V2.0.6

2024.10

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 value (byte 5~10); [P3]
   - 3.2. Add control quantites effectiveness (bit B2) into status (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 pod status (byte 5); [P5]
   - 5.2. Delete exposure mode (bit B11) from camera status (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 status (bit B10) into camera status (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 values 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]

Date	Document Version	Protocol Version
2024.06.20	V2.0.5	V0.2

1. Main Data Frame from Host Computer:
   1.1 Add explaination about control value effectivity (bit B2) in description of status (byte 11) . [P3]
2. Main Data Frame from GCU:
   2.1 Rename FPV to angle control 1 and add angle control 2 in pod operating mode (byte 5). [P5]
   2.2 Rename camera status(byte 6~7) to pod status. [P5]
3. Sub Data Frame from GCU:
   3.1 Add error code (byte 41~42). [P6]
   3.2 Add thermal camera status (byte 63). [P6]
   3.3 Add camera status (byte 64~65). [P7]
   3.4 Add time zone (byte 66). [P7]
4. Command & Feedback:
   4.1 Add commands of OSD coordinate, image auto reverse and time zone setting. [P8]
   4.2 Modify descriptions of angle control 1 (original FPV), head follow and Euler angle control. [P8]
   4.3 Add command of angle control 2. [P10]
   4.4 Modify the parameter range of palatte ([0,100]->[0,10]). [P11]
   4.5 Add commands of area temperature measurement, temperature alert, isotherm and spot temperature measurement. [P11~P12]
   4.6 Add function of switching to specified mode in pic-in-pic. [P12]
   4.7 Add commands of target detection and zoom camera digital zoom. [P13]
5. Add Appendix 2: Example of Transformation of Data Frame from GCU. [P16~P18]
6. Renew Appendix 5: Example Data Package. [P20~P28]
7. Add Appendix 7: Pod Code. [P30]

Date	Document Version	Protocol Version
2024.10.24	V2.0.6	V0.2

1. Main Data Frame from GCU:
   1.1 Rename Angle control 1 to Angle control and Angle control2 to FPV in Pod operating mode (byte 5).[P4]
2. Command & Feedback：
   2.1 Split Feedback into Order and Execution state.[P9]
   2.2 Modify descriptions of commands relevant to pod function.[P9]
3. Renew Appendix 7: Pod Code.[P31]
4. Add Appendix 8: Supported Command List.[P32]

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 opposite end should be set to TCP Clint mode. The remote IP address should be the same as GCU, and the remote port should be 2332.

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.

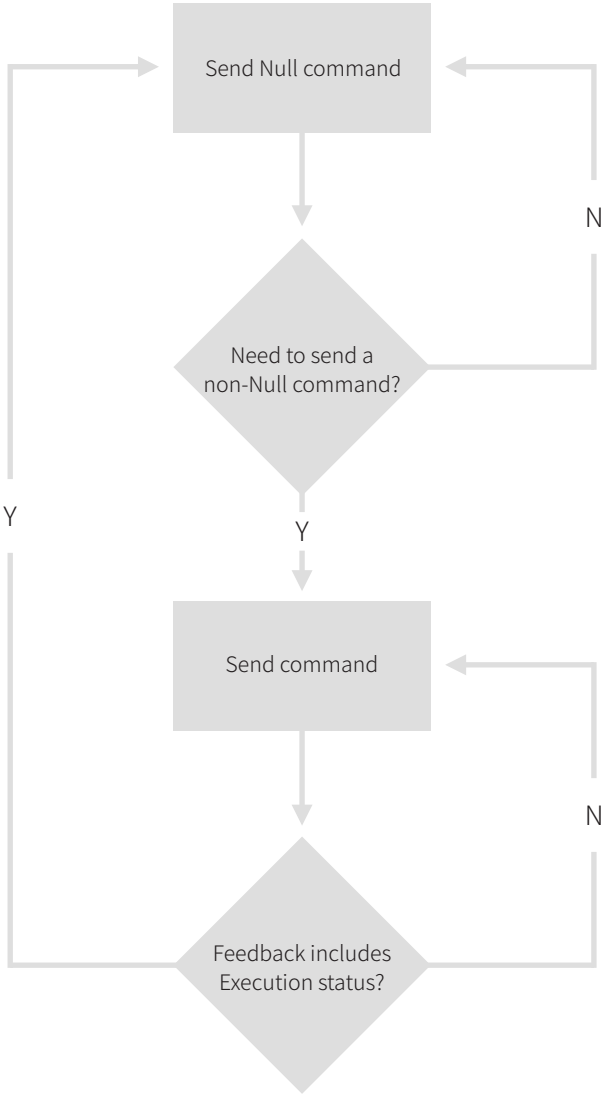
The structure of the data package is shown as below.

