雲端物聯網監測系統於農業生產環境之自動化建模及診斷之應用

臺南區農業改良場作物環境課
農業機械研究室
李健 楊清富 王志瑋

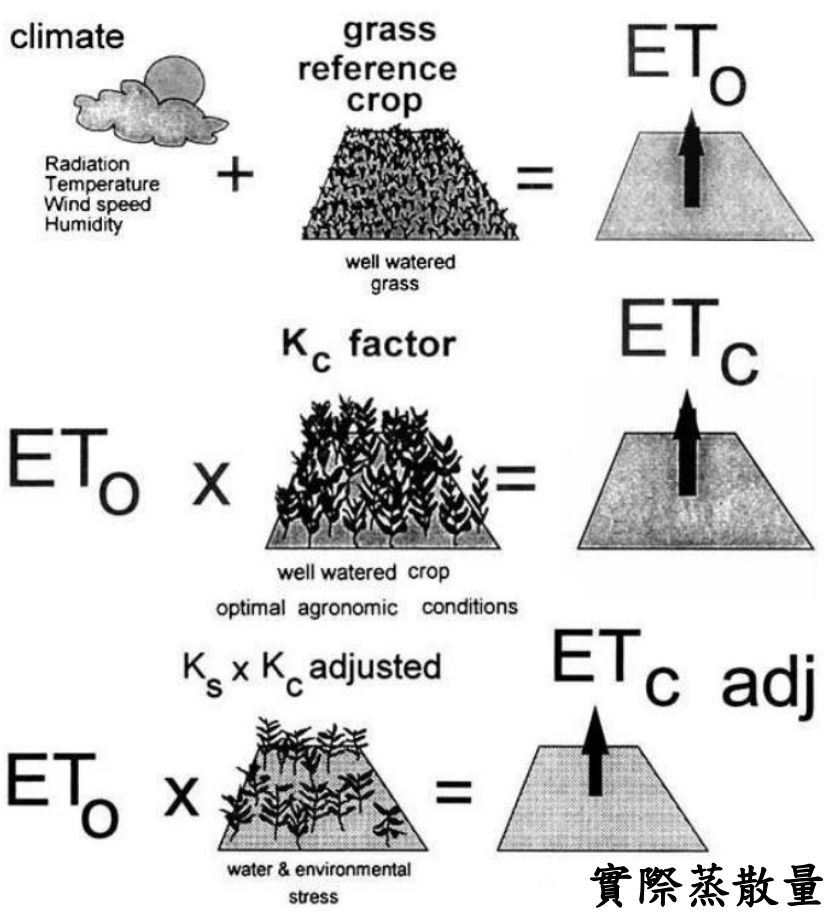
基於蒸發散量之作物生理指標監測

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Penman–Monteith equation

ET_o reference evapotranspiration [mm day^{-1}],
R_n net radiation at the crop surface [MJ m^{-2} day^{-1}],
G soil heat flux density [MJ m^{-2} day^{-1}],
T mean daily air temperature at 2 m height [°C],
u_2 wind speed at 2 m height [m s^{-1}],
e_s saturation vapour pressure [kPa],
e_a actual vapour pressure [kPa],
$e_s - e_a$ saturation vapour pressure deficit [kPa],
D slope vapour pressure curve [kPa °C^{-1}],
γ psychrometric constant [kPa °C^{-1}].

- **Reference crop evapotranspiration (ET_o)**
- **Crop evapotranspiration under standard conditions (ET_c)**
- **Crop evapotranspiration under non-standard conditions ($ET_{c\ adj}$)**

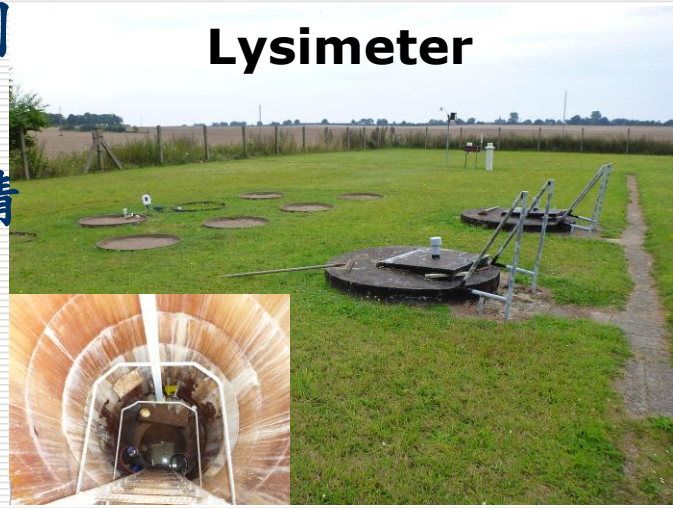


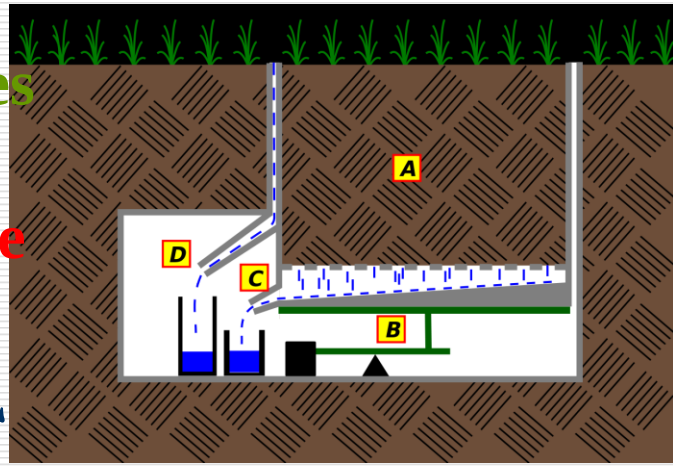
$$ET_o \times K_s \times K_{c\ adj} = ET_{c\ adj}$$

由氣象資料去計算　診斷參數 作物密度品系決定

受控(封閉)環境對基礎研究的重要性

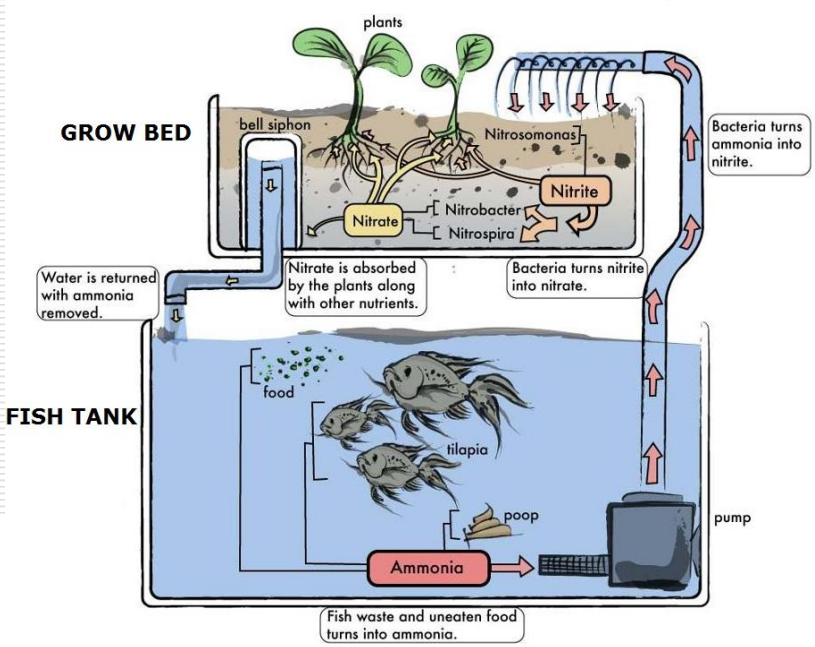
- 農業實際蒸發散(evapotranspiration)量測量的困難與挑戰
- 水循環魚菜共生系統或精密設施栽植可精準量測蒸發散量
- Factors such as soil salinity, poor land fertility, limited application of fertilizers, the presence of hard or impenetrable soil horizons, the absence of control of diseases and pests and poor soil management may limit the crop development and reduce the evapotranspiration—*FAO Irrigation and drainage paper 56* 聯合國糧食及農業組織報告





