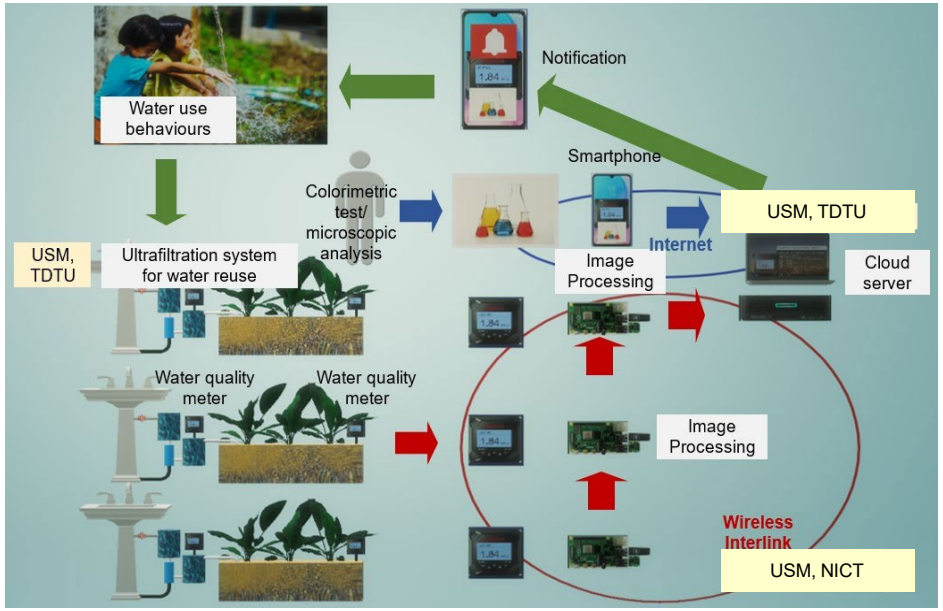
Project Title: IoT for water reuse in developing cities

Background :

Due to the limited water resources, the increasing urban water demand and the climate change, many urban water systems are facing the ever- increasing pressure to supply potable water. Water reuse technologies has been extensively developed over the years under the promotion of city sustainability. Many water reuse projects failed in the past due to the insufficient monitoring and maintenance. Hence, it should be paired up with ICT technologies which allow the real-time analysis and monitoring of water quality to preserve the water reuse system and the safety of vulnerable citizen. Moreover, big data should be collected through IoT to improve water management in cities.

Targets:

- To develop low cost and sustainable membrane filter for water reuse.
- To develop image processing for the analysis an d recording of water quality.
- To gain insights from water quality, reusability a nd use behaviors in ASEAN countries.



Speaker: Assoc. Prof. Ir. Dr. Leo Choe Peng

Project Title: IoT for water reuse in developing cities

Project Members :

Ir. Dr. Leo Choe Peng
Universiti Sains Malaysia

Ir. Dr. Yen Kin Sam
Universiti Sains Malaysia

Dr. Yu Kok Hwa
Universiti Sains Malaysia

Dr. Ho Ngo Anh Dao
Ton Duc Thang University

Mr. Nguyen Thanh Quang
Ton Duc Thang University

Dr. Huan-Bang Li
National Institute of Information and Communications Technology

Dr. Takeshi Matsumura
National Institute of Information and Communications Technology

Project Duration :

2 Years

Project Budget:

