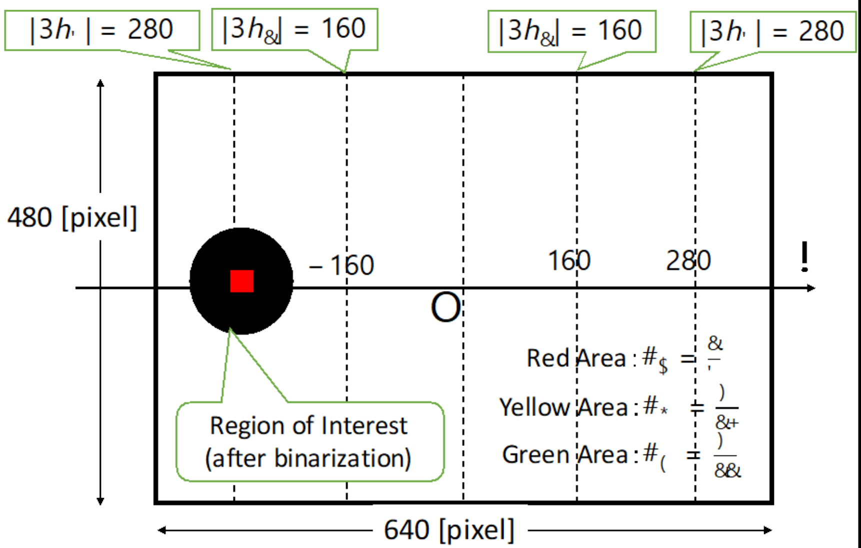


ξ : x-Coordinate of Gravity Point in RoI

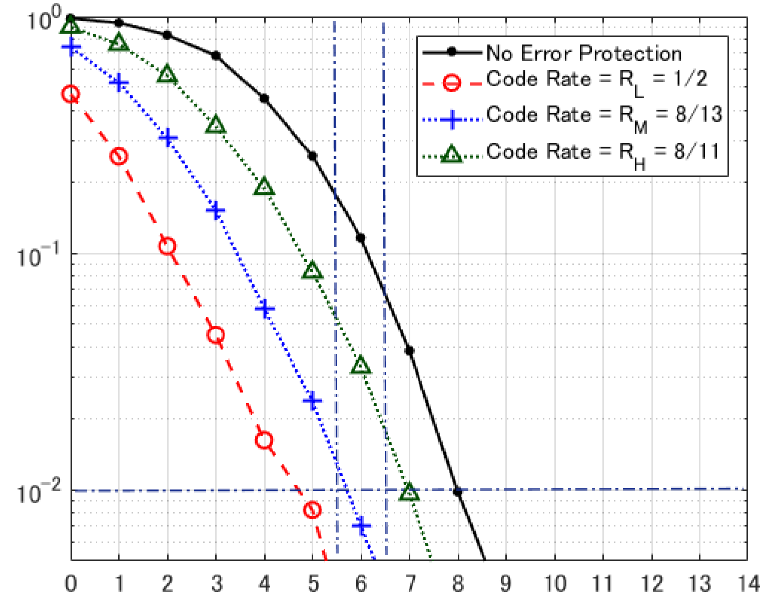
ξ_d : x-Coordinate of Desired Value

$$\mathbf{K} = \frac{\mathbf{1}\ [\text{deg}]}{\mathbf{320}\ [\text{pixel}]} = \frac{\mathbf{1}}{\mathbf{320}}\ \text{(Const.)}$$