魚菜共生系統

- 複雜及多樣性的複合農業生產系統
- 資源循環再利用
- 封閉特性適合做基礎研究

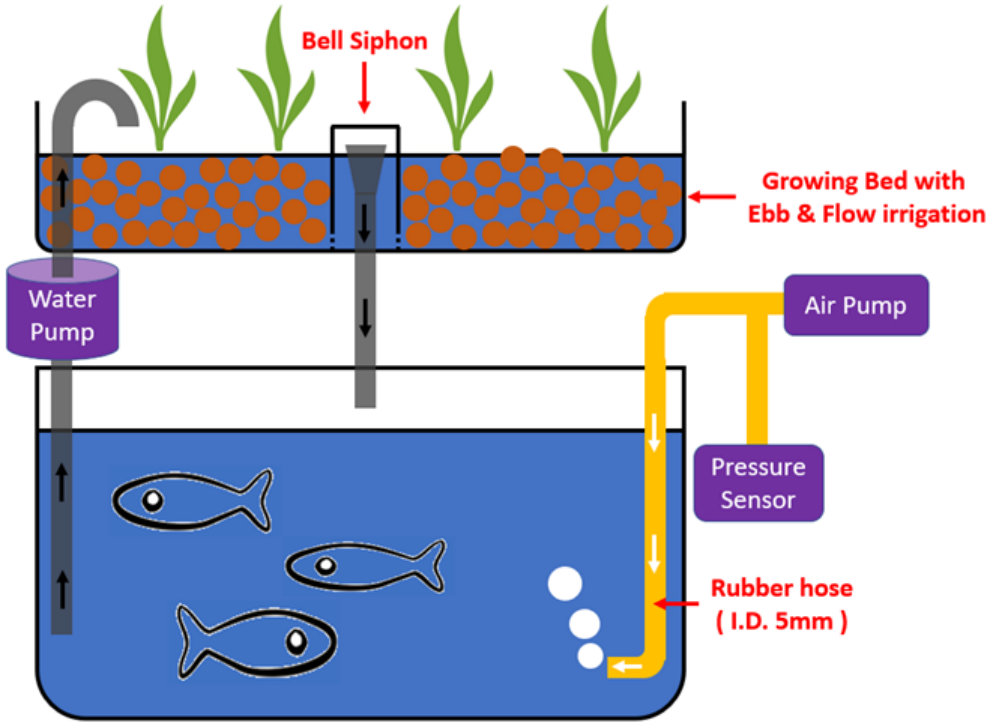


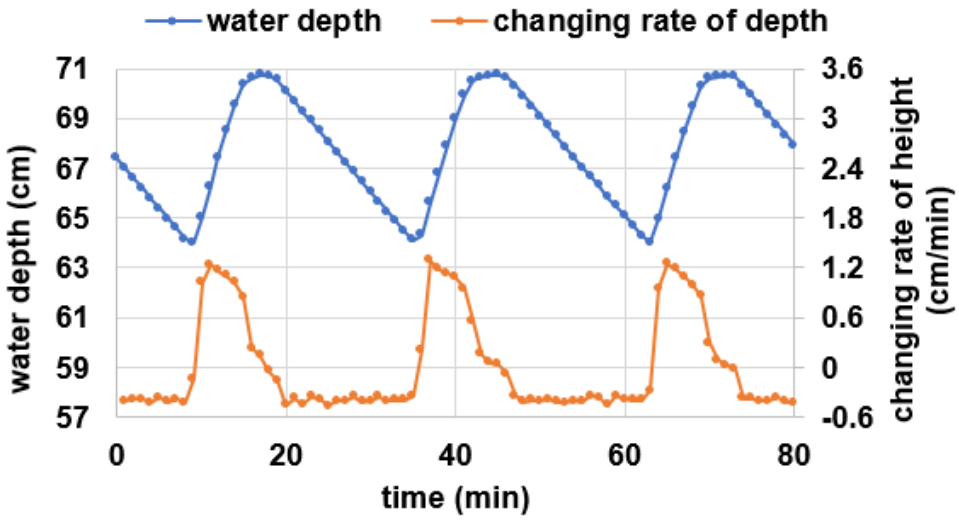
臺南場陽台式魚菜共生系統

- 雲端物聯網監測系統試驗場域
  1) 結合農業氣象及蒸發散模型之植物生理指標監測
  2) 魚活動(locomotion activity)與水質(pH、溶氧DO)交互作用特徵模型研究

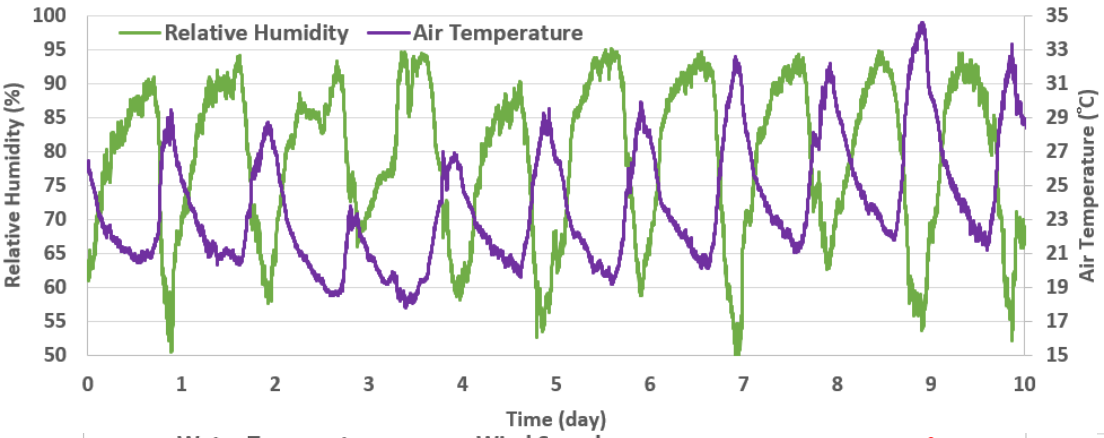
水循環魚菜共生系統蒸發散量量測

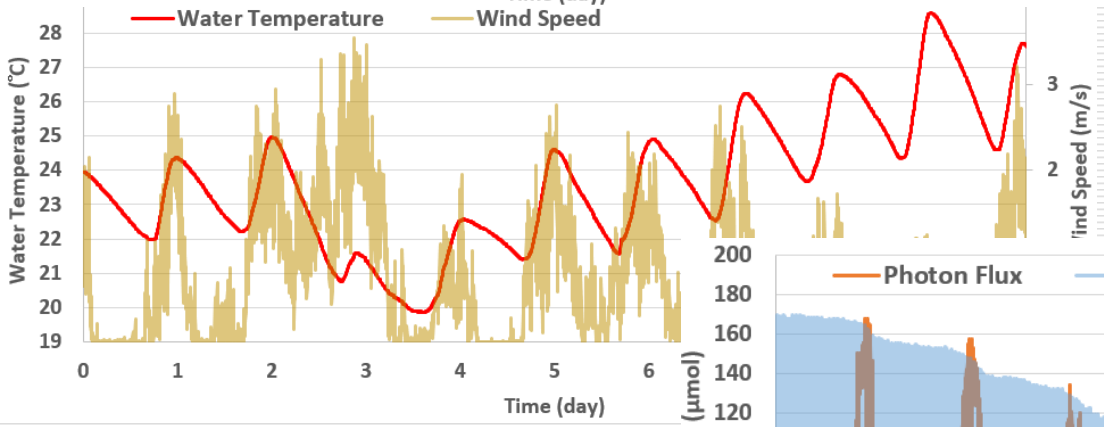
- 利用氣壓原理來監測水位高度變化
- 兼具診斷水循環系統的功能(流速、潮汐灌溉循環次數)





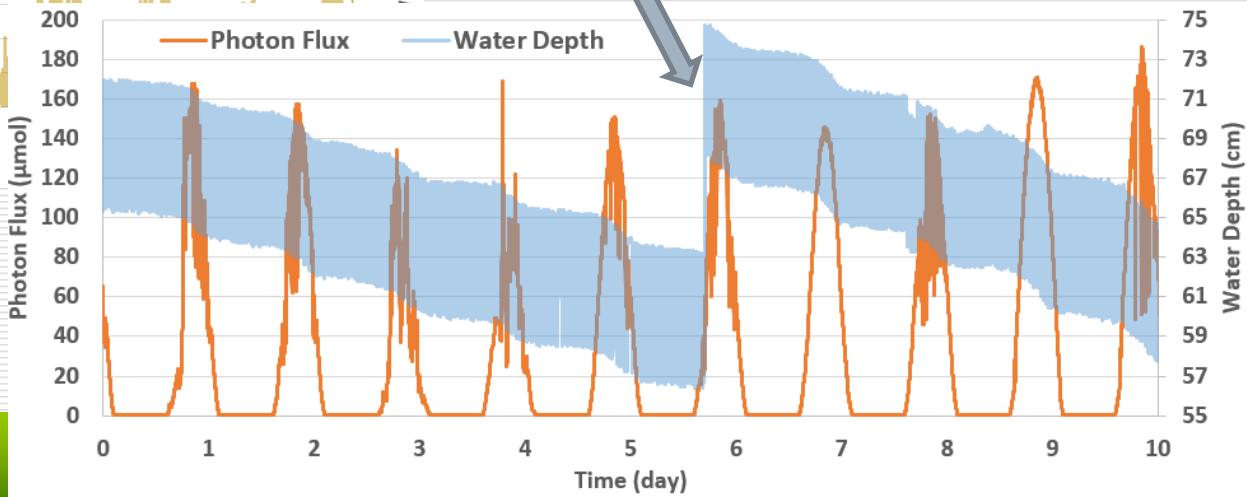
10天蒸發量量測及氣候數據





- 相對濕度
- 氣溫
- 風速
- 水溫
- 水深
- 日照(PAR)

