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ISSUES AND EXPLOIT POSSIBILITY OF IMAGES TAKEN BY DRONES FOR DETECTING ROOF DAMAGE
-A Case Study of Murakami City at 2019 Yamagata-oki Earthquake-

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Abstract

Recently, UAV has been popular in our society, and it has been easy for us to operate it. Under this background, it is expected that UAV could be utilized for capturing whole picture of disaster damage immediately after disaster occurrence. On June 18th, 2019, Murakami city was attacked by Yamagata-oki Earthquake, and there were many damaged buildings. Local city officers had to inspect each housing damage in order to grant certification for each victim. Especially, some of wooden housings were damaged on their roofs, and we decided to operate drones for taking pictures of roof damage from a birds-eye view.

Firstly, we designed flight plan covering affected area efficiently. Then, we operated a drone and took pictures of all buildings in affected area. We created orthophoto mosaic from those pictures. In this operation, we set high-performance computer in our laboratory and transfer those photos to it through internet because it could take much time and resources to do it. Then, we uploaded the orthophoto mosaic to cloud-based GIS in order to enable city officers to refer it easily. In city office, we established the environment for city officers to browse it. They utilized it to judge the damage level of roof of each building because it was hard to check roof damage from ground. Furthermore, they utilized tablet computer in inspecting building damage to record the result of inspection. Thus, we implemented survey form for operators to refer the orthophoto mosaic on their tablet computers from cloud-based GIS. By this implementation, building damage inspection was proceeded efficiently, and it was realized that they grant certification of the degree of building damages to victims. Aftermath, Murakami city shifted the response phase to recovery. Understanding this damage situation, they established new relief program to support for victims to repair roof of their housings. This means our activity contributed to promote their support for victims’ life reconstruction.

Additionally, in performing life reconstruction process, victims wanted to confirm the roof damage situation of their housings in order to judge they should repair roof immediately or not. In granting certification of the degree of building damage, city officers responded to consultation from victims utilizing the orthophoto mosaic on web-browser. However, the orthophoto mosaic was created by image processing, and it was not with high-quality. Then, when they found the roof of housing, they retrieved original image taken by drones around the roof-damaged housing in web-GIS. In this process, we designed and developed a web application for them to search and look those original images easily. This support gave a sense of security to victims.

In this challenge, we found that it was useful for them to grasping the situation of roof damage of each housing. However, we found some issues to be solved. First is establishing a base of operation to charge batteries and retrieve image data from drones. Second is securing network to transfer images from affected area to the office for processing images to create orthophoto mosaic. Third is designing flight plan to capture all of roof damage in affected area efficiently. Fourth is considering the weather to operate drones, because pervasive and general drones cannot fly in bad weather. Fifth is securing operators for drones. In this research, we introduced the detail of issues and exploit possibility of images taken by drones for detecting roof damage in a case study of Murakami city at 2019 Yamagata-oki Earthquake. Furthermore, we tried to verify the possibility to apply the created object detection model to other disaster.

Keywords: UAV; Aerial Photo; Life Reconstruction; Roof Damage

1. Introduction and Background

Once disaster occurs, we have to respond to damages in our society immediately and effectively. In order to do it, we have to develop "Common Operational Picture" as shown in Fig.1, in which damage situation is detected and visualized [1]. So, first of all, local responders have to detect damages in our society. However, in our previous survey, we found that it took about 6 months for national government to grab the whole picture of building damage at 2011 East Japan Earthquake in 2011. It is necessary for us to develop some methodology or technology to reduce time-cost to detect damage situation.

In addition, ICT has been improved and popularized in our society recently. Especially UAV including drones and AI were popularized and we can treat them easily and quickly. Under this background, it is expected that UAV and AI could be utilized for capturing the whole picture of disaster damage immediately after disaster occurrence.

In this research, we tried to utilize UAV and AI for detecting building damage immediately and to develop the methodology to do it. We designed workflow for utilizing images taken by UAV for our objectives, and implemented it in a case study of 2019 Yamagata-oki Earthquake. In this work, we create the orthophoto mosaic from images taken by drones in which buildings with damaged roof were found. Furthermore, we focused on blue-sheets covering over damaged roof, detected them by human, treated the detected spots of damaged roof with blue-sheets as training data for AI, and developed an object detection model in AI. Finally, we validated our proposed methodology and technology, and it was found that the object detection model can abstract about 60% of damaged roof covered with blue-sheets.