Proposal A: Adaptive *Error* Control Scheme



Proposal A.1: Positions-Based UEP



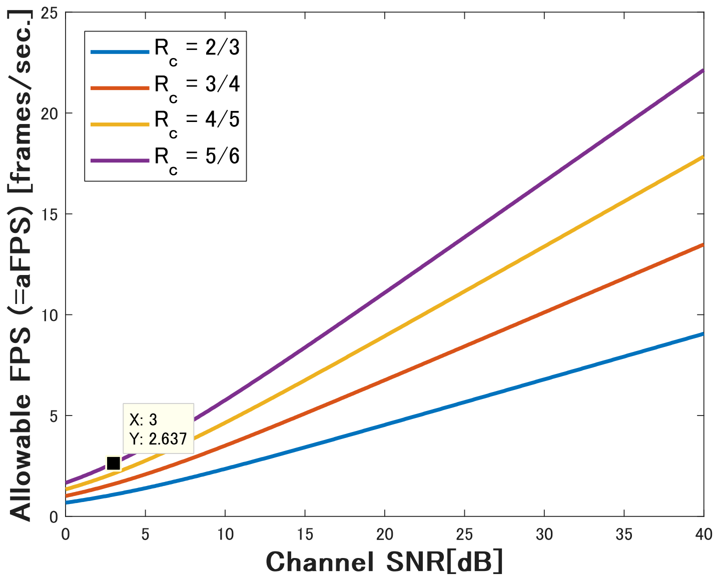
Proposal A.2: SNR-Based UEP

Changing the code rate for the control command packets based on the position of Region of Interest(RoI)

Changing the code rate for the control command packets based on the channel state information

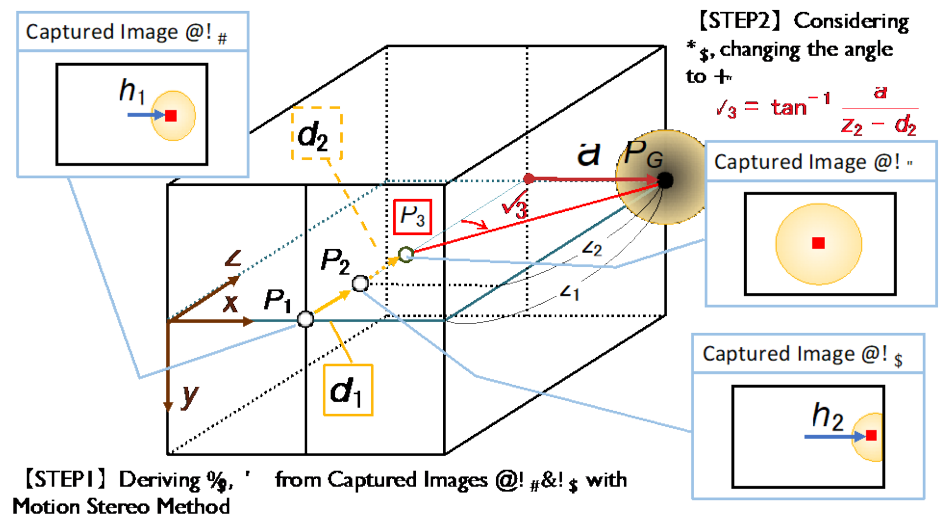
※UEP: Unequal Error Protection

Proposal B: Adaptive *Delay* Control Scheme



Proposal B.1: FPS Control

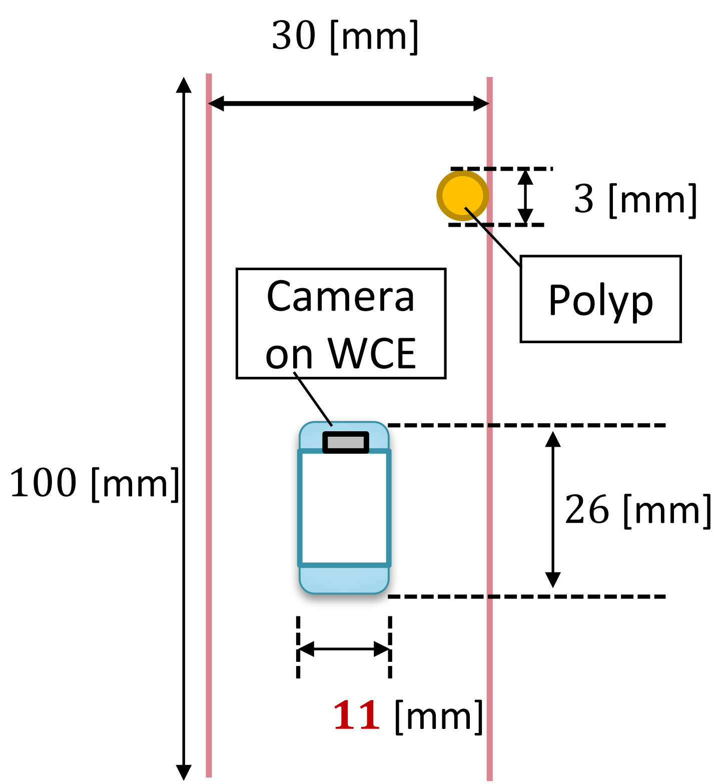
Changing the FPS within aFPS
Based on the size of Region of Interest (RoI)