Structure of package from host computer									
0	1	2~3	4	5~36	37~68	69	70~S-3	S-2	S-1
0xA8	0xE5	Length	Version	Main data frame	Sub data frame	Order	Parameter	CRC high	CRC low
		U16	U8	32 bytes	32 bytes	U8	Variable length	U16	
Structure of package from GCU									
0	1	2~3	4	5~36	37~68	69	70~S-3	S-2	S-1
0x8A	0x5E	Length	Version	Main data frame	Sub data frame	Order	Execution state	CRC high	CRC low
		U16	U8	32 bytes	32 bytes	U8	Variable length	U16	

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

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

There is no Byte 70~S-3 in the package from host computer when there is no command parameter. There is no Byte 70~S-3 in the package from GCU when there is no command execution state.


Send Null command
N
Need to send a non-Null command?
Y
Y
Send command
N
Feedback includes Execution status?

Data Frame

Main Data Frame from Host Computer

Byte	Content	Description	
5~6	Roll control value, only work in FPV mode and Euler angle control mode and be invalid in other modes	S16. When the control value is desired angluar velocity, the data range is [-1500,1500] and the resolution is 0.1/current main screen's zoom rate (deg/s); When the control value is desired Euler angle, the data range is [-18000,18000] and the resolution is 0.01deg; When the control value is desired relative angle between pod and carrier, the data range is [-18000,18000] and the resolution is 0.01deg	
7~8	Pitch control value		
9~10	Yaw control value		
11	Status	B7~B3: Reserved. These bits are 0 B2: 0 – Control value invalid; 1 - Control value 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 pod 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	Pod operating mode	0x10 - Angle control 0x11 - Head lock 0x12 - Head follow 0x13 - Orthoview 0x14 - Euler angle control 0x16 - Gaze 0x17 - Track 0x1C - FPV
6~7	Pod status	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. These data are calculated from the motor encoder angles and do not depend on carrier's INS data
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]
20~21	Absolute pitch angle of camera	S16. [-18000,18000)
22~23	Absolute yaw angle of camera	U16. [0,36000)
24~25	X-axis absolute angular velocity of camera	S16. Resolution 0.01deg/s.
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	Pod code	Details as per Appendix 7	
41~42	Error code	B15: GCU hardware error B14: GNSS unpositioned B13: MAVLink communication frequency anomaly B12~B8: Reserved B7: Pod hardware error B6~B0: 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	These data depend on carrier's INS data
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	Thermal camera status	B7: 0 - Temperature measurement unavailable 1 - Temperature measurement available B6: 0 - Area temperature measurement off 1 - Area temperature measurement on B5: 0 - Temperature alert off 1 - Temperature alert on B4: 0 - Isotherm off 1 - Isotherm on B3: 0 - Spot temperature measurement off 1 - Spot temperature measurement on B2: Reserved B1: High temperature alert B0: Low temperature alert	