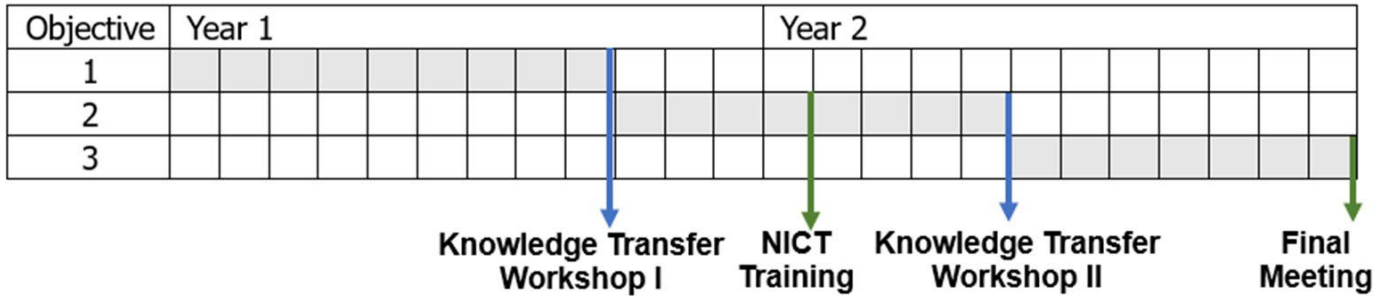
USD 69,500.00
current budget balance : 45,477.60 USD;
Budget to be spent by end of Nov 2022: 15,85260 USD
maximum budget that can be carried over 2022: 29,625.00 USD

Project Activities:

Milestones

- Completed: design and implementation of ultrafiltration system for greywater treatment (USM and TDTU) by December 2021.
- Completed: development of water quality analysis and monitoring procedures using image processing (USM, TDTU, UBD) as well as the D2D wireless system (NICT) by August 2022.
- In progress: development and implementation cloud-based application software for water quality analysis and monitoring (USM, UBD, NICT) by December 2023.

Gantt Chart



Knowledge Transfer Workshop I Completed

NICT Training Completed

Knowledge Transfer Workshop II Completed

Final Meeting Planned (January 2024)

Project Meeting by USM

- Virtual meetings were conducted biweekly except public holidays or the absence of project leader.
- Physical meeting was organized once the control of borders under pandemics were lifted.

29/8/2022 (USM)	Activities	Participant
8.30-10.30am	Report and discussion on progress Part I	Huan-Bang Li; Matsumura Takeshi; Leo Choe Peng; Yu Kok Hwa; Ho Ngo Anh Dao
10.30-11.00am	Tea Break	
11.00-1.00pm	Report and discussion on progress Part II	Huan-Bang Li; Matsumura Takeshi; Leo Choe Peng; Yu Kok Hwa; Ho Ngo Anh Dao
1.00-2.00pm	Lunch	
2.00 – 4.00pm	Visit to the D2D system and water reuse system	Huan-Bang Li; Matsumura Takeshi; Leo Choe Peng; Yu Kok Hwa; Ho Ngo Anh Dao
4.00-4.30 pm	Tea Break	
4.30 – 5.30pm	Visit to School of Mechanical Engineering	Huan-Bang Li; Matsumura Takeshi; Leo Choe Peng; Yu Kok Hwa; Ho Ngo Anh Dao

Knowledge Transfer Workshop by USM

- Knowledge transfer workshop include 36 participants from NICT, TDTU, USM (Engineering Campus and Main Campus), Universiti Malaysia Perlis, Monash University, Universiti Kebangsaan Malaysia, local industry, and representative from the Institution of Engineers, Malaysia.

30/8/2022 (Iconic Hotel)	Activities	Speaker
8.30-9.00 am	Welcome remarks	Project Leader
9.00-9.30 am	Opening remarks	The Dean of the School of Chemical Engineering
9.30-10.00 am	Introduction to NICT	NICT
10.00 -10.30 am	Tea Break	
10.30 -11.30 am	Membranes for water reuse	Assoc. Prof. Dr. Poh Phaik Eong (Monash University)
11.30 am -12.30 pm	D2D Technology	Prof. Dr. Huan-Bang Li (NICT)
12.30 pm – 1.00 pm	Networking Session	Participants to exchange name cards and network.
1.00 -2.00 pm	Lunch	
2.00-3.00 pm	The transformative powers of Big Data and the Internet of Things (IoT).	Mr. Chan Zhen Yu, WyseTime Technologies Sdn. Bhd.
3.00-4.00 pm	IR4.0 for water recovery	Assoc. Prof. Dr. Mohamad Hanif Md Saad (Institute of IR4.0, UKM)
4.00-5.00 pm	Dielectrophoresis for water quality monitoring (Virtual)	Dr. Muhamad Ramdzan Buyong (Institute of Microengineering and Nanoelectronics)
5.00-5.10 pm	Closing remarks	Project Leader
5.10 – 5.30 pm	Networking and tea break	Participants to exchange name cards and network.