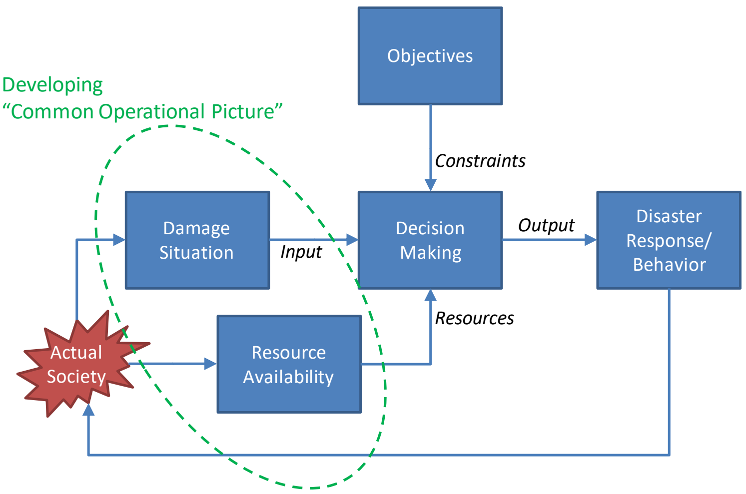

Fig. 1 – Framework of information management for effective disaster response

2. Murakami city affected by 2019 Yamagata-oki Earthquake

In Japan, we were attacked by M6.7 earthquake in Yamagata-oki at 22:22 on June 18th, 2019, which is called "Yamagata-oki Earthquake". By this earthquake, JMA 6 plus was observed in Murakami city in Niigata prefecture, and JMA 6 minus was observed in Tsuruoka city in Yamagata prefecture [2]. Furthermore, 2 minutes later disaster occurred, Tsunami warning was insured in all costal area in Niigata prefecture and Noto area in Ishikawa prefecture. Due to insuring tsunami warning, some of residents was evacuated to safe buildings or evacuation centers, however tsunami was so small and it did not cause any damage. By this earthquake, 9 people were severely injured and 34 people were slightly injured as human damage. Furthermore, 36 housings were half-collapsed and 1,245 housings were partially damaged as building damage [3]. However, Disaster Relief Act was not applicated to this disaster because the total damage was not so severe. On the other hand, human and building damage was caused, then local responders

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started to respond to those damage immediately toward to supporting survivors' life reconstruction whose housings were damaged in Murakami city and Tsuruoka city.

Especially, in this research, we focused on the response in Murakami city, because they decided to support survivors' life recovery from quite an early stage. Furthermore, they understood the building damage were spread and many householders had to repair the building damage for them to live in those housings in the affected area. In Japan, Cabinet office of Japan defined the methodology for inspecting building damage level [4]. Murakami city should also follow this defined methodology to each damaged housing. After detecting damage level of each housing, they detect the residents who should be supported their life reconstruction, and they would establish some kinds of support programs which affected residents are eager to.

Understanding the circumstance of Murakami city, we decided to support their respond with some kinds of information technologies, especially we focused on utilization of drones and AI in order to detect building damage situation and utilize for survivors' life reconstruction support.

3. Building Damage Inspection for Survivors' Life Reconstruction in Murakami City

3.1 Effective and Efficient Workflow for Survivors' Life Reconstruction Support

In our previous research, we established the workflow in order to proceed survivors' life reconstruction support as shown in Fig.2 [5]. Following this workflow, local responders have to detect the damage level of each building first of all. To do this, they have to follow the methodology to inspect building damage defined by Cabinet office of Japan as described in previous chapter. Our research team made studies of establishing effective and efficient way for building damage inspection following the methodology defined by Cabinet Office of Japan in previous research [6]. Furthermore, to make it efficient, we found the tablet-PC was so useful because it took much time for local responders to manage collected data in high-quality as digital-data in other previous research [7]. This research let us know that ICT could support local responders to make their respond efficient, so we decided to search exploit possibility of ICT including drones and AI much more in this research for efficient respond for building damage inspection.

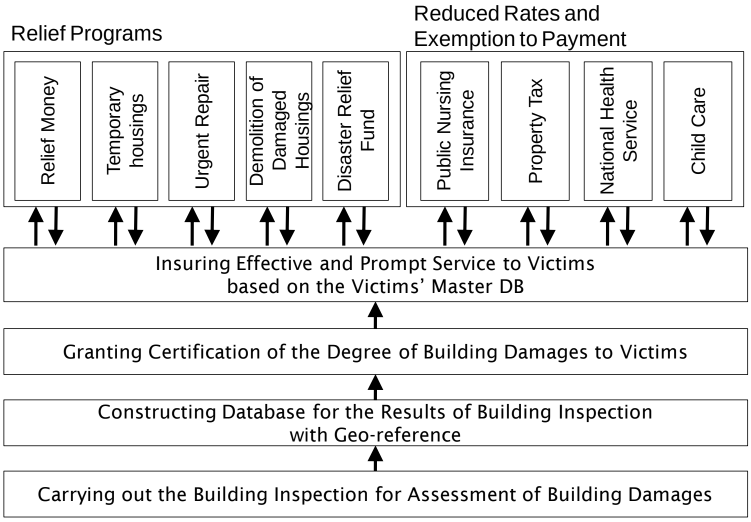

Fig. 2 – Effective and efficient workflow for survivors' life reconstruction support

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After building damage inspection, they have to grant certification of degree of building damage with acceptance from survivors. When the degree of building damage was fixed and agreed, it is decided that who can apply to which kind of support programs. Then, local responders should manage the situation of provision of support program to survivors centrally as victims master database, and they should monitor the progress of life reconstruction process of each survivor by referring victims master database, and detect survivors who have to be supported more [8].

3.2 Actual Situation of Building Damage Inspection in Murakami City

A responder in charge of building damage inspection in Murakami city experienced that he supported the response to 2018 Hokkaido Iburi Eastern Earthquake at Abira town in Hokkaido, and he understood the whole process of lire reconstruction support. Furthermore, Niigata prefecture also understood it, and they asked us to support the response relating to survivors' life reconstruction and to make it by utilization of ICT.

However, the work volume was so high against the number of local responders in Murakami city, so Niigata prefecture decided to send "Team Niigata" which was consisted of officers in other unaffected cities to support Murakami city. In this case, 20 officers from other cities and towns in Niigata prefecture participated in Team Niigata, and they proceed building damage inspection with local responders in Murakami city [9]. They accomplished the detection of building damage level for 644 buildings in 3 days as shown in Table 1. Aftermath, they started to grant certification of degree of building damage from the next day of accomplishment of building damage inspection, and 331 certifications were granted as to August 16th, 2019.


Fig. 1 – Support by "Team Niigata" in Murakami city
(left; briefing process, right; granting certification of building damage degree)

Table 1 – Achievement of building damage inspection by Team-Niigata

Inspection Date	Counts	Degree of Building Damage				
		Totally Collapsed	Almost Collapsed	Half Collapsed	Partially Collapsed	Non-damaged
23rd, June	166	0	0	4	142	20
24th, June	262	0	0	6	220	36
25th, June	216	0	3	10	191	12
Total	644	0	3	20	553	68

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4. Creating Orthophoto Mosaic over Affected Area from Images Taken by Drones

After disaster occurrence, Murakami city grab the damage situation of buildings roughly. Through this process, they found that roofs of many buildings were damaged although the damage level is not so high. In building damage inspection, they had to reflect roof damage situation to the damage level. However, it was difficult for field inspectors to detect roof damage certainly because they look at it from the ground. If the width of road is not enough, they stand nearby building and they can check only a part of roof.

Against this issue, we decided to utilize drones to take images from sky to detect roof damage and to reflect it to building damage inspection. Authors had the experience to take images by drones from the sky in order to clarify damage situation in disaster drill which was coordinated in CyborgCrowd project [10]. This drill was implemented in Tsubame city, so officers of Murakami city has known this activity and expected us to utilize drone to detect roof damage. When we operate drones in affected area, we have to be authorized for flight from the city or cities or Ministry of Land, Infrastructure and Transport in Japan, depending on the height of flight and restricted area. In this case, Murakami city offered us to do it, so we designed the flight plan meeting with their needs, and we got authority to our flight plan. In this flight plan, we designed it for taking images over 4 affected areas; Fuya, Iwasaki, Nakahama and Igureno. Finally, we developed the flight plan as shown in Fig.3, and we started to fly a drone from June 21st, 2019.

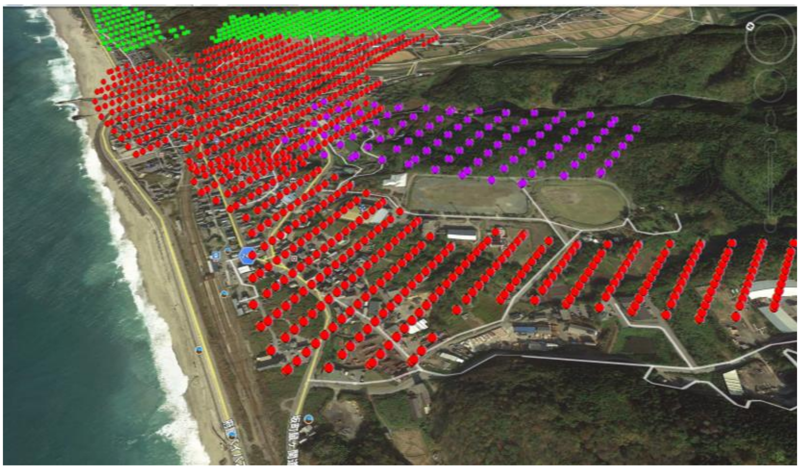

Fig. 3 – Flight plan for drone operation (on Google Earth)

In order to take images for roof damage of buildings, we prepared a latest drone, which is MAVIC 2 pro produced by DJI. This drone can fly for 30 minutes with one battery and take 4K picture [11]. Generally, the limitation of drone operation was affected by battery power and resolution of picture. So, when we utilize this drone, it could be accomplished in short-time to take images over whole affected area. After preparing a drone, we decided the height of flight. When we take image from high altitude, flight time could be reduced. However, in Japan, we cannot operate drone higher than 150m without authorization by Ministry of Land, Infrastructure, Transport and Tourism. Furthermore, the taken image cannot be able to endure to detect roof damage. Then, we decided 140m as height of flight. In next step, we have to decide the overlap rate between each image. We have to create orthophoto mosaic, because the images should be overlaid in GIS to connect roof damage to each building. Generally, to create orthophoto mosaic, the overlap rate should be set high. In this case, we set from 80% to 85% as overlap rate understanding battery power and extent of affected area.

After designing the settings of flight plan, we determined landing-takeoff bases in each affected area understanding flight route, and we obtained permission the locations as bases for a drone from owner of the land. Following this flight plan, we operated a drone to take images in 5 hours. Due to the effective design, we took images over 4 areas quickly and efficiently in limited duration.

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Then, we created orthophoto mosaic with images taken by the drone using "Drone2Map for ArcGIS" which is a commercial product by esri corporation [12]. This software able us not only to create orthophoto mosaic easily but also to publish it to cloud-based GIS platform. In order to create orthophoto mosaic, we set Ground Control Points from each image to actual location in that software, and we created orthophoto mosaic in 4 hours. In this operation, we supposed that it could take much time for image processing, so we use 2 machines parallelly to reduce time of processing remotely by transferring images to powerful machine located in our laboratory. Finally, we publish the result of orthophoto mosaic to cloud-based GIS platform from remote machine directly, and share it with local responders in Murakami city.

However, in the process of creating orthophoto mosaic, the image resolution was got low. Against this issue, we also publish original images with geolocation overlaying on the orthophoto mosaic in the same platform to browse images with high resolution. Utilizing this platform, local responders in Murakami city refer the damage situation of each roof as shown in Fig.4. Following this workflow, they reflect the actual damage situation of roof to each building damage level certainly. This means it was realized that they combined two kinds of inspection from sky and ground. It was new challenge, and they regarded this challenge.

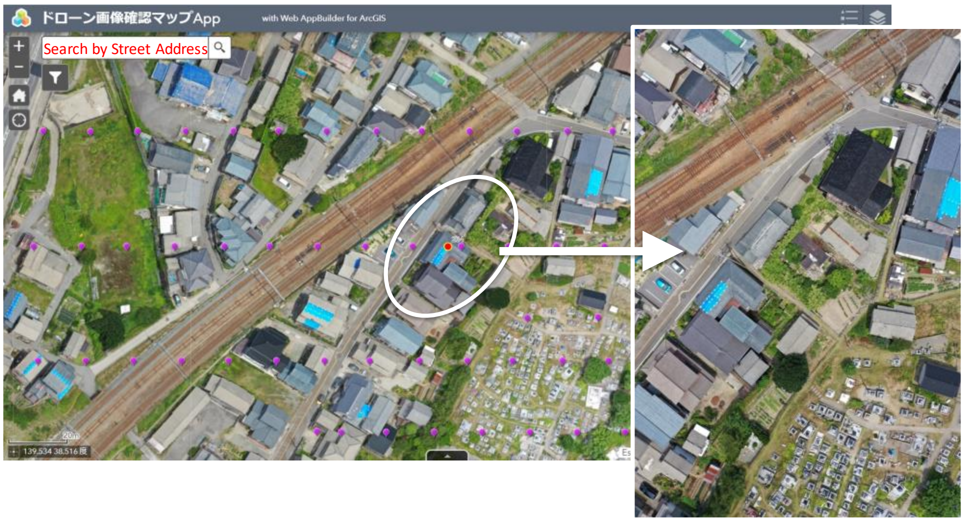

Fig. 4 – Referring high-resolution images taken by a drone by photographing location

5. Three Exploit of Utilizing Images Taking by Drones

5.1 Monitoring Progress of Life Reconstruction Process

The flight plan was saved on the tablet-PC as controller for a drone. Using this saved flight plan, we can operate a drone over same area continuously and periodically. Then, we operated a drone to take images again about 2 months later from disaster occurrence, and created orthophoto mosaic again. We uploaded it to the same cloud-based GIS platform, and we developed the application which abled us to compare orthophoto mosaic from 1st flight and one from 2nd flight as shown in Fig.5. By utilizing this application, we found that some blue-sheets covering on damaged roof were removed. This means the building with damaged roof was repaired, and the life reconstruction of residents in those buildings were proceeded. On the other hand, some of buildings, which had not been covered with blue-sheets in 1st flight, were covered with blue-sheets, this means they had not responded to damaged roof as soon after disaster occurrence and they respond to it temporarily in 2 months. As described here, we can monitor the progress of survivors' life reconstruction by tracking the transition of the situation of roof damage from orthophoto mosaic.

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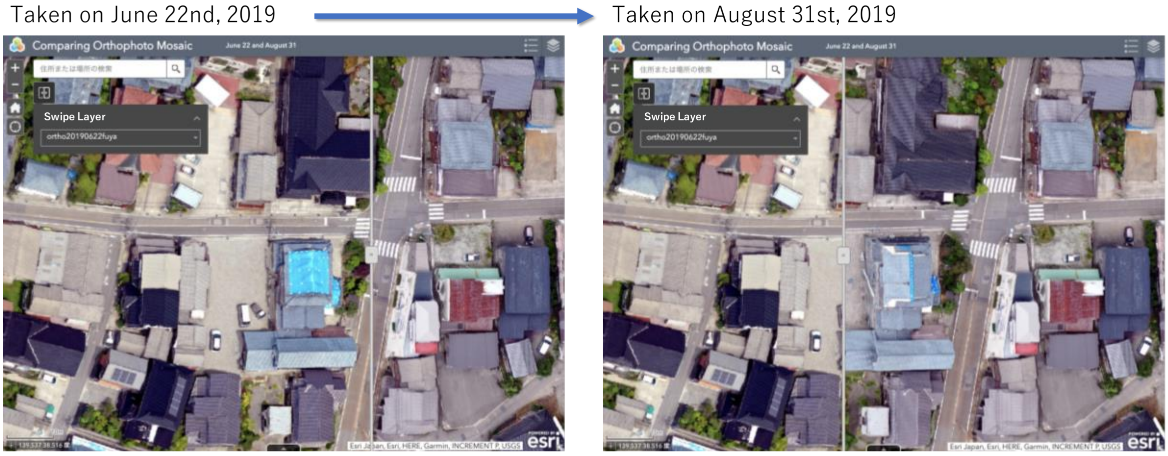

Fig. 5 – Transition of roof damage situation in 2 months

5.2 Establishing New Support Program for Survivors

By this disaster, no housing was totally collapsed, 24 housings were half-damaged, and 588 housings were partial damaged. This situation let them consider how to support survivors living in partial damaged housings, because almost of damaged housings could not be supported. On the other hand, the whole of roof damage situation was clarified, and Murakami city corroborated that many survivors were suffered by roof damage in their live. When Disaster Relief Act applicated, survivors living in damaged housings can apply to emergency repair support program. However, at 2019 Yamagata-oki Earthquake was not applicated Disaster Relief Act, thus survivors in severely damaged housing cannot get emergency repair support. Against this condition, Murakami city themselves established new support program for survivors to repair the damaged roofs in order to assist their life recovery [13]. This establishment of new support program was brought out due to clarifying volume of buildings with damaged roofs immediately.

5.3 Feedback to Survivors for Indication of Roof Damage Situation

Many survivors were in anxiety how their housings were damaged by this disaster. The damage of walls, bases or poles can be seen by themselves, however the damage of roof cannot be seen by themselves. To understand roof damage situation, there was no way than they asked other people such as carpenters because it was danger for them to get up on the roof. Thus circumstanced, they were looking for some way to check the roof damage situation of their housings by themselves. Against this issue, we provide the application to browse the orthophoto mosaic in cloud-based GIS to survivors controlling that they cannot browse the damage situation of other buildings by zooming to only their housings after detecting their housings. By checking the situation of roof damage, they judged that they should be repair the damaged roof or not immediately. This pushed their life reconstruction process forward, and this activity contributed to rapid life reconstruction in Murakami city.

6. Utilizing AI to Detect Blue-sheets with Human-in-the-Loop

6.1 Detecting Blue-sheets by Utilizing AI

As described in previous chapter, visualization and detection of roof damage brought some kinds of exploits to affected city and survivors. Furthermore, considering the efforts of monitoring life reconstruction progress, we should create orthophoto mosaic and detect damaged roof periodically and continuously. To do it, we should develop the workflow to reduce work volume and time cost. Against this issue, we decided to utilize

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AI for detecting blue-sheets from orthophoto mosaic automatically following the framework of Human-in-the-Loop [14][15], which is a model type that requires human interaction during runtime.

Firstly, we should prepare training data to develop a graph in AI, then we simplified work-flow to create training data and let one person operate the work-flow with web-based GIS application which we developed as shown in Fig.6. Secondly, AI learned the training data and it created an object detection graph for blue-sheet from orthophoto mosaic created from images taken by drones. In this case study, we utilized a deep learning application for AI implemented on GIS software, because we have to detect the geolocation of blue-sheet finally. We developed AI model for blue-sheet detection, then we validated the accuracy of blue-sheet detection with our developed model by confidence rate which was proposed by AI. The result of validation is shown in Table 2. As this result shows, the accuracy rate was not so high. The reason of this low accuracy rate was that the prepared training data was not enough and AI was not educated sufficiently. Against this issue, we are planning to utilize a crowdsourcing for gathering more training data quickly after disaster occurrence, and to improve the object detection model for damaged roof covered with blue-sheet by using gathered training data.

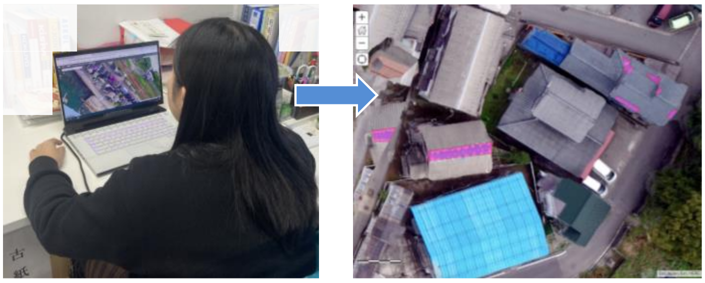

Fig.6 – Creating training data in web-based GIS application

Table 2 – Result of accuracy rate of damaged roof detection using AI

Confidence Rate	Accuracy Rate
≧ 0.95	0.60
≧ 0.90	0.58
≧ 0.85	0.59
≧ 0.80	0.58
≧ 0.75	0.56
≧ 0.00	0.49

6.2 Applying Object Detection Model to Other Disaster

On September 9^{th}, 2019, Typhoon #1915 landed to Japan from Chiba area. Central pressure of Typhoon #1915 was 955hPa, and maximum wind speed was 40m/s. This typhoon was most strong one in Kanto area ever. This disaster caused one dead person, 13 severely injured people as human damage, and 342 totally collapsed housings, 3,927 half-collapsed housings and 70,397 partial damaged housings as building damage [16]. Especially, Oshima town in Tokyo was affected by this typhoon and some of roofs were damaged on residential housings. This disaster was different from earthquake which we treated as a case study in this research, however we thought that our methodology could be applied to this typhoon disaster.

Then, we designed effective and efficient flight plan for taking images by drone covering affected area in Oshima town, operated a drone, took images over all affected area detected by Oshima town, and create

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orthophoto mosaic. Aftermath, we apply the object detection model for damaged roof which had been developed in the case study of 2019 Yamagata-oki Earthquake, and verified the possibility of this application. In this application, many spots over the sea were detected as damaged roof. We cannot reveal how the model were educated and what kinds of factors are influenced to the model. So, to improve the accuracy of damaged roof detection, we utilized geoprocessing function to remove detected spot located over the sea. Finally, we validate the accuracy of blue-sheet detection by confidence rate as shown in Table 3. From this result, when we select only detected spots with confidence rate over than 0.95, the accuracy rate was made 0.35. However, the accuracy rate was not so high. The reasons could be 2 factors; first is that the training data was not enough, second is that the object detection model was not customized for blue-sheets detection. In near future, we will gather more training data and try to improve blue-sheets detection model.

Table 3 – Result of accuracy rate in adapting our proposed model to a case of Oshima town

Confidence Rate	Accuracy Rate		Increase / Decrease
	Non-Processing	With GIS Processing	
≧ 0.95	0.32	0.35	+0.03
≧ 0.90	0.34	0.32	-0.02
≧ 0.85	0.37	0.35	-0.02
≧ 0.80	0.36	0.33	-0.03
≧ 0.75	0.34	0.31	-0.03
≧ 0.00	0.20	0.31	+0.11

7. Conclusion

In order to realize effective and efficient disaster response, it is necessary for local responders to develop the common operational picture. To do it, they have to grab the whole picture of damage situation by building and human damage inspection. In addition, ICT and UAV have been improved recently, and it has been easy for us to utilize them for disaster response. In this research, we tried to utilize them to grab building damage situation immediately, and confirmed the effort of them in a case study of 2019 Yamagata-oki Earthquake.

Firstly, we designed the flight plan to take images by drones over affected area by 2019 Yamagata-oki Earthquake in Murakami city in Niigata prefecture, and operate a drone to do it. Secondly, we created orthophoto mosaic from images taken by drones to detect building damage situation. Especially, almost of buildings were damaged on their roofs in this disaster, so we focused on how to detect damaged roof and to utilize the result of detection of damaged roof effectively and efficiently in this research. Thirdly, we published the developed orthophoto mosaic in cloud-based GIS platform to share with local responders under secured and limited network, and we validate the efforts of this activity. Then, we found three exploits brought out in utilizing orthophoto mosaic including location and situation of damaged roof; 1) monitoring progress of life reconstruction process, 2) establishing new support program for survivors, 3) feedback to survivors for indication of roof damage situation. Furthermore, we tried to utilize object detection function in AI in order to detect damaged roof automatically. To do this, we developed training data by human and made AI learn the training data to develop the object detection model for damaged roof. Finally, we validate the accuracy of detection model in a case study of 2019 Yamagata-oki Earthquake, and it was found that the model detected 60% of damaged roofs, however it was not so high. Additionally, we tried to apply developed object detection model to other disaster which was a case of Oshima town affected by Typhoon #1915. However, in this case study, the developed model could detect only 35% of damaged roofs with blue-sheets. This result indicated our developed model had not been maturated and the model was perhaps relying

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to local characteristics. If so, we should develop the object detection model in each disaster and each area after disaster occurrence immediately.

In reviewing our research, we generalized effective and efficient data management process for detecting damaged roofs utilizing UAV and AI as shown in Fig. 7. However, there were 3 issues which occurred in actual operation at 2019 Yamagata-oki Earthquake. First issue happened in the process of data transfer from the affected area to our laboratory. Images taken by drones had 4K resolution and the volume of data was so huge. Furthermore, the internet speed was low because the affected area was rural area. Thus, it took much time to transfer image data. Second issue happened in the process of GCP (Ground Control Point) detection. In order to create orthophoto mosaic from images taken by drones, we had to detect which point in images was located in actual world in the GIS referring satellite images with accurate geolocation. However, in rural area, most of images photographed forest, farm and sea, so it was difficult to detect the actual geolocation in each image. Third issue happened in the process of detecting blue-sheets by AI. To do this, we had to prepare the training data, however the number of damaged roofs with blue-sheets was not large, so the accuracy and confidence of object detection model developed with the training data were not so high. Especially, advanced ICT will solve former 2 issues in near future. For example, against issue about data transfer, 5G infrastructure will be established in Japan, so the time to transfer huge data will become short, and against GCP issue, the cost of the drone with high-spec for taking geolocation will be cheap, and we will be able to take them easily and it will become easier for us to manage GCP than now. On the other hand, we have to struggle with the issue of gathering training data. Now, we plan to connect crowdsourcing and AI following the framework of Human-in-the-Loop in order to develop a lot of training data efficiently and rapidly after disaster occurrence. We will design the workflow of this activity and verify the effort of it in near future. Finally, we are eager to establish and publish the platform for realizing collaboration between crowdsourcing and AI for gathering training data about images including damaged roofs with blue-sheets, and to contribute for improving the capacity of disaster management in Japan.

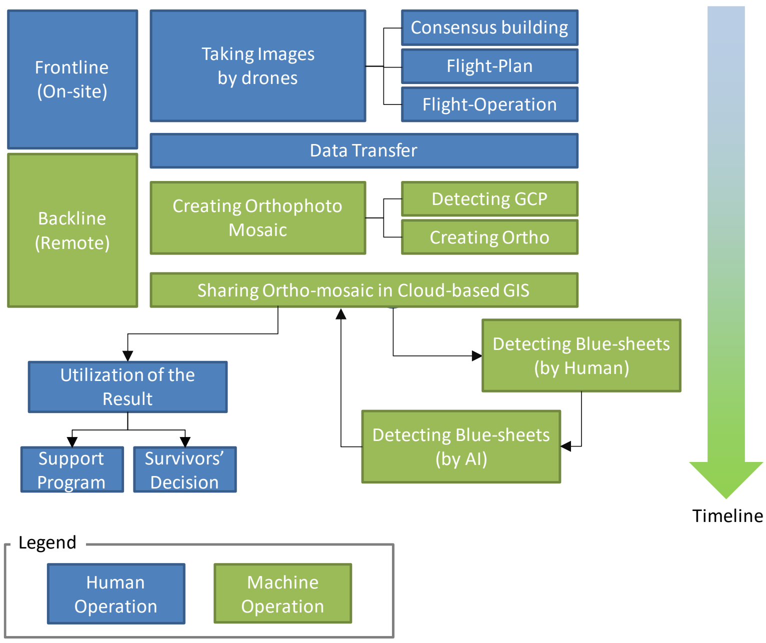

Fig. 7 – Processing flow for utilization of images taken by drones

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