補充養殖槽水量

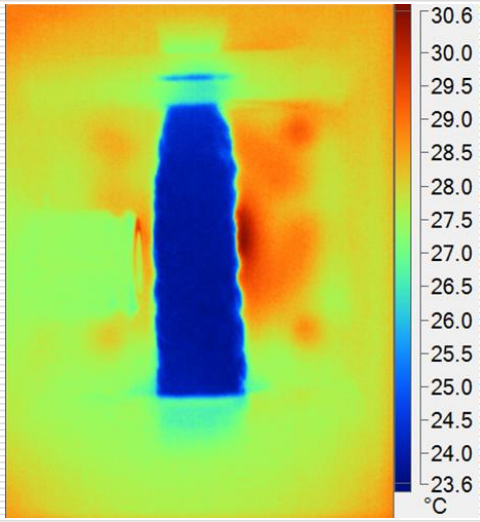


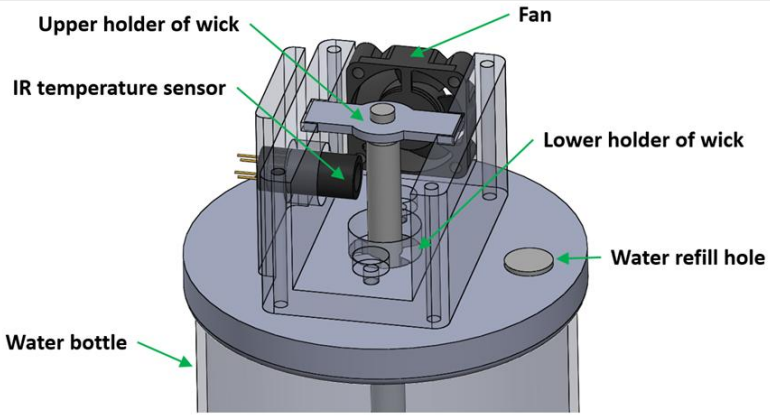
作物生理監測重要技術研究

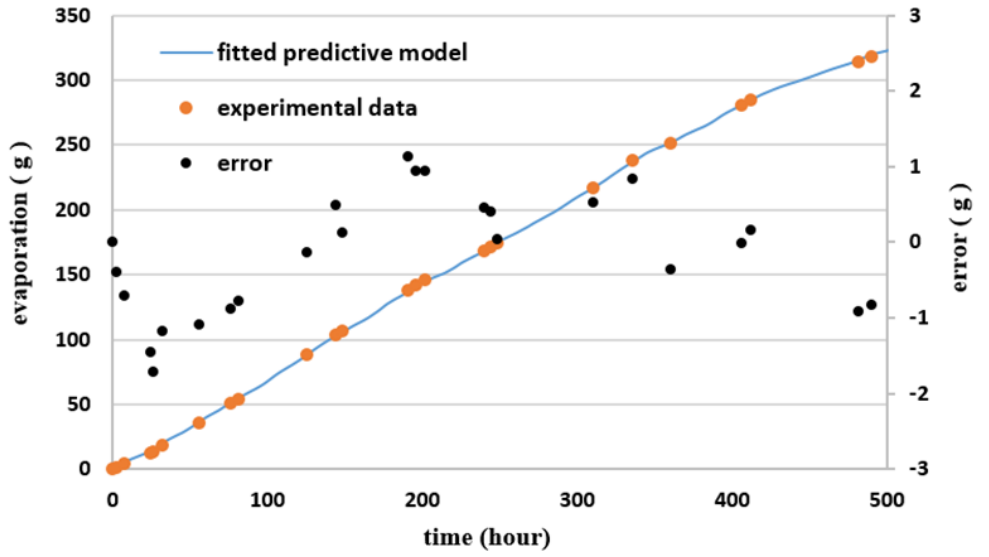
- 蒸發散量直接測量
  - ☻精密設施栽培可準確量測
  - 傳統土耕需以灌溉量搭配其他模型估算
- 氣候量測及模型
  - ☻高可靠度空氣濕度量測技術
- 以氣候為基礎之蒸發散模型
  - eddy covariance
  - 大數據、統計迴歸、AI
- 作物生理直接量測
  - ☻葉溫感測
    - 濕球溫度演算法、評估基準建立
- 雲端物聯網技術整合

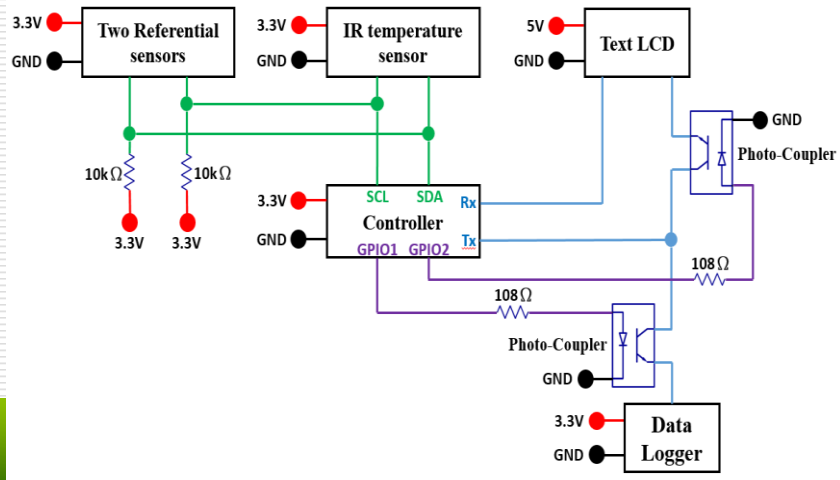
紅外線乾濕球濕度計

- 利用紅外線單體感測技術
- 智慧水份蒸散感測技術









紅外線乾濕球濕度計

- 發表於 **Biosystems Engineering 160 (2017) 84-94**

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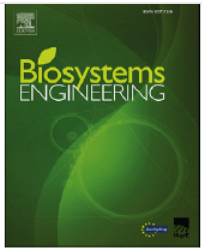


Research Paper

Psychrometer based on a contactless infrared thermometer with a predictive model for water evaporation

Chien Lee [a,b,*], *Yu-Jen Wang* [a]

[a] *Department of Mechanical and Electromechanical Engineering, National Sun Yat-sen University, No. 70 Lienhai Rd., Kaohsiung, Taiwan*
[b] *Tainan District Agriculture Research and Extension Station, Council of Agriculture, No. 70 Mu Chang, Sin Hua District, Tainan, Taiwan*

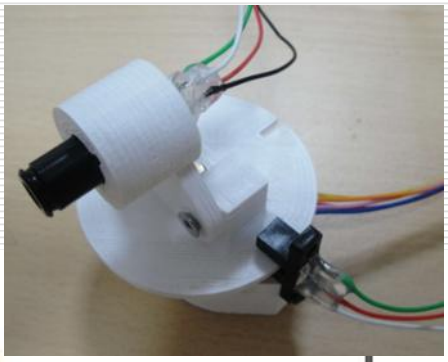
$$\frac{d\widehat{E}}{dt}=\frac{\left(\frac{de_s}{dT}\right)\big|_{T=T_{dry}}\times R_n+\alpha P_{atm}\times 0.643(1+0.536\times V)\Delta e}{\lambda_v\left[\left(\frac{de_s}{dT}\right)\big|_{T=T_{dry}}+\alpha P_{atm}\right]}(\text{mm day}^{-1})$$

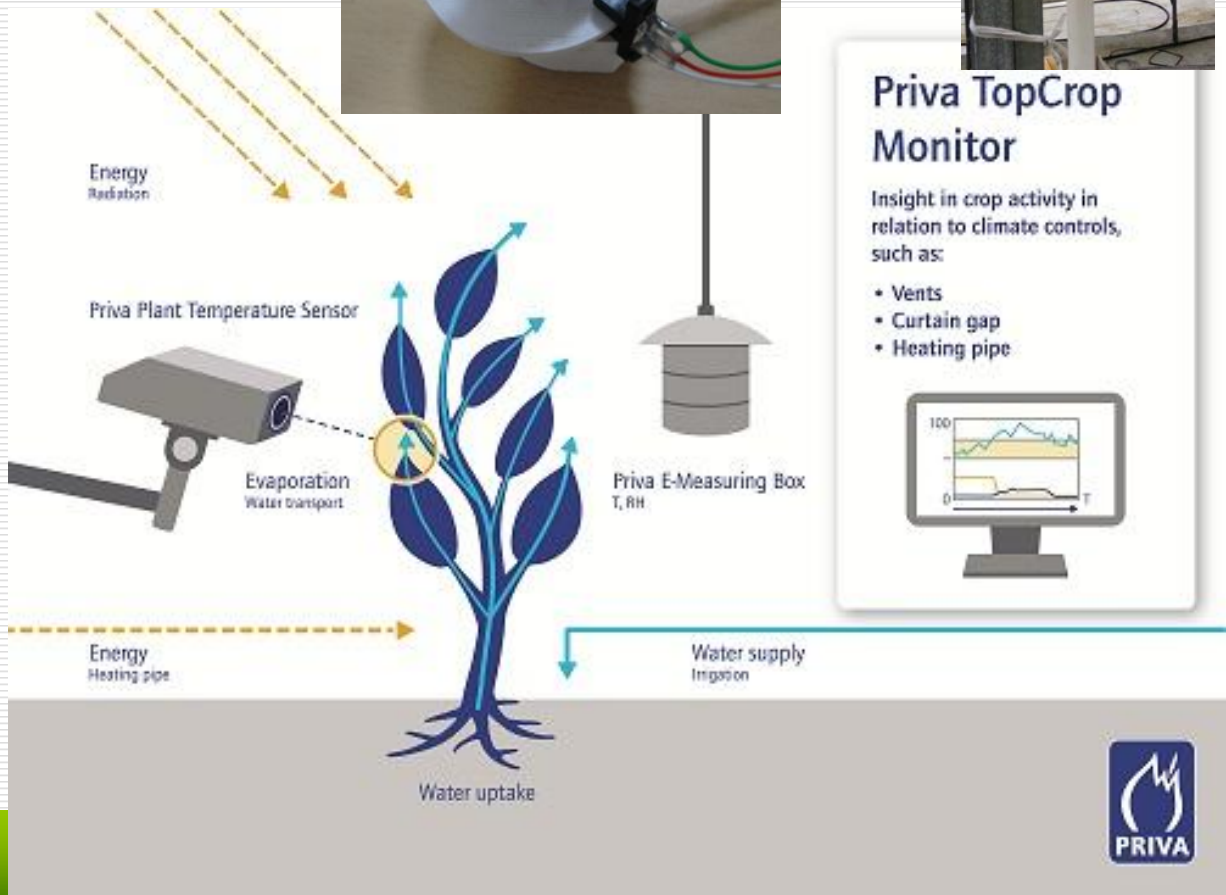
$$E=G\Delta t\sum\frac{\Delta e}{\left(\frac{de_s}{dT}\right)\big|_{T=T_{dry}}+\alpha P_{atm}}(\text{g})$$

$$\begin{aligned}\frac{de_s}{dT}\approx\frac{d\overline{e}_s(T)}{dT}&=0.444+2.848\times10^{-2}T+8.145\times10^{-4}T^2+10.788\\&\quad\times10^{-6}T^3+13.925\times10^{-8}T^4\\&=((((0.13925T+10.788)T+814.5)T+28480)T\\&\quad+444000)\times10^{-6}\end{aligned}$$

葉溫感測

- 荷蘭Priva公司使用紅外線葉溫感測
- 配合氣象量測來做為灌溉管理系統的參考數據
- 目前架構皆只能做單顆植株單點量測。





濕球溫度快速精確演算技術

- 發表於 **Measurement 128 (2018) 271–275**
- 發展一套嚴謹標準程序，能導出濕球溫度的精確快速演算公式。
- 取代傳統圖表計算法

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

A novel method to derive formulas for computing the wet-bulb temperature from relative humidity and air temperature

Chien Lee[a,b], Yu-Jen Wang[a,*]

[a] Department of Mechanical and Electromechanical Engineering, National Sun Yat-sen University, No. 70 Lienhai Rd., Kaohsiung, Taiwan
[b] Tainan District Agriculture Research and Extension Station, Council of Agriculture, No. 70 Mu Chang, Sin Hua District, Tainan, Taiwan

ARTICLE INFO

Keywords:
Wet-bulb temperature
Relative humidity
Psychrometric equation
Separation of variables
Inverse function
Interpolation

ABSTRACT

A novel and accurate analytical method to derive the formula for computing the wet-bulb temperature inversely from the relative humidity (or dewpoint temperature) and the air temperature is proposed, based on the separation of temperature variables for the psychrometric equation and the interpolation for their virtual inverse function. Computational accuracy can be adjusted by selecting the temperature range and the order of the interpolation. In this article, an example for creating the 5th-order polynomial formula for temperature range of 0–50 °C is presented; errors in the wet-bulb temperature range from −0.076 °C to 0.019 °C with a mean absolute error of 0.025 °C and root mean square error of 0.034 °C. Compared with previous works, the method in this article is easier to utilize, and the derived polynomial formulas are more efficient to calculate. Most importantly, the proposed method is more accurate than prior formulas and maintains the same level of accuracy as the iterative calculation method.

審查者評語

- This is a very interesting paper that will be valuable to environmental engineers as well as to meteorologists.
- The result is ready for scientists and engineers to use.
- Their approach of separating variables and approximating the inverse function is indeed novel, and makes a lot of sense.

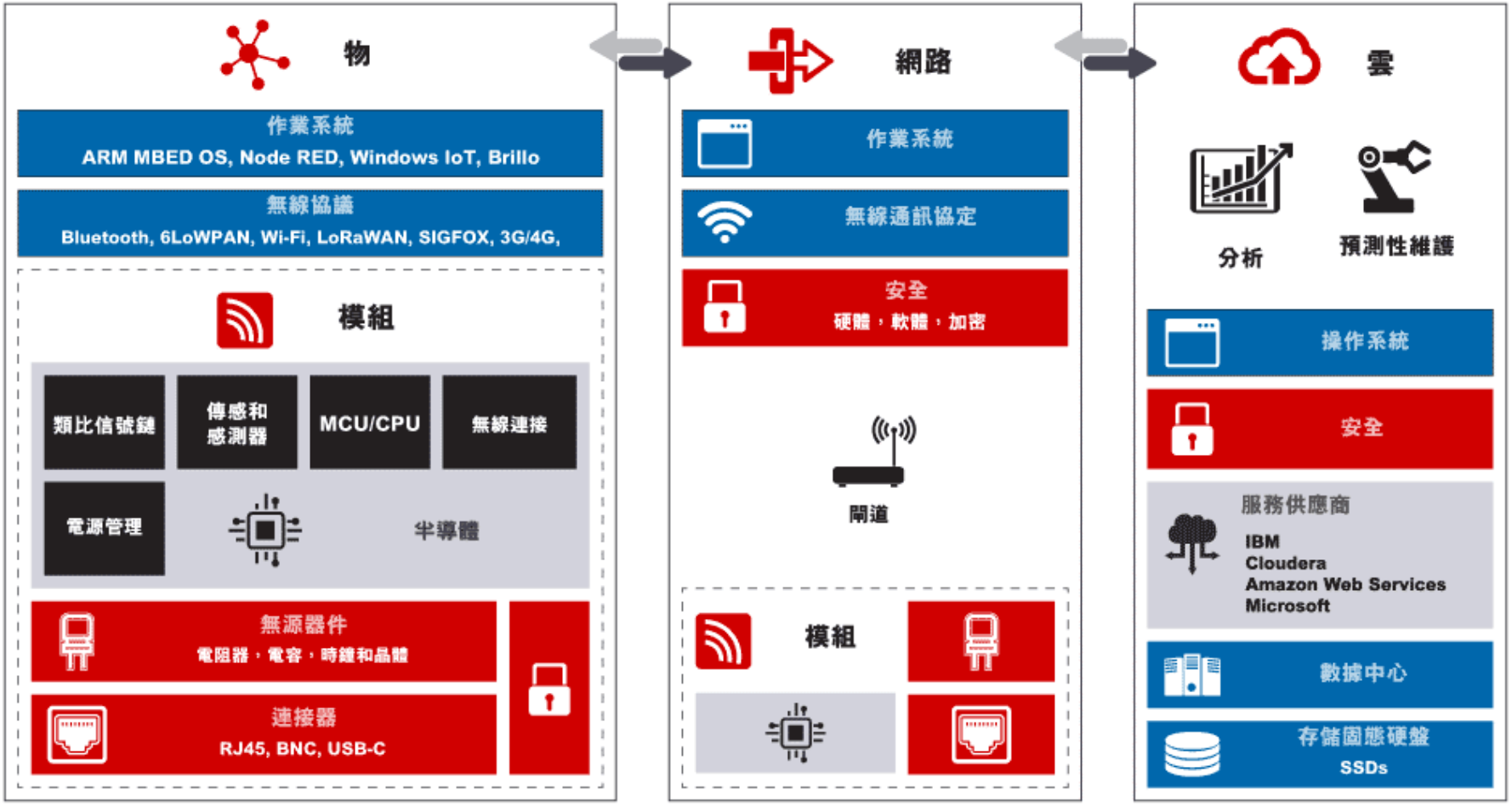
什麼是物聯網(IoT)?

- 物聯網依賴大量的技術才得以成形
  - 裝置連線到網際網路的技術
  - 開發介面
  - 雲端平台、據管理工具
  - 預測分析、AI和機器學習
  - 感測及鑑別技術(sensor、RFID)
- 應用物聯網的目的
  - 自動化
  - 降低錯誤
  - 解除地理空間限制
  - 分析及優化操控參數

