28th Satellite Design Contest Satellite Overview

Application category

Design Section

1. Work information/Applicants information

Work title (less than 20 words) The Artificial Intelligence of Locale ICE jam floods (ALICE)		
Subtitle (Only when you wish to make a special case. This may be removed from official documents.)		
	Name	Affiliation including faculty, department (Lab) and year of study
Group representative	Chih, Jhao-Sian	Department of Aeronautics and Astronautics, 3rd Year (Junior)
Group representative (Sub)		
Member 1	Huang, Hong-Sheng	Department of Aeronautics and Astronautics, 3rd Year (Junior)
Member 2	Fan, Yu-Hao	Department of earth science, 4th Year (Senior)
Member 3	Wang, Yan-Jun	Department of physics, 4th Year (Senior)
Member 4	Tsai, Feng-Yang	Department of physics, 2nd Year (Sophomore)
Member 5	Li, Jie-Lin	Department of earth science, 2nd Year (Sophomore)
Member 6		
Member 7		
Member 8		

2. Outline of the satellite (approx. 200 words)

The main objective of ALICE mission is set to monitor the ice jam flood that occurs in the wintertime, say October to April in the North Hemisphere. Six identical satellites with an initial altitude of 620 km and the inclination angle of 120 degrees are programmed in this mission. The payload of the ALICE mission consists of an RGB imager with a high resolution and enough field of view. The images taken by this camera are processed onboard autonomously and rivers will be identified by an artificial intelligence (AI) algorithm running on an M300-Xavier Processor. Comparing the geometry of the rivers derived by ALICE observation with an onboard database, the flood can be detected and warmed in the early time and the images and analysis result can be also sent to the ground station immediately. With the assistance of the AI and large onboard storage, the raw images can be processed in the space instead of downloading all of them to the ground, the idea of the ALICE mission can greatly reduce the response time in the natural disaster warning, and effectively help to prevent the damages by early warnings.

3. Mission requirement (Aims of satellite) and significance

(a) Mission requirement (Aims of satellite)

The Artificial Intelligence of Locale ICE jam floods (ALICE) is proposed to monitor the ice floods and ice jams by using the low earth orbiting satellites. And the space-borne deep learning model is developed to determine the possibility of ice-jam flooding and provide an early warning to the ground segment.

(b) Importance, technical significance

The satellite technology is important for early warning of natural disasters. Ice-jam floods is a significant issue because the location of ice-jam occurring is mostly remote, but it's a serious issue about people safe and climate change. The current method that download the raw data to process and observe ice-jam is too slow to predict and prevent the loss or damage from ice-jam floods. The artificial intelligent algorithm is the technical significance of ALICE. It can directly to judge the correction data from payload, and warning for the disaster.

4. Anticipated results

The ice-jam flood occurs in the mid- to high-latitude area every year and may cause damages. To this day, the remote sensing satellites capable of monitoring the ice-jam floods are still few. However, the ice-jam flood happens in high latitude area, it's highly related about global warming and ice layer melting. ALICE can provide the early warnings of ice-jam flood and images the focused flooding area intelligently. From the view of safety and economy, the early warning by the ALICE mission can have more time to evacuate the residents with high risk and greatly reduce the loss from the ice-jammed flood. From the view of study and nature, the image data is valuable for study to understand the ice-jam and protect the environment.

5. Originality and/or social effects

The originality of ALICE includes the AI model on the satellite and the instant messaging system set up with Iridium. The ALICE mission is proposed firstly to monitor the ice-jam flood by artificial intelligent. With climate change, the various disaster threatens human life and nature environment. According to the Sustainable Development Goals, climate change and environmental degradation is the global challenges all human facing. Ice-jam flood is one of a disaster closely related the climate and environment. To face the challenge and solve the problem, more understand of ice-jam is necessary.

6. Result of satellite design

(a) System (overall configuration, shape, mass, function, operational orbit)

The configuration of the ALICE microsatellite consists of a GPS receiver, ADCS sensors, EPS system, Antenna for communication, Camera and processor for early warning and studying of ice-jam flood. It is the low earth orbiting satellites with an initial altitude of 620 km and the inclination angle of 120 degrees. The total mass of one satellite is 19.273 kg. The dimension is 24 x 50 x 50 cm^3 include folding solar panels. The solar panels is installed to the ±Y plane and facing to -Z direction.

(b) Experimental system including ground stations

The ground station in NCKU will be used in the operation of ALICE, and it will be equipped with a Ku-Band antenna and communication system supplied by SpaceX.

(c) Operational procedure including data acquisition

The data received by the ground station is include warning for flood, image and satellite health condition. The warning message include the longitude and latitude computed by the attitude and position of satellite. After the team receive the warning from ALICE, they can notice the organizations concerned immediately. The image will be sent to the ground station later, and the team can do further studies on the ice-jam flood. The final products of scientific data and health condition data will be opened to scientific community, engineering team to get more feedback of analysis and application.

7. Concrete achievement methods, range and budget for manufacturing

ALICE microsatellite will be developed by the NCKU team, associated with several institutes including Physics, Aeronautics & Astronautics, Electrical Engineering department in NCKU. The total cost of a ALICE satellite is about 479000 USD not included Engineering model, testing fees, and labor cost.

8. Development, manufacture and launch schedule

The development of the ALICE mission is a difficult procedure. Before the preliminary design review (PDR), the local investigation of target river must complete essentially. The Science Working Group have to decide the aims and science requirement of the mission. The training data from other satellite remote sensing image is according to the investigation. The team spend 3 month that collect training data and train the U-net model at same time using Tesla V100. In order to train a high accuracy and reliability model, the team will iteratively optimize the model, the time of design is following the detail U-net model architecture and the hardware condition. After all of the subsystem design is complete CDR), flight model will begin to manufacture and test. The ALICE satellite will be launched in 2027.

1. Aims and purposes of the satellite

1.1 Primary mission objective

The mission of the Artificial Intelligence of Locale ICE jam floods (hereafter ALICE) is purposed to predict the ice jams floods and ice jams and uses the low earth-orbiting (LEO) satellite to increase the observation data. And a space-borne artificial intelligent model is employed to warn the potential ice-jam flooding in the early time.

Ice jams, an accumulation of ice forming where a river snakes or narrows, usually occurs in the springtime as the river ice begins to break up and in early winter during freeze-up. The ice jam flood is a kind of natural phenomenon caused by ice jams, the upstream river ice melt when downstream ice still is frozen. In the spring, the river flow increasing and rise in the temperature fracturing the river ice and separating it from the shore. The river ice possibly forms ice jams that causes an upstream flooding. The sudden failure of an ice jam can release a huge amount of river ice and water that may cause damages to nearby human beings and the environment.

Figure 1.1 Downtown in Fort McMurray were swamped after an ice jam flood [1]

Observing ice-jam floods becomes important because of this phenomenon usually causes a severe catastrophe. In 2010, the cost of ice-jam floods in the Lena river reached up to 23.53 million US dollars (USD). In April 2020, the ice-jam flood in Fort McMurray displaced some 13,000 people and damaged 1,200 houses (Figure 1.1). Figure 1.2 is imaged by Copernicus Sentinel-2 satellites and shows the flood extent in Fort McMurray. Besides, the feature of ice-jam floods is hard to predict, therefore the prediction of the ice-jam flood occurrence becomes a critical challenge. River ice jams are a prime source of flood risk in the mid- and high-latitude regions.

Figure 1.2 Ice jam flooding in Fort McMurray [2]

In the past, scientists must spend many hours for image download after satellites fly over ground stations, then process and analyze the images to make decisions. This time-consuming process is hard to provide an early warning to ice-jam floods such natural disasters and results only to form search and rescue teams to do the aftermath. However, the ALICE mission is able to process the images onboard the satellite with the assistance of the artificial intelligence and just send the warning messages via the Iridium communication network to provide an early warning instead of conventional image downloading and post-processing. From obtaining images by the camera, it will only take 40 to 60 seconds for U-net identification on the programmed rivers and comparison with an onboard river database, a maximum of 1800 seconds for broadcasting the warning and downloading processed images to the ground station (23Mb/12800 seconds) by the Iridium network or conventional communications. So, it will take a maximum of 31 minutes to complete an early warning. Figure 1.3 is an ice-jam flood observed by the Sentinel-2, the flooding is severe to destroy a large area of the natural environment. ALICE is capable to identify such the flood exceeding the river border in the early time and this in-time response is great helpful to save lives and reduce damages in the natural disasters.

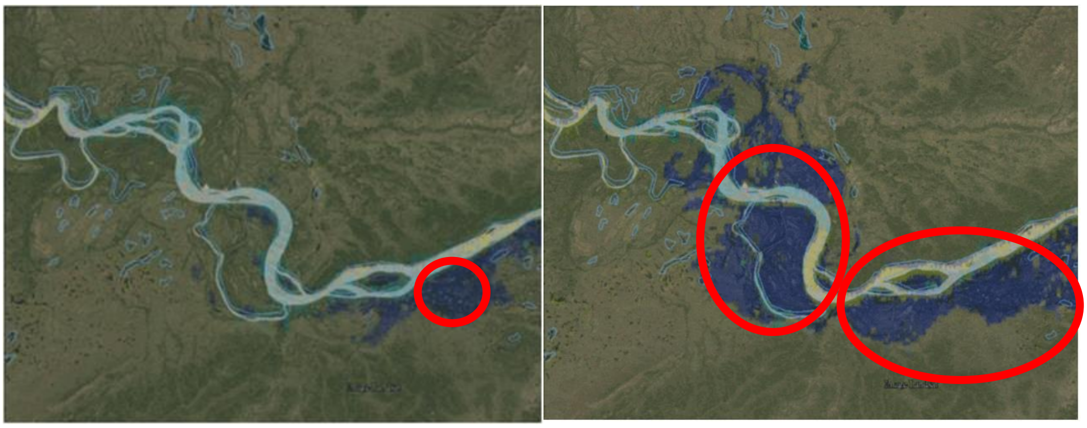


Figure 1.3 Ice-jam floods imagery from the Suomi NPP satellite changed in 12 hours (the red region is flooding water) [3]

ALICE operates with an initial orbital altitude of 620 km and it will image the specific rivers and process the images by an artificial intelligent model to directly identify the possible flood and only download the warnings and auxiliary information. The Iridium network is employed to send above information to the ground station in time. And a team in NCKU notice the possible organizations or governments immediately to take necessary actions in response to the possible natural crisis.

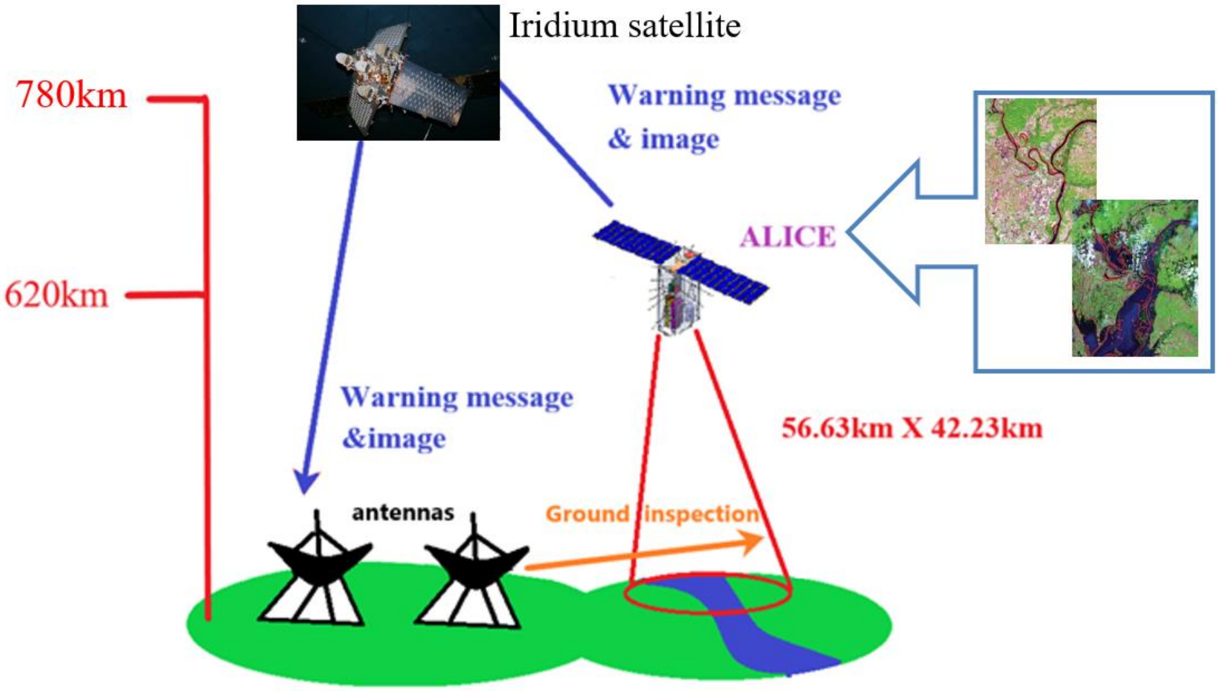


Figure 1.4 The schematic diagram of the ALICE mission

There are different types of reasons that lead ice jam flooding happen. The database on ALICE will combine the field survey. Ice jam floods are more difficult to predict than other types of flood because it depends on more factors: (1) how much snow and how fast it melts, (2) how much water and the ice are flowing in the river, (3) how thick and how strong the ice is. These factors are difficult to monitor whole river every day. When ice jams blocks a river, water levels rise very fast and ice jams release quickly. It can occur anywhere on river, but often occur over a short section of river. An ice jam can only be detected remotely if it forms near a gauging station. However, the gauging station can't site anywhere along the river. The data of the distribution of ice masses and the level of water in the river are useful for predicting ice jams but hard to collect and uplink to ALICE. The intelligence alert system of ALICE can use past statistic records to complete the artificial intelligent algorithm.