Byte	Content	Description
64~65	Camera status	B15: 0 - Target detection off 1 - Target detection on B14: 0 - Digital zoom off 1 - Digital zoom on B13: 0 - OSD off 1 - OSD on B12: 0 - OSD displays carrier's coordinate 1 - OSD displays target's coordinate B11: 0 - Image auto reverse on 1 - Image auto reverse off B10~B5: Reserved B4: 0 - Not recording 1 - Recording B3: Reserved B2~B0: uint_t. Pic-in-pic mode
66	Time zone	S8
67~68	Reserved	-

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

Command & Feedback

Null Command

Function	Order	Parameter	Execution State	Description
Null	0x00	-	-	To separate commands with same order

Pod Function

Function	Order	Parameter	Execution State	Description
Calibration	0x01	-	Success:0x00 Fail: 0x01 Operating: 0x02	The pod should keep static while calibrating, which lasts a few seconds
Neutral	0x03	-	Success: 0x00 Fail: 0x01	Pod returns its pitch and yaw neutral position without switching operation mode while in Head lock and Head follow mode; Pod returns its yaw neutral position without switching operation mode while in Orthoview mode; Pod does not response while in Angle control, Euler angle control, Gaze, Track and FPV mode; The control values should be invalid while this command is in progress
Angle control	0x10	-	Success: 0x00 Fail: 0x01	Control values: Roll – Desired Euler angle; Pitch – Desired Euler angle; Yaw – Desired relative angle
Head lock	0x11	-	Success: 0x00 Fail: 0x01	Control values: Roll – Invalid; Pitch – Desired angular velocity; Yaw – Desired angular velocity
Head follow	0x12	-	Success: 0x00 Fail: 0x01	Control values: Roll – Invalid; Pitch – Desired angular velocity; Yaw – Desired angular velocity (follows the carrier when be 0 or invalid)
Orthoview	0x13	-	Success: 0x00 Fail: 0x01	Control values: Roll – Invalid; Pitch – Invalid (-90deg Euler angle); Yaw – Desired angular velocity (follows the carrier when be 0 or invalid after switching from Head follow)
Euler angle control	0x14	-	Success: 0x00 Fail: 0x01	Control values: Roll – Desired Euler angle; Pitch – Desired Euler angle; Yaw – Desired Euler angle

Function	Order	Parameter	Execution State	Description
Gaze (Geo-coordinates guide)	0x15	PP PP PP PP QQ QQ QQ QQ RR RR RR RR	Success: 0x00 Fail: 0x01	The pod constantly aims the target geo-coordinate point when the control values are 0 or invalid; 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; The pod will switch to Gaze (geo-target lock) if the control values are valid and not 0
Gaze (Geo-target lock)	0x16	-	Success: 0x00 Fail: 0x01	The pod constantly aims the geographic target in the center of view when the control values are 0 or invalid; Control values： Roll – Invalid; Pitch – Desired angular velocity; Yaw – Desired angular velocity; To implement this function, ensure the GCU receiving vaild carrier's INS data
Track	0x17	0x01 TT X0 X0 Y0 Y0 X1 X1 Y1 Y1	Success: 0x00 Fail: 0x01	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 pod's built-in image processing unit; The control values are invalid

Function	Order	Parameter	Execution State	Description
Click to aim	0x1A	0x01 X0 X0 Y0 Y0	Success: 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; The control values should be invalid while this command is in progress. The pod will switch to Headlock mode after executing this command
			Fail: 0x01	
FPV	0x1C	-	Success: 0x00	The control values are desired relative angles between the pod and carrier. The pod follows the carrier while the control values are invalid.
			Fail: 0x01	

Camera Function

Function	Order	Parameter	Execution State	Description
OSD coordinate	0x06	TT	Success: 0x00	TT: U8 0x00 - Carrier's coordinate 0x01 - Target's coordinate
			Fail: 0x01	
Image auto reverse	0x07	TT	Success: 0x00	TT: U8 0x00 - Auto reverse on 0x01 - Auto reverse off
			Fail: 0x01	
Time zone	0x08	TT	Success: 0x00	TT: S8
			Fail: 0x01	
Shutter	0x20	0x01	Success: 0x00	-
			Fail: 0x01	
Record start / stop	0x21	0x01	Success: 0x00	-
			Fail: 0x01	
Continuously zoom in	0x22	KK	Success: 0x00	-
			Fail: NN	
Continuously zoom out	0x23	KK	Success: 0x00	-
			Fail: NN	
Zoom stop	0x24	KK	Success: 0x00	-
			Fail: 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	Parameter	Execution State	Description
Zoom to specified rate	0x25	KK ZZ ZZ	Success: 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: NN	
Focus	0x26	0x01	Success: 0x00	-
			Fail: 0x01	
Palette	0x2A	0x02 TT	Success: 0x00	TT: U8,[0,10]. Desired palette mode. 0x00 - Next palette option
			Fail: 0x02	
Night vision	0x2B	0x01 TT	Success: 0x00	TT: U8. 0x00 – Night vision off; 0x01 -Night vision on; 0x02 - Auto
			Fail: 0x01	
Area temperature measurement	0x30	0x02 TT X0 X0 Y0 Y0 X1 X1 Y1 Y1	Success: 0x00	TT: U8. 0x00 - Area temperature measurement off. 0x01 - Area temperature measurement on. X0 X0 / Y0 Y0 / X1 X1 / Y1 Y1: U16. [0,10000]. Horizontal / vertical coordinate of measurement area's top-left / lower-right corner. Origin as the top-left corner of the screen. Rightwards as X-axis positive and downwards as Y-axis positive. The coordinates of the top-left corner and the lower-right corner of the screen are [0,0] and [10000,10000], respectively.
			Fail: 0x02	

? 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	Parameter	Execution State	Description
Temperature alert	0x31	0x02 TT HH HH LL LL	Success: 0x00	TT: U8. 0x00 - Area temperature measurement off. 0x01 - Area temperature measurement on. HH HH / LL LL: S16. High / low alert temperature. Resolution 0.1° C
			Fail: 0x02	
Isotherm	0x02	0x02 TT HH HH LL LL	Success: 0x00	TT: U8. 0x00 - Isotherm off. 0x01 - Interval mode HH HH / LL LL: S16. High/ low temperature threshold. Resolution 0.1° C
			Fail: 0x02	
Spot temperature measurement	0x33	0x02 TT X0 X0 Y0 Y0	Success: 0x00	TT: U8. 0x00 - Spot temperature measurement off. 0x01 - Spot temperature measurement on. X0 X0 / Y0 Y0: U16, [0,10000]. Horizontal / vertical coordinate of measurement point. Origin as the top-left corner of the screen. Rightwards as X-axis positive and downwards as Y-axis positive. The coordinates of the top-left corner and the lower-right corner of the screen are [0,0] and [10000,10000], respectively.
			Fail: 0x02	
OSD	0x73	TT	Success: 0x00	TT: U8. 0x00 - OSD display 0x01 - OSD undisplay
			Fail: 0x01	
Pic-in-pic	0x74	TT	Success: 0x00	TT: U8, [0,4]. Desired pic-in-pic mode. 0x00 - Next pic-in-pic option.
			Fail: 0x01	

Function	Order	Parameter	Execution State	Description
Target detection	0x75	TT	Success: 0x00 Fail: 0x01	TT: U8. 0x00 - Target detection off. 0x01 - Target detection on.
Zoom camera digitial zoom	0x76	TT	Success: 0x00 Fail: 0x01	TT: U8. 0x00 - Digitial zoom off. 0x01 - Digitial zoom on.
Lighting	0x80	TT	Success: 0x00 Fail: 0x01	TT: U8, [0,255]. Lighting intensity
Continuously ranging	0x81	TT	Success: 0x00 Fail: 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	V0.2	-	02
5-6	Roll Control Value	0	0	00 00
7-8	Pitch Control Value	100	100	64 00
9-10	Yaw Control Value	-100	-100	9C FF
11	Status	Control Value 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 08
26-27	Eastward Velocity of Carrier	-21.123m/s	-2112	C0 F7
28-29	Upward Velocity of Carrier	21.123m/s	2112	40 08
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	-	-	5D 1B

The complete data package from the host computer:

A8 E5 48 00 02 00 00 64 00 9C FF 05 94 FB 65 00 C0 5D 70 00 90 FF 70 00 40 08 C0 F7 40 08 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 5D 1B

Appendix 2 Example of Transformation of Data Frame from GCU

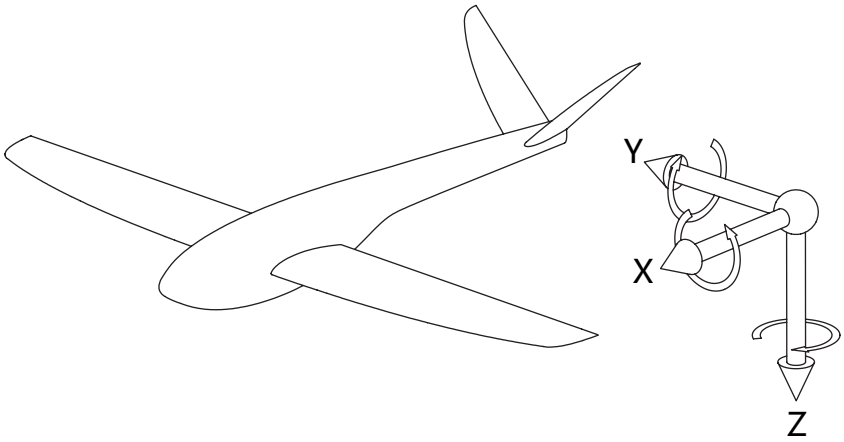
The complete data package from GCU:

8A 5E 49 00 02 12 01 80 0C FE F4 01 DD FC 20 00 4A 18 FF FF A5 03 47 18 FF FF 01 00 FE FF 00 00 00 00 00 00 00 01 1F 32 29 00 00 06 17 00 00 24 F2 DF 65 16 EE AA 16 A3 A0 00 00 2B 01 14 00 00 00 00 08 00 00 20 00 EC 85

Byte	Content	Original Data (Hexadecimal)	Parsed Data
0	Header	A8	0xA8
1		5E	0x5E
2~3	Package Length	49 00	73
4	Protocol Version	02	V0.2
5	Pod Operation mode	12	Head follow
6~7	Pod Status	01 80	0000 0001 1000 0000 Ranging on. Range and target corrdinate valid.
8~9	Horizontal target-missing	0C FE	-500
10~11	Vertical target-missing	F4 01	500
12~13	X-axis relative angle of camera	DD FC	-8.03°
14~15	Y-axis relative angle of camera	20 00	0.32°
16~17	Z-axis relative angle of camera	4A 18	62.18°
18~19	Absolute roll angle of camera	FF FF	-0.01°
20~21	Absolute pitch angle of camera	A5 03	9.33°
22~23	Absolute yaw angle of camera	47 18	62.15°
24~25	X-axis absolute angular velocity of camera	FF FF	-0.1deg/s
26~27	Y-axis absolute angular velocity of camera	01 00	0.1deg/s
28~29	Z-axis absolute angular velocity of camera	FE FF	-0.2deg/s
30~36	Reserved	00 00 00 00 00 00 00	-
37	Sub header	01	-
38	Hardware version	1F	3.1
39	Firmware version	32	5.0
40	Pod code	29	D-90AI
41~42	Error code	00 00	-
43~46	Distance from target	06 17 00 00	589.4m
47~50	Longitude of target	24 F2 DF 65	170.9175332
51~55	Latitude of target	16 EE AA 16	38.0300822
55~58	Altitude of target	A3 A0 00 00	41.123m
59~60	Current zoom rate of camera 1	2B 01	29.9x