物聯網架構

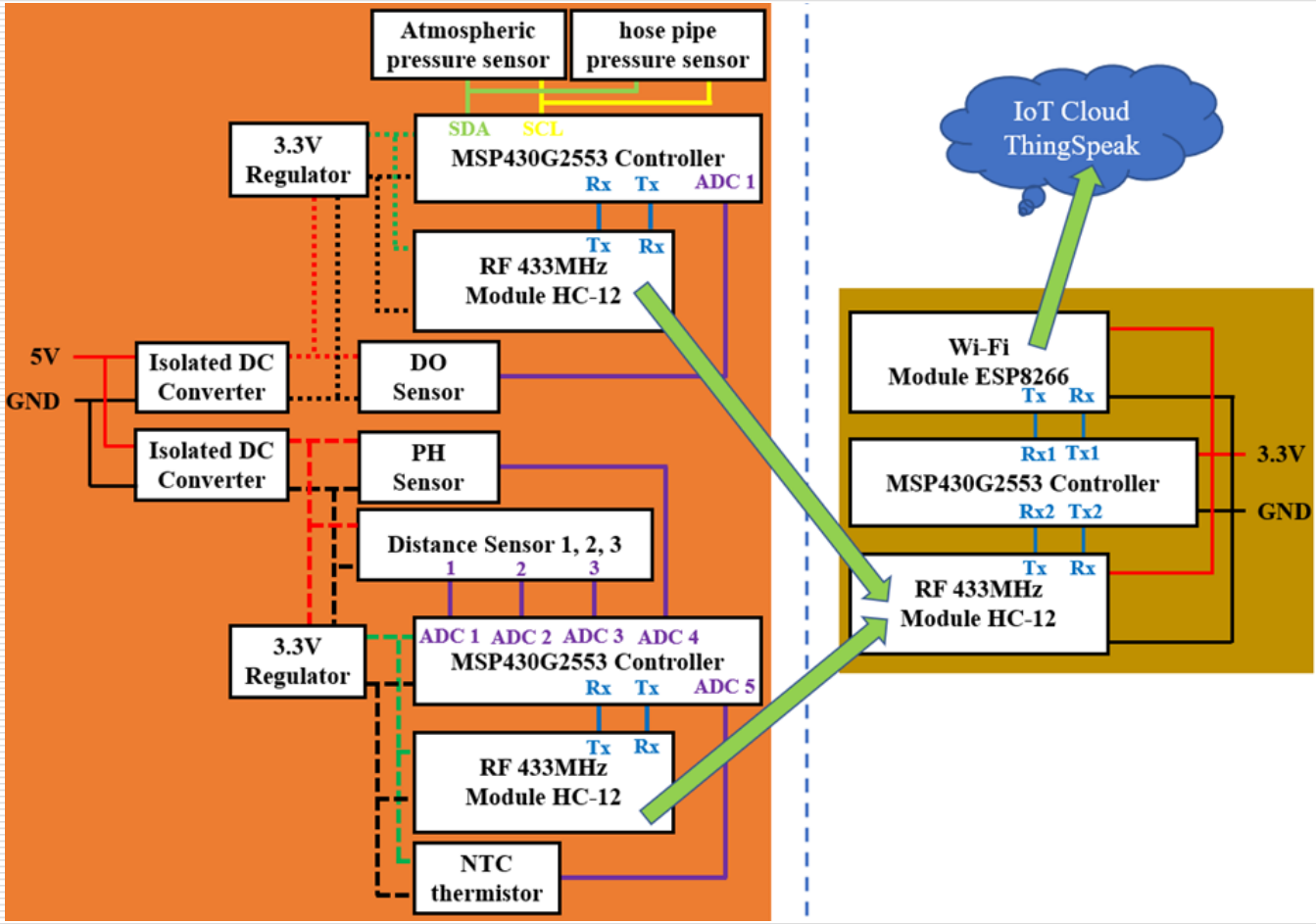
三大核心要素

物件、網路、雲端



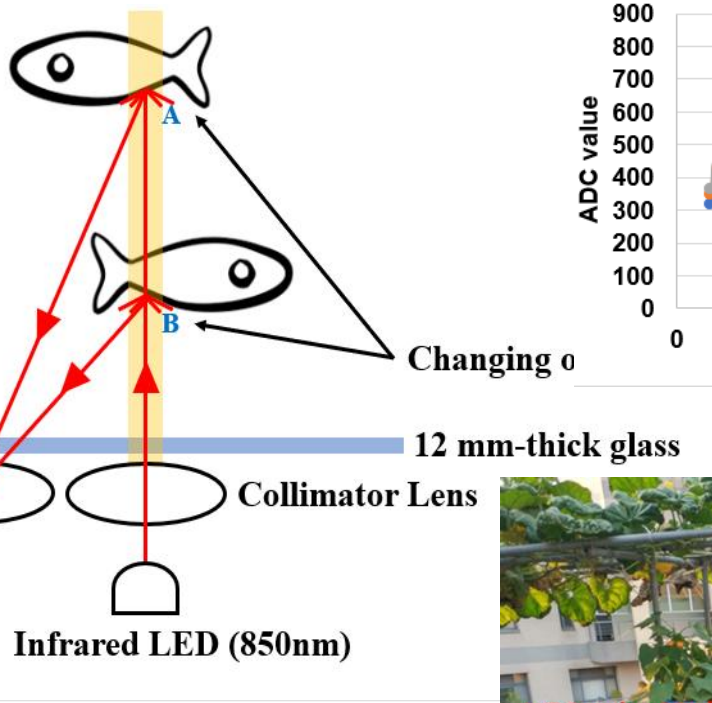
感測模組電路設計架構

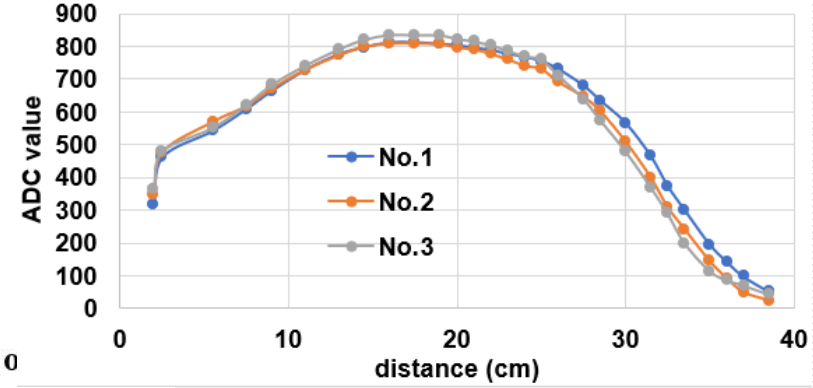
- 電氣隔離設計避免電化學感測探棒在同水體造成相互干擾。

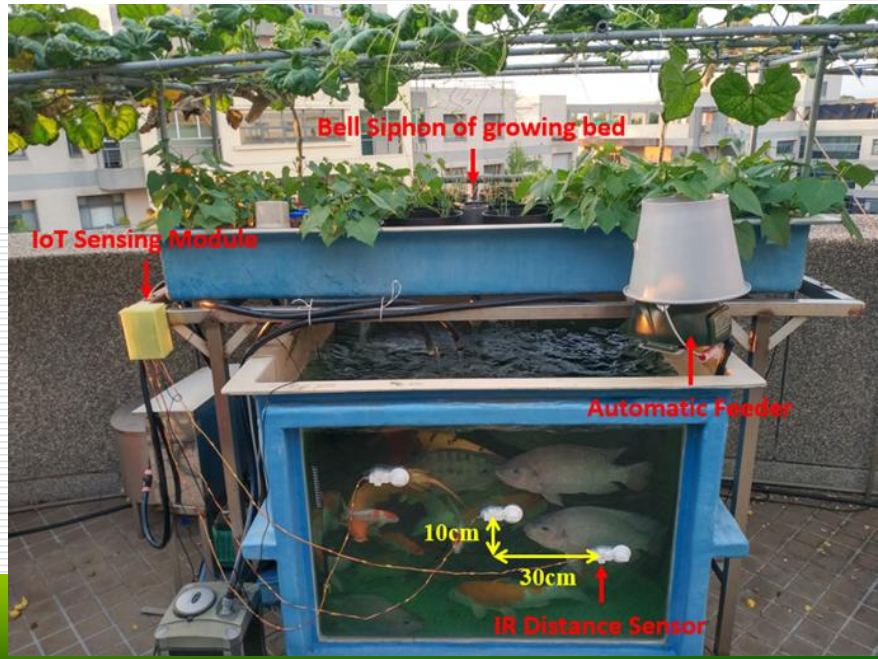


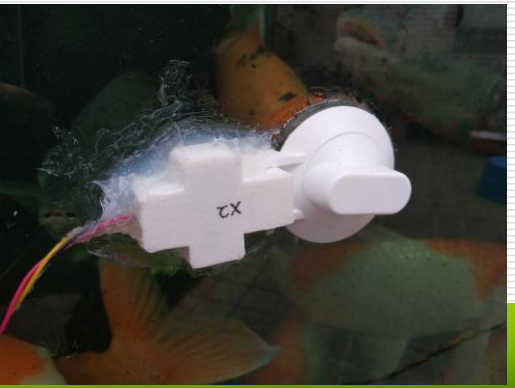
魚活動次數感測器開發


SHARP
2Y0A02 F 26


A
B
Changing o
12 mm-thick glass
Converging Lens
Collimator Lens
Linear Image Sensor
B A
Infrared LED (850nm)
Changing of Focused Spot

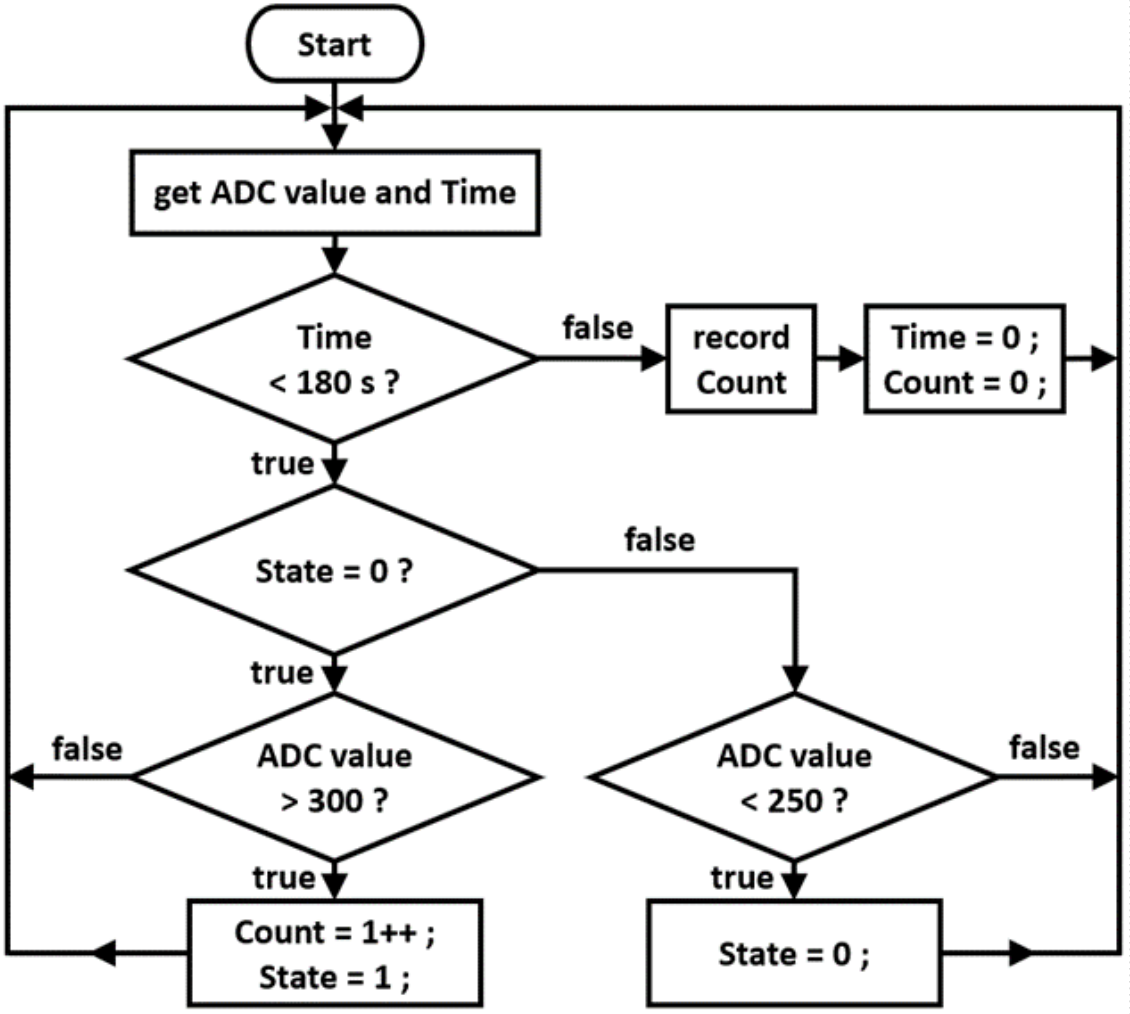

ADC value
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
distance (cm)
No.1
No.2
No.3