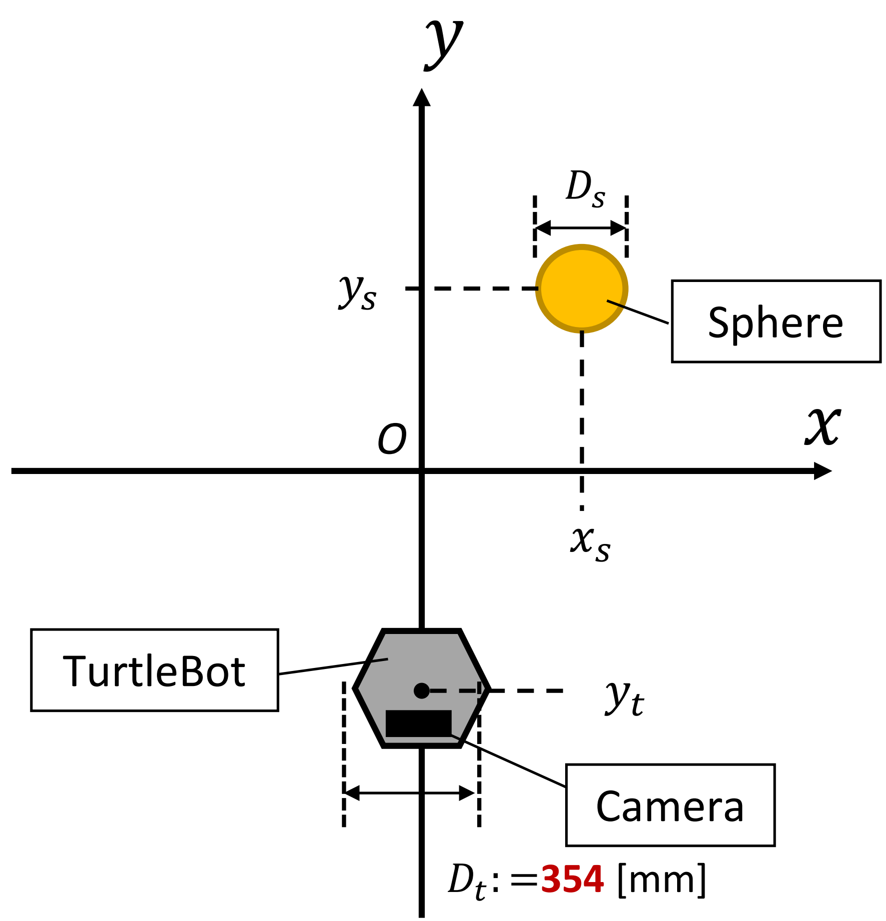
Proposal B.2: Visual Predictive Control

Realizing the stereo vision with the motion stereo method

Layout for the Evaluation of Proposal A.1