The programmed rivers in the ALICE missions includes the Argun River, Irtysh River, Songhua River, etc. The green area in Figure 1.5 shows the survey regions and the location of the programmed rivers which are marked by red color. In November to February, ALICE operates for the main mission that monitors the specific rivers and warns the ice-jam flood. According to the STK simulation, the revisit interval is approximate one day in high-latitude region and it is sufficient to provide an in-time early warning.

Typically, the river flows rise in the early spring due to more rapid snowmelt. The phenomenon could lead to an increase in ice-jam floods and the duration of the floodplain. Compared to open water floods, the ice-jam floods occur during the ice-free season and could result in two to three times higher water depths than open water floods. The damage caused by ice-jam floods may become severe under current climate change. The Sustainable Development Goals (SDGs) were adopted by all United Nations Member States in 2015. One of the 17 SDGs is climate change, the issue of ice-jam floods is needed to have an in-depth exploration and response.

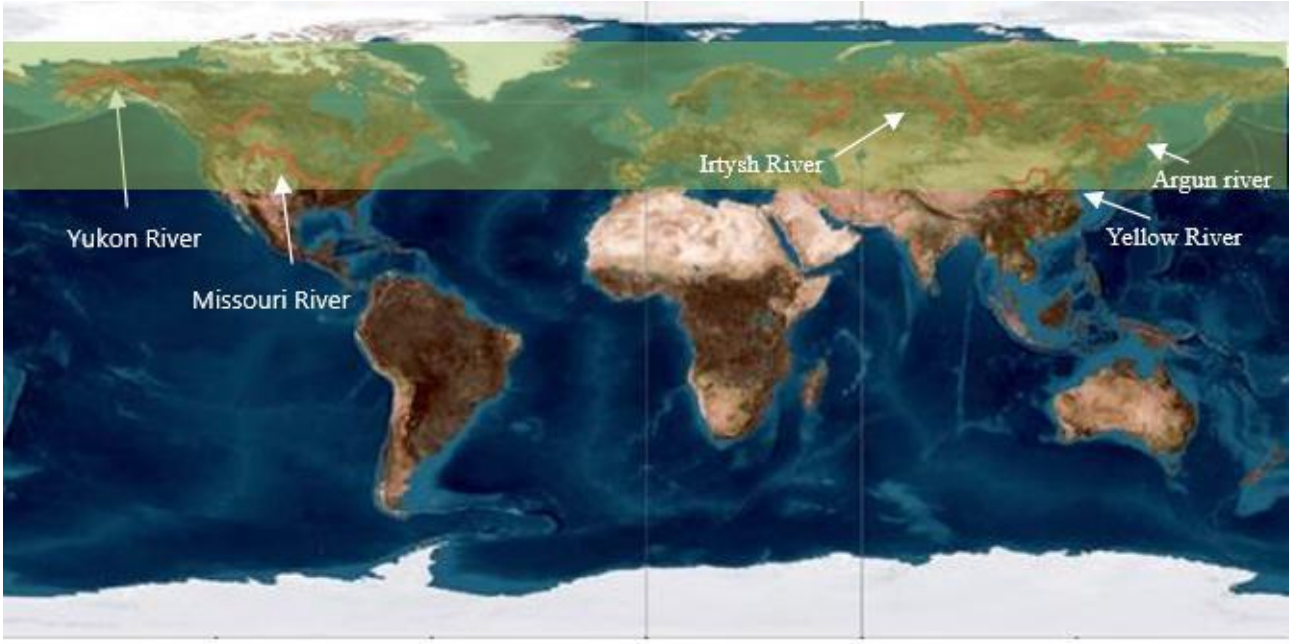


Figure 1.5 The main target area of ALICE

1.2 Secondary mission objective

In the period of March to October, the ALICE mission is purposed for its secondary mission objective. The RGB camera and database onboard satellite can help to image the general floods occurring around the world. Recently, Yellow river, which is in China, is flooding. It caused hundreds of thousands of people under danger. ALICE is capable of flood warning despite it might be caused by a different source. With the capability of the detections for water spilling over the river, ALICE also possibly help for typical floods. If ALICE is now operating in the space, it can help to evacuate the residence along Yellow River to safe shelter as early as possible.

2. Design result

2.1.1 Orbital Analysis

Table 2.1 The requirement of ALICE orbit

The requirements of the ALICE orbit
At least 5-year mission lifetime
Revisit every 5 hours at least
A low earth orbit for a remote sensing with a high spatial resolution

The mission objective of ALICE is to monitor the ice-jam flood that occurs in Octorber to April, and the target river locates on Russia and Canada with a 50°~60° in latitude. In the winter and spring, the night at Russia and Canada becomes shorter because of the 23.5° of earth's axial inclination. When the satellite accesses the target area, the sunlight must be irradiated on the ground and reflect the camera on ALICE. ALICE mission operates with an initial altitude of 620 km, and the inclination angle of 120° is selected to satisfy the following scientific requirements that ALICE must fly over the target rivers that locate on high latitudes. The maximum latitude of 65 degrees avoids the high-energy particles above the polar region. The altitude of satellites' orbit is an essential issue. An STK simulation with an initial altitude of 620km at a sol ar minimum garantees the mission lifetime of 5 years at least, even without a propulsion system. Because of the orbital precession, the retrograde orbit makes the orbit plane change direction be the same as the Earth rotation. The orbit is stability, and the mission mode of the satellite no need to switch frequently. According to the recently report [13], the water flood cause by the ice jam lead to water levels abrupt rise to peak within 5 hours. This event occur at Ratzdorf (Oder River), which located on German–Polish border in February 2012. The authors want to develop an ice jam flood forecasting system for the Oder River with microwave satellite image, and the research is complete and typically. Therefore, to fulfil the requirement of 5-hours revisit, ALICE system will be a constellation consisting of 6 satellites to monitor the target river every day.

Table 2.2 Orbit parameters of ALICE

Satellite Number	No.1	No.2	No.3	No.4	No.5	No.6
Altitude (km)	620	620	620	620	620	620
Eccentricity	0	0	0	0	0	0
Arg. (°)	0	0	0	0	0	0
Inclination (°)	120	120	120	120	120	120
RAAN (°)	0	60	120	180	240	300
Mean Anomaly (°)	0	180	0	180	0	180
Orbit Period (min)	97	97	97	97	97	97

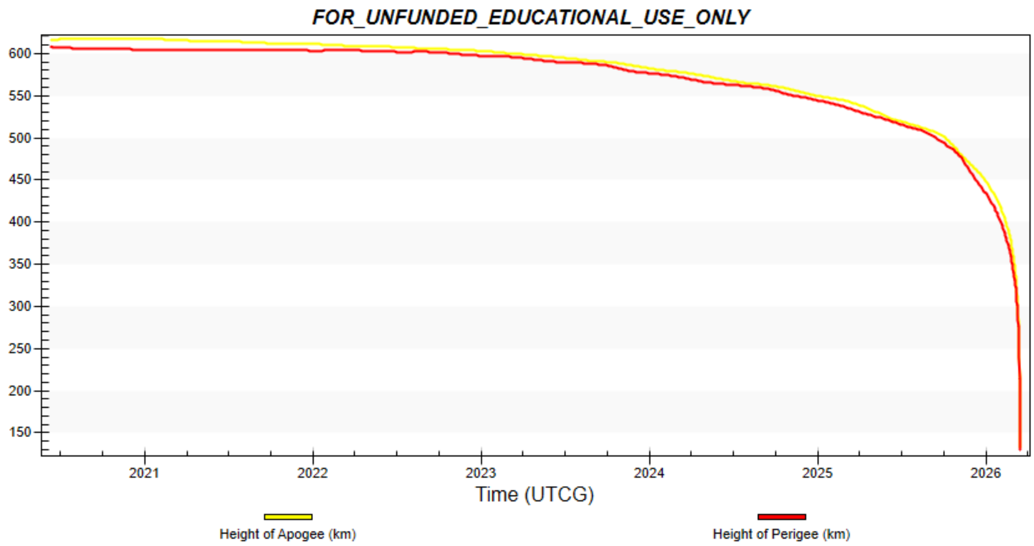


Figure 2.1 Altitude of ALICE satellite

2.1.2 ALICE systems

The ALICE mission consists of a space segment and a ground system. The space segment includes both the ALICE satellite and the Iridium communication system, and the ground segment is located in NCKU. The communication system of Iridium will be set up in the ground station and full-time work as it can.

There are six subsystems in the ALICE microsatellite, including Structure and Mechanisms Subsystem (SMS), Thermal Control Subsystem (TCS), Attitude Determination and Control Subsystem (ADCS), Electrical and Power Subsystem (EPS), Telemetry and Tracking and Command subsystem (TT&C), and Command and Data Handling subsystem (C&DH). The primary payload of ALICE is a high-resolution RGB camera. This camera takes images on the programmed rivers and process the images by a TPU with an artificially intelligent algorithm. This algorithm is capable of identifying the borders of the rivers and obtain an up-to-date geometry information to compare with the existing one stored in an onboard database. If a possible flood is detected, the warning message will be sent to the ground station immediately, and the remote sensing images is downloaded at once or later. When the ground station receives the warning, a ground team can take urgent action for prevent or reduce damages.

2.2 Satellite design

2.2.1 Structure and mechanisms subsystem (SMS)

The configuration of the ALICE microsatellite is shown in Figure 2.2. The mass and volume of each instrument and the total mass of one ALICE microsatellite showed in Table 2.3.

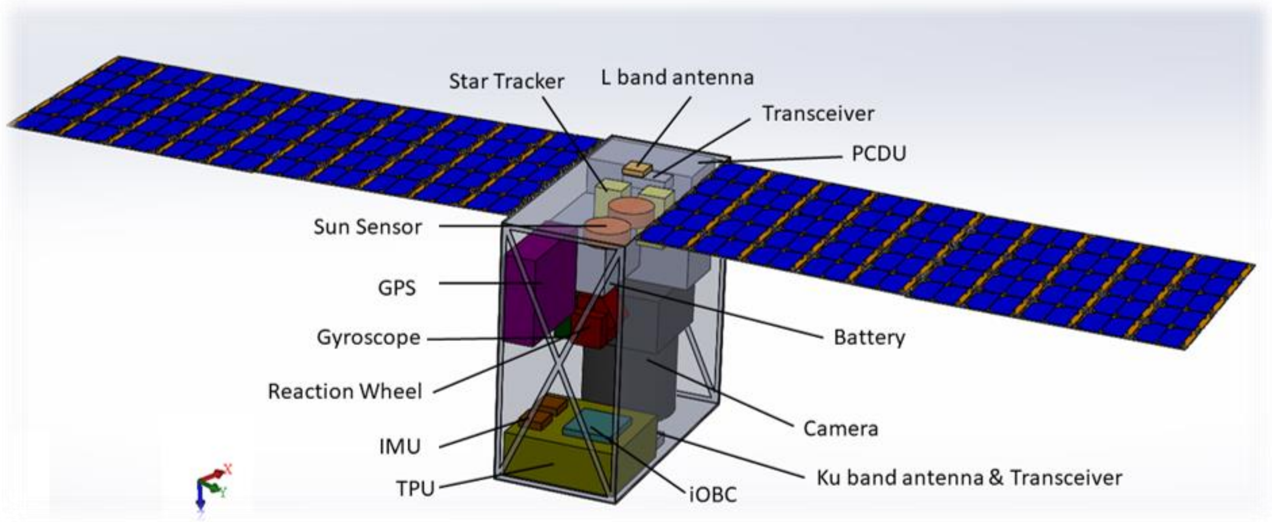


Figure 2.2 The major instruments of the ALICE microsatellite

Table 2.3 Mass budget, the mass and volume of each instrument in the ALICE.