Photos of workshop:

Knowledge Transfer Workshop II by TDTU

16-17/2/2023

Knowledge transfer workshop II include 3 participants from NICT, 3 participants from USM besides researchers and students from TDTU.
7 speakers from TDTU shared their research for future collaboration.

Date and time	Activities	Participant
9.30 -10.00	Tea Break	Participants to exchange name cards and network
10.00 -10.45	Topic 1: Application of AnMBR for seafood processing wastewater treatment	Assoc. Prof. Tran Le Luu
10.45-11.30	Topic 2: Application of IoT techniques for measuring & surveying energy consumption of air conditioning system under different environmental conditions	Dr. Dinh Hoang Bach
11.30 -13.00	Lunch	
13.00 – 13.45	Topic 3: IoT based smart water quality monitoring system: A case study in Vietnam	Dr. Tran Thi Phuong Quynh
13.45 – 14.30	Topic 4: Environmental monitoring using IoT web based NodeRed	Dr. Tran Viet Hung
14.30 – 15.15	Topic 5: IoT system for water reuse in Mekong Delta region	Dr. Kim DoKyong
15.15 – 15.30	Tea break	Participants to exchange name cards and network
15.30 – 16.15	Topic 6: Water environment monitoring of aquaculture ponds	Mr. Mai Minh Man Mr. Le Duc Phuong
16.15 – 17.00	Topic 7: Wireless communication for IoT devices	Dr. Tu Lam Thanh
17.00 – 17.15	Closing remarks	Representative of TDTU Project Leader

Wireless Communication and Intellectual Property Training by NICT

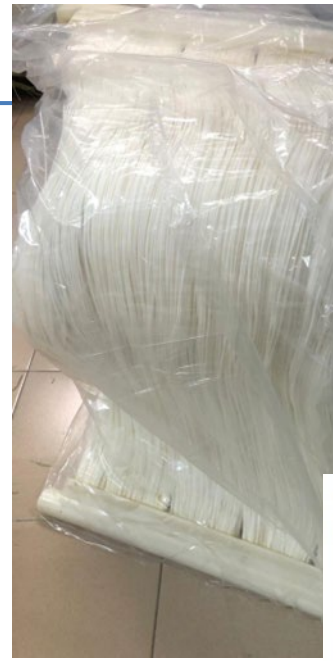
1. Visit to NICT facilities at Wireless Systems Laboratory, Yokosuka
Date: 28/08/2023
Venue: 3-4, Hikarino Oka, Yokosuka, Kanagawa.
2. Technical training on wireless communication
Date: 28 & 30/8/2023
Venue: 3-4, Hikarino Oka, Yokosuka, Kanagawa.
3. Visit to NICT headquarters at Koganei
Date: 29/8/2023
Venue: 4-2-1, Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan.

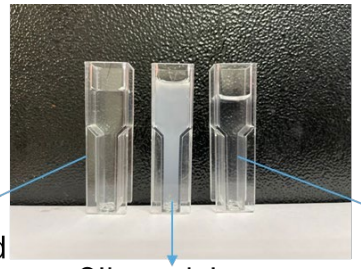
Workshop 1: Introduction of D2D technology and application of D2D systems in field work.
Workshop 2: Review and update on experiment results of current project. (Objective 3)
Workshop 3: Introduction of NICT patents related to D2D technology. Discussion on possible future cooperation. (Objective 3)
Workshop 4: Discussion on interface between sensor system and D2D system.
Lab visit to wireless communication lab and interactive lab on Aug 28, hosted by Dr. Morio Toyoshima, Dr. Matsumura Takeshi and Dr. Huan-Bang Li. Lab visit to satellite communication lab on Aug 29, hosted by Dr. Alberto Carrasco-Casado and Dr. Dimitar Kolev.
Lab visit to remote sensing lab on Aug 29, hosted by Dr. Seiji Kawamura and Dr. Philippe Baron. Lab visit to 5G communication lab on Aug 29, hosted by Dr. Norihiko Sekine.