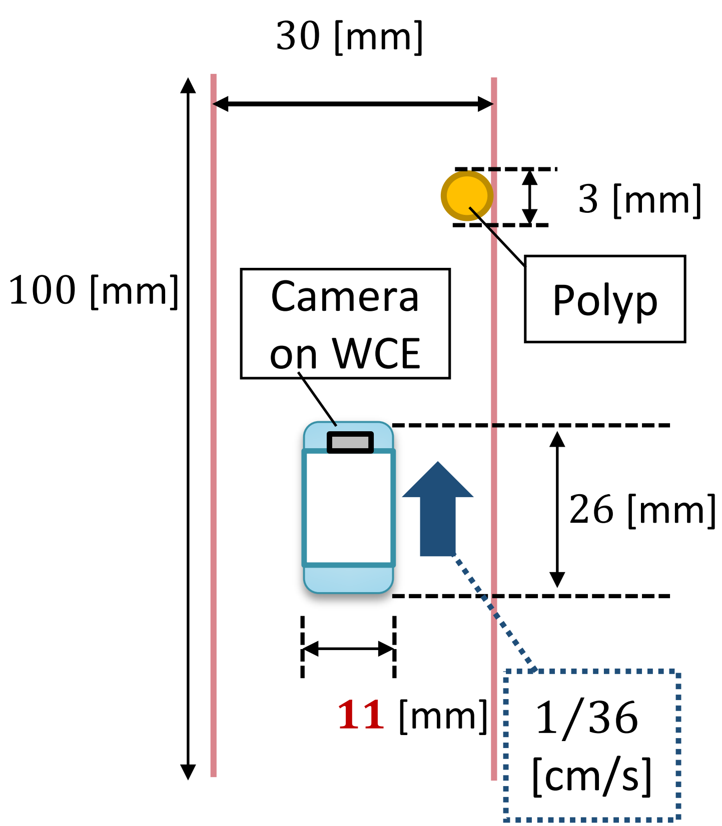
Assumed Layout



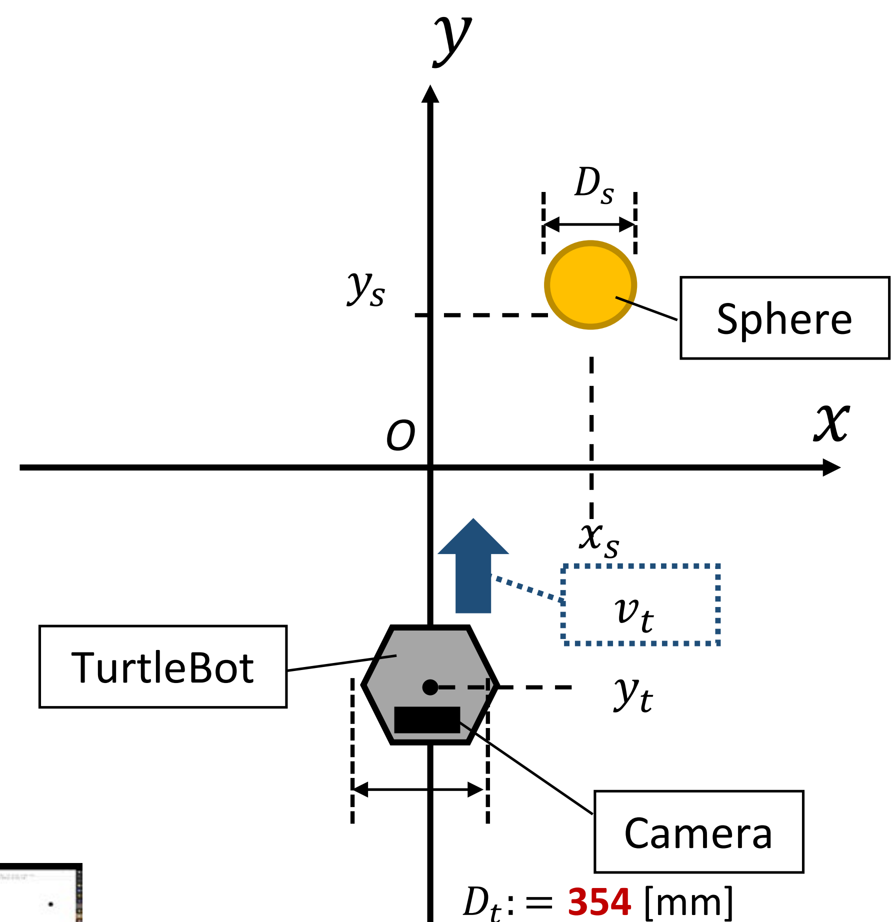
Layout for Evaluations

 Satoshi Seimiya(YNU), Ryuji Kohno(YNU/CWC-Nippon)