Bell Siphon of growing bed
IoT Sensing Module
Automatic Feeder
10cm
30cm
IR Distance Sensor



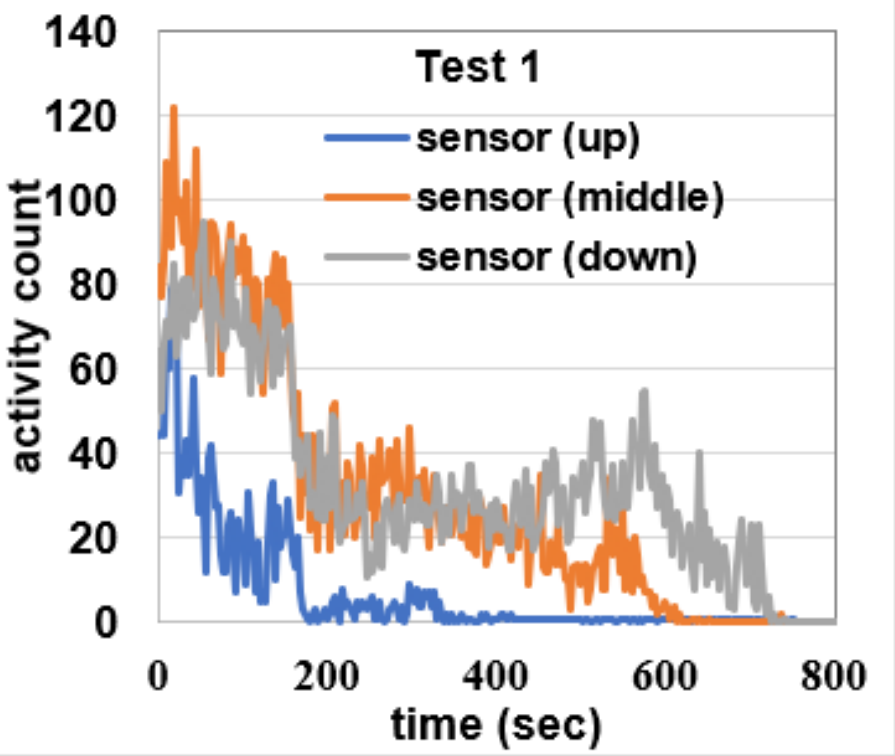
魚活動次數演算

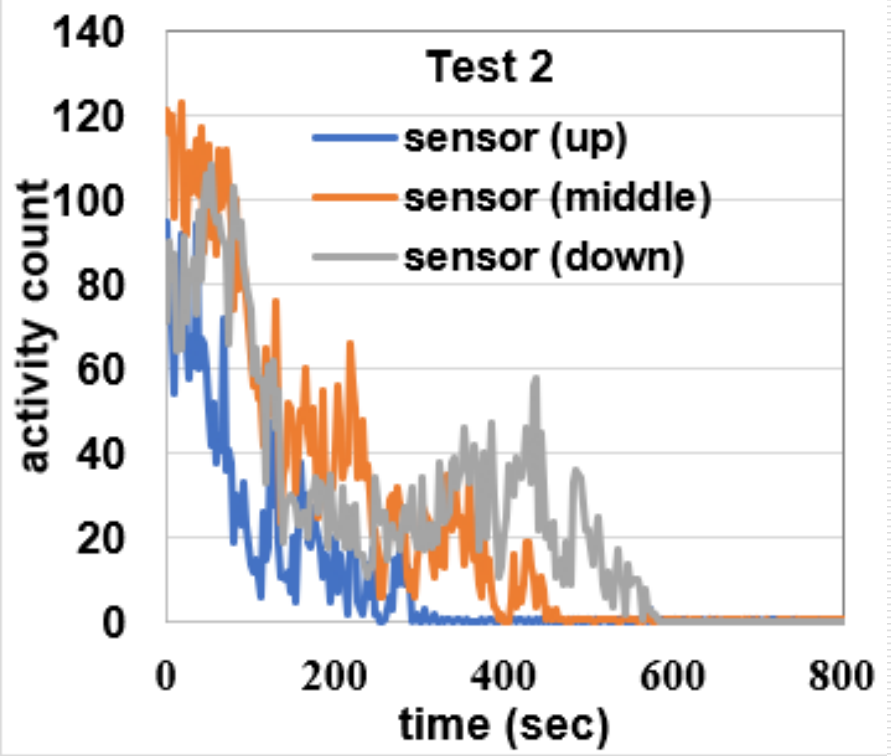
- 感測器ADC值變化需由小於250增加至大於300時計次才會累加1次



洩水測試

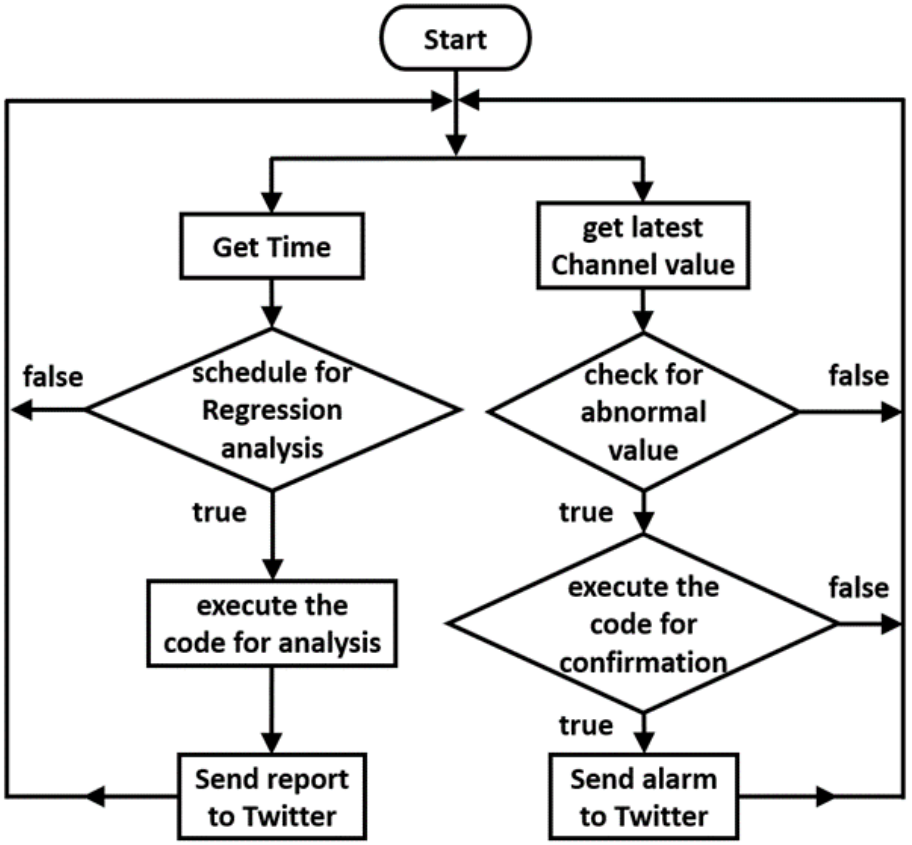
- 不同高度的測距器配置亦具有水位高度異常預警的功能

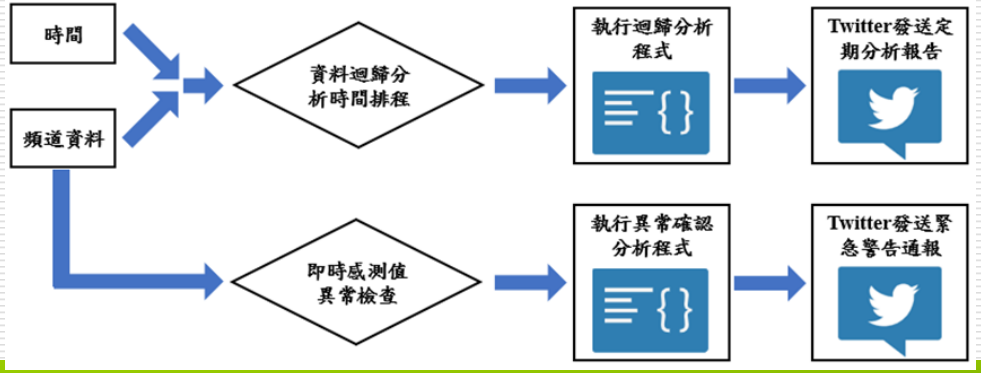




雲端物聯網診斷架構

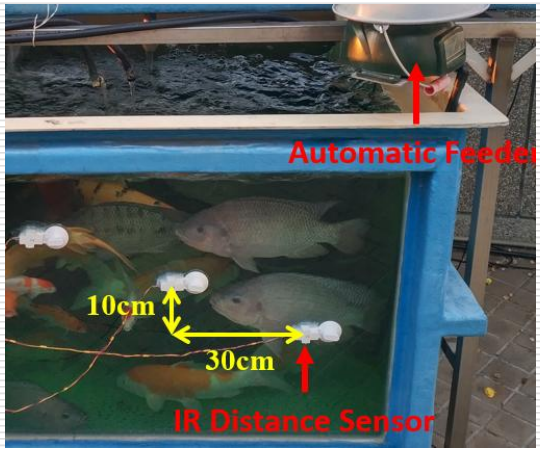
- 利用ThingSpeak™雲端資料平台，並可利用平台工具做到定期資料迴歸分析及即時預警

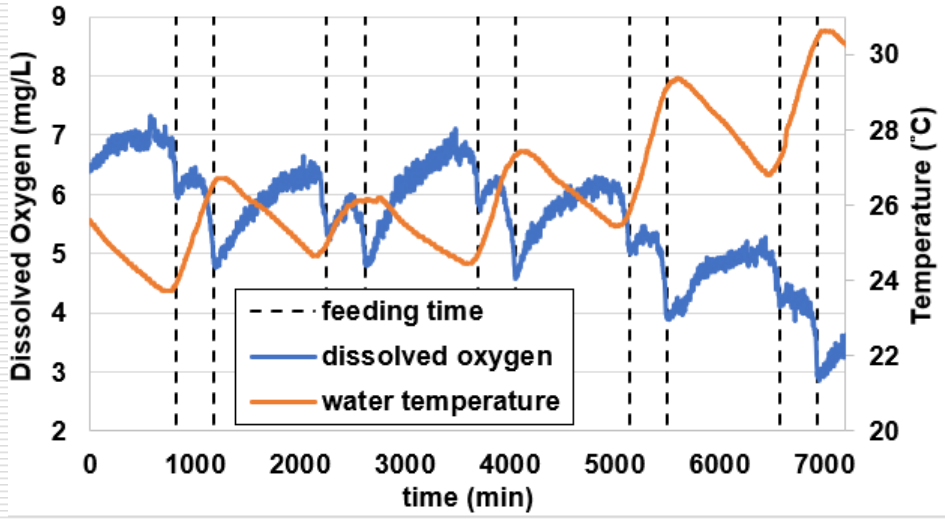


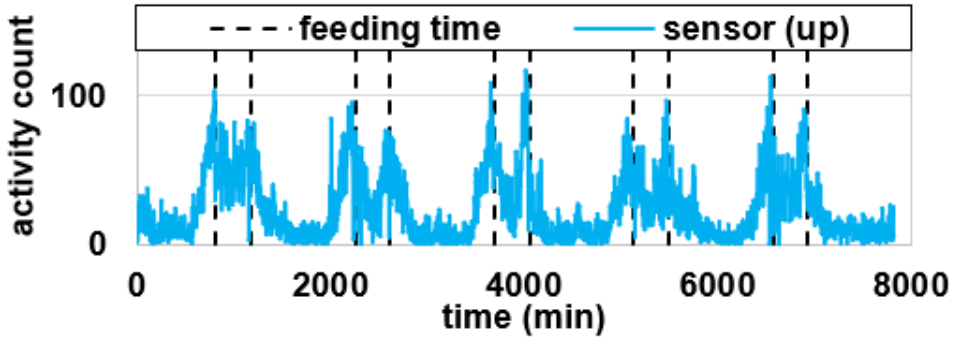


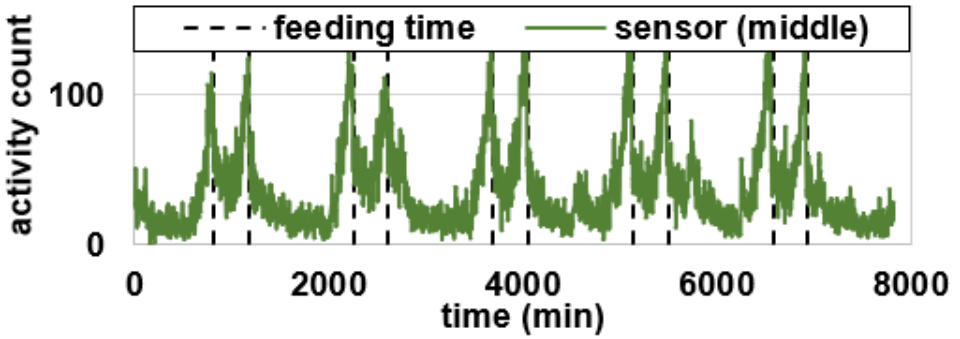
魚活動習性適應餵食時間點

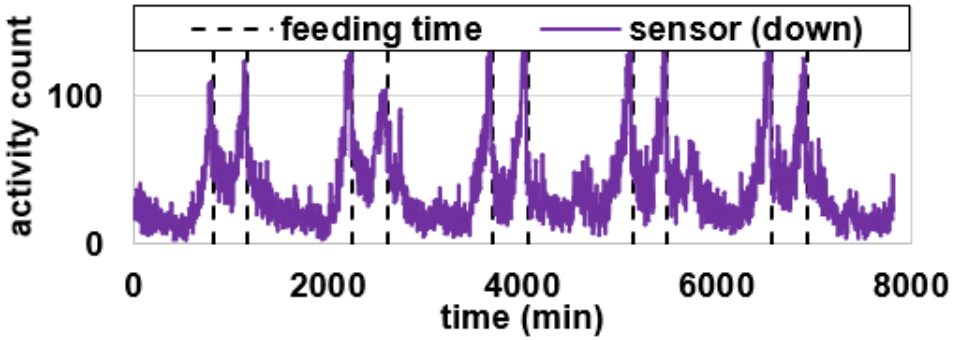
- 魚群群體行為
- 餵食前虎視眈眈
- 餵完了一哄而散









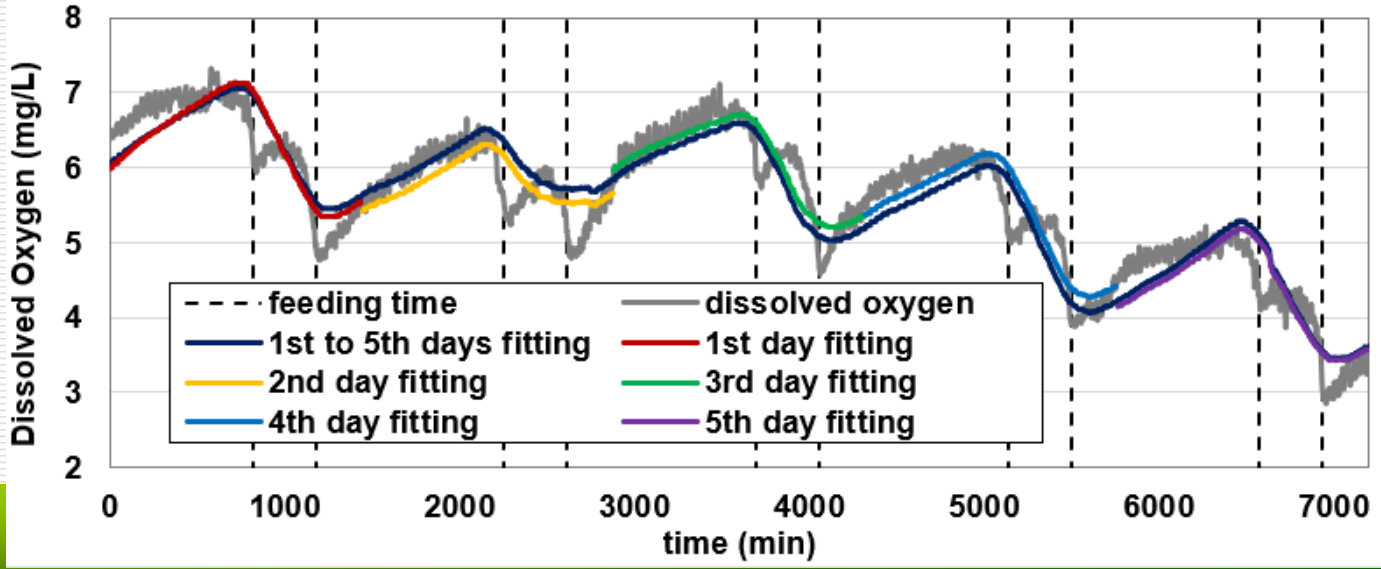


溶氧值(DO)與其對飽和溶氧(DO_S)迴歸分析算出之擬合曲線

- 飽和溶氧DO_S由水溫去換算
- 溶氧擬合誤差(DO殘差)在餵食時間點附近最大

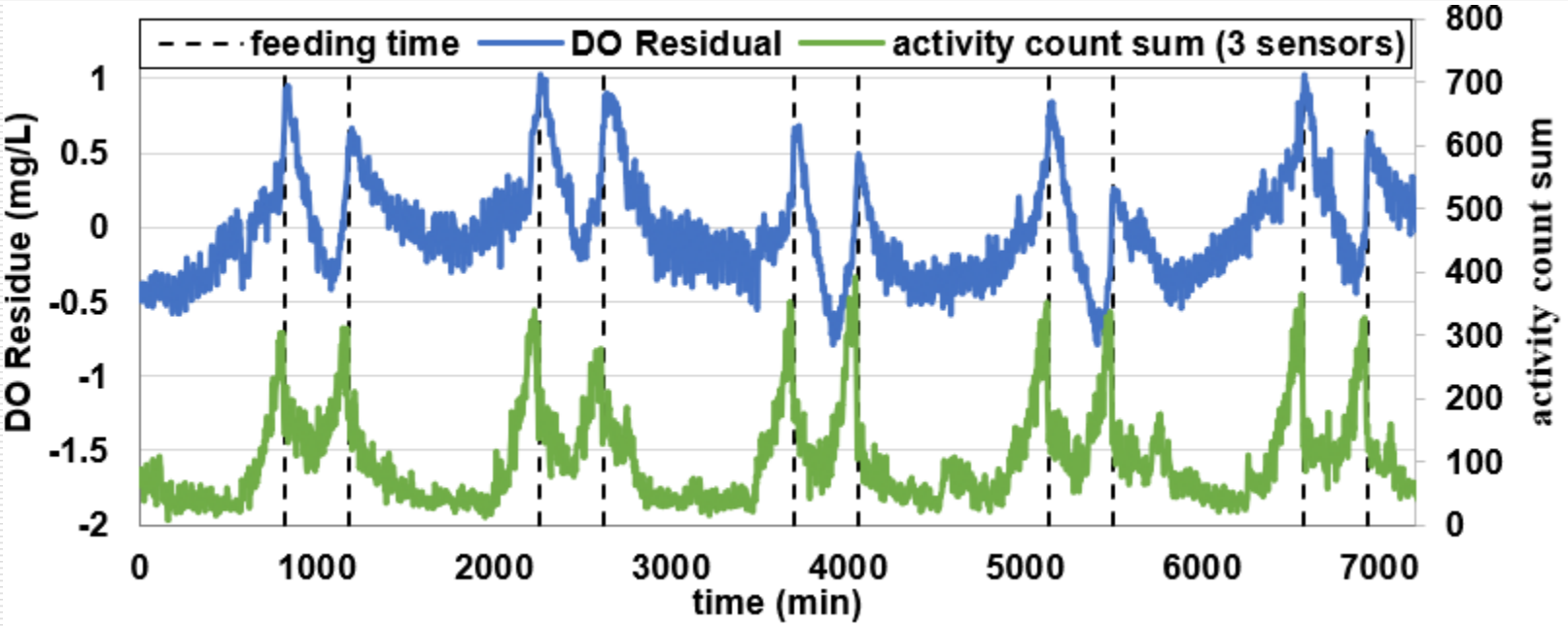
formula：$DO = A + B \times DO_S$

	A	B	RMS error	R-sq
1st day	−27.027	4.0420	0.3534	73.94%
2nd day	−22.870	3.5110	0.3112	41.27%
3rd day	−22.261	3.4737	0.2581	80.25%
4th day	−22.275	3.5323	0.3071	81.83%
5th day	−22.243	3.4943	0.3290	75.37%
1st to 5th days	−24.881	3.7800	0.3278	89.23%



