國　立　清　華　大　學

National Tsing Hua University

碩　士　論　文

設計與實作雲端自動化之錄影系統

On the design and implementation of cloud based automatic recording system

系所別：資訊系統與應用研究所

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Abstract

Algriculture plays a key role in human history. Increasing of food productivity allows people to develop technology and civilization. Although been benefited from modern technology, such as agricultural machinery and farming methods, genetic technology, techniques for achieving economies of scale in production. We still face some problem, for example, farm security, population increasing, plant diseases, cattle diseases and abnormal behaviour. Increasing productivity and decreasing diseases damage of food resource in crop and stock is crucial mission for us. Previous research have used AI technology to do image recognition and classification for crop related research by collecting photo as training data. But if it comes to stock farming this might become issue. Although some analysis about animal can be done by photo, abnormal behaviour is hard to analyze because continous behaviour is the range of actions and mannerisms. In other words, it is hard to be recognized by a single photo. Video training data is kind of thing we need. In this thesis, we proposed a recording streaming system which is efficient, automatic and cloud based. It can preset time scheduling for specific timing to record and register events to trigger record process when sonething critical happened. Also, we use AWS as our cloud service which improve storage limit, difficulty of maintaining system and developing new feature etc.. At last, We can manage all of the camera in experimental field located all over Taiwan.

摘要

農業在人類文明發展上扮演著極為重要的角色，生產力的提升讓人類有餘力去發展創新科技。但現代中，雖有近代科技輔助，像是機械化農機具，基因改造科技和殺蟲劑等幫助。人們仍然面對諸如農場安全、人口劇增、作物疾病、牲畜疾病和動物異常行為等問題。因此增加食物產量及降低疾病帶來的損失是目前在農業和畜牧業的一個重要任務。前人的研究中使用照片訓練集來訓練 AI 影像辨識來達成對作物的相關分析研究。在畜牧業情況就變得比較複雜，雖然有一些動物相關的 AI 分析，例如動物品種辨識，也可以用照片來做訓練，但如果是跟動物行為就比較難用照片當作訓練集。因為動物的行為是一連串連續的動作，難以用單一照片來判斷行為的區別。本論文中設計並實作出一套基於雲端服務的全自動錄影串流系統，來解決收集影像資料的問題。該系統可以預約錄影時間，讓攝影機在特定時間收集資料，也可以註冊事件觸發，讓攝影機能在特定重要事件觸發時開啟錄影功能記錄當下狀況，並也可以手動開啟錄影功能。最後我們使用 AWS 雲端整合服務，解決儲存空間限制、降低維護系統及開發新功能的難度，並可以同時管理全台灣多個場域的攝影機。

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Chapter 1

Introduction

One of the most critical improvement of technology human beings have ever made must be the domestication of plants during the agricultural revolution 8-12,000 years ago at multiple sites around the world [4] [5]. These innovation of new food resource created civilizations and other new technology by steady and predictable supply of calories through human work. The human population have drastically increased to 7.97 billion as of September 2022 according to the most recent United Nations estimates elaborated by Worldometer [6]. This has been made possible by an efficient and productive agricultural basis [7]. Another critical invention is livestock farming. Domesticated animals are raised in an agricultural field. It can offer labor and produce food resuorce such as meat and milk [8]. Overall, livestock provides 33% percent of the protein for human diet [9]. Thanks to industrial revolution that happened between the 17th century and the mid-19th century. Human took advantage of mechanize technology, such as using pesticides to reduce damage of pests, applying synthetic fertilizer to supply plant nutrients and mechanised device greatly increasing crop worker productivity. Although industrial revolution helps a lot, we still face some problems. Crop farming is threatened by infectious diseases and damage of pests due to globalization combined with climate change [10]. Diseases occured in either stock or crop farming that need to be improved. As the human population becomes larger and larger. Productivity of food need to further increase to provide even more calories and nutrition. In fish farming, it is costly and tiring operation that require a lot of man power, more than 67% of farm costs go to the workforce [11]. We need some more advanced technology to solve the problems for diseases and automation.

When it comes to modern technology, we will mention about Artificial Intelligence(AI) and Internet of Things(IOT). We call farm which combine with AI and IOT as smart farm. Smart farm has tremendous potential to solve the problem whilch we mention above based on AI computer vision and communications via internet. Previous research about dragonfruit [12] design a precise agriculture system for classifying different ripeness of dragonfruits, then transmit the prediction result to refitted fruit gravity classifier which can grade dragonfruits automatically. It is more complex in stock farming. For reognition or classification of crop, it uses photo data to train AI model. Although there are also some tasks that use photo as trianing set, behaviour analysis soon becomes problem. Because behaviour is the range of actions and mannerisms. In other words, it is hard to be recognized by a single photo. Thus, continuous motion data, video data, is considered better than single static data in this case. For example, in [13], It used video files to extract the identification of fish trajectories and analyze their behaviors through trajectories. In [14], video data were used for the real-time capture of rutting behavior and hoof or back characteristics. [15] classified the behavior of a single laying hen. Allow user to identify three different types of individual behavior (standing, walking, and scratching).

In this thesis, we propose a automatic cloud based recording system implemented in Smart Farming Platform [16]. Smart Farming Platform is a platform built by National Tsing Hua University High Speed Network Lab. This recording system has multiple services that are capable of executing different type of collecting data tasks. For example, our system provide user to manually start record task by clicking a button. Also, it can let user schedule its own timing to trigger record tasks. At last, user can register some event which is critical. When the event occurs, system will dynamically start record process. All of the services is based on the basic function of Smart Farming Platform. It is easy for user to use for collecting video data empowered by automatical system. It is flexible, storage limitless, easy to maintain. Most of the system is implemented in AWS cloud service [17]. In chapter 2, we will introduce some related work about recording system. Chapter 3 will explain the detail of the system by each user case. Chapter 4 will show the result of the system including demonstration of the various user cases and analyze the performance of the system. Chapter 5 will make conclusion and show the future work.

Chapter 2

Related works

In this chapter, we briefly introduced the related techniques used in our system. In section 2.1, we describe basic concept of Internet of Thing. In section 2.2, we introduce the steaming protocols we usually used in streaming. In section 2.3, we present the operation mechanism of a protocal, MQTT.

2.1 IOT

Internet of Thing, also known as IOT, is a system of network that decribes physical objects with sensors, processing ability, software and variety of computing device, whose power of computation are often worse than normal computers and only served for specific tasks, instead of general propose. For example, connect, collect and exchange data with other devices and systems over the internet or other communication protocols [18]. Fig. 2.1 shows a schematic diagram of IOT system that the structure of the Internet of Things can be divided into three layers. First layer, sensing layer, is consisted of various IOT devices that are responsible for collecting data from field and controlling physical devices that is manully commanded by human or automatically executed. Second layer, network layer, the data that's collected by all of these devices needs to be transmitted and processed. That's the network layer's job. It connects these devices to other smart objects, servers and network devices. It also handles the transmission of all of the data. Third layer, application layer, is what user interacts with. It's responsible for delivering applicaion specific services to the user of overall hub that collates the data collected by the sensing layer and makes analysis or notifies users or gives control commands. This can be a smart home implementation, for example, where users tap a button in the app to turn on a coffee maker.