Subsystem	Instrument	Number	Mass (kg)	Volume (mm)
ADCS	GPS	1	2.500	180 x 160 x 60
	Star Tracker	2	0.165	45 x 50 x 95
	Sun Sensor	2	0.100	d:80 h:27
	Gyroscope	2	0.090	34 x 38 x 66
	IMU	2	0.070	47 x 44 x 14.2
	Reaction Wheel	4	0.330	70 x 70 x 25
EPS	PCDU	1	1.500	206 x 215 x 110
	Battery	1	3.950	160 x 120 x 110
TT&C	Transceiver	1	1.000	80 x 40 x 20
	Antenna	1	0.053	100 x 100 x 10
Payload	Camera	1	2.000	150 x 100 x100
C&DH	iOBC	1	0.100	96 x 90 x 12.4
	M300-Xavier	1	5.000	190 x 210 x 80
Harness		1	1.000	500 x 190 x 155
Total Mass	19.273 kg			

2.2.1.1 Structural Requirement

In the structure design, ALICE will have to satisfy the requirement of launch environment provided by the H-IIA rocket as summarized in Table 2.4~2.7 The configuration and mass are designed to satisfy the limitations: dimensions should be controlled within 50 x 50 x 50 cm^3 and the total weight of the satellite cannot exceed 50 kg.

Table 2.4 Quasi-Static Acceleration

Axis direction	Axis orthogonal direction
+5.0G / -6.0G	±5.0G

Table 2.5 Sine Wave Vibration

	Axis direction	Axis orthogonal direction
Frequency	5~100	5~100
Acceleration	2.5G	2.0G

Table 2.6 Rigidity Request

Axis direction	Axis orthogonal direction
more than 120 Hz	more than 60Hz

Table 2.7 Random Vibration

Frequency Width (Hz)	Acceleration (G^2/Hz)
20~200	+3 (db/oct)
200~2000	0.032 (G^2/Hz)
Effective value	7.8 (Grms)

2.2.1.2 Material selection

The importance of the structure is to withstand high acceleration and violent vibrations and to protect the satellite from being damaged. During the design process, the design should meet the restriction of launch mass, the specification of the launch vehicle and space environment when it's in operation.

The 7075-T735 aluminum alloy is selected as the frame material, which has great stress resistance properties, is the common material in aerospace engineering and it can offer improved stress-corrosion cracking resistance. The alloy is the mixture of aluminum, magnesium, and manganese (Al-Mg-Mn), Table 2.8 summarizes the selected parameters of the alloy.

Table 2.8 Properties of material 7075-T735 aluminum alloy

Density	2.81 g/ml
Tensile Strength, Ultimate	505 MPa
Tensile Strength, Yield	435 MPa
Modulus of Elasticity	72 GPa
Poisson's Ratio	0.33
Shear Modulus	26.9 GPa
Specific Heat Capacity	0.96 J/g-°C

2.2.1.3 Structural analysis

For the ALICE mission, natural frequency structural analysis is performed to prevent fatigue destruction problems. In the natural frequency analysis, there are 10 modes to be calculated to investigate the frequencies that affected the structure significantly. Table 2.9 shows the first 10 natural frequencies of the ALICE's structure. The first mode occurs at 197.88 Hz, larger than the requirement of 120 Hz. Exploring different mode can prevent the ALICE from fatigue under these conditions. Figure 2.3 shows the final shape of the structure and stress distribution under different modes the areas in red represent that they are highly stressed while those in blue indicate lower-stressed parts.

Table 2.9 First 10 Natural frequencies.

Mode	Frequency (Hz)	Mode	Frequency (Hz)
1	197.88	6	809.06
2	314.49	7	939.27
3	387.90	8	1181.40
4	500.14	9	1233.20
5	734.60	10	1299.50

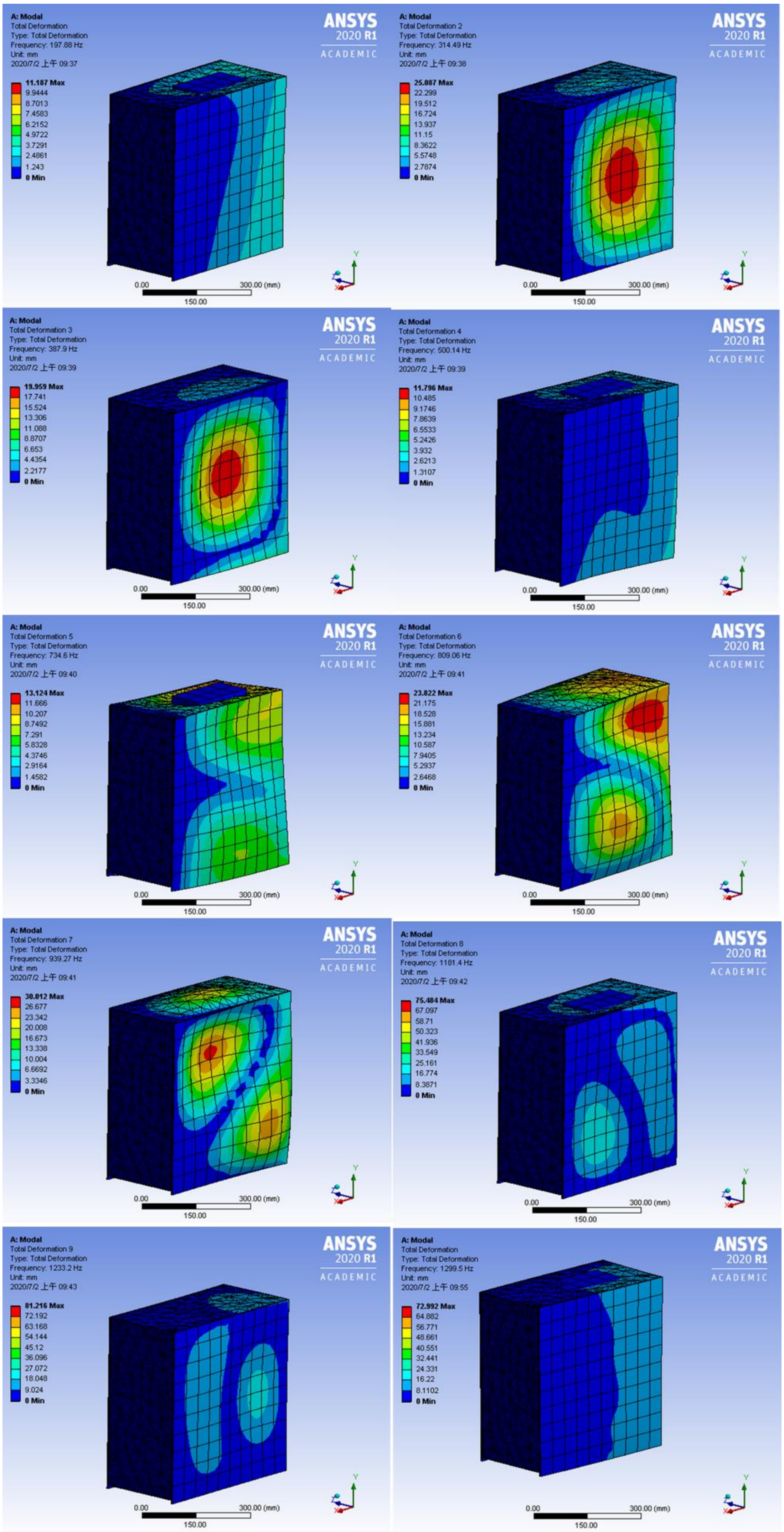


Figure 2.3 Illustration of modal analysis, from modal analysis of ANSYS

2.2.2 Thermal control subsystem (TCS)

2.2.2.1 External heat source

There are three kinds of sources that affect the temperature of the satellite. The most significant source is direct solar flux. Eqs (1) is the method to calculate heat flux from direct solar flux. In Eqs (1), $\dot{q}_s$ is Solar constant(direct Solar flux), σ is Stefen-Boltzmann constant ($5.670373 \times 10^{-8} W/m^2K^4$), T is earth temperature, R_S is the radius of the sun, and R_d is average of the distance between sun and earth. Owing to the distance between the sun and earth is not fixed. The range of $\dot{q}_s$ is estimated from 1318 to 1422 (W/m^2), and the average value is 1365 (W/m^2).

$$\dot{q}_s = \sigma T^4 \left(\frac{R_s}{R_d}\right)^2 \approx 1365 \ \ (W/m^2) \tag{1}$$

The second source is heat flux from earth reflecting solar radiation. Eqs (2) is the method to calculate reflected solar radiation. $\dot{q}_a$ is heat flux from the earth reflecting solar radiation, α is the absorptivity of satellite surface, ρ_α is albedo from earth surface, I_s is the intensity of solar radiation on earth surface, F_A is view factor, and A is the irradiated area of satellite.

$$\dot{q}_a = \alpha \rho_\alpha I_s F_A A \tag{2}$$

The last source is Earth infrared. Supposed Earth is a diffuse surface blackbody, and its temperature is 255K. Eqs (5) is the method to calculate earth infrared with regard to low Earth orbit. $\dot{q}_{IR}$ is Earth infrared, σ is Stefen-Boltzmann constant($5.670373 \times 10^{-8} W/m^2K^4$), T is Earth temperature, R_e is Earth radius, and h is orbit altitude.

$$\dot{q}_{IR} = \sigma T^4 \left(\frac{R_e}{R_e+h}\right)^2 \tag{3}$$

Summarized all external heat source on satellite. We analyze the two extreme conditions to determine the operating temperature range of the device, Hot case and Cold case, shown as Eqs (6) and Eqs (7).

$$\text{Hot case: } T_{max} = \left[\frac{\dot{q}_s \alpha A_p}{\sigma \varepsilon A} + \frac{\dot{q_\alpha} \alpha A_p}{\sigma \varepsilon A} + \frac{\dot{q_{IR}} \alpha A_p}{\sigma \varepsilon A}\right]^{0.25} \tag{4}$$

$$\text{Cold case: } T_{min} = \left[\frac{\alpha_{IR} A_p \dot{q_{IR}}}{\sigma \varepsilon A}\right]^{0.25} \tag{5}$$

According to the pimples above, we use the STK to simulate the thermal analysis, the thermal parameters are shown in Table 2.10 and the result simulates by these parameters are shown in Figure 2.4, 2.5. This is one period(~98mins) that the time which satellite round the earth once, the maximum temperature is 47.561℃, and the minimum temperature is -37.091℃ by average.

Table 2.10 The thermal parameters

Solar Flux at 1 AU	1323.936~ 1324.058 W/m^2
Earth Albedo(average)	36.7%
Shape	Plate
Cross sectional Area	1.250 m^2
Material Emissivity (7075 Al alloy)	0.810
Material Absorptivity (7075 Al alloy)	0.870
Plate Normal Vector	Earth (True) (based on Satellite)
Internal Power Dissipation	59.3 ~ 170 W

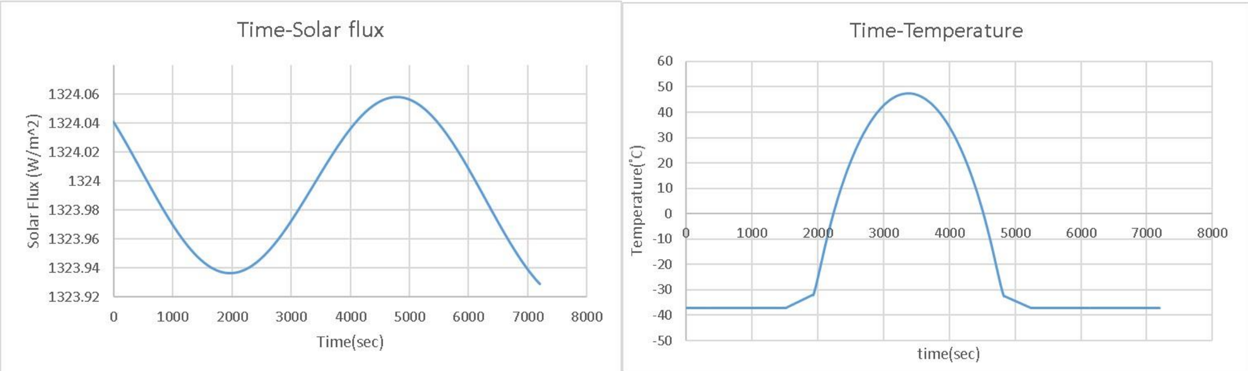


Figure 2.4 The change of Solar flux in one period (left) and the satellite temperature change in one period(~98mins) (right)

2.2.2.2 Internal heat source

It is assumed that the maximum value of the temperature change of the internal componentsent is driven by the thermal energy which is converted from the consumed electrical power. When setting up the components, place the components with a high temperature change on close to the side panels of the microsatellite, so that the thermal energy is easily dissipated, and the components is hard not be malfunctional due to a temperature anomaly. However, not 100% of the consumed electrical energy turns into thermal energy, so the internal heating of each component become less significant than the estimated value. Table 2.11 displays the energies required by each component and the temperature variation under extreme conditions.