R&D results:

Membrane modification for water reuse
by Assoc. Prof. Ir. Dr. Leo Choe Peng

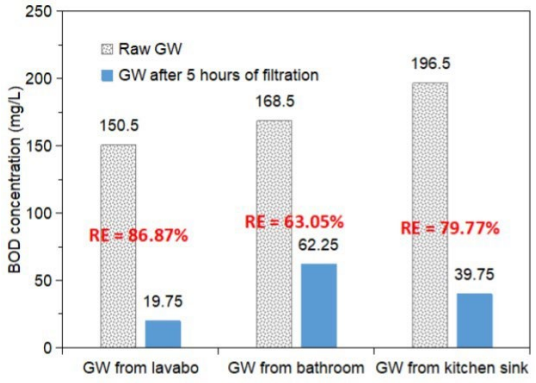
- The commercial hollow fiber membranes with oil rejection of 34.2% were chemically modified and rearranged into a membrane module.
- The removal of oil in the feed was improved from 77.3% to 83.2% by changing the coating material from ethanol to lignin.
- However, the water permeation was reduced (> 40%) and $CaCO_3$ was added as the pore template for lignin coating.
- Oil rejection was improved to 90% and permeate flux was enhanced (permeation reduction <20%).
- In addition, electrically conductive membrane and electrochemical cleaning were developed.

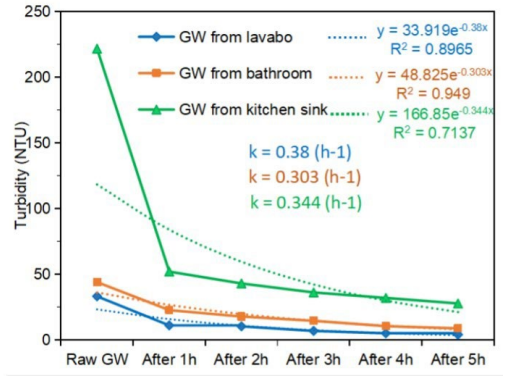


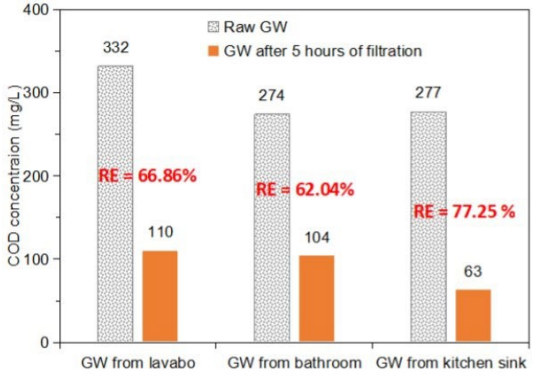


Greywater treatment for irrigation at TDTU
by Dr. Ho Ngo Anh Dao

- The membrane modification methods were transferred from USM to TDTU and the modified membrane was installed into a greywater treatment system in TDTU.
- The treated greywater from lavabo fulfilled standard C stated in TCVN 12180-2:2017, ISO 16075-2:2015 for irrigation purposes.







Coliform MPN/1ml with dilution of 1000 times

Type of GW	Raw GW	After 5h	RE (%)
GW from lavabo	$350x10^5$	$166x10^5$	52.57
GW from bathroom	$63x10^5$	$43x10^5$	31.74
GW from kitchen sink	$10080x10^5$	$5580x10^5$	44.64

UV Treatment

by by Dr. Ho Ngo Anh Dao and Assoc. Prof. Ir. Dr. Leo Choe Peng

- UV light reduced E. coli and Total coliform significantly.
- The water quