V2.0.4

2024.03

GCU

Private Protocol

Using this Manual – Legend

 Important

 Tips

 Explanation

Revision History

Date	Document Version	Protocol Version
2023.06.19	V2.0	-

Date	Document Version	Protocol Version
2023.08.09	V2.0.1	V0.0

1. UART baudrate changes into self-adaptive. Add TCP Server mode in Network communication. [P1]
2. Add protocol version into data package. Correct the mistake of header in package from GCU. [P2]
3. Main data frame from host computer:
   - 3.1. Add desired euler angle and desired relative angle into roll/pitch/yaw control quantity (byte 5~10); [P3]
   - 3.2. Add control quantites effectiveness (bit B2) into statue (byte 11). [P3]
4. Sub data frame from host computer:
   - 4.1. Delete distance from Home (byte 57~60); [P4]
   - 4.2. Add relative height (byte 57~60) . [P4]
5. Main data frame from GCU:
   - 5.1. Add FPV mode and euler angle control mode into gimbal statue (byte 5); [P5]
   - 5.2. Delete exposure mode (bit B11) from camera statue (byte 6~7). [P5]
6. Sub data frame from GCU:
   - 6.1. Delete content of byte 59~61; [P6]
   - 6.2. Add current zoom rate of camera 1 (byte 59~60) and camera 2 (byte 61~62). [P6]
7. Command & Feedback:
   - 7.1. Add description of null command; [P7]
   - 7.2. Add command of FPV mode, euler angle control mode, external tracking mode and OSD; [P7~P9]
   - 7.3. Detail description of gaze mode; [P8]
   - 7.4. Modify parameters of shutter, record, focus, palette and Night vision command. [P8~P9]
8. Renew example data package. [P11~P16]

Date	Document Version	Protocol Version
2023.10.12	V2.0.2	V0.1

1. Add explanation on byte order of the protocol. [P2]
2. Main data frame from host computer:
   - 2.1 Add coordinate system definition into description of absolute roll, pitch and yaw angle of carrier (byte 12~17). [P3]
3. Main data frame from GCU:
   - 3.1 Add lighting statue (bit B10) into camera statue (bit B10). [P5]
   - 3.2 Correct the mistake of coordinate axis direction ("upward as positive" → "downward as positive") of vertical target-missing (byte 10~11). [P5]
   - 3.3 Add value range into description of X-ward/ Y-ward target-missing (byte 8~11). [P5]
   - 3.4 Add coordinate system definition and rotate order into description of X-axis/ Y-axis/ Z-axis absolute angular velocity of camera (byte 24~29). [P5]
4. Command & Feedback:
   - 4.1 Modify explanations on control quantities in descriptions of FPV mode, head lock mode and head follow mode. [P7]
   - 4.2 Correct the mistake of false feedback ("0x015 0x01" → "0x15 0x01") of gaze mode (geo-coordinates guide). [P8]
   - 4.3 Add coordinates of target frame’ s top-left corner and lower-right corner into description of track mode. [P8]
   - 4.4 Add coordinates of screen’ s top-left corner and lower-right corner in description of click to aim command. [P8]
   - 4.5 Add target-missing of screen’ s center, top-left corner and lower-right corner in description of external track mode. [P9]
5. Add appendix 1: example of transformation of data frame from host computer. [P12]
6. Add appendix 2: definition of carrier’ s coordinate system. [P13]
7. Add appendix 3: definition of camera’ s coordinate system and rotate order. [P14]
8. Add appendix5: GPS time & UTC conversion function.[P21]

Catalog

Port Configuration

UART Configuration

- **UART level**: TTL
- **Data bits**: 8
- **Stop bits**: 1
- **Parity**: None
- **Communication mode**: Full duplex
- **Baudrate**: 115200, 250000, 500000 and 1000000.
- **Communication frequency**: The recommended communication frequency range is 30~50Hz. The higher the frequency is, the better the effect of controlling is. There should not be too low frequency or data stop. There should not be BUS idle in one data package.