Table 2.11 The energies required and the temperature change by each instrument

	Energy (J)	Temperature Change (˚C)
GPS	52920	2.65
Star Tracker	11760	0.59
Sun Sensor	11760	0.59
Gyroscope	14112	0.71
IMU	12936	0.65
PCDU	176400	8.83
iOBC	2352	0.12
Transceiver	9408	0.47
Camera	9114	0.46
Reaction Wheel	11760	0.59
M300-Xavier	323400	16.20

Combining the external and internal heat sources, we can evaluate the heating and heat dissipation and estimate the temperature range of each instrument when the satellite is opearting in space. Table 2.12 shows the operation temperature of each component. By comparing the estimated temperatures with the operation temperature, it is also confirmed that the components used in the ALICE mission can operate in space within their required temperature ranges. Figure 2.5 shows the estimated and operation temperature ranges of each component. The blue bars indicate the range of the estimated temperatures of the components, and the red bars mark the temperatures higher or lower than the operation temperatures.

Table 2.12 The operation temperature of each instruments

Subsystem	Instrument	Number	Operation Temperature (˚C)
ADCS	GPS	1	-34 ~ +71
	Star Tracker	2	-40 ~ +80
	Sun Sensor	2	-45 ~ +80
	Gyroscope	2	-40 ~ +80
	IMU	2	-40 ~ +80
	Reaction Wheel	4	-40 ~ +80
EPS	PCDU	1	-40 ~ +80
	Battery	1	-20 ~ +60
TT&C	Transceiver	1	-40 ~ +60
	Antenna	1	-40 ~ +80
Payload	Camera	1	-40 ~ +80
C&DH	iOBC	1	-25 ~ +65
	M300-Xavier	1	-40 ~ +85

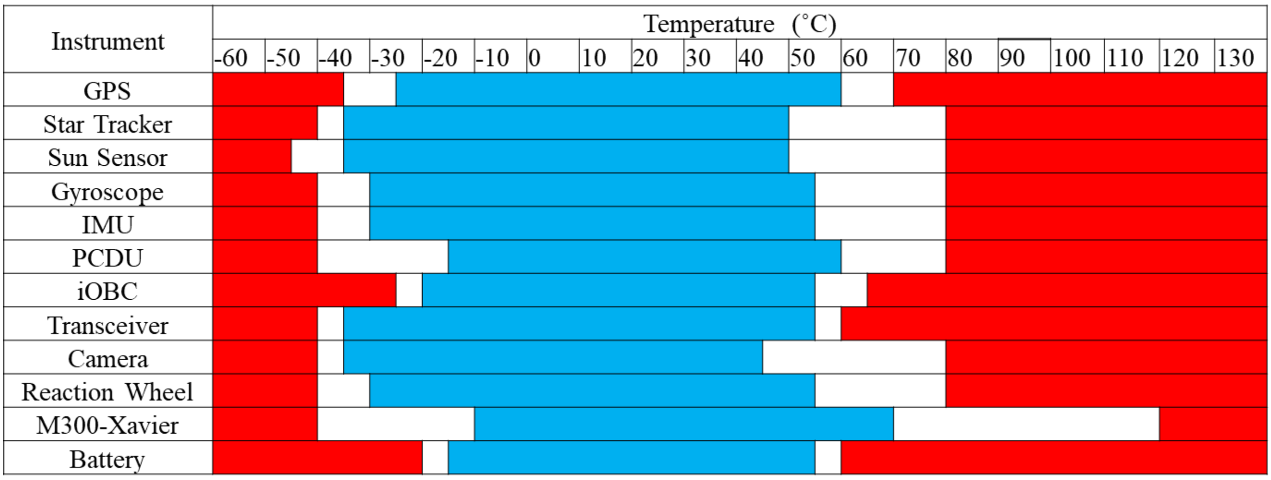


Figure 2.5 The estimated and operation temperature range of each instruments.

2.2.3 Attitude determination and control subsystem (ADCS)

There are two important requirements for attitude determination and control system. First, the pointing accuracy of satellite bounded by 0.3 degrees cause the 3 kilometers error of the field of view. To take a river clearly and accurately, the sensor which determines the satellite of ALICE is important to satisfy the requirement. Second, the autonomous position of the GPS receiver is 4 meters to determine the position on the orbit. Using satellite attitude from other sensors and position from GPS receiver, ALICE will compute the geodetic latitude and longitude of the image, and the artificial intelligent algorithm will refer to the geographic information of the specific river.

The following table is the properties of the sensor to determine the altitude. The ADCS consist of four reaction wheels, a sun sensor, a star tracker, a gyroscope, and a GPS receiver. The satellite position and attitude could be determined through these measurements, and the reaction wheels are employed for satellite stabilize or adjusting attitude for mission operation.

After satellite separation from launcher, the ALICE employs three-axis attitude controls by means of reaction wheels. Therefore, the ADCS should be not only controlled against external disturbances but also checking the angular-rate and detumbling of the satellite to stabilize the attitude and implement the imaging mission.

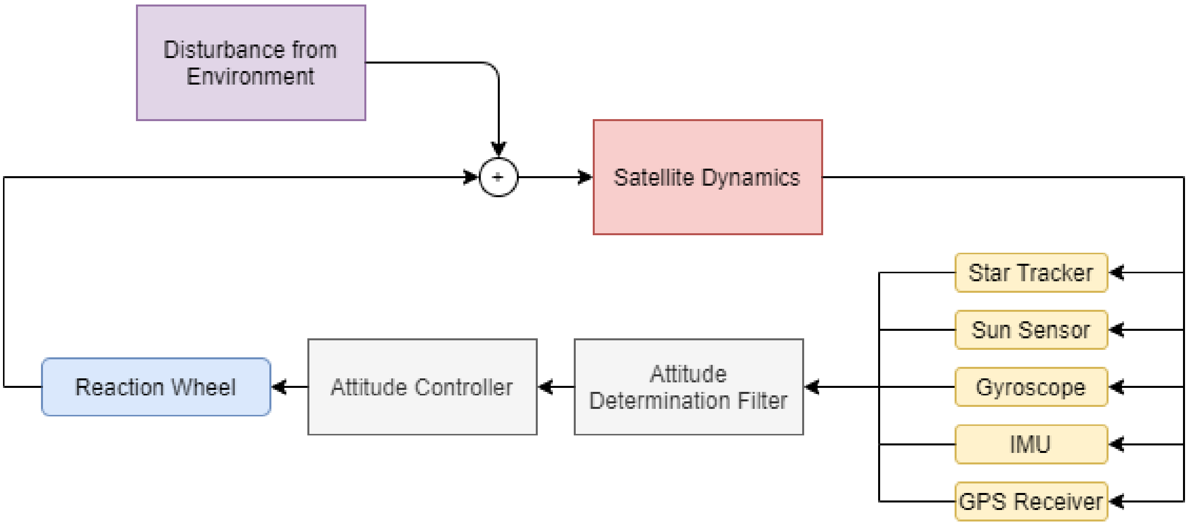


Figure 2.6 The architecture of ADCS in the ALICE satellite

Table 2.13 Properties of sensors

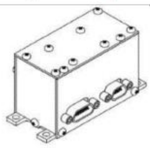
	NST-3 Nano Star Tracker	Sun Sensor ISS-D25	Gyroscope
			
Number	2	2	2
Volume	45 x 50 x 95 mm	d:80 h:27 mm	34 x 38 x 66 mm
Mass	165g	100g	90g
Accuracy	<7 arcsec. (3σ)	< 0.3 deg.	0.005deg/s
Exclusive Angle	<35 deg.	50 deg	250deg/s

Table 2.14 Actuator and Navigation instrument

IMU		RWP100, Reaction Wheel	
			
Number	2	Number	4
Volume	47 x 44 x 14.2 mm	Volume	70 x 70 x 25 mm
Mass	70g	Mass	330g
Angular rate control performance	0.153 deg./s (1σ)	Momentum	0.1 Nms
Gyroscope operation range	Up to 500 deg/sec in all axes	Power consumption	<0.5 W (0.5 momentum) <1.0 W (full momentum)
Accelerometer operation range	Up to 16 G in all axes		
Magnetometer operation range	Up to 16 G in all axes		
Power consumption	< 1.1 W		

Table 2.15 Properties of GPS

	Sentinel M-Code GPS Receiver
	
Autonomous Position	4.0 m(1σ), < 1 m typical
Autonomous Velocity	< 2 cm/s(1σ), < 0.5 cm/s typical
Clock and 1PPS Absolute	< 50 ns (1σ), < 5 ns typical
Time Strobe Input	< 50 ns(1σ)
Optional Relative PVT Mode	0.5m, 0.5 cm/sec, 4 ns(1σ)

2.2.4 Telemetry, Tracking and Command subsystem (TT&C)

The ALICE mission communicates with the ground station through its TT&C system. Three kinds of satellite data are necessary and have to be downloaded from the ALICE microsat.

1. The geographic location of overflowing river (~100bytes of a warning message)
2. Status of satellite's health (~72888bytes a day) (as table 1 below)
3. Specific images for ground staff to confirm the accuracy of AI (~186Mb/1 image)

Table 2.16 Estimation of data size per day

GPU working parameters	measurement	Daily data (Bytes)
Attitude	20 Bytes/30 S	57600
Temp.	1 Bytes/300 S	288
Power (each element)	5 Bytes/30 s	14400
total		72888

The most important and having high immediacy data is the first, geographic location of the overflowing river. It is expected that the warning message is delivered as soon as the AI algorithm onboard the satellite identifies the water flooding out the river. Instead of conventional satellite communication, perhaps 1~5 times ground contact per day, ALICE has its unique method to increase contact frequency. There are two ways in ALICE's communication system. One is the conventional way, satellite communicates with the ground station in the Ku band, the transmitted data type mainly are status of satellite's health, Specific images, and command. The other one is linking with the worldwide-covered- satellite-constellation Iridium, also known as the world satellite's phone alarm system. This way mainly transmitted the geographic location of the overflowing river, would be almost real-time messages with Iridium and ALICE.

Iridium is a communication program developed by Iridium Communications Inc. It mainly uses 66 small satellites to build a world-coverage global communication system. This program started its commercial activity in 1998. Until now, it still provides a stable wild communication survey and keeps on satellite constellation's maintenance and update.

For the goal of linking with Iridium, the communication band of ALICE must be identical to the Iridium's custom frequency. According to the document released from the Federal Communications Commission (FCC). The frequency which is used to communicating between satellite and user terminals on the ground is 1616 – 1626.5 MHz (L band) for downlink and uplink. Because the band must be the same in two-terminal on communication, the band of ALICE communication system is selected as the L band.

Due to ALICE microsat is placed at a 620 km height and the Iridium constellation satellites fly much higher than the ALICE spacecraft (at the orbit of 781km height). The L band signal mainly comes from the zenith direction, and the ALICE's Iridium antenna must face to the zenith to ensure a sufficient signal-to-noise ratio (SNR). By subtracting the Iridium satellite's altitude from ALICE's, we can get the communication distance at least being 161 km.

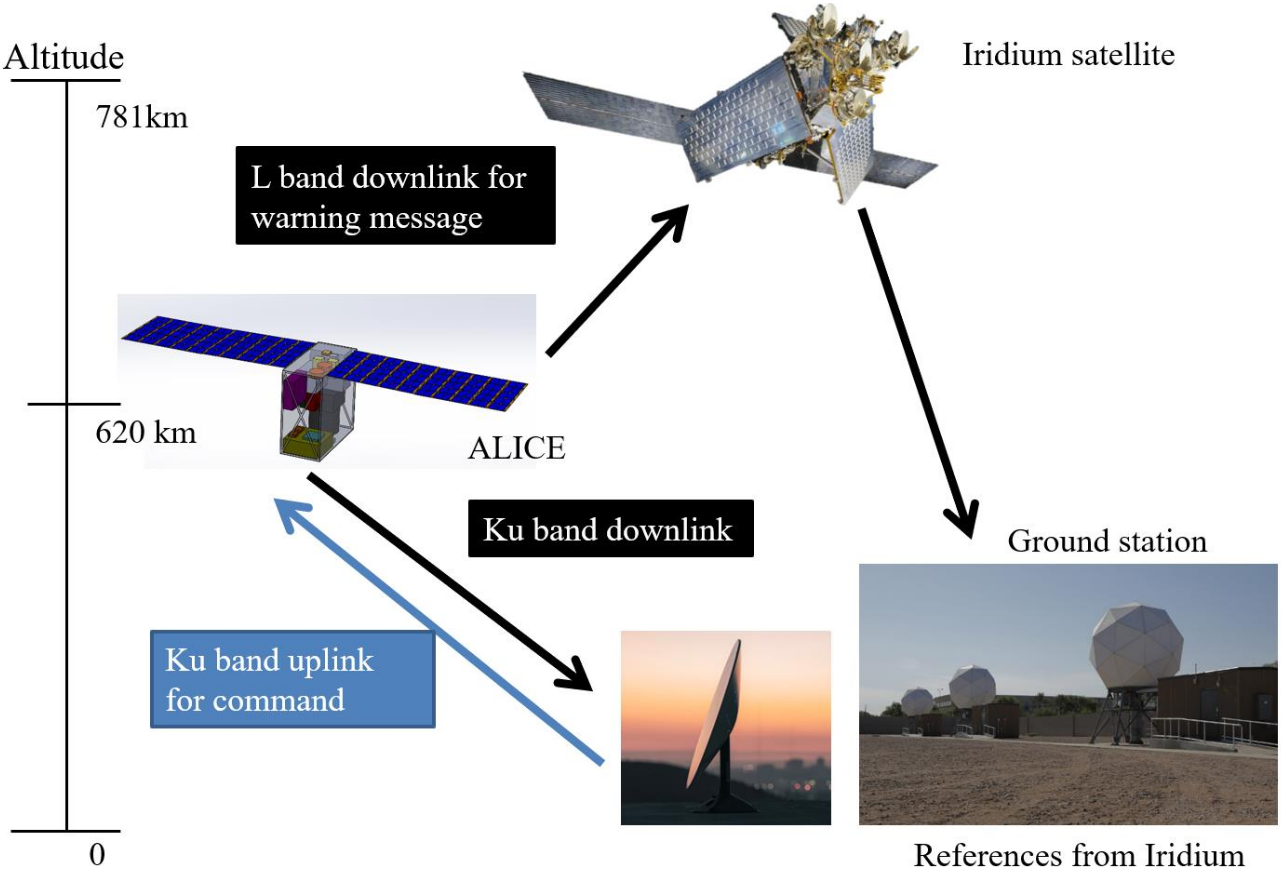


Figure 2.7 TT&C schematic diagram

Two transceiver/receiver (Ku band & L band) module and two phased-array-antenna are employed for ALICE. The combination of Ku band(14-16GHz) is used to commute with the ground, transfer ALICE's health status, specific image, and occasional alarm message, so it is equipped on the ALICE's minus z surface. The data rate of ALICE downlink is programmed as 12800bps. According to the beginning of the TT&C session, three types of data must be download, and this data rate of 12800 bps is also enough for the second kind of data, the Status of satellite's health. By this rate, we know the specific images will at least need 5000 seconds to reach the ground while ALICE contact with the ground station. This Ku band combination contains a 16-dBi-patch antenna and a Ku band transceiver. The link budget of this system is as below.