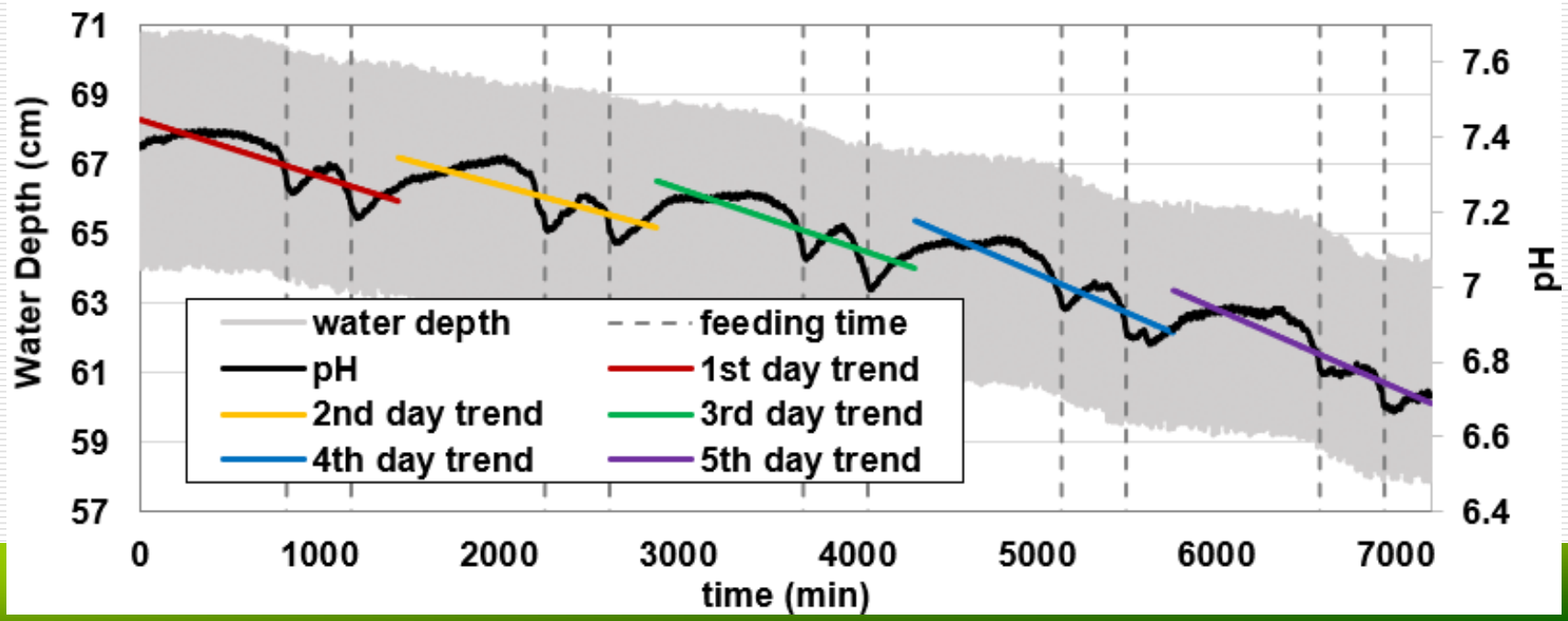
溶氧殘差(residual)與魚總活動次數(activity sum)的比較

- 魚活動是短時間尺度影響水質溶氧關鍵
- 打氣設備可以配合水溫或者魚活動率進行調控，節省電力。



酸鹼值(pH)變化曲線以及其每天的線性趨勢線

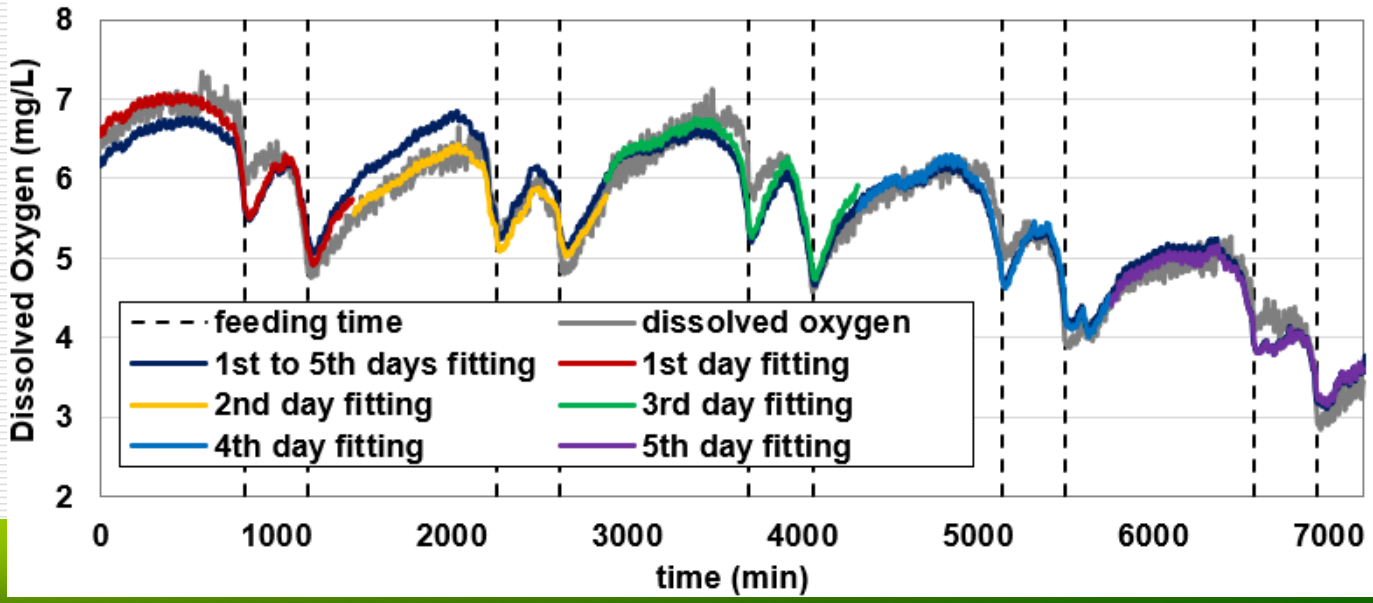
- 餵食點附近pH值會有下降後又回升的局部特徵
- 魚活動次數高時，水中CO_2濃度增高，部分與水化合形成碳酸H_2CO_3
- 水分蒸發會使離子濃度增加，酸化水質



溶氧值(DO)與其對酸鹼值(pH)及時間迴歸分析算出之擬合曲線

- F可用來描述DO與pH單位時間變化量(亦即微分)的關聯

formula：$DO = E + F \times pH + G \times t$					
	E	F	G	RMS error	R-sq
1st day	−66.45	9.902	0.000185	0.2346	88.47%
2nd day	−47.99	7.370	0.000468	0.1389	88.25%
3rd day	−63.25	9.608	0.000662	0.2327	83.89%
4th day	−64.76	9.917	0.000666	0.1778	93.90%
5th day	−52.43	8.257	0.000440	0.2046	90.45%
1st to 5th days	−58.73	8.802	0.000450	0.2642	93.00%



謝謝聆聽