Layout for the Evaluation of Proposal B.1

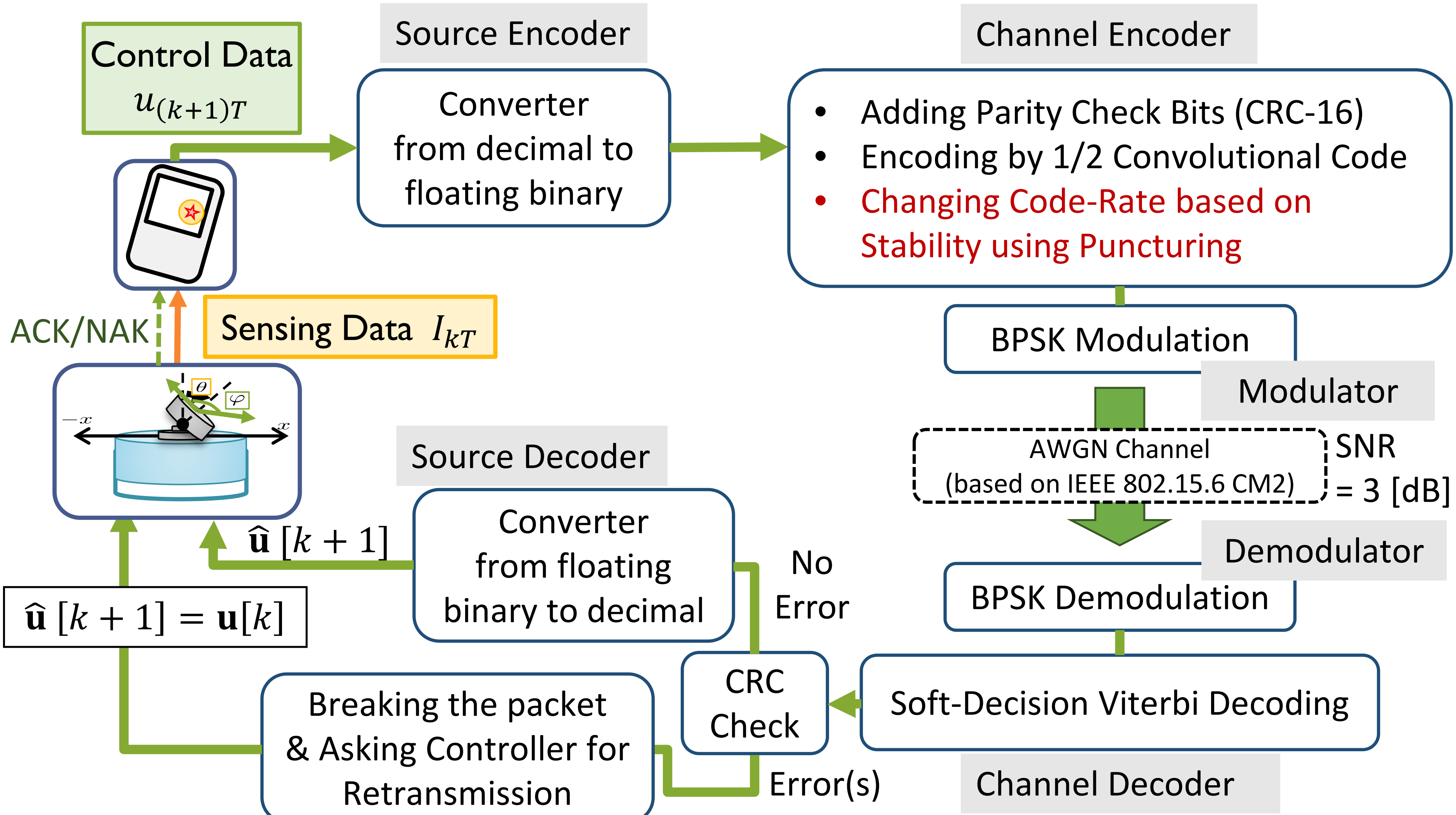


Assumed Layout

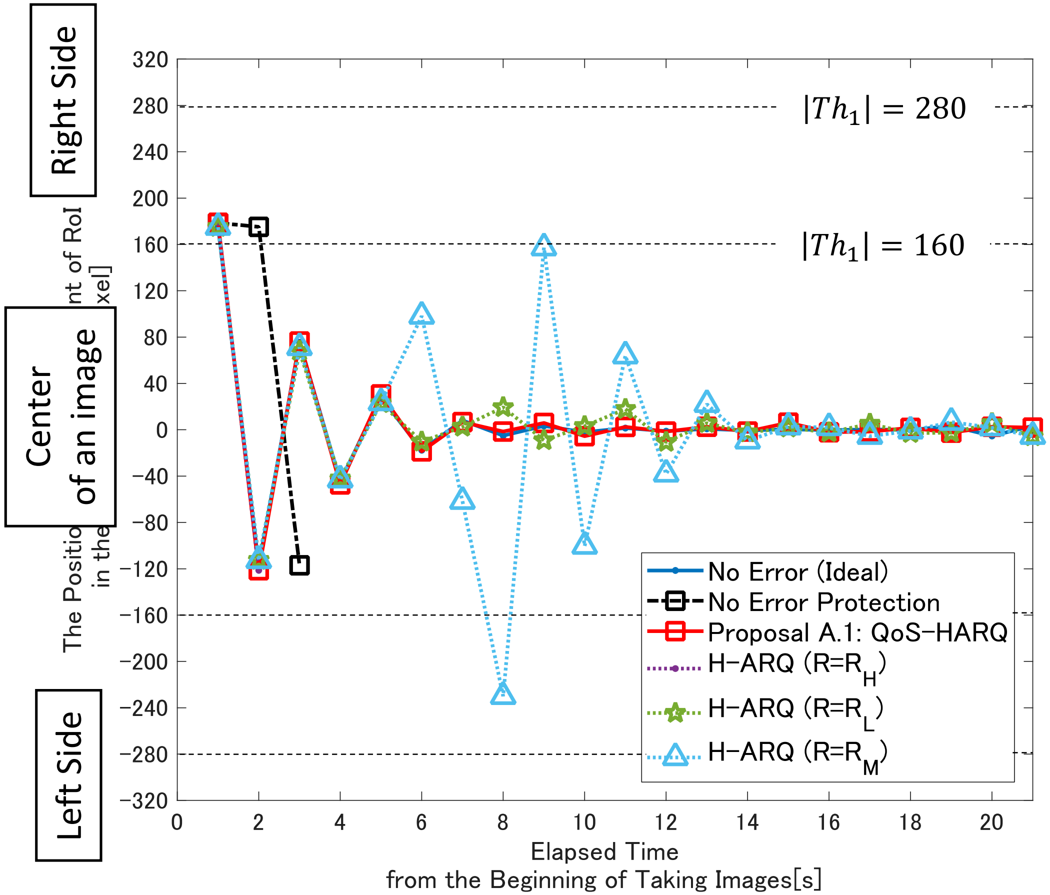


Layout for Evaluations

Wireless Comm. Department



【Scenario#1】 When the Camera is Stopped



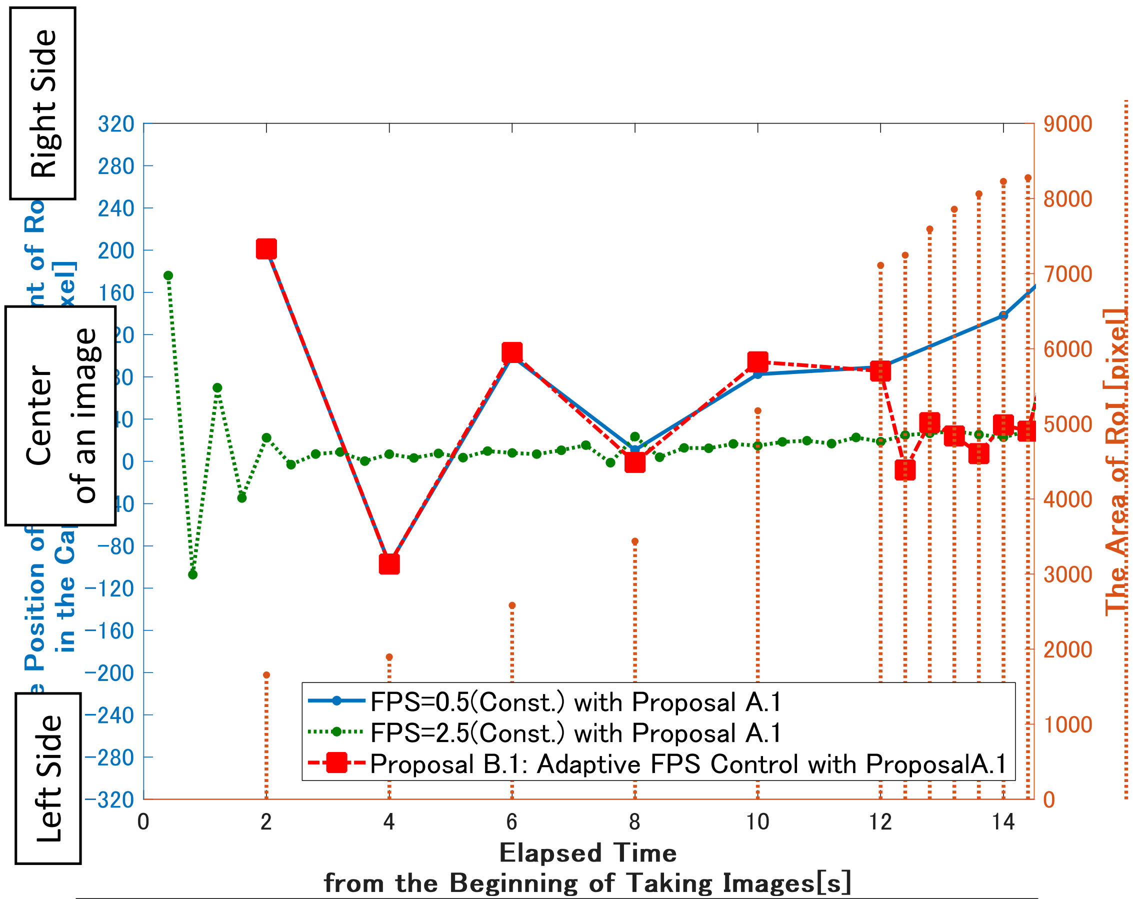
The Performance Evaluation Result of Proposal A.1: UEP Based on Positions(FPS=1)

<u>Consideration</u>

◎By changing the error correcting capability based o the position of the RoI, it enables to almost all of the same quality of control as the H-ARQ($R = R_L$)

✓ How to optimize the threshold of changing the code rate($=|Th_1|, |Th_2|$) is a challenging issue

【Scenario#2】When the Camera is Moved



The Performance Evaluation Result of
Proposal B.1: Adaptive FPS Control(FPS=1)

*R_{th} =0.02

Consideration

◎By changing FPS based on the size of RoI*, it enables to

- Capture the target at center of images
- with less number of capturing

✓ How to prevent from missing the target when the capturing interval is large(=FPS is low) is a challenging issue

※FPS: Frames per Second

Summary

【Error】
- Comm. Error…(∵Multipath Fading, Shadowing, …etc.)
- Control Error…(∵Comm. Error, Comm. Delay, …etc.)

(Proposal A.1) RoI's Positions-Based UEP
(Proposal A.2) Channel SNR-Based UEP

【Delay】
- Comm. Delay…(∵Limited Bandwidth, Retransmissions, …etc.)
- Control Delay…(∵Processing time, Comm. Delay)

(Proposal B.1) Adaptive FPS Control under aFPS
(Proposal B.2) Visual Predictive Control