Table 2.18 ALICE-to-ground

Downlink Telemetry Budget:		
Parameter:	*Value:*	*Units:*
Spacecraft:		
Spacecraft Transmitter Power Output:	2.0	watts
In dBW:	3.0	dBW
In dBm:	33.0	dBm
Spacecraft Total Transmission Line Losses:	1.2	dB
Spacecraft Antenna Gain:	16.0	dBi
Spacecraft EIRP:	17.8	dBW
Downlink Path:		
Spacecraft Antenna Pointing Loss:	0.2	dB
S/C-to-Ground Antenna Polarization Loss:	3.0	dB
Path Loss:	172.0	dB
Atmospheric Loss:	1.1	dB
Ionospheric Loss:	0.8	dB
Rain Loss:	0.0	dB
Isotropic Signal Level at Ground Station:	-159.2	dBW
Ground Station (EbNo Method):		
------- Eb/No Method -------		
Ground Station Antenna Pointing Loss:	1.1	dB
Ground Station Antenna Gain:	34.7	dBi
Ground Station Total Transmission Line Losses:	2.3	dB
Ground Station Effective Noise Temperature:	300	K
Ground Station Figure of Merrit (G/T):	7.6	dB/K
G.S. Signal-to-Noise Power Density (S/No):	75.9	dBHz
System Desired Data Rate:	12400	bps
In dBHz:	40.9	dBHz
Telemetry System Eb/No for the Downlink:	34.9	dB
Demodulation Method Seleted:	BPSK	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1.0E-05	
Demodulator Implementation Loss:	1	dB
Telemetry System Required Eb/No:	9.6	dB
Eb/No Threshold:	10.6	dB
System Link Margin:	24.3	dB

Table 2.19 ground-to-ALICE

Uplink Command Budget:		
Parameter:	*Value:*	*Units:*
Ground Station:		
Ground Station Transmitter Power Output:	4.1	watts
In dBW:	6.1	dBW
In dBm:	36.1	dBm
Ground Stn. Total Transmission Line Losses:	2.2	dB
Antenna Gain:	33.2	dBi
Ground Station EIRP:	37.1	dBW
Uplink Path:		
Ground Station Antenna Pointing Loss:	1.1	dB
Gnd-to-S/C Antenna Polarization Losses:	3.0	dB
Path Loss:	171.4	dB
Atmospheric Losses:	1.1	dB
Ionospheric Losses:	0.4	dB
Rain Losses:	0.0	dB
Isotropic Signal Level at Spacecraft:	-139.9	dBW
Spacecraft (Eb/No Method):		
------- Eb/No Method -------		
Spacecraft Antenna Pointing Loss:	0.6	dB
Spacecraft Antenna Gain:	16.0	dBi
Spacecraft Total Transmission Line Losses:	2.3	dB
Spacecraft Effective Noise Temperature:	316	K
Spacecraft Figure of Merrit (G/T):	-11.3	dB/K
S/C Signal-to-Noise Power Density (S/No):	76.8	dBHz
System Desired Data Rate:	9600	bps
In dBHz:	39.8	dBHz
Command System Eb/No:	37.0	dB
Demodulation Method Seleted:	BPSK	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1.0E-05	
Demodulator Implementation Loss:	1.0	dB
Telemetry System Required Eb/No:	9.6	dB
Eb/No Threshold:	10.6	dB
System Link Margin:	26.4	dB

L band(1.62GHz) combination is used to commute with Iridium, mainly transfer alarm message to increase the warning's immediacy, so it is equipped on the ALICE's z surface. The warning's data size is roughly equal to 100bytes, and 2400bps data rate of Iridium is enough to deal with it. The L band antenna is a 3dBi-Iridium-specialized-antenna, this system's link budget is as Table 2.20. Considering the floatability of satellite's orbit the distance in calculation is 500km.

Table 2.20 ALICE-to-Iridium

Downlink Telemetry Budget:		
Parameter:	Value:	Units:
Spacecraft:		
Spacecraft Transmitter Power Output:	2.3	watts
In dBW:	3.6	dBW
In dBm:	33.6	dBm
Spacecraft Total Transmission Line Losses:	1.1	dB
Spacecraft Antenna Gain:	3.0	dBi
Spacecraft EIRP:	5.5	dBW
Downlink Path:		
Spacecraft Antenna Pointing Loss:	0.2	dB
S/C-to-Ground Antenna Polarization Loss:	3.0	dB
Path Loss:	150.6	dB
Atmospheric Loss:	1.1	dB
Ionospheric Loss:	0.0	dB
Rain Loss:	0.0	dB
Isotropic Signal Level at Ground Station:	-149.4	dBW
Ground Station (EbNo Method):		
------- Eb/No Method -------		
Ground Station Antenna Pointing Loss:	21.0	dB
Ground Station Antenna Gain:	30.0	dBi
Ground Station Total Transmission Line Losses:	2.3	dB
Ground Station Effective Noise Temperature:	300	K
Ground Station Figure of Merrit (G/T):	2.9	dB/K
G.S. Signal-to-Noise Power Density (S/No):	61.1	dBHz
System Desired Data Rate:	2400	bps
In dBHz:	33.8	dBHz
Telemetry System Eb/No for the Downlink:	27.3	dB
Demodulation Method Seleted:	QPSK	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1.0E-05	
Demodulator Implementation Loss:	1	dB
Telemetry System Required Eb/No:	9.6	dB
Eb/No Threshold:	10.6	dB
System Link Margin:	16.7	dB

2.2.5 Electrical power subsystem (EPS)

The EPS supplies electricity to each subsystem and payloads during the mission operation. The EPS consists of components of the solar cells, batteries, and DC/DC converter. The power budget refers to the following table. The DC/DC converter is used to regulate voltage (3.3 Volt, 24 Volt, and 28 Volt). The maximum power consumption of the TPU requires 100 watts when it deals with the image from the camera, but when it standby in the shadow of the earth requires only 10% power. To save electricity energy, there are 4 modes for this mission as the following table. The mode 1-1 is applied to EPS from November to February at sunlight time and the mode 1-2 is applied at shadow time. The mode 2-1 is applied to EPS on the other month at sunlight time and mode 2-2 is applied at shadow time. Because the purpose of mode 1 is the primary mission objective monitoring the ice-jam floods, the TPU switch on in this mode, and it switches off in mode 2 which the purpose is secondary mission objective.

Table 2.21 Power budget in difference mode

Subsystem	Instrument	Consumption (W)	Mode 1		Mode 2	
			1-1	1-2	2-1	2-2
ADCS	GPS	9	○	○	○	○
	Star Tracker	2	○	○	○	○
	Sun Sensor	2	○	○	○	○
	Gyroscope	2.4	○	○	○	○
	IMU	2.2	○	○	○	○
	Reaction Wheel	4	○	/	○	/
EPS	DC/DC converter	30	○	○	○	○
TT&C	Transceiver	2(1.2)	○	/	○	/
Payload	Camera	3 (0.1)	○	/	○	/
C&DH	iOBC	0.4	○	○	○	○
	M300-Xavier	100 (10)	○	/	/	/
total			157	59.3	67	59.3

○ : on / : standby

2.2.5.1 Solar Panel and Battery

The solar cell of ALICE is produced by DHV Technology with a conversion efficiency of 30%. The solar cell array is assembled in Aluminum honeycomb substrates with Carbon Filter Reinforced Plastic. To compute the area of Solar Panel, the power requirement of the end of the life (EOL) can be known by the equation:

$$P_{sa}(EOL) = \frac{\left(\frac{P_e T_e}{X_e} + \frac{P_d T_d}{X_d}\right)}{T_d} = 207.4\,\mathrm{W} \tag{11}$$

According to the equation, P_d(=157 W) and P_e(=59.3 W) is the power of satellite in the sunlight and shadow, T_d (=65.3 min) and T_e (=32.7 min) is the time per period of satellite in the sunlight and shadow, X_d(=0.9) and X_d(=0.9) is the efficiency of electric power transmission of a satellite in the sunlight and shadow.

The angle of the solar panel and the sunlight and the orbit of the satellite influence the efficiency of solar cells. The temperature effect and time decay also need to be concerned.

$$P_{BOL} = \frac{P_{sa}(EOL)}{\eta_{life}\cos(\theta)\Upsilon} = 343.1\ \mathrm{W} \tag{12}$$

The P_{BOL} is the power of the beginning of the life, $\eta_{life}(= 0.9)$ and $\Upsilon(= 0.95)$ is the decay of the life and temperature effect. The decay of the temperature effect is known by the equation. θ *is* the angle of the solar panel and the sunlight. As θ is a variant along with orbit kinematics, it's assumed to be 45 degrees.

$$\mathrm{S} = \frac{P_{BOL}}{I_s E_{cell}} = 0.85\ m^2 \tag{13}$$

The S is the requirement area of solar panels. The I_s(=1350) is solar constant. E_{cell} is the efficiency of solar cells. According to the equation, the required area of the solar panels is $0.91m^2$. ALICE be design to the developable panel to satisfy the requirement. According to the simulation, although the energy surplus of mode 1 and mode 2 are both enough, the angle of the solar panel and the sunlight vary along with orbital precession. The total capacity of the battery in satellite 31 Ah, it is enough to support the satellite during the half of the period.

Table 2.22 Properties of battery and solar cell

Battery		Solar cell	
15.5 Ah Lithium-Ion Space Battery		Customized	
Manufacturer	EaglePicher	Manufacturer	DHV Technology
Nominal voltage	28.8V	Supply Voltage	3.3V
Operating Voltage	32.0V-33.6V	Open Circuit Voltage	5.4 V
Capacity (BOL)	15.5Ah	Short Circuit Current	0.52 A
Charge Current (Max)	7.2 A	Voltage at max. Power	4.82 V
		Current at max. Power	0.5 A
Number	1	Number	200

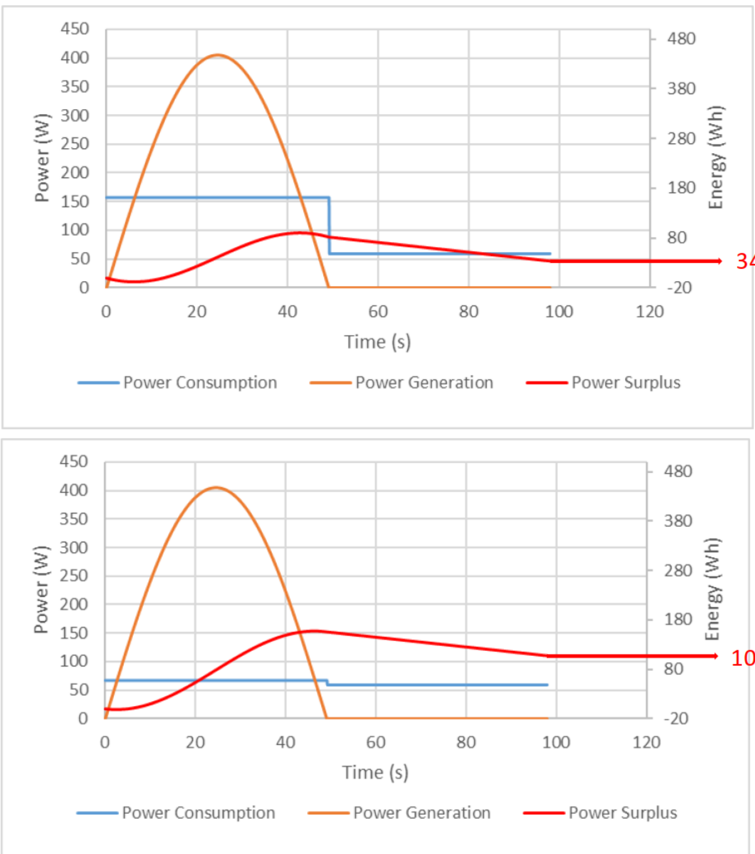


Figure 2.8 Power and energy of mode 1 (top) and 2 (bottom)

2.2.6 Command and data handling subsystem (C&DH)

The Command and Data Handling Subsystem is the core of the satellite. C&DH has many important functions to support the ALICE system working, it is in charge of monitoring the health of each subsystem and payload, and alert anomaly as well as takes contingent actions if necessary. It also controls the on/off status of payloads and tells EPS how much power it should supply to other subsystems and the payload.