Network Configuration

- UDP mode: The source port is 2337 and the default destination is the LAN broadcast address. The target port is 2338.
- TCP Server mode: the port is 2332 and only support single client connecting.

Summary

The communication uses Q&A mode. The host computer transmits data package firstly. After receiving the correct package, the GCU returns its package. A complete data package is made up of protocol header, package length, main data frame, sub data frame, command / feedback and CRC data. The length of the package is S bytes. The length of command / feedback part is variable.

The command / feedback part includes order and parameter. Different order maps different parameter. Details as per chapter *Data Frame* in this document. The GCU will execute only once while continuously receiving commands with same order (even if the parameters are different). To trigger one same function, the data packages should be separated by a package with null command (Except *External track* command).

The structure of the data package is shown as below.

<table>
<tr><td colspan="9">Structure of package from host computer</td></tr>
<tr><td>0</td><td>1</td><td>2~3</td><td>4</td><td>5~36</td><td>37~68</td><td>69~S-3</td><td>S-2</td><td>S-1</td></tr>
<tr><td rowspan="2">0xA8</td><td rowspan="2">0xE5</td><td>Length</td><td>Version</td><td>Main data frame</td><td>Sub data frame</td><td>Command</td><td>CRC high</td><td>CRC low</td></tr>
<tr><td>U16</td><td>U8</td><td>32 bytes</td><td>32 bytes</td><td>Variable length</td><td colspan="2">U16</td></tr>
<tr><td colspan="9">Structure of package from GCU</td></tr>
<tr><td>0</td><td>1</td><td>2~3</td><td>4</td><td>5~36</td><td>37~68</td><td>69~S-3</td><td>S-2</td><td>S-1</td></tr>
<tr><td rowspan="2">0x8A</td><td rowspan="2">0x5E</td><td>Length</td><td>Version</td><td>Main data frame</td><td>Sub data frame</td><td>Feedback</td><td>CRC high</td><td>CRC low</td></tr>
<tr><td>U16</td><td>U8</td><td>32 bytes</td><td>32 bytes</td><td>Variable length</td><td colspan="2">U16</td></tr>
</table>

The data checked by CRC is Byte 0~S-3.

This protocol uses little-endian byte order (except CRC).

Data Frame

Main Data Frame from Host Computer

Byte	Content	Description	
5~6	Roll control quantity, only work in FPV mode and Euler angle control mode and be invalid in other modes	S16. When the control quantity is desired anglar velocity, the data range is [-1500,1500] and the resolution is 0.1/current main screen's zoom rate (deg/s); When the control quantity is desired euler angle, the data range is [-18000,18000] and the resolution is 0.01deg; When the control quantity is desired relative angle between gimbal and carrier, the data range is [-18000,18000] and the resolution is 0.01deg	
7~8	Pitch control quantity		
9~10	Yaw control quantity		
11	Statue	B7~B3: Reserved. These bits are 0 B2: 0 – Control quantity invalid; 1 - Control quantity valid; B1: Reserved. This bit is 0 B0: 0 – Carrier's INS invalid; 1 – Carrier's INS valid	
12~13	Absolute roll angle of carrier	S16, [-18000,18000). Euler angle. Resolution as 0.01deg	The definition of carrier's coordinate system is as per Appendix 2
14~15	Absolute pitch angle of carrier	S16, [-9000,9000]. Euler angle. Resolution 0.01deg	
16~17	Absolute yaw angle of carrier	U16, [0,36000). Euler angle. Resolution 0.01deg	
18~19	Northward acceleration of carrier	S16. Resolution 0.01m/s^2. Northwards as positive	These three accelerations are all 0 when the carrier is static or flying straightly at a constant speed.
20~21	Eastward acceleration of carrier	S16. Resolution 0.01m/s^2. Eastwards as positive	
22~23	Upward acceleration of carrier	S16. Resolution 0.01m/s^2. Upwards as positive	
24~25	Northward velocity of carrier	S16. Resolution 0.1m/s. Northwards as positive	
26~27	Eastward velocity of carrier	S16. Resolution 0.1m/s. Eastwards as positive	
28~29	Upward velocity of carrier	S16. Resolution 0.1m/s. Upwards as positive	
30	Request code of sub frame	Header of requested sub data frame from GCU	
31~36	Reserved	0x00	

Byte 12~29 are very important. Incorrect data will cause error of gimbal altitude calculation

Sub Data Frame from Host Computer

Byte	Content	Description
37	0x01	Header
38~41	Longitude of carrier	S32. Resolution 1e-7deg
42~45	Latitude of carrier	S32. Resolution 1e-7deg
46~49	Altitude of carrier	S32. Resolution 1mm
50	Available satellites	U8
51~54	GNSS microsecond	U32
55~56	GNSS week	S16
57~60	Relative height	S32. Resolution 1mm. Can be 0 if unneeded
61~68	Reserved	0x00

Byte 37~68 are all 0x00 if there is no sub frame data.

Main Data Frame from GCU

Byte	Content	Description	
5	Gimbal statue	0x10 – FPV mode 0x11 - Head lock 0x12 – Head follow 0x13 – Orthoview 0x14 – Euler angle control mode 0x16 - Gaze 0x17 – Track	
6~7	Camera statue	B15~B13: Reserved B12: 0-Downward power-on; 1-Upward power-on B11: Reserved B10: 0 - Lighting off; 1 - Lighting on B9: 0 - Night vision off; 1 - Night vision on B8: 0 - Ranging off; 1 - Ranging on B7: 0-Range and target coordinate invalid; 1-Range and target coordinate valid B6~B1: Reserved B0: 0 - Tracking fail; 1 - Tracking success	
8~9	Horizontal target-missing	S16. [-1000,1000]. Origin as center of the screen. Rightward as positive	
10~11	Vertical target-missing	S16. [-1000,1000]. Origin as center of the screen. Downward as positive	
12~13	X-axis relative angle of camera	S16. [-18000,18000). Relative angle to carrier of camera. Resolution 0.01deg. The definition of camera's coordinate system and the rotate order are as per Appendix 3	
14~15	Y-axis relative angle of camera		
16~17	Z-axis relative angle of camera		
18~19	Absolute roll angle of camera	S16. [-9000,9000]. Euler angle. Resolution 0.01deg	
20~21	Absolute pitch angle of camera	S16. [-18000,18000). Euler angle. Resolution 0.01deg	
22~23	Absolute yaw angle of camera	U16. [0,36000). Euler angle. Resolution 0.01deg	
24~25	X-axis absolute angular velocity of camera	S16. Resolution 0.01deg/s.	The definition of camera's coordinate system and the rotate order are as per Appendix 3
26~27	Y-axis absolute angular velocity of camera	S16. Resolution 0.01deg/s.	
28~29	Z-axis absolute angular velocity of camera	S16. Resolution 0.01deg/s.	
30~36	Reserve		

Sub Data Frame from GCU

Byte	Content	Description
37	0x01	Header
38	Hardware version	U8
39	Firmware version	U8
40	Gimbal code	Details as per table Gimble Code
41~42	Error code	Reserved
43~46	Distance from target	S32. Measurement from ranger finder. Resolution 0.1m. -1m or 0m represents invalid measurement
47~50	Longitude of target	S32. Resolution 1e-7deg
51~54	Latitude of target	S32. Resolution 1e-7deg
55~58	Altitude of target	S32. Resolution 1 mm
59~60	Current zoom rate of camera 1 (visible-light zoom camera by default)	U16. Resolution 0.1x
61~62	Current zoom rate of camera 2 (thermal camera by default)	U16. Resolution 0.1x
63~68	Reserved	

Byte 37~68 are all 0x00 while an illegal sub frame header is requested.

Gimble Code

Code	Model
0	Z-6A
2	Z-6C
3	M-2400G2
21	Z-8TA
22	Z-8TB
24	Z-8RA
25	Z-8RB
26	Z-8RC
27	Z-8LA
30	Z-9A
31	Z-9B
40	D-80AI
41	D-90AI
44	D-80Pro

Command & Feedback

Function	Order	Parm	Feedback	Description
Null	0x00		0x00	To separate commands with same order
Calibration	0x01		Success:0x01 0x00 Fail:0x01 0x01 Operating:0x01 0x02	The gimbal should keep static while calibrating, which lasts a few seconds
Neutral	0x03		Success:0x03 0x00 Fail:0x03 0x01	Gimbal returns its pitch and yaw neutral position without switching operation mode while in Head lock and Head follow mode. Gimbal returns its yaw neutral position without switching operation mode while in Orthoview mode. Gimbal returns its pitch and yaw neutral position and exit tracking while in Track mode. Gimbal does not response while in FPV, Euler angle control and Gaze mode.
FPV	0x10		Success:0x10 0x00 Fail:0x10 0x01	The attitude of the gimbal follows the carrier. The control quantities of pitch, roll and yaw are desired relative angle between gimbal and carrier.
Head lock	0x11		Success:0x11 0x00 Fail:0x11 0x01	The control quantities are desired pitch and yaw angular velocities. The gimbal locks current euler angles
Head follow	0x12		Success:0x12 0x00 Fail:0x12 0x01	The control quantities are desired pitch and yaw angular velocities. The pitch angle locks current euler angle while pitch control quantity is 0. The heading of the gimbal follows the carrier while yaw control quantity is 0, otherwise the gimbal rotates at desired yaw angular velocity
Orthoview	0x13		Success:0x13 0x00 Fail:0x13 0x01	The pitch angle of the gimbal locks -90 deg. The yaw angle locks current Euler angle and is controllable after switching from the head lock mode. Otherwise the yaw angle follows the carrier
Euler angle control	0x14		Success:0x14 0x00 Fail:0x14 0x01	The control quantities are desired euler angles

Function	Order	Parm	Feedback	Description
Gaze (Geo-coordinates guide)	0x15	PP PP PP PP QQ QQ QQ QQ RR RR RR RR	Success:0x15 0x00	PP PP PP PP / QQ QQ QQ QQ / RR RR RR RR: Longitude / latitude / altitude of the point of interest PP PP PP PP: S32. Revolution 1e-7deg QQ QQ QQ QQ: S32. Revolution 1e-7deg RR RR RR RR: S32. Revolution 1mm. To implement this function, ensure the GCU receiving vaild carrier's INS data
			Fail:0x15 0x01	
Gaze (Geo-coordinates lock)	0x16		Success:0x16 0x00	Gimbal constantly aims current position in the center of the view when desired angular velocities are 0. To implement this function, ensure the GCU receiving vaild carrier's INS data
			Fail:0x16 0x01v	
Track	0x17	KK TT X0 X0 Y0 Y0 X1 X1 Y1 Y1	Success:0x17 0x00	TT : U8. 0x01 – Start tracking; 0x00-Exit tracking X0 X0 / Y0 Y0 / X1 X1 / Y1 Y1: U16, [0,10000]. Horizontal / vertical coordinate of target frame's top-left corner and lower-right corner. Origin as the top-left corner of the screen. Rightwards as X-axis positive. Downwards as Y-axis positive.The coordinates of top-left corner and lower-right corner of the screen are [0,0] and [10000,10000], respectively. This function is realized by gimbal's built-in image processing unit
			Fail:0x17 NN	
Click to aim	0x1A	KK X0 X0 Y0 Y0	Success:0x1A 0x00	X0 X0 / Y0 Y0: U16, [0,10000]. Horizontal / vertical coordinate of the target. Origin as the top-left corner of the screen. Rightwards as X-axis positive. Downwards as Y-axis positive. The coordinates of top-left corner and lower-right corner of the screen are [0,0] and [10000,10000], respectively
			Fail:0x1A NN	

? The KK/NN(U8) is ordinal of operation triggered/failed cameras. B7~B0 correspond camera 8~1. A certain bit being 1 means its corresponding camera being tagged. For example, 0x03 (00000011) means camera 1 and camera 2. Camera 1 is visible-light zoom camera by default and camera 2 is thermal camera by default.

Function	Order	Parm	Feedback	Description
External track	0x1B	KK PP PP VV VV TT	Success:0x1B 0x00	PP PP / VV VV: S16, [-1024,+1024]. Horizontal / vertical missdistance of the target. Origin as the center of the screen. Rightwards as X-axis positive. Downwards as Y-axis positive. The target-missings, while the target is at the center, top-left corner and lower-right corner of the screen, are [0,0], [-1024,-1024] and [1024,1024] respectively Both of the PP PP and VV VV should be greater than equal to 3071 to indicate an invalid data when tracking fails. TT: U8. 0x02- Start tracking 0x00- Exit tracking This function is realized by an external device processing image and control the gimbal to aim at the target
			Fail:0x1B NN	
Shutter	0x20	0x01	Success:0x20 0x00	
			Fail:0x20 0x01	
Record start / stop	0x21	0x01	Success:0x21 0x00	
			Fail:0x21 0x01	
Continuously zoom in	0x22	KK	Success:0x22 0x00	
			Fail:0x22 NN	
Continuously zoom out	0x23	KK	Success:0x23 0x00	
			Fail:0x23 NN	
Zoom stop	0x24	KK	Success:0x24 0x00	
			Fail:0x24 NN	
Zoom to specified rate	0x25	KK ZZ ZZ	Success:0x25 0x00	ZZ ZZ: S16, [-32768, -10], [1, 10000]. The negative value is desired zoom rate, resolution 0.1x. The positive value is desired ratio of zoom rate, 1 corresponds the minimum rate and 10000 corresponds the maximum rate. The attainable maximum rate of this order will be subject to actual presentation of the product. Take a maximum 30x camera as an example. -10 and 1 cooresponds 1x, -150 and 5000 cooresponds 15x, -300 and 10000 cooresponds 30x
			Fail:0x25 NN	

? The KK/NN(U8) is ordinal of operation triggered/failed cameras. B7~B0 correspond camera 8~1. A certain bit being 1 means its corresponding camera being tagged. For example, 0x03 (00000011) means camera 1 and camera 2. Camera 1 is visible-light zoom camera by default and camera 2 is thermal camera by default.

Function	Order	Parm	Feedback	Description
Focus	0x26	0x01	Success:0x26 0x00 Fail: 0x26 0x01	
Palette	0x2A	0x02 TT	Success:0x2A 0x00 Fail:0x2A 0x02	TT: U8,[0,100]. Desired palette mode. 0x00 - Next palette option
Night vision	0x2B	0x01 TT	Success:0x2B 0x00 Fail:0x2B 0x01	TT: U8. 0x00 – Night vision off; 0x01 -Night vision on; 0x02 - Auto
OSD	0x73	TT	Success:0x73 0x00 Fail:0x73 0x01	TT:U8. 0x00 - OSD display 0x01 - OSD undisplay
Pic-in-pic	0x74	TT	Success:0x74 0x00 Fail:0x74 0x01	TT: U8. 0x00 – Next view
Lighting	0x80	TT	Success:0x80 0x00 Fail:0x80 0x01	TT: U8, [0,255]. Lighting intensity
Continuously ranging	0x81	TT	Success:0x81 0x00 Fail:0x81 0x01	TT: U8. 0x00 - Ranging off; 0x02-Ranging on

Turing on light will turn on night vision at the same time. Turning off light will not turn off night vision.

CRC Function

```
uint16_t CalculateCrc16(uint8_t *ptr,uint8_t len)
{
	uint16_t crc;
	uint8_t da;
	uint16_t crc_ta[16]={
	0x0000,0x1021,0x2042,0x3063,0x4084,0x50a5,0x60c6,0x70e7,
	0x8108,0x9129,0xa14a,0xb16b,0xc18c,0xd1ad,0xe1ce,0xf1ef,
	};
	crc=0;
	while(len--!=0)
	{
		da=crc>>12;
		crc<<=4;
		crc^=crc_ta[da^(*ptr>>4)];
		da=crc>>12;
		crc<<=4;
		crc^=crc_ta[da^(*ptr&0x0F)];
		ptr++;
	}
	return(crc);
}
```

Appendix 1 Example of Transformation of Data Frame from Host Computer

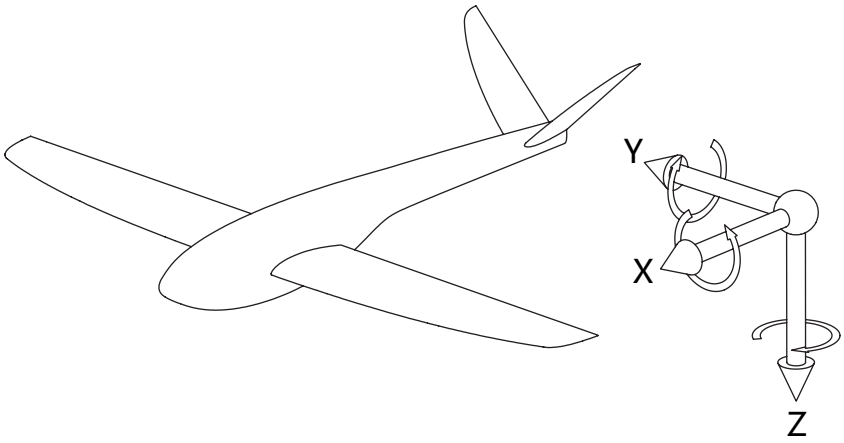
Byte	Content	Original Data	Accuracy or Binary Conversion	Hexadecimal (Little-endian)
0	Header	0xA8	-	A8
1		0xE5	-	E5
2-3	Package Length	72	72	48 00
4	Protocol Version	0x01	-	01
5-6	Roll Control Quantity	0	0	00 00
7-8	Pitch Control Quantity	100	100	64 00
9-10	Yaw Control Quantity	-100	-100	9C FF
11	Statue	Control Quantity Valid Carrier's INS Valid	0000 0101	05
12-13	Absolute Roll Angle of Carrier	-11.3213°	-1132	94 FB
14-15	Absolute Pitch Angle of Carrier	1.01°	101	65 00
16-17	Absolute Yaw Angle of Carrier	240°	24000	C0 5D
18-19	Acceleration of Carrier	1.123m/s^2	112	70 00
20-21	Eastward Acceleration of Carrier	-1.123m/s^2	-112	90 FF
22-23	Upward Acceleration of Carrier	1.123m/s^2	112	70 00
24-25	Northward Velocity of Carrier	21.123m/s	2112	40 80
26-27	Eastward Velocity of Carrier	-21.123m/s	-2112	C0 F7
28-29	Upward Velocity of Carrier	21.123m/s	2112	40 80
30	Request Code of Sub Frame	0x01	-	01
31-36	Reserved	-	-	00 00 00 00 00 00
37	Header of Sub Frame	0x01	-	01
38-41	Longitude of Carrier	170.917533212	1709175332	24 F2 DF 65
42-45	Latitude of Carrier	38.030082231	380300822	16 EE AA 16
46-49	Altitude of Carrier	41.1231m	41123	A3 A0 00 00

Byte	Content	Original Data	Accuracy or Binary Conversion	Hexadecimal (Little-endian)
50	Available Satellites	19	19	13
51-54	GNSS Microsecond	352718000	352718000	B0 0C 06 15
55-56	GNSS Week	2278	2278	E6 08
57-60	Relative Height	12.12m	12120	58 2F 00 00
61-68	Reserved	-	-	00 00 00 00 00 00 00 00
69	Null Command	0x00	-	00
70-71	CRC	-	-	E9 D4 (Big-endian)

The complete data package from the host computer:

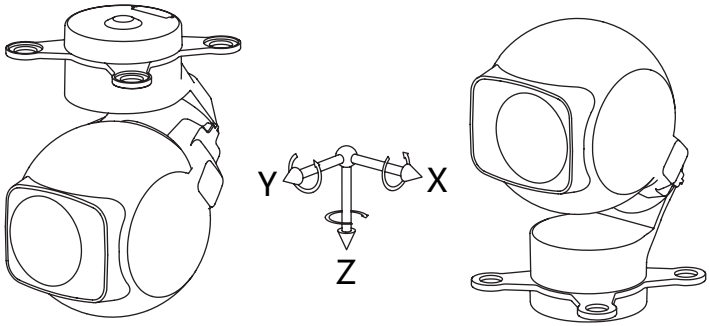
A8 E5 48 00 01 00 00 64 00 9C FF 05 94 FB 65 00 C0 5D 70 00 90 FF 70 00 40 80 C0 F7 40 80 01 00 00 00 00 00 00 01 24 F2 DF 65 16 EE AA 16 A3 A0 00 00 13 B0 0C 06 15 E6 08 58 2F 00 00 00 00 00 00 00 00 00 00 00 E9 D4

Appendix 2 Definition of Carrier's Coordinate System



Appendix 3 Definition of Camera's Coordinate System and Rotate Order

1. Coordinate system definition



Downword Power-on　　Upword Power-off

The control port of the gimbal should point to negative X-ward of the carrier. The damping platform should be parallel to the XOY plane of the carrier. The gimbal should be mount as close as possible to the C.G. of the carrier.

2. Rotate order: Z → Y → X.

3. Angles transformation：
Define:
CamPhi: Absolute roll angle of camera (Main data frame from GCU, byte 18~19)
CamThe: Absolute pitch angle of camera (Main data frame from GCU, byte 20~21)
CamPsi: Absolute yaw angle of camera (Main data frame from GCU, byte 22~23)
AngleX: X-axis absolute angle of camera
AngleY: Y-axis absolute angle of camera
AngleZ: Z-axis absolute angle of camera
The parameters above are transformed as below
AngleZ += 90;
WARP (AngleZ , 360);
CamPhi = +AngleY;
CamThe = -AngleX;
CamPsi = +AngleZ;

Appendix 4 Example Data Package

Null command
A8 E5 48 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 28 B2

Pitch control (keep current control mode, control quantity 100)
A8 E5 48 00 01 00 00 64 00 00 00 04 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 32 3E

Pitch control (keep current control mode, control quantity -100)
A8 E5 48 00 01 00 00 9C FF 00 00 04 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 DA AF

Yaw control (keep current control mode, control quantity 1000)
A8 E5 48 00 01 00 00 00 00 E8 03 04 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 09 C8

Neutral
A8 E5 48 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 03 18 D1

FPV (Roll 0° , Pitch 0° , Yaw 0°)
A8 E5 48 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 10 D4 27

FPV (Roll 0° , Pitch 45° , Yaw 60°)
A8 E5 48 00 01 00 00 94 11 70 17 04 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 10 9F F2

FPV (Roll 20° , Pitch 0° , Yaw 60°)
A8 E5 48 00 01 D0 07 00 00 00 00 04 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 10 D0 56

Head lock
A8 E5 48 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 11 2A A2

Switch to head lock and meanwhile yaw control (control quantity 1000)
A8 E5 48 00 01 00 00 00 00 E8 03 04 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 11 0B D8

Head follow
A8 E5 48 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 12 1A C1

Orthoview
A8 E5 48 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 13 0A E0

Euler angle control
A8 E5 48 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 14 94 A3

Euler angle control (Roll 0° , Pitch -45° , Yaw 0°)
A8 E5 48 00 01 00 00 6C EE 00 00 04 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 14 70 CB

Start tracking (X0=100, Y0=100, X1=105, Y1=105)
A8 E5 52 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 17 01 01 64 00 64 00 69 00 69 00 13 F0

Exit tracking
A8 E5 52 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 17 01 00 64 00 64 00 69 00 69 00 F8 D3

Click to aim (X=100(0x64), Y=100(0x64))
A8 E5 4D 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 1A 01 64 00 64 00 C0 D8

Click to aim (X=5000(0x1388), Y=5000(0x1388))
A8 E5 4D 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 1A 01 88 13 88 13 66 BE

Click to aim (X=10000(0x271), Y=10000(0x2710))
A8 E5 4D 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 1A 01 10 27 10 27 DB 12

Click to aim (X=10000(0x2710), Y=5000(0x1388))
A8 E5 4D 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 1A 01 10 27 88 13 3C 87

Shutter
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 01 61 B4

Record start/stop
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 21 01 52 85

Camera 1 continuously zooms in
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 22 01 07 D6

Camera 1 continuously zooms out
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 23 01 34 E7

Camera 1 continuously zooms stop
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 24 01 AD 70

Camera 1 continuously zooms to specified rate (5000, corresponds to half of max rate)
A8 E5 4B 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 25 01 88 13 D3 27

All cameras zoom to specified rate (-10(1.0x))
A8 E5 4B 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 25 FF F6 FF 56 0A

All cameras zoom to specified rate (-55(5.5x))
A8 E5 4B 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 25 FF C9 FF 43 A1

Camera 1 zooms to specified rate (-603(60.3x))
A8 E5 4B 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 25 01 A5 FD D5 F7

Focus
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 26 01 CB 12

Next palette option
A8 E5 4A 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 2A 02 00 C4 FF

Night vision on
A8 E5 4A 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 2B 01 01 B6 BD

Night vision off
A8 E5 4A 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 2B 01 00 A6 9C

Lighting on (255)
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 80 FF 72 1B

Lighting off (0)
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 80 00 6C EB

Continuously ranging on
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 81 02 7F 98

Continuously ranging off
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 81 00 5F DA

OSD display
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 73 01 82 B8

OSD undisplay
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 73 00 92 99

Next view of pic-in-pic
A8 E5 49 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 74 00 B3 EE

Appendix 5 GPS time & UTC conversion function (without leap second processing)

```
static const uint16_t gpst0[] = {1980, 1, 6, 0, 0, 0};
uint64_t epoch2time(const uint16_t *ep)
{
        const uint16_t _day[] = {1, 32, 60, 91, 121, 152, 182, 213, 244, 274, 305,
        335};
        uint64_t seconds = 0;
        uint16_t days, year = ep[0], mon = ep[1], day = ep[2];
        if (year < 1970 || 2099 < year || mon < 1 || 12 < mon) return seconds;
        /* leap year if year%4==0 in 1901-2099 */
        days=(year-1970)*365+(year-1969)/4+_day[mon-1]+day-2+(year%4==0
        && mon>=3?1:0);
        seconds = floor(ep[5]);
        seconds = (uint64_t)days * 86400 + ep[3] * 3600 + ep[4] * 60 + seconds;
        return seconds;
}
uint64_t gpst2time(int16_t week, uint32_t sec)
{
        uint64_t t = epoch2time(gpst0);
        if (sec < -1E9 || 1E9 < sec) sec = 0.0;
        t += 86400 * 7 * week + sec;
        return t;
}
uint8_t time2gps(uint64_t time, int16_t *week, uint32_t *msec)
{
        uint64_t t = epoch2time(gpst0);
        t = time - t;
        *week = t / 604800; // 604800=7*86400
        *msec = (t % 604800) * 1000;
        return 1;
}
```