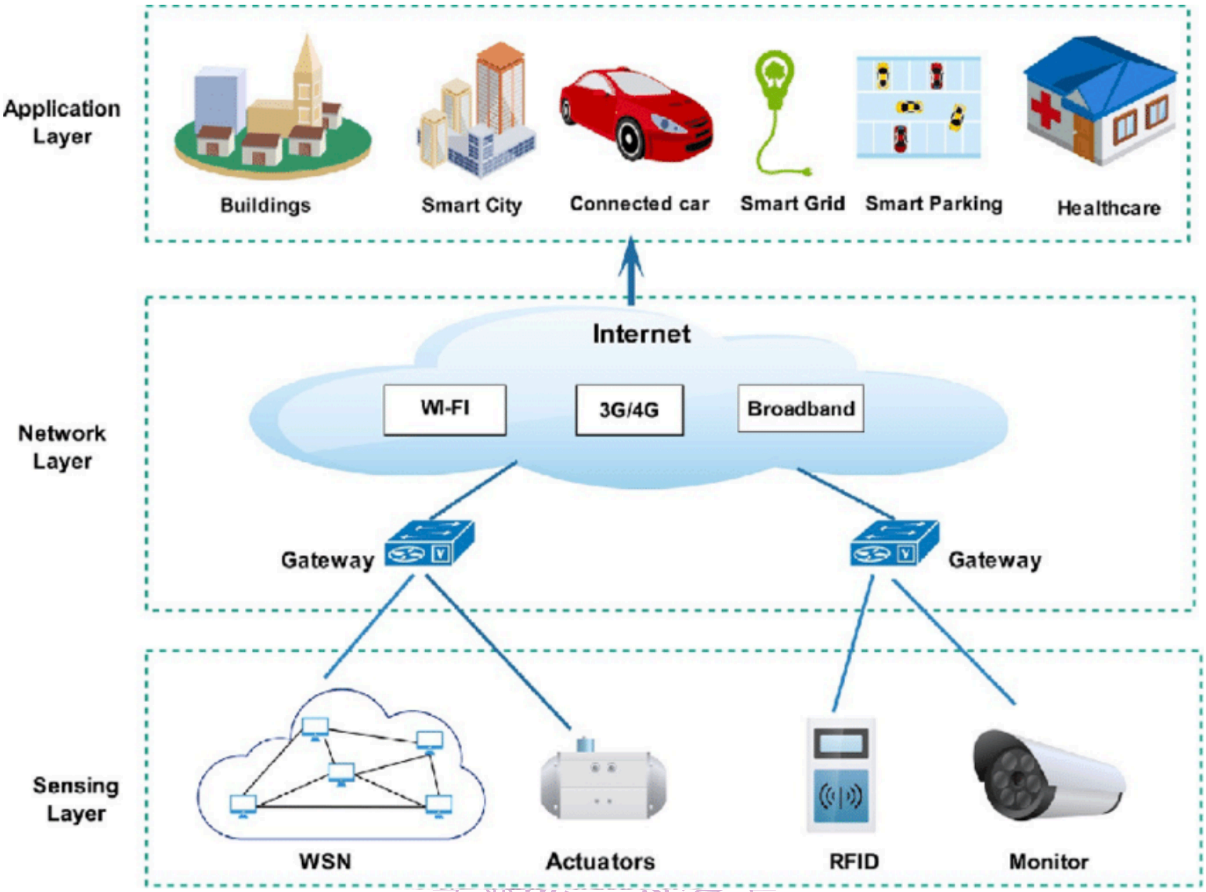


Figure 2.1: The architecture of the Internet of Things system [1]

2.2 Streaming Protocols

Streaming Protocols is a set of rules for transmitting multimedia files between 2 communication systems. It defines how your video files will be broken into small data packets and the order in which they'll be transmitted over the internet. In this sections, we gonna enumerate two frequently used protocols, and describe its pros and cons to determine which one we will choose for IP cam.

First steaming protocol, RTSP, also known as Real Time Streaming Protocol, is an application-level network protocol which are designed for multiplexing and packetizing multimedia transport streams(e.g. interactive mediam video and audio). RTSP was designed and researched by RealNetworks, Netscape [19] and Columbia University [20]. RTSP is widely apllied in such system of entertainment and communications to control straming media servers. The protocol itself is applied for building and controlling media sessions between endpoints. Pros of RTSP is that users can continue to watch a stream while it's still downloading video. Cons is that it isn't widely used for boardcasting multi-media via internet.

Second, RTMP, also known as Real-Time Messaging Protocol, is a usual protocol for live or on-demand video streaming developed by Macromedia [21]. It is initially designed for a stable connection between media server and flash player. Pros of RTMP is that it is good at boardcasting multi-media with stable conneciton. Cons of RTMP is that it isn' t compatible with HTML5 players. So if you want to watch video, you often need to install addtional protocol to support it, such as HLS.

We can summary that RTMP is good at broadcasting while RTSP is good at localized streaming. Both RTMP and RTSP are designed for efficient and low-latency streaming of video files. At last, we choose RTMP for our streaming protocol due to the usage of our IOT platform is to boardcasting. Additionally, we need to know the IP of the camera in order to establish connection with camera by RTSP. This cause another problem that it is time consuming and expensive to apply a static IP in Taiwan. And if we want to use dynamic IP then we need to use other techniques such as port forward or VPN to access to camera which is also time comsuming. RTMP don't have this disadvantage since live stream of camera will push to a single steaming server as shown in fig. 2.2. What we have to do is only need to know the IP and sercuriy setting of the server then we can access to the stream we want. The difficuly to establish a camera streaming is far easier than RTSP.

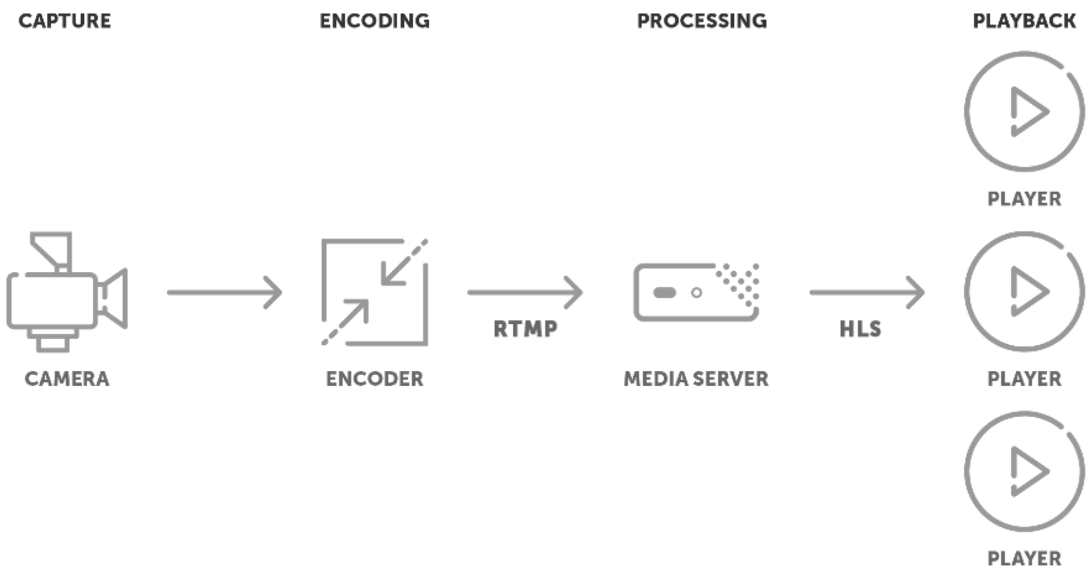


Figure 2.2: Data flow of RTMP streaming [2].

2.3 MQTT

Message Queuing Telemetry Transport, also known as MQTT [22] is a TCP level communication protocol. It is designed for low computing power of hardware devices and poor quality of internet environment and used for transmission between IOT devices. MQTT is a publish–subscribe pattern [23] where senders of messages, called publishers, do not program the messages to be sent directly to specific receivers, called subscribers, but instead categorize published messages into topics without knowledge of which subscribers, if any, there may be. Similarly, subscribers express interest in one or more topics and only receive messages that are of interest, without knowledge of which publishers, if any, there are. Information is organized in a hierarchy of topics. When a publisher has a new item of data to distribute, it sends a control message with the data to the connected broker. The broker then distributes the information to any clients that have subscribed to that topic. Fig. 2.3 show the architecture of an IOT device using MQTT communication.

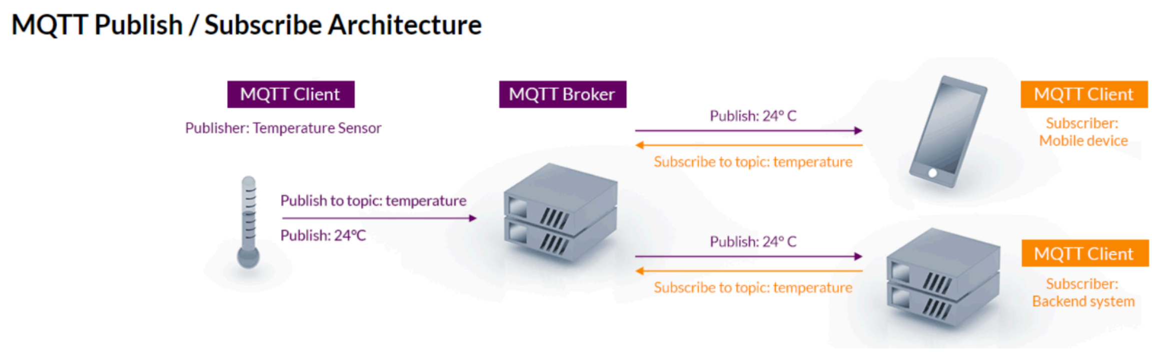


Figure 2.3: Data flow of MQTT communication [3].

2.4 Related data collecting streaming system

We will enumertate other related data collecting systems in this section and compare the difference of characteristic between us and others.

In agriculture research, there are two type of device which can help crop and stock farmer to monitor and collect image data, Unmanned Aerial Vehicles(UAVs) [24], or more commonly known as drones and Stationed ground-based surveillance and monitoring system as shown in Fig. 2.4 and Fig. 2.5. Both of these systems share many similarities. In summary, there are much more efficient than human beings in capturing and storing data. Both have some disadvantages. For drones, law limitation, expensive cost, safety, weather dependent, vulnerable and considerable pilot training etc. are its shortage. For ground-based monitoring system, limitation of movement and less freedom compared to UAVs are its shortage. We choose ground-based system because it meet most of our need to monitor and collect data. Because it is cheaper compared to UAV and UAV is mush more harder to train pilot since we don't need to train peeple to pan and tilt camera.

Figure 2.4: Unmanned aerial vehicle is flying in the sky

Figure 2.5: CCTV camera is monitoring the field

In ground-based monitoring system, they usually have 4 parts, cameras, storage, monitors and internet as shown in Fig. 2.6. Cameras are located at the place that we wish to monitor. The network connects other 3 parts together. It enable camera send live streaming to storage and monitoring station and share with other advanced services.

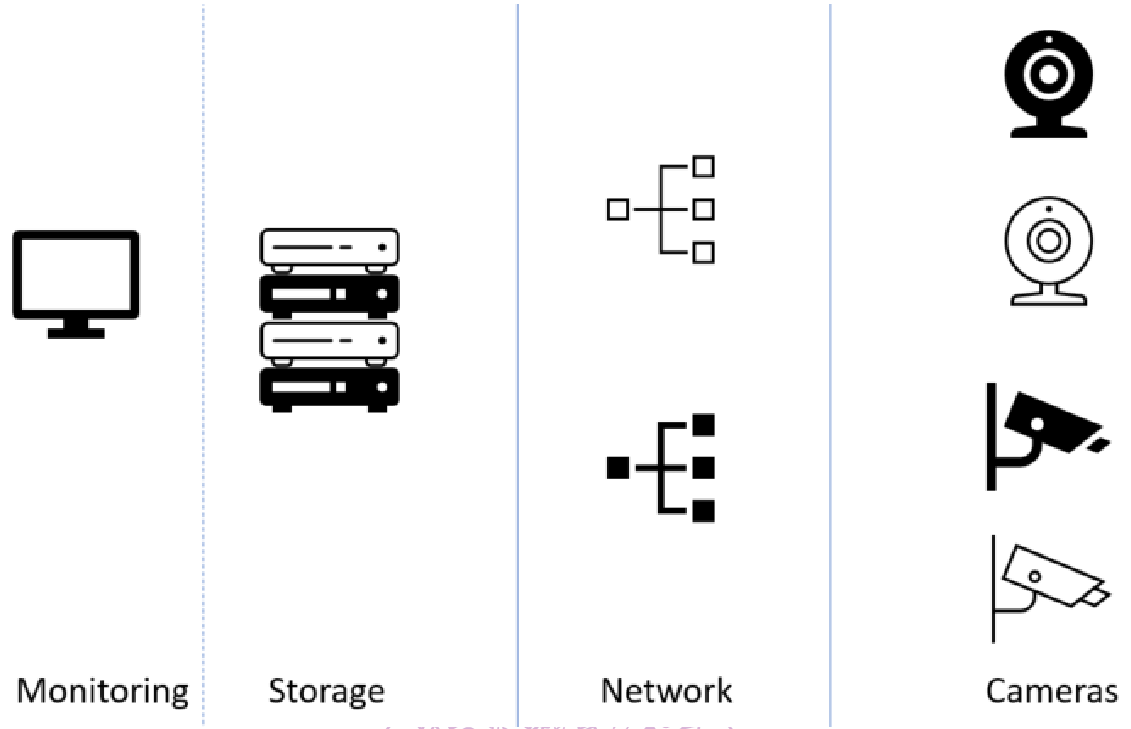


Figure 2.6: Basic components of a CCTV System

2.4.1 GenBest Technology digital video recording system

GenBest company [25] provides the most common traditional system we can find in our daily life. It has basic function for monitoring the specific field. It can see all live stream locally and remotely from internet such as web browser and access history stream which is stored in a local digital video recorder. Due to storage limit, it use technique called loop recording. To achieve never-ending recording, Loop recording will erase the previously recorded material and replacing it with the new content if the disk storage is full. Fig. 2.7 shows the system overview of the whole system. At last, they can improve service by updating software instead of hardware.

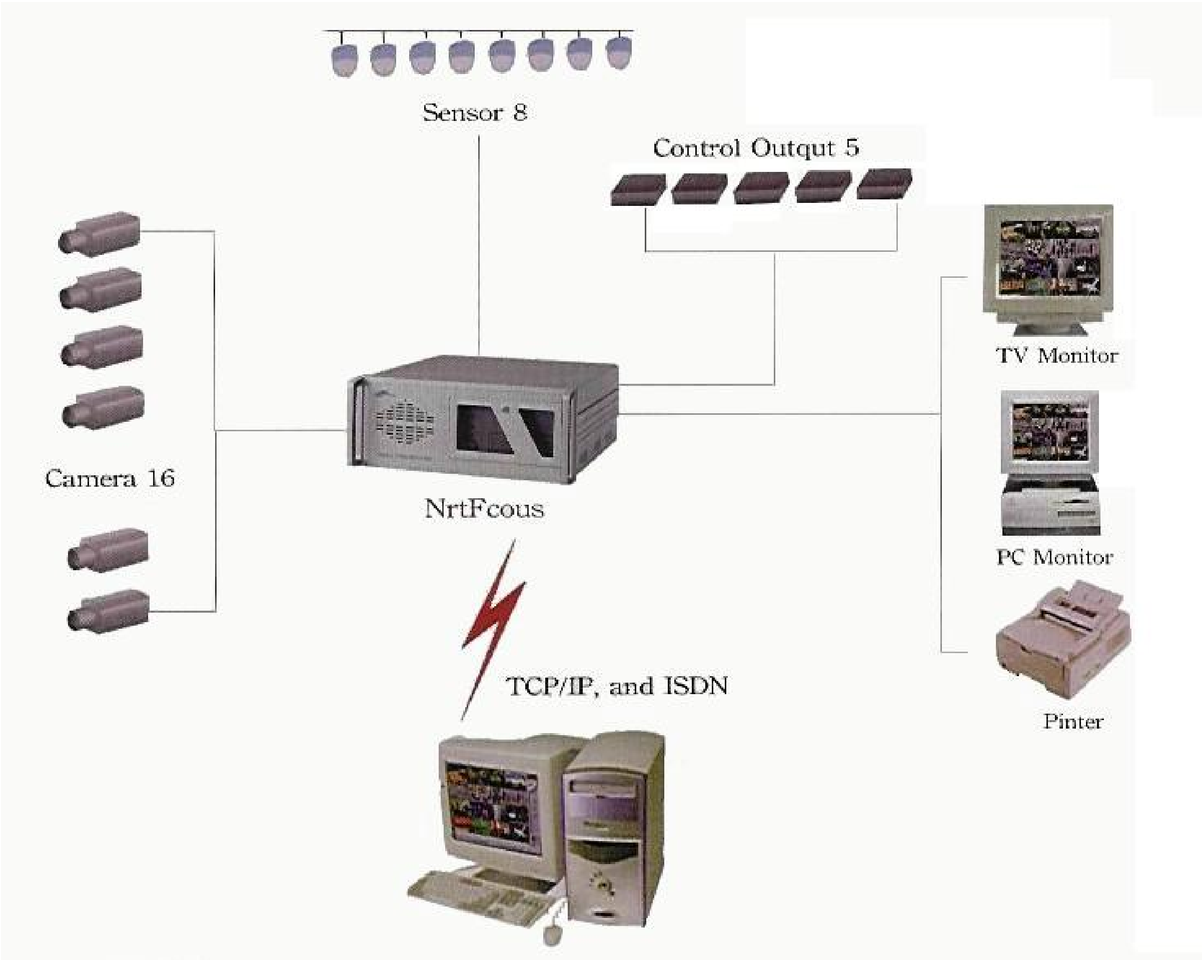


Figure 2.7: Monitoring system overview of GenBest

2.4.2 Luda farm

Luda farm [26] provides farmers across the world products and services that make everyday work easier, safer and more efficient by IOT system as shown in Fig. 2.8. This system not only have most of the services of GenBest but also combined with IOT tech. such as sensors and apps in order to fulfill multiple requirement. For data collecting and monitoring perspective, as shown in Fig. 2.9, different to previous system, they not only have usual recording function to monitor animal but also use event triggered record by motion detection for criminal activity. And they have ptz doom cameras for better vision for the field. Furthermore, they have various type of cameras(e.g. doom, bullet and ptz camera etc.) to choose for different purposes and budgets.

Figure 2.8: Overview of Luda farm system

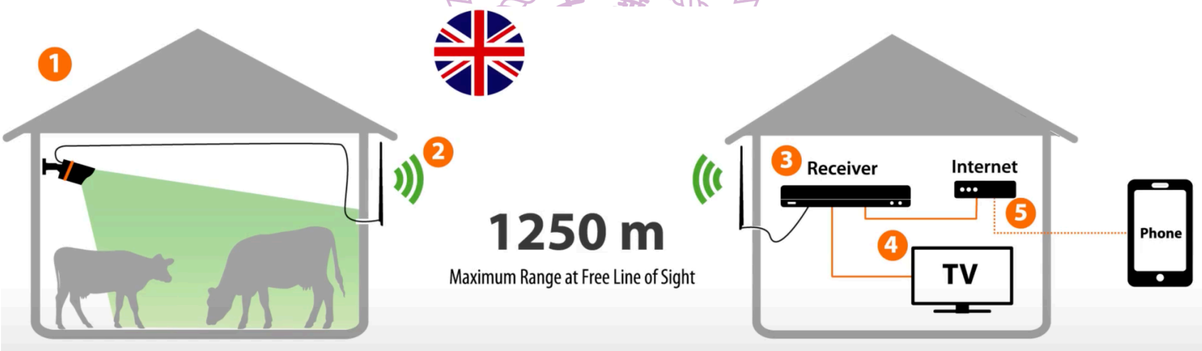


Figure 2.9: Overview of Luda farm CCTV system

2.4.3 Speices recognition for wild animal

They [27] use camera-trap technologies to monitor wild animals since some of wild animals are afraid of human. It is hard to capture these kind of animals when there are human nearby. The images captured by the camera traps are triggered by a motion sensor and send to AWS cloud for annotating. As shown in Fig. 2.10, They use AWS cloud service as computing and annotating resource and send data to private NAS which stores all of the post-process image data. At last, they use these data to traing and test their AI model.

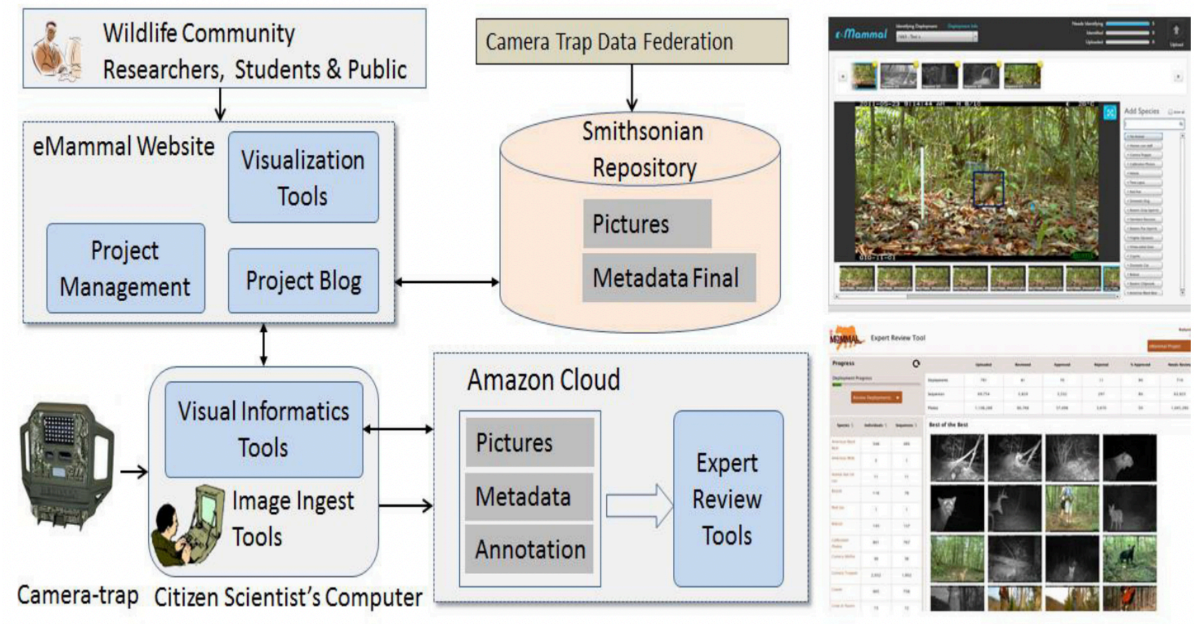


Figure 2.10: The framework of eMammal cyber-infrastructure

We can find out that each system has its benefits and limitations. Our system has camera that can control its degree remotely through internet by 180 vertical and 360 horizontal degree. It have 3 recording types. First, event triggered will send MQTT command to start recording process when specific event happened. Second, we can set a specific timing to trigger recording process. Third, User can click button in Smart Farming Platform webpage to start record manually. Our system use AWS cloud service to achieve central management. Improve storage limit by AWS S3 [28] and software extensibility by AWS Lambda [29] and Greengrass [30].

	GenBest Tech.	Luda farm	Wild animal recognition	Ours
Camera control flexibility	X	PTZ, 180 vertical and 360 horizontal	X	PTZ, 180 vertical and 360 horizontal and manual
Agility of dynamic record	X	Event triggered	Event triggered	Event triggered, time scheduling
Multi-field capability	X	V	V	V
Cloud based management	X	Limited	AWS service support	AWS service support
Software extensibility	Limited	Unknown	Cloud based extendable	Cloud based extendable

Table 2.1: Monitoring-system comparison..

Chapter 3

System design and implementation

3.1 System overview

Fig. 3.1 shows the schematic diagram of the whole system. We will first introduce smart farm platform because this is where we implement our system. Second, we briefly introduce each components in the system. Third, we will describe the user cases which we designed and the sequence diagram behind each case, including critical case. At last, we focus on the detail design of PI and recording server.

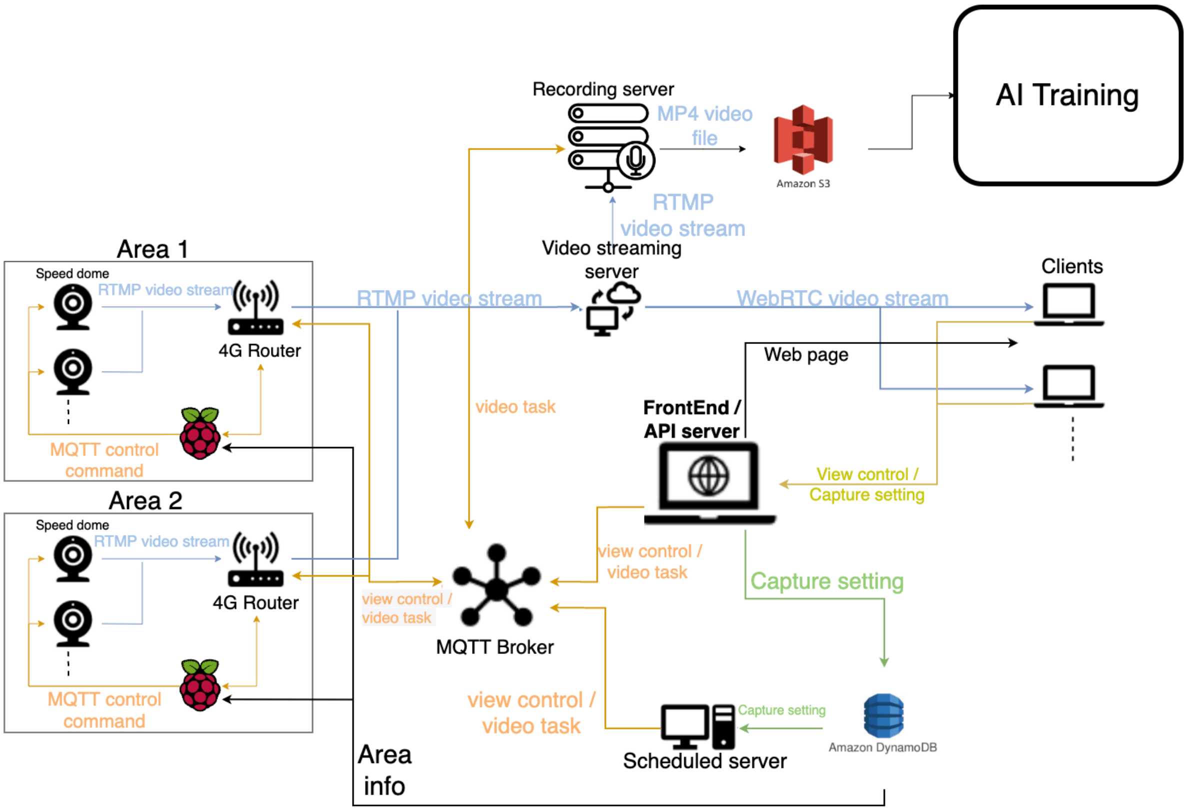


Figure 3.1: Schematic diagram of system

3.2 Smart farm platform

Smart Farming Platform [16] is established by National Tsing Hua University High Speed Network Lab(HSNL). HSNL installed sensor and camera on site in order to capture data such as image, live stream, soil moisture or any other sensor data. Process data and upload it to platform then show on webpage for expert to analyze or used as training data set for AI model. Also, users are able to update their farming log to preserve critical information and recieve important message by LINE notifications [31] from platform. Although it has the ability to capture images, it cannot record video for advanced training. Our system is integrated into this platform to execute recording tasks.

3.3 Components explanation

Here, we will discribe what each component are responsible to.

3.3.1 Speed dome

Speed dome [32] is a Pan/Tilt/Zoom(PTZ) doom camera bought in hertone company [33] as shown in Fig. 3.2. User can control camera remotely by API calling. It have such wide vision that it can rotate 180 degree vertically and 360 degree horizontally. It can push RTMP streaming to server and has night vision. For video quality perspective, it have resolution of 1920x1080 and frame per second(FPS) of 30. At last, user can adjust camera to a special angle and store the angle as preset. If user want to rotate to that special angle next time, it only need to call API to command camera to rotate automatically. This is one of the main feature for our recording system.

Figure 3.2: Speed dome camera

3.3.2 Raspberry PI

Raspberry Pi [34] is a series of small single-board computers which is cheaper than standard personal computer as shown in Fig. 3.3. It is placed in experimental field with Speed dome. PI acts as a edge management device. It recieves command from other servers by MQTT [22] protocol then commands camera by API request and recording server to execute. Spec of CPU is Quad core, ARM Cortex-A72(v8) 64bytes 1.5GHz and RAM is 4GB LPDDR4-2400 SDRAM and storage is 16 GB MicroSD.

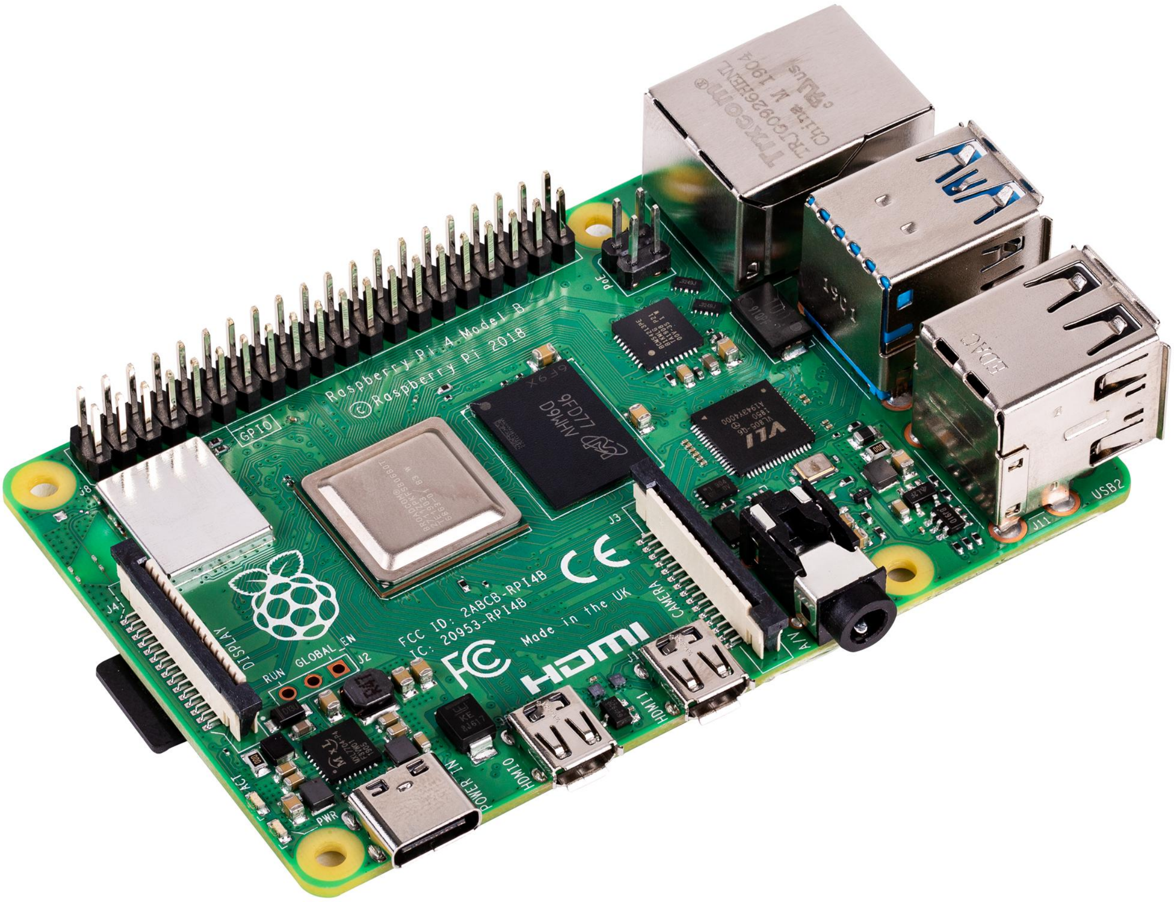


Figure 3.3: Raspberry PI

3.3.3 Video streaming server

Video streaming server [35] is open sourcing streaming server. It is a simple, high efficiency and realtime video server, supports RTMP/WebRTC/HLS/HTTP-FLV/SRT. It is used to recieve RTMP streaming from Speed dome.

3.3.4 Recording server

Recording server receives command from PI. It is reponsible to pull live streaming from video streaming server then make into video file. After finish recording, it upload file to AWS S3. Our recording process uses the feature of OpenCV [36] as our backbone. It has some advantage such as easy to use, Support multi stream protocol(RTMP, RTSP ···etc.) and less bug.

3.3.5 File Storage and Database

We utilize AWS S3 to store video file and AWS DynamoDB [37] as database. DynamoDB will store various metadata, including scheduled time for record, meta data for PI in edge side.

3.3.6 Scheduled server

Scheduled server fetch information from DynamoDB and is responsible to send recording request to PI when some events or specific timing occured.

3.4 User cases enumeration

Here, we will show the user cases for our system. We explain how our system work through sequence diagram for each user case.

3.4.1 Manual case

In this user case, User will click the recording button in the streaming web page to manually start recording as shown in Fig. 3.4.

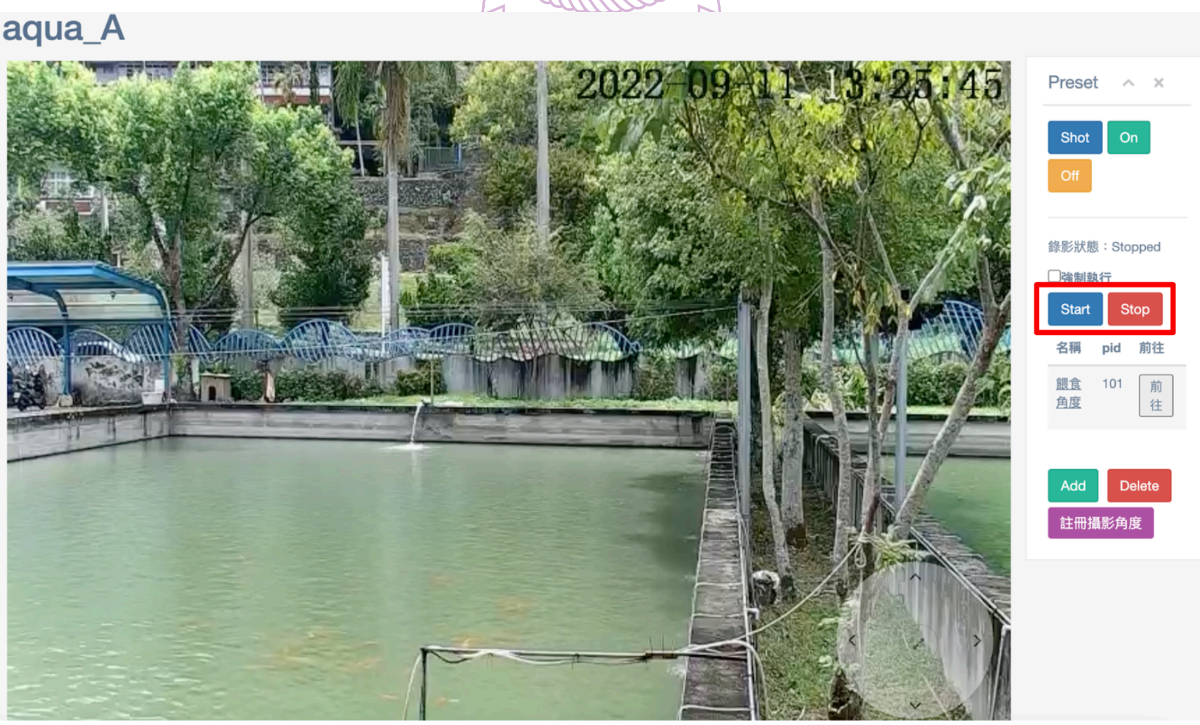


Figure 3.4: Click start button to start recording and Press stop button to stop

As shown in Fig. 3.5, we show the data flow of the whole system from starting the recording task to terminate it. In this manual case, there are 5 components involved, Front-end server, API server(Back-end server), Raspberry PI, Recording system and Video streaming server. When Front-end server sends API request, Back-end will query PI for the permission of the camera. If PI allows the request, it will inform Back-end server that it allows to recieve recording request. Front-end will recieve permission response from Back-end then start to initiate WebSocket [38] connection with Back-end. After WebSocket connection is complete, Back-end will send MQTT record command to PI to start recording process. PI will inform recording server to start connection with streaming server and wait until the connection is complete. Recording system will inform PI that connection is complete then PI will inform recording system to start recording. At the same time, PI will also inform Front-end that the recording process has started. If user want to terminate the recording task, he/she can press the stop button. Front-end will disconnect WebSoceket. When Back-end detect WebSocket connection has been shut down, it will send stop command to inform PI to stop the process. At last, recording system will stop connection with Video streaming server then upload the video file to AWS S3 [28].

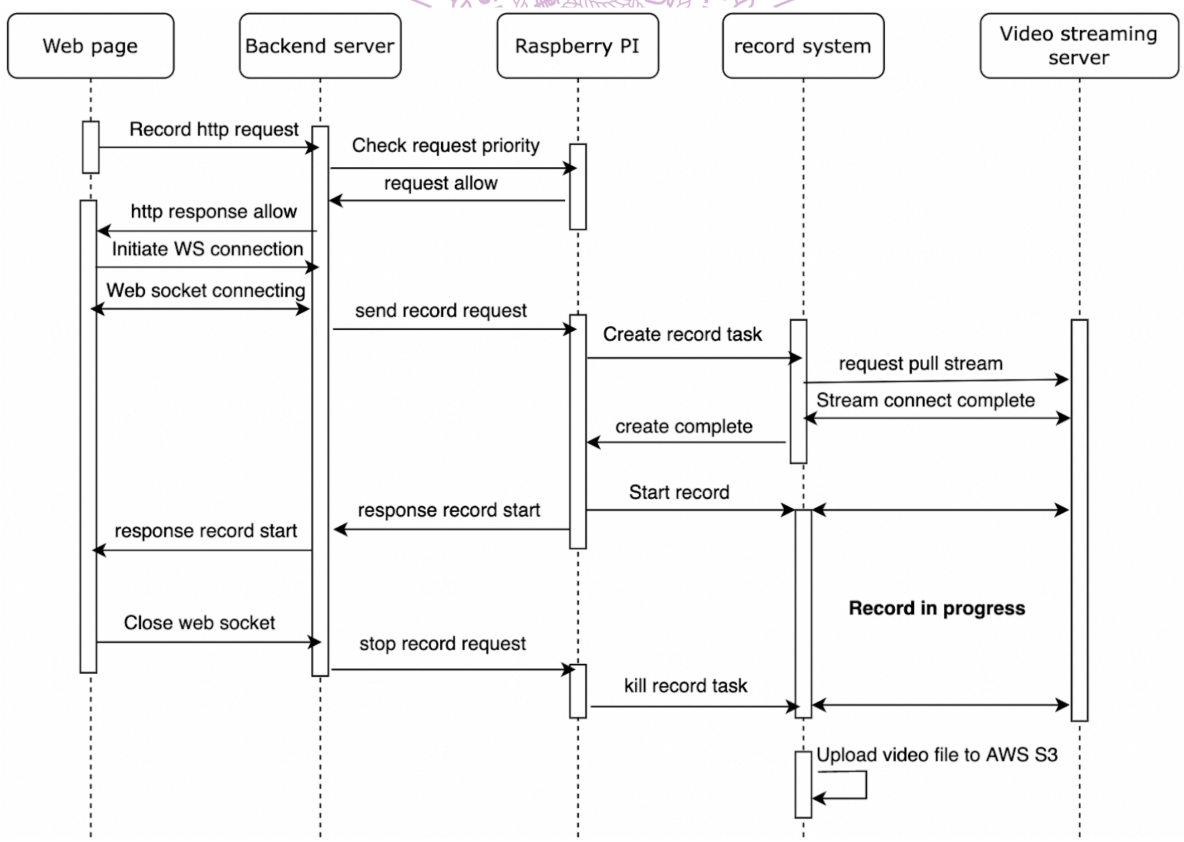
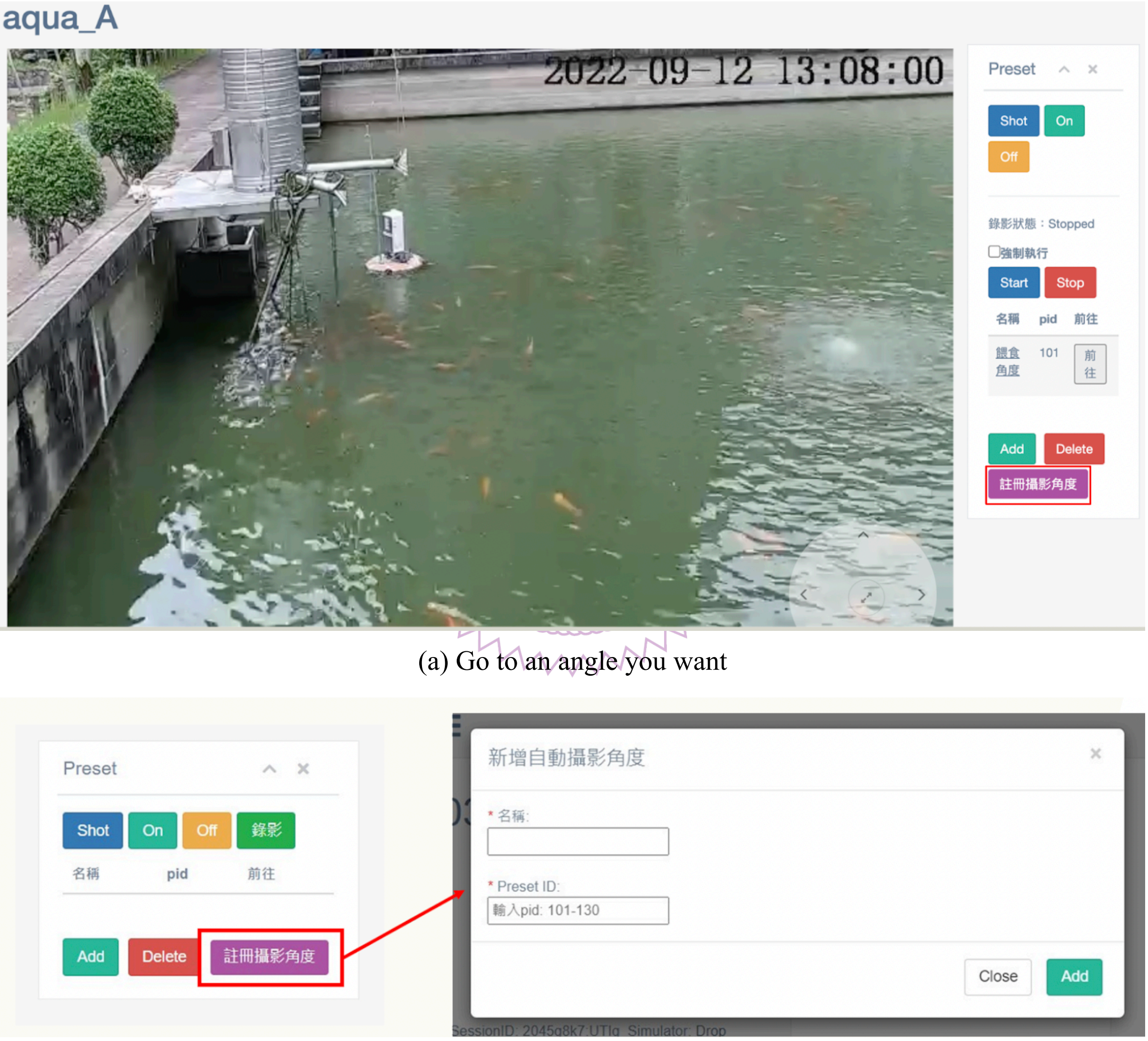


Figure 3.5: Data flow of manual case

3.4.2 Event triggered case

In this case, recording process will start if specific event occured. User have to register the event they want(e.g. Some sensor value exceed specific threshold.) to record. The steps are shown in Fig. 3.6. First, in Fig. 3.6a, user can rotate camera to the angle they want then press the purple button to store the angle. Second, in Fig. 3.6b, user can set a name for this angle. Third, in FIg. 3.6c, user will set the recording duration, angle name, the type of event.



(a) Go to an angle you want

(b) Set a name for this angle

Figure 3.6: User flow of event triggered case

(c) Choose an event

Figure 3.6: User flow of event triggered case(cont.)

We will also show the sequence diagram of event case below from registering event to recording process terminated in Fig. 3.7. In this case, there are 6 components involved, Front-end server, API server(Back-end server), Scheduling server, Raspberry PI, Recording system and Video streaming server. When user register a event, Back-end will send the event information, including camera angle, recording duration and task type, to scheduling server. When event occured, scheduling server will send recording request to recording server. Similar to manual case, PI will inform recording server to start connection with streaming server and wait until the connection is complete. Recording system will inform PI that connection is complete then PI will inform recording system to start recording for X seconds. Recording server will shut down video process when time's up. At last, recording system will stop connection with Video streaming server then upload the video file to AWS S3.

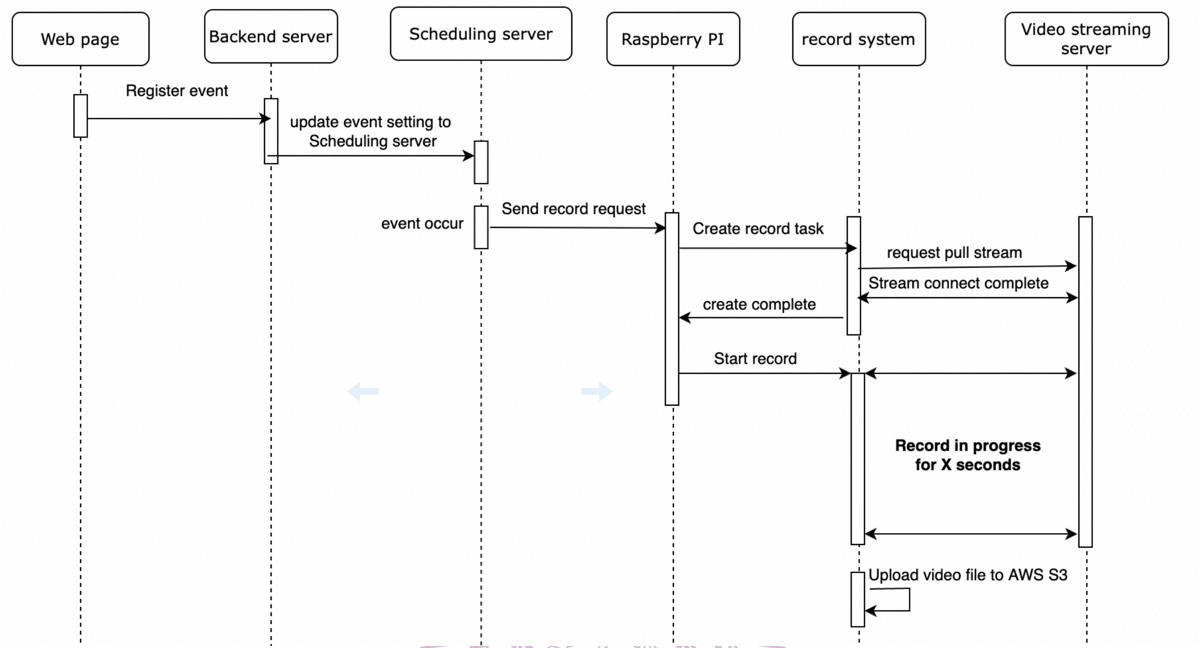


Figure 3.7: Data flow of event triggered case

3.4.3 Time period triggered case

In this case, record process will be triggered at a specific timing. Similar to event register, as shown in Fig. 3.8a, user can rotate camera to the angle they want then press the purple button to store the angle then in Fig. 3.8b user can set a name for this angle. At last, in Fig. 3.8c, we can set the time period, recording duration and recording angle.

(a) Go to an angle you want

(b) Set a name for this angle

Figure 3.8: User flow of time period triggered case

(c) Choose an time

Figure 3.8: User flow of time period triggered case(cont.)

Similar to event trigger case, it has 6 components, Front-end server, API server(Back-end server), Scheduling server, Raspberry PI, Recording system and Video streaming server. The sequence diagram is shown below. In Fig. 3.9, when user reigister time setting, Back-end will update the information whilch is identical to event trigger case except the task ID to schduling server. When the time comes, scheduling server will send recording request to PI then do the exact same process in event triggered case. PI will inform recording server to start connection with streaming server and wait until the connection is complete. Recording system will inform PI that connection is complete then PI will inform recording system to start recording for X seconds. Recording server will shut down video process when time's up. At last, recording system will stop connection with Video streaming server then upload the video file to AWS S3.

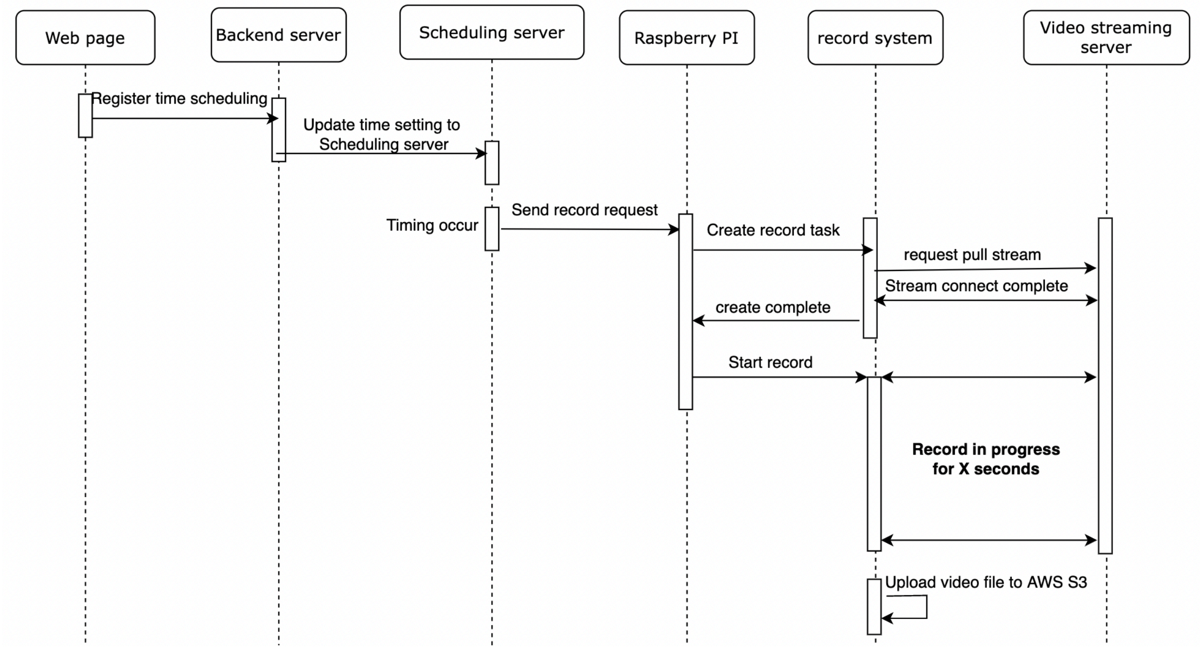


Figure 3.9: Data flow of time period triggered case

3.4.4 Critical case: Preemptive case

We have shown normal cases that run on our system. Here, we want to point out a special situation. Normally, camera is only capable of executing one recording request. As shown in Fig. 3.10, What if there are multiple recording request inbond at the same time?(e.g. At the moment, user A and B want to record manually and an event also trigger the recording process.) It is obvious that camera cannot handle more than one recording request. It doesn't know that which tasks should be executed. We implement priority method to handle such situation in Raspberry PI. If there are multiple cases, PI can check the importance of each task to decide which task can be executed. For example, PI is running task A. Next, task B comes in and request to record. PI will compare the importance, or prioirty, between task A and B. If B is lower than A, PI will reject the request from B. If B is higher than A, PI will stop task A and turn the permission to task B.

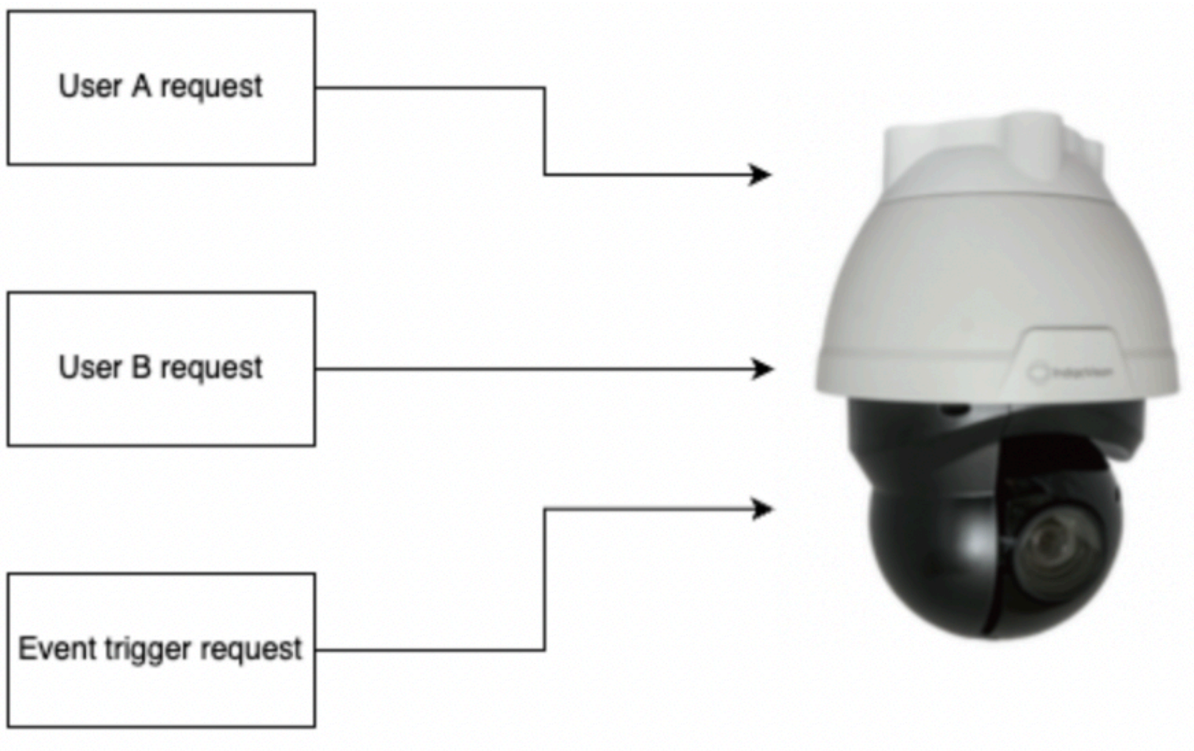


Figure 3.10: 3 request come at the same time

References

[1] Hany F. Atlam, Gary B. Wills, ″Chapter Three - Intersections between IoT and distributed ledger″ Advances in Computers, vol. 115, Pages 73-113, 2019.

[2] RTMP introduction, https://www.wowza.com/blog/rtmp-streaming-real-time-messaging-protocol.

[3] N. Naik, 'Choice of effective messaging protocols for IoT systems: MQTT, CoAP, AMQP and HTTP,' 2017 IEEE International Systems Engineering Symposium (ISSE), 2017, pp. 1-7.

[4] "agriculture," https://en.wikipedia.org/wiki/Agriculture.

[5] Diamond, J. Evolution, consequences and future of plant and animal domestication. Nature 418, 700–707 (2002).

[6] World population, https://www.worldometers.info/world-population/.

[7] Borlaug, N. E. 2000. The green revolution revisited and the road ahead. Special 30th Anniversary Lecture, Norwegian Nobel Institute, Oslo.

[8] Livestock, https://en.wikipedia.org/wiki/Livestock.

[9] Suryawanshi, K., Redpath, S., Bhatnagar, Y., Ramakrishnan, U., Chaturvedi, V., Smout, S., Mishra, C., 2017. Impact of wild prey availability on livestock predation by snow leopards. Roy. Soc. Open Sci. 4 (6).

[10] Bourne, J. E. 2015. The End of Plenty: The Race to Feed a Crowded World. W. W.Norton.

[11] FAO, b. Monitoring, record keeping, accounting and marketing.

[12] C. -W. Hsu, Y. -H. Huang and N. -F. Huang, 'Real-time Dragonfruit′ s Ripeness Classification System with Edge Computing Based on Convolution Neural Network,' 2022 International Conference on Information Networking (ICOIN), 2022, pp. 177-182,.

[13] Omar Anas, Youssef Wageeh, Hussam El-Din Mohamed, Ali Fadl, Noha ElMasry, Ayman Nabil, Ayman Atia, Detecting Abnormal Fish Behavior Using Motion Trajectories In Ubiquitous Environments, Procedia Computer Science, Volume 175, 2020, Pages 141-148,.

[14] Gu J Q, Wang Z H, Gao R H, Wu H R. Cow behavior recognition based on image analysis and activities. Int J Agric & Biol Eng, 2017; 10(3): 165–174.

[15] Leroy T, Vranken E. A computer vision method for on-line behavioral quantification of individually caged poultry. Transactions of the ASABE, 2006; 49(3): 795–802.

[16] Smart Farming Platform, https://nthu-smart-farming.kits.tw/.

[17] AWS cloud service, https://aws.amazon.com/tw/.

[18] Gillis, Alexander (2021). 'What is internet of things (IoT)?'. IOT Agenda. Retrieved 17 August 2021.

[19] InfoWorld Media Group, Inc. (2 March 1998). InfoWorld. InfoWorld Media Group, Inc. p. 18. ISSN 0199-6649.

[20] Rafael Osso (1999). Handbook of Emerging Communications Technologies: The Next Decade. CRC Press. p. 42. ISBN 978-1-4200-4962-6.

[21] Macromedia, https://en.wikipedia.org/wiki/Macromedia.

[22] MQTT, https://mqtt.org/.

[23] Pub-sub pattern, https://en.wikipedia.org/wiki/Publish-subscribe_pattern.

[24] UAVs, https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle.

[25] GenBest Technology digital video recording system, http://www.genbest.com.tw/genbest/dvr/ec.htm.

[26] Luda farm, https://www.luda.farm/farm-video-surveillance/.

[27] G. Chen, T. X. Han, Z. He, R. Kays and T. Forrester, 'Deep convolutional neural network based species recognition for wild animal monitoring," 2014 IEEE International Conference on Image Processing (ICIP), 2014, pp. 858-862.

[28] AWS S3, https://aws.amazon.com/tw/s3/.

[29] AWS lambda, https://aws.amazon.com/tw/lambda/.

[30] AWS greengrass, https://aws.amazon.com/tw/greengrass/.

[31] Line notify, https://notify-bot.line.me/zh-TW/.

[32] Speed dome, http://www.hertone.com/home/?page_id=161.

[33] Hertone company, http://www.hertone.com/home/.

[34] Raspberry Pi, https://en.wikipedia.org/wiki/Raspberry_Pi.

[35] Ossrs, https://github.com/ossrs/srs.

[36] openCV, https://opencv.org/.

[37] AWS DynamoDB, https://aws.amazon.com/tw/dynamodb/.

[38] WebSocket, https://zh.wikipedia.org/zh-tw/WebSocket.