C&DH is also the interface for managing the communication of subsystems and payloads. After the camera image the specific river, the image data must be transferred to TPY to do image processing and deal with by artificial intelligent algorithm. The GPS receiver will get position information at the same time and compute the geodetic latitude and longitude of the image.

On the other hand, C&DH must handle the command from Iridium and preparing the data for returning including the health, ephemeris, attitude, image data, and warning from the AI algorithm. The ISIS Onboard computer equips an ARM9 32-bit 400MHz processor with low power consumption and excellent performance. I2C provides a convenient interface to communicate with each subsystem. And the RTC (real-time clock) frees the system from time-critical tasks, and it is more accurate. It also provides the capacity of two 16GB high-reliability SD cards, which stores the image data imaging from the camera, the geographic information of the specific river, and the status of the health records as temperatures, voltages, and currents collected from internal sensors. These data will be stored in the SD cards until they transmitted to the Earth, and then be overwritten by the new image and the health data.

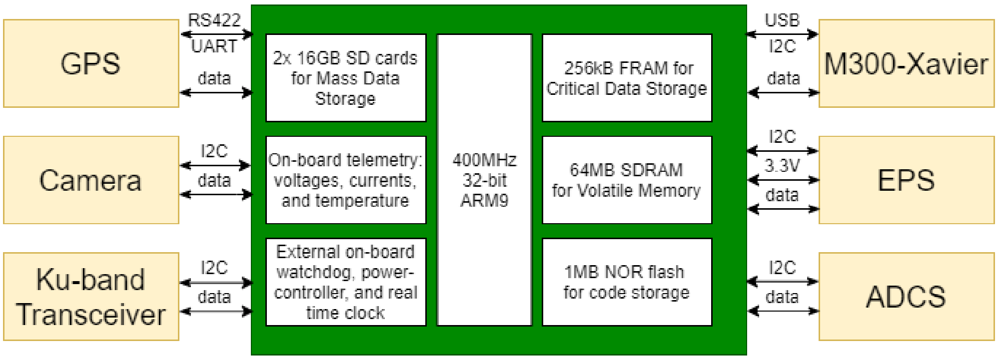


Figure 2.9 The functional block diagram of iOBC

2.2.6.1 Processor for Artificial Intelligence

The TPU selected for training the artificial intelligent model and operating the monitoring mission on ALICE is M300-Xavier. M300-Xavier is a fanless robotic controller taking advantage of the server-class performance of NVIDIA® Jetson AGX Xavier™ to enable autonomous monitoring of the river floods with the remote sensing image from the camera on the satellite.

Table 2.23 Properties of TPU

Model	M300-Xavier
	
Mass	5 kg
Volume	190 x 210 x 80 mm
Processor	NVIDIA Jetson AGX Xavier
Memory	Onboard 16G
eMMC	32GB on module

2.2.6.2 Radiation Tolerance

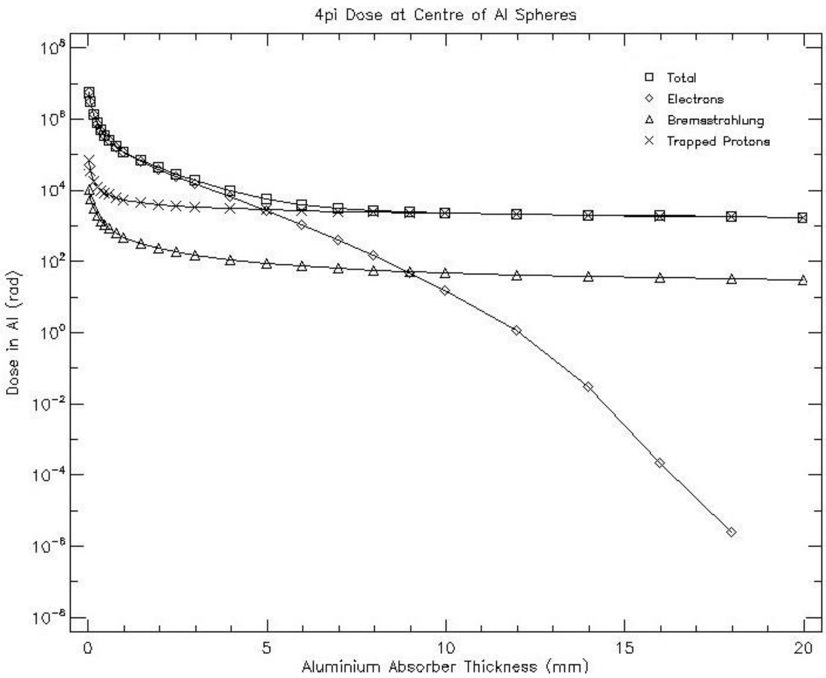


Figure 2.10 Radiation Dose on 620 kilometers

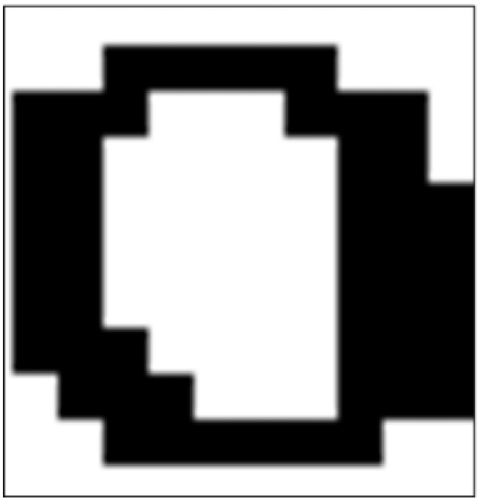
According to the Figure 2.10, the M300-Xavier have the 4mm aluminum housing, and 2.5mm circuit board to resist radiation damage.

2.2.7 Artificial Intelligent Algorithm

The artificial intelligence used by ALICE is U-net. U-net was presented by Olaf Ronneberger, Philipp Fischer, and Thomas Brox in 2015. The reason why we choose U-net as the AI theorem of ALICE is that U-net is simple, high efficiency, and also easy to customize. Moreover, in the competition named Airbus Ship Detection Challenge held by Kaggle, a large science data community, U-net is the most popular algorithm during all competitor. The mission in this contest is that finding ships on satellite images as quickly as possible. The accuracy of U-net reach 84.7%. Our mission for ALICE is similar to it. So, we want to give it a try.

2.2.7.1 Convolution

The picture shown in Figure 2.10 is a number “0“(Pixel=10*10=100). Left image is what human see, while right image is image recognized by computer.



255	255	255	255	255	255	255	255	255	255
255	255	0	0	0	0	0	255	255	255
0	0	0	255	255	255	0	0	0	255
0	0	255	255	255	255	255	0	0	255
0	0	255	255	255	255	255	0	0	0
0	0	255	255	255	255	255	0	0	0
0	0	255	255	255	255	255	0	0	0
0	0	0	255	255	255	255	0	0	0
255	0	0	0	255	255	255	0	0	0
255	255	0	0	0	0	0	0	255	255

Figure 2.11 A number “0“

Filter image= image*Operator mask (Note: * isn’t a multiplication sign but a convolution operator.)

The Figure 2.11 is an operator mask we design as an example (Size 3X3)

0	0	0
1	1	1
0	0	0

Figure 2.12 An operator mask

Now we can start to do convolution for every pixels. The pixels framed by red line will be multiplied by operator mask. Finally, we add them all together then we can get the result. This procedure is called convolution.

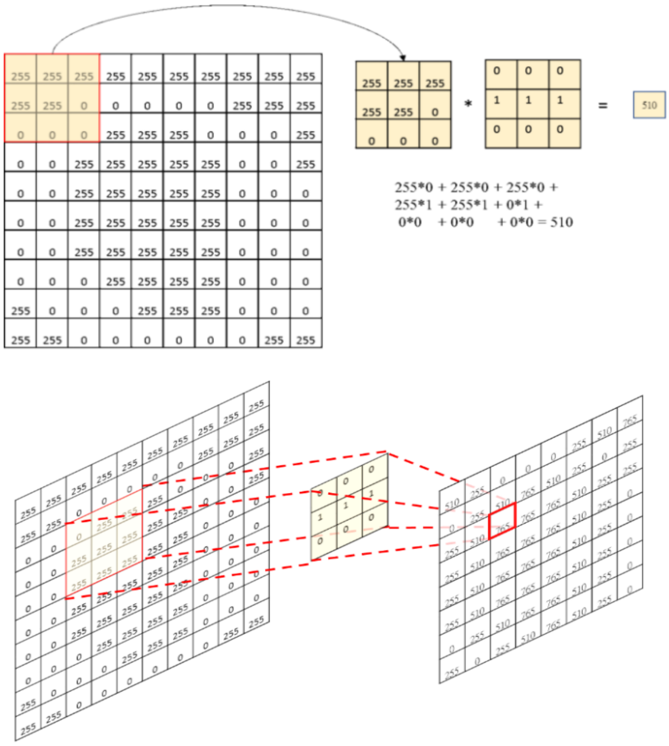


Figure 2.13 The schematic diagram of convolution (I)

The whole filter image is that we need to convolute each parts of the image. Typically we begin from the left-topside of the image, then we move rightward. When approaching the rightmost part, we move downward 1 pixel and still begin again from leftmost pixel.

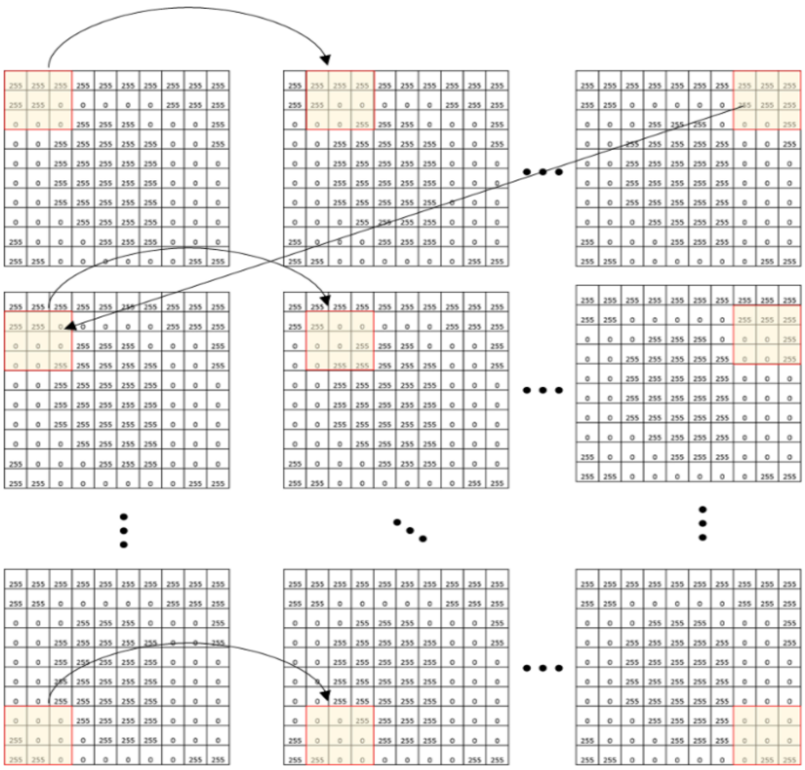


Figure 2.14 The schematic diagram of convolution (II)

The left image in Figure 2.15 is original image and the right image is the result after convolute by mask.

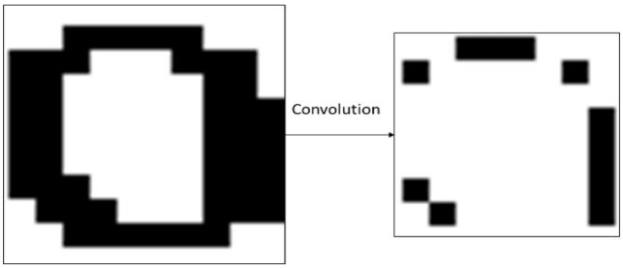


Figure 2.15 The result of convolution

Note:

1. If you don't want image after convolution will become smaller than the original image size, you can do some skills like padding, which means we can add several columns or rows to expand original image to let it avoid become smaller after convolution.

   The picture shown in Figure 2.15 is an example how to add rows and column.

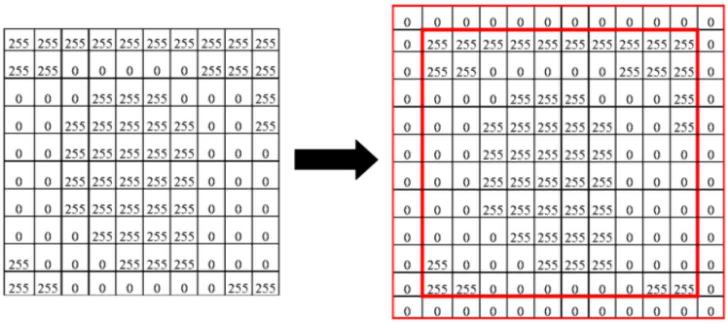


Figure 2.16 An example how to add rows and column

Then the next picture is the image after convolution.

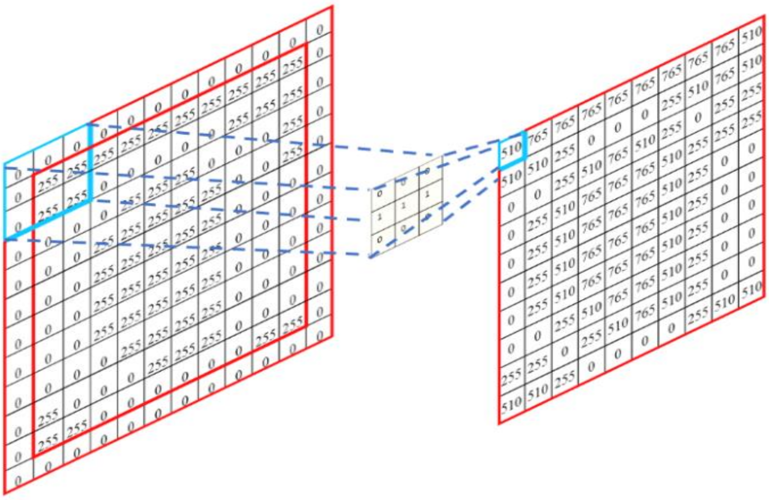


Figure 2.17 The image after convolution.

2. Convolution can move any pixel each step as you want. You can adjust the stride number. For example, in tensorflow, you can set stride = 2 to let each step move 2 pixels.

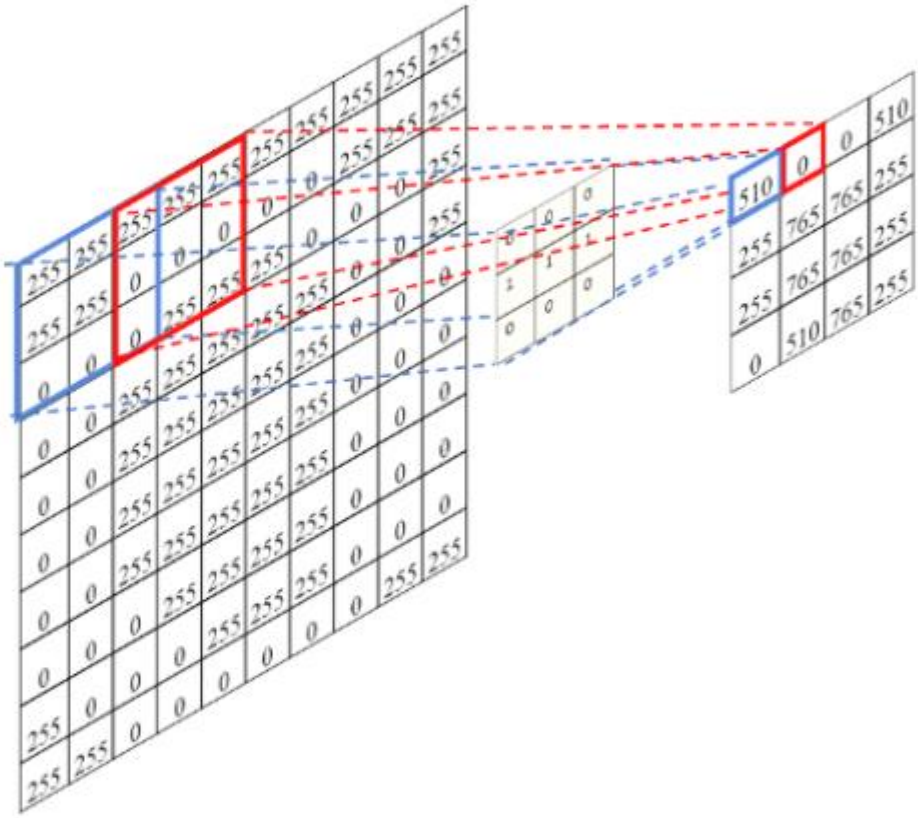


Figure 2.18 The schematic diagram of convolution (III)

2.2.7.1.2 Upsampling

In U-net structure, upsampling is a process which make image have higher resolution. The simplest methods are resampling and interpolating. Maxpooling is a procedure after convolution, as shown in the following picture. The whole image is separated to several parts. Each parts only pick the biggest number.

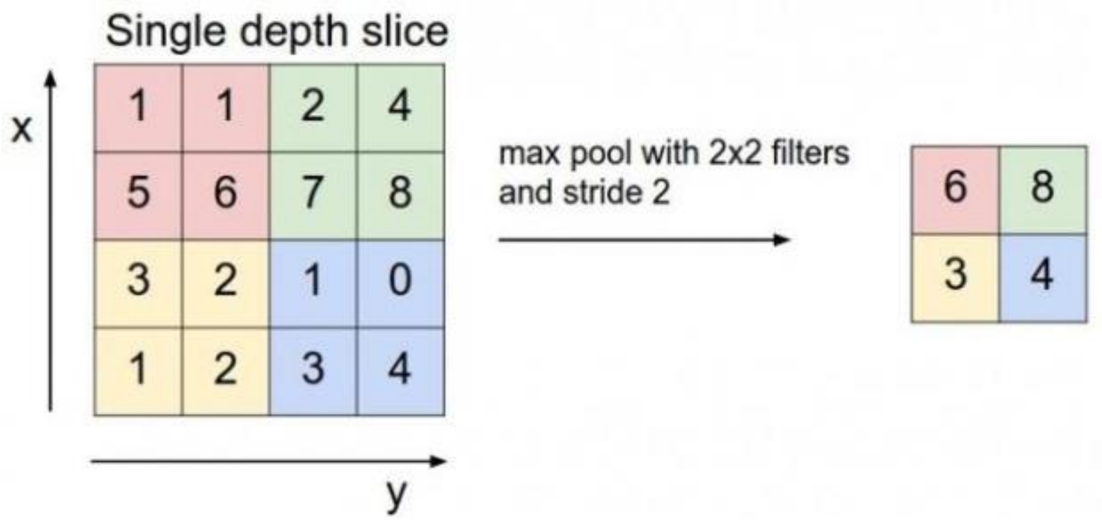


Figure 2.19 The schematic diagram of maxpooling

After doing maxpooling, we can use the pixels we get from the maxpooling do the upsampling step.

There are lots of method to help us execute this step. One of them is duplicate.

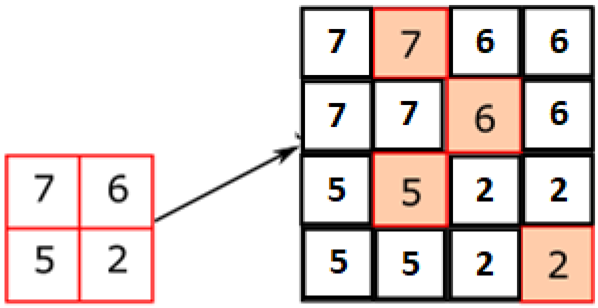


Figure 2.20 The schematic diagram of upsampling

2.2.7.1.3 Introduction of U-net

U-net build upon a more elegant architecture, the so-called “fully convolutional network”. We modify and extend this architecture such that it works with very few training images and yields more precise segmentations; see Figure 2.21. The main idea in FCN is to supplement a usual contracting network by successive layers, where pooling operators are replaced by upsampling operators. Hence, these layers increase the resolution of the output. In order to localize, high resolution features from the contracting path are combined with the upsampled output. A successive convolution layer can then learn to assemble a more precise output based on this information. One important modification in our architecture is that in the upsampling part we have also a large number of feature channels, which allow the network to propagate context information to higher resolution layers. As a consequence, the expansive path is more or less symmetric to the contracting path and yields a u-shaped architecture. The network does not have any fully connected layers and only uses the valid part of each convolution, i.e., the segmentation map only contains the pixels, for which the full context is available in the input image. This strategy allows the seamless segmentation of arbitrarily large images by an overlap-tile strategy (see Figure 2.21). To predict the pixels in the border region of the image, the missing context is extrapolated by mirroring the input image. This tiling strategy is important to apply the network to large images, since otherwise the resolution would be limited by the GPU memory.

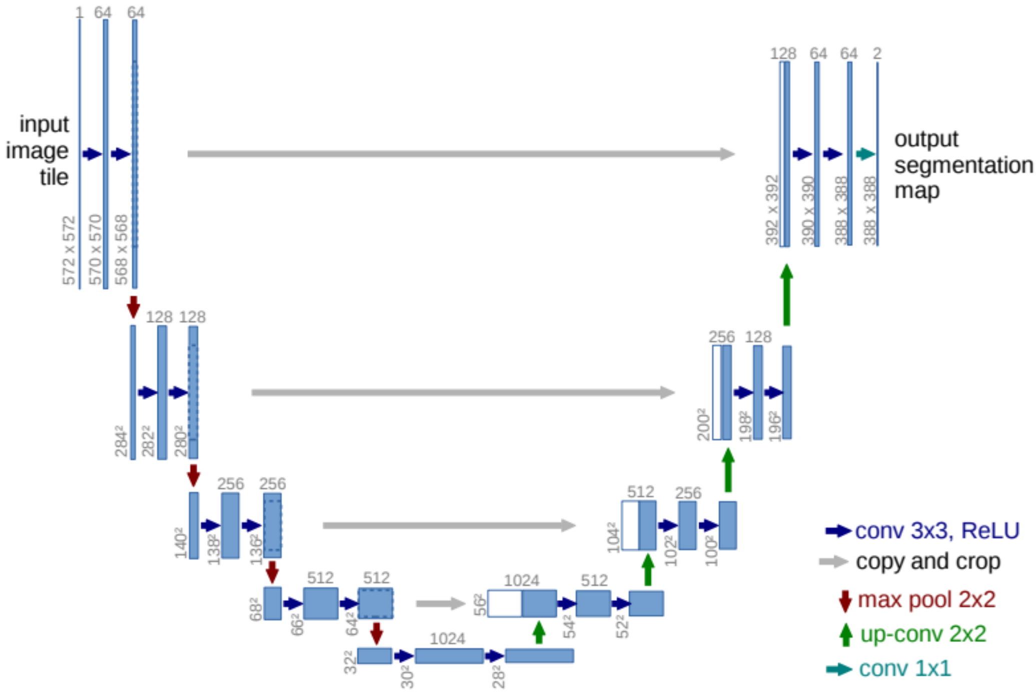


Figure 2.21 U-net architecture (example for 32x32 pixels in the lowest resolution). Each blue box corresponds to a multi-channel feature map. The number of channels is denoted on top of the box. The x-y-size is provided at the lower left edge of the box. White boxes represent copied feature maps. The arrows denote the different operations.

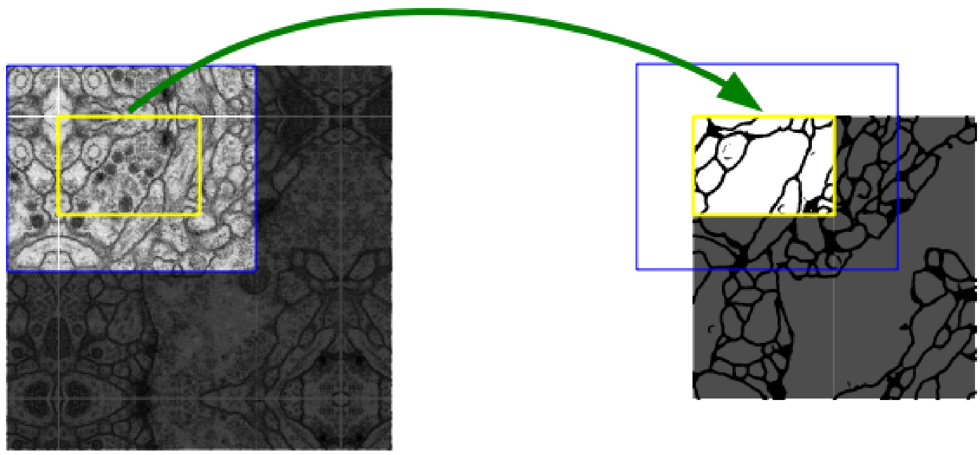


Figure 2.22 Overlap-tile strategy for seamless segmentation of arbitrary large images (here segmentation of neuronal structures in EM stacks). Prediction of the segmentation in the yellow area, requires image data within the blue area as input. Missing input data is extrapolated by mirroring.