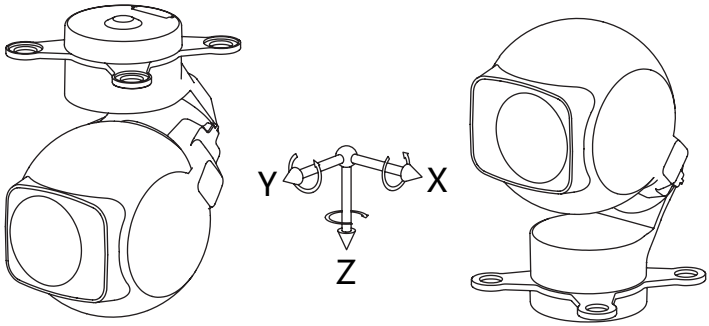
Byte	Content	Original Data (Hexadecimal)	Parsed Data
61~62	Current zoom rate of camera 2	14 00	2x
63	Thermal camera status	00	-
64~65	Camera status	00 00	-
66	Time zone	08	UTC+8
67~68	Reserved	00 00	-
69~70	Feedback	20 00	Shutter success
71~72	CRC	EC 85	-

Appendix 3 Definition of Carrier's Coordinate System



Appendix 4 Definition of Camera's Coordinate System and Rotate Order

1. Coordinate system definition



Downword Power-on　　Upword Power-off

The control port of the pod should point to negative X-ward of the carrier. The damping platform should be parallel to the XOY plane of the carrier. The pod 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 5 Example Data Package

Null command
A8 E5 48 00 02 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 00 00 00 00 FD 13

Pitch control (keep current control mode, control value 100)
A8 E5 48 00 02 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 00 00 00 00 E7 9F

Pitch control (keep current control mode, control value -100)
A8 E5 48 00 02 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 00 00 00 00 0F 0E

Yaw control (keep current control mode, control value 1000)
A8 E5 48 00 02 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 00 00 00 00 DC 69

Neutral
A8 E5 48 00 02 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 00 00 00 03 CD 70

OSD displays carrier's coordinate
A8 E5 49 00 02 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 00 00 06 00 E7 0D

OSD displays target's coordinate
A8 E5 49 00 02 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 00 00 06 01 F7 2C

Image auto reverse on
A8 E5 49 00 02 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 07 00 D4 3C

Image auto reverse off
A8 E5 49 00 02 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 07 01 C4 1D

Time zone setting (UTC-2)
A8 E5 49 00 02 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 08 FE CA D3

Angle control (control values invalid)
A8 E5 48 00 02 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 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 01 86

Angle control (Euler angle: roll 0° , pitch 45° , yaw 60°)
A8 E5 48 00 02 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 00 10 4A 53

Angle control (Euler angle: roll 20° , pitch 0° , yaw 0°)
A8 E5 48 00 02 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 05 F7

Head lock (control values invalid)
A8 E5 48 00 02 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 FF 03

Head lock (relative angular velocity +10° /s)
A8 E5 48 00 02 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 11 DE 79

Head follow (control values invalid)
A8 E5 48 00 02 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 12 CF 60

Orthoview (control values invalid)
A8 E5 48 00 02 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 13 DF 41

Euler angle control (control values invalid)
A8 E5 48 00 02 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 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 41 02

Euler angle control (Euler angle: roll 0° , pitch -45° , yaw 0°)
A8 E5 48 00 02 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 14 A5 6A

Start tracking (X0=100, Y0=100, X1=105, Y1=105)
A8 E5 52 00 02 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 17 01 01 64 00 64 00 69 00 69 00 20 55

Exit tracking
A8 E5 52 00 02 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 17 01 00 64 00 64 00 69 00 69 00 CB 76

Click to aim (X=100, Y=100)
A8 E5 4D 00 02 00 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 1A 01 64 00 64 00 48 AF

Click to aim (X=5000, Y=5000)
A8 E5 4D 00 02 00 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 1A 01 88 13 88 13 EE C9

Click to aim (X=10000, Y=10000)
A8 E5 4D 00 02 00 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 1A 01 10 27 10 27 53 65

Click to aim (X=10000, Y=5000)
A8 E5 4D 00 02 00 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 1A 01 10 27 88 13 B4 F0

FPV (control values invalid)
A8 E5 48 00 02 00 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 1C 2E AE

Shutter
A8 E5 49 00 02 00 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 20 01 5B 6C

Start/stop recording
A8 E5 49 00 02 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 00 00 00 00 00 21 01 68 5D

Camera 1 continuously zooms in
A8 E5 49 00 02 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 00 00 00 00 00 22 01 3D 0E

Camera 1 continuously zooms out
A8 E5 49 00 02 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 00 00 00 00 00 23 01 0E 3F

Camera 1 stop zooming
A8 E5 49 00 02 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 00 00 00 00 00 24 01 97 A8

Camera 1 zooms to specified rate (5000, corresponds to half of max rate)
A8 E5 4B 00 02 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 00 00 00 00 00 25 01 88 13 73 0C

All cameras zoom to specified rate (1.0x)
A8 E5 4B 00 02 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 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 F6 21

All cameras zoom to specified rate (5.5x)
A8 E5 4B 00 02 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 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 E3 8A

Camera 1 zooms to specified rate (60.3x)
A8 E5 4B 00 02 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 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 75 DC

Focus
A8 E5 49 00 02 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 26 01 F1 CA

Next palette option
A8 E5 4A 00 02 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 2A 02 00 8B E6

Palette mode 3
A8 E5 4A 00 02 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 2A 02 03 BB 85

Night vision on
A8 E5 4A 00 02 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 2B 01 01 F9 A4

Night vision off
A8 E5 4A 00 02 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 2B 01 00 E9 85

Area temperature measurement on (X0=4000, Y0=4000, X1=6000, Y1=6000)
A8 E5 52 00 02 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 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 30 02 01 A0 0F A0 0F 70 17 70 17 BE 6D

Area temperature measurement off

A8 E5 52 00 02 00 00 00 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01 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 30 02 00 00 00 00 00 00 00 00 00 33 96

Temperature alert on (high alert temperature 30.2 ° C, low alert temperature 20.0° C)

A8 E5 4E 00 02 00 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 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 31 02 01 2E 01 C8 00 E8 93

Temperature alert off

A8 E5 4E 00 02 00 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 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 31 02 00 2E 01 C8 00 42 C2

Isotherm on (interval mode, 15.0° C~25.2° C)

A8 E5 4E 00 02 00 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 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 32 02 01 FC 00 96 00 6F FA

Isotherm off

A8 E5 4E 00 02 00 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 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 32 02 00 FC 00 96 00 C5 AB

Spot temperature measurement on (X=4000, Y=5000)

A8 E5 4E 00 02 00 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 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 33 02 01 A0 0F 88 13 C3 8D

Spot temperature measurement off

A8 E5 4E 00 02 00 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 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 33 02 00 00 00 88 13 AF 9B

OSD on
A8 E5 49 00 02 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 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 B8 60

OSD off
A8 E5 49 00 02 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 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 A8 41

Next pic-in-pic option
A8 E5 49 00 02 00 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 89 36

Pic-in-pic mode 3
A8 E5 49 00 02 00 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 03 B9 55

Target detection on
A8 E5 49 00 02 00 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 75 01 AA 26

Target detection off
A8 E5 49 00 02 00 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 75 00 BA 07

Zoom camera digital zoom on
A8 E5 49 00 02 00 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 76 01 FF 75

Zoom camera digital zoom off
A8 E5 49 00 02 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 76 00 EF 54

Lighting on (255)
A8 E5 49 00 02 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 80 FF 48 C3

Lighting off
A8 E5 49 00 02 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 80 00 56 33

Continuously ranging on
A8 E5 49 00 02 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 81 02 45 40

Continuously ranging off
A8 E5 49 00 02 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 81 00 65 02

Appendix 6 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;
}
```

Appendix 7 Pod Code

Code	Model
0	Z-6A
2	Z-6C
25	Z-8RB
26	Z-8RC
31	Z-9B_V3
40	D-80AI
41	D-90AI
44	D-80Pro
45	D-90Pro(TA)
49	Z-1Pro
50	Z-1Mini
52	Z-2Mini
53	D-125AI(T)
55	D-90DE
57	D-125AI(V)
58	Z-9B_V4(T)
59	Z-9B_V4(V)
60	D-90Pro(VA)
61	D-90Pro(T)
62	D-90Pro(V)

(T): Thermometry Type
(TA): Thermometry Type + AICore
(V): View Type
(VA): View Type + AICore

Appendix 8 Supported Command List

Commands not listed in the table are supported by all models.

Command	Z-6A	Z-6C	Z-8RB	Z-8RC	Z-9B_V3	D-80AI
Track	●	○	●	○	●	●
OSD coord.	○	○	○	○	○	○
Image reverse	○	○	○	○	○	○
Time zone	○	○	○	○	○	○
Specified rate	○	○	○	○	○	●
Focus	●	●	●	●	●	●
Palette	○	○	○	○	●	○
Night vision	●	●	●	●	●	●
Area temp.	○	○	○	○	○	○
Temp. alert	○	○	○	○	○	○
Isotherm	○	○	○	○	○	○
Spot temp.	○	○	○	○	○	○
OSD	○	○	○	○	○	●
Pic-in-pic	○	○	○	○	●	●
Detection	○	○	○	○	○	○
Digitial zoom	○	○	○	○	○	○
Lighting	○	○	○	○	●	●
Ranging	○	○	●	●	●	○

Command	D-90AI	D-80Pro	D-90Pro(TA)	Z-1Pro	Z-1Mini	Z-2Mini
Track	●	●	●	●	●	●
OSD coord.	○	○	●	●	●	●
Image reverse	○	○	●	●	●	●
Time zone	○	○	●	●	●	●
Specified rate	●	●	●	●	●	●
Focus	●	●	●	○	○	○
Palette	●	○	●	○	○	●
Night vision	●	●	●	○	○	○
Area temp.	○	○	●	○	○	○
Temp. alert	○	○	●	○	○	○
Isotherm	○	○	●	○	○	○
Spot temp.	○	○	●	○	○	○
OSD	●	○	●	●	●	●
Pic-in-pic	●	○	●	○	○	●
Detection	○	○	●	●	●	●
Digitial zoom	○	○	●	○	○	○
Lighting	○	●	○	○	○	○
Ranging	●	○	●	○	○	○

Command	D-125AI(T)	D-90DE	D-125AI(V)	Z-9B_V4(T)	Z-9B_V4(V)
Track	●	●	●	●	●
OSD coord.	●	○	●	●	●
Image reverse	●	○	●	●	●
Time zone	●	○	●	●	●
Specified rate	●	●	●	●	●
Focus	●	●	●	●	●
Palette	●	○	●	●	●
Night vision	●	●	●	●	●
Area temp.	●	○	○	●	○
Temp. alert	●	○	○	●	○
Isotherm	●	○	○	●	○
Spot temp.	●	○	○	●	○
OSD	●	●	●	●	●
Pic-in-pic	●	●	●	●	●
Detection	●	○	●	●	●
Digitial zoom	●	○	●	●	●
Lighting	○	○	○	●	●
Ranging	●	●	●	●	●

Command	D-90Pro(VA)	D-90Pro(T)	D-90Pro(V)
Track	●	○	○
OSD coord.	●	●	●
Image reverse	●	●	●
Time zone	●	●	●
Specified rate	●	●	●
Focus	●	●	●
Palette	●	●	●
Night vision	●	●	●
Area temp.	○	●	○
Temp. alert	○	●	○
Isotherm	○	●	○
Spot temp.	○	●	○
OSD	●	●	●
Pic-in-pic	●	●	●
Detection	●	○	○
Digitial zoom	●	●	●
Lighting	○	○	○
Ranging	●	●	●