As for our tasks there is very little training data available, we use excessive data augmentation by applying elastic deformations to the available training images. This allows the network to learn invariance to such deformations, without the need to see these transformations in the annotated image corpus.

2.2.7.1.4 Explanation of U-net structure

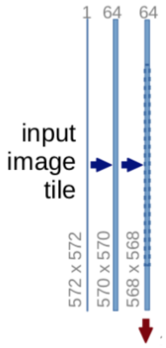


Figure 2.23 Beginning of U-net structure

This is the contracting path. We should notice that each process constitutes two convolutional layers, and the number of channel changes from 1 to 64, as convolution process will increase the depth of the image. The red arrow pointing down is the max pooling process which halves down size of image, and the size reduction is due to padding issues, but the implementation here uses same padding.

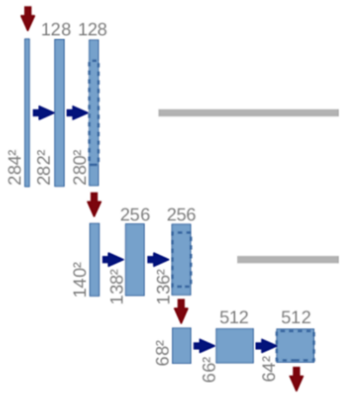


Figure 2.24 Beginning of U-net structure

The process is repeated 3 more times

Figure 2.25 Bottommost of U-net structure

It is the bottommost structure of U-net. Still 2 convolutional layers are built, but with no max pooling. The image at this moment has been resized to 28x28x1024. Now let's get to the expansive path.

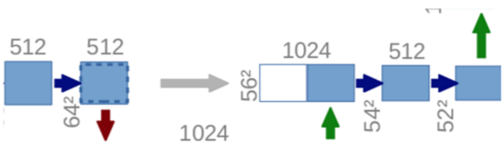


Figure 2.26 Expansive path of U-net structure

In the expansive path, the image is going to be upsized to its original size. The formula follows conv 2d transpose, concatenate, then conv_layer1, and finally conv layer2. Transposed convolution is an upsampling technic that expands the size of images. Basically, it does some padding on the original image followed by a convolution operation.

After the transposed convolution, the image is upsized, and then, this image is concatenated with the corresponding image from the contracting path and together makes an image of size 56x56x1024. The reason here is to combine the information from the previous layers in order to get a more precise prediction.

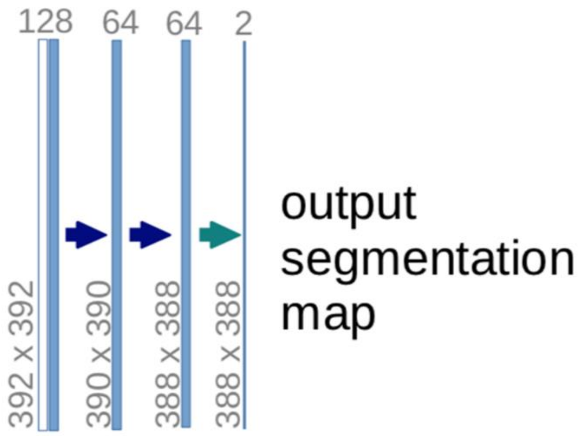


Figure 2.27 The end of U-net structure

It is the uppermost of the architecture, the last step is to reshape the image to satisfy our prediction requirements. The last layer is a convolution layer with 1 filter of size 1x1(notice that there is no dense layer in the whole network). And the rest left is the same for neural network training.

In conclusion, U-net first use convolution and pooling to get the obvious characteristic of target image, which allow U-net easier to learn. However, both convolution and pooling will let the dimension of the image becoming smaller. In order to recover the dimension, we need upsampling to expand the dimension. The left side of the structure is called contracting path, right side is called expanding path. Before both contracting and expanding path, it will do two layers of convolution, which is called successive convolution. Another feature of U-net is it maintains the high amount of channel in upsampling process. It makes relative position relationship and detail characteristic can be combined together more amply. Apart from this, U-net can mirror border region of the image, so that the identification of the border region can be improved. In addition, it won't occupy the consumption of the GPU.

2.2.7.2 Training Data

The training data needs to prepare two kinds of images from other satellite imagery data. One is the original picture from the camera, the other one is still the same image, but the pixels of the river is painted by white and the remaining pixels are painted by black. It needs at least 300 pictures to run a cycle. After finishing each cycle, U-net will provide a model to analyze. If this model doesn't satisfy the accuracy we set, we need to run another cycle until we get the model which accurate enough.

Figure 2.28 Original image (left) and mask (right)

2.2.7.3 Procedures in Space

First, we will get an image of a specific river by the camera. And, we will know the altitude of our satellite, latitude, and longitude of the river section in the image. Second, after image recognition, we will know the range of the river and the number of pixels for river width. By using a resolution, we can calculate the river width. Third, we compare the river width database for the normal river width in a specific coordinate. Finally, if the river width calculates by image recognition is larger than the database, ALICE will notice and transmit the images to the ground TT&C station. It takes 40 to 60 seconds for U-net identification. The database we need is the width of the river. Every 1-kilometer records one river width data. The type of database is a text file. It is unnecessary to put the database into ALICE onboard storage, we can upload the data by Iridium when U-net finishes identification. In this way, it can save our memory.

2.2.7.4 Simulation

Table 2.25 Simulation Environment

CPU	Intel i7-7820
GPU	Nvidia Geforce GTX 1060
Python	Version 3.6
Cuda	Version 10.2
Keras	Version >=1
Tensorflow	Version 2.2

1. The model is trained for 12 epochs

2. After 12 epochs, calculate accuracy is about 0.97
3. Loss function for the training is basically just a binary cross entropy

These two RGB images are downloaded from Sentinel 2. We use current remote sensing images to test whether U-net can meet our mission requirements or not. From these two images, U-net successfully identifies the contour of the riverside (red lines). However, accuracy needs to be improved. As you can see, the flood image is not well identified, especially the pixels which are under the cloud. It is caused by insufficient training and computer performance. The training computer CPU and GPU we used are I7-7820 and GeForce 1060. If training data and training time can expand, the testing model can meet our mission requirements. The testing data is imaging from Landsat 5. ALICE is capable of identifying the flood. The only thing we need is that we should build a database for the normal width of rivers. As long as we have the database, ALICE can satisfy the flood early warning.

Figure 2.29 The original image (left) and the flood image (right) with test result [5]

2.2.8 Primary Payload

To confirm if water had been overflowing from the river, ALICE equipped a camera with a resolution of 5 m to observe the earth's surface. This camera's optical telescope type is refraction and simple structure parameters are as table 2.23 below. In our calculation of the optical system, we choose the "Omnivision_OV64A" as the CMOS which is equipped in its payload. It can collect general RGB (R=570~700nm, G=450~630nm, B=400~530nm) digital images by its build-in filter and A/D conversion of each chip. Due to the camera's optical telescope type is refraction, there would be an achromatic lens group placed behind the main lens group.

High pixel number (9248×6944) and small pixel size (1.008μm) are the main features of this CMOS. Under the same resolution, the observing range would be much vast with the bigger pixel number. With the vaster observing range, ALICE's alarm system would work with better function. According to the parameters above, ground resolution=5m, pixel number =9248×6944, altitude of satellite=620km, we can know the area of each image is 46.24km× 34.72km and the Field-of-view(FOV) of this camera is 4.27°×3.2°.

Under the same FOV, if pixel size could be smaller, the focal length would be shorter, and the volume of this optical system would also be smaller. So now we need to know how small this payload is. First, as we know the relation between focal length, resolution, observing distance, and pixel size, we can know the focal length of this system equal to 0.069 m.

$$\text{focal length} = \frac{\text{observing distance} \times \text{pixel size}}{\text{resolution}} = \frac{620km \times 1.008\mu m}{5m} \simeq 0.125m \quad (9)$$

Second, under the Rayleigh criterion's restriction, we know the aperture must greater to 0.068m. The lens whose aperture equals to 0.07m (0.07>0.068m) can be used in this payload.

$$D_{limit} = 1.22 \times \frac{\lambda}{\theta} = 1..22 \times \frac{900*10^{-9}m}{\frac{5m}{620km}} = 0.136m \quad (10)$$

According to the simple calculation above, we have a general cognition of the volume of this optical system (D=0.136m, f=0.125m), so it is reasonable to define this payload including the optical system, electrical system and mechanical structure can be packaged by a box which size is $0.15 \times 0.15 \times 0.15$ m.

Table 2.26 The parameters of camera

Optics	Fl= 0.125m, F/0.91
FOV	5.27°×3.2°
FOV ($km \times km$)	46.24×34.72
Sensor	OV64A, CMOS
Pixel number	~64M
Pixel size	1.008μm, square
Scope Type	Refraction
Ground resolution	5m

2.3 Ground segment

2.3.1 Ground station

The basic role of the ground station is to communicate with satellites including upload commands and download the data include warning for flood, image, and satellite health condition. The ground station in NCKU will be used in the operation of ALICE, and it will be equipped with a Ku-Band antenna and communication system supplied by SpaceX.

The warning message includes the longitude and latitude computed by the attitude and position of the satellite. After the team receives the warning from ALICE, they can notice the organizations concerned immediately. The image will be sent to the ground station later, and the team can do further studies on the ice-jam flood.

2.3.2 Mission operations system

The ground station will transmit uplink commands to the satellite, receive downlink image data, health condition from the satellite, and warning message. The Mission operations system operates the system and maintains the satellite in space. The team of ALICE processes the massager and image to analyze the accuracy of warning from ALICE and makes the system complete and perfect. Because the error from a distorted image cannot avoid, the repeated improvement and theoretical basis are indispensable to complete the system.

2.3.3 Data distribution

Data distribution is to deal with the warning message and image from the camera. After the data is downloaded by the ground station, it is sent to the operator in the ground station. And the data will be sent to the organizations concerned immediately. The organizations concerned can deal with the problem at the first timing. About half of hour later, the image processed by the U-net model on ALICE will be sent to the ground station. The ALICE team will analyze the warning whether it is false positive or not.

3. Anticipated results

The ice-jam flood occurs in the mid- to the high-latitude area every year and may cause damages. To this day, the remote sensing satellites capable of monitoring the ice-jam floods are still few. However, the ice-jam flood happens in high latitude area, it’ s highly related to global warming and ice layer melting. ALICE can provide the early warnings of ice-jam flood and images of the focused flooding area intelligently. From the view of safety and economy, the early warning by the ALICE mission is able to have more time to evacuate the residents with high risk and greatly reduce the loss from the ice-jammed flood. From the view of study and nature, the image data is valuable for study to understand the ice-jam and protect the environment.

4. Originality and/or social effect

In science, the ALICE mission is proposed firstly to monitor the ice-jam flood by artificial intelligence and Iridium. The observation can decrease the loss from flood disasters and provide the study data for scientific research. The impact of this mission is not only essential to avoid loss from ice-jam floods but is helpful to understand the ice-jam science. The artificial intelligence applied to the satellite and the high-speed communication by Iridium is a point for the development of space technologists.

5. Range and budget for manufacturing

ALICE microsatellite will be developed by the NCKU team, associated with several institutes including Physics, Space Science, Aeronautics & Astronautics, Electrical Engineering department in NCKU.

Table 5.1 Range and budget for manufacturing

Components	Estimated Cost (USD)
Structure	10,000
Solar Cells	200,000
Sentinel M-Code GPS Receiver	50,000
NST-3 Nano Star Tracker	34,000
Sun Sensor ISS-D25	20,000
Gyroscope	10,000
IMU	10,000
Reaction Wheel	30,000
PCDU	20,000
Transceiver	40,000
Camera	20,000
iOBC	15,000
TPU	20,000
Total	479,000

6. Development, manufacture and launch schedule

The development of the ALICE mission is a difficult procedure. Before the preliminary design review (PDR), the local investigation of the target river must complete essentially. The Science Working Group have to decide the aims and science requirement of the mission. The training data from other satellite remote sensing image is according to the investigation. The team spends 3 months that collect training data and train the U-net model at the same time using Tesla V100. In order to train a high accuracy and reliability model, the team will iteratively optimize the model, the time of design is following the detail U-net model architecture and the hardware condition. After all the subsystem design is complete, the Iridium situation is the key. In 2024, Iridium will have deployed the half of constellation that can supply ALICE instant messaging. Iridium will have deployed the complete constellation in 2027. Therefore, the best time for launch is in 2027.

7. Conclusion

The primary propose of the ALICE mission is the early warning and study of the ice-jam flood which is possibly related to the climatic change to avoid the large economic loss and mass casualties. ALICE will bring the large data of ice-jam flood including the image and happened frequency. People will more understand the natural disaster and be far away from the risk of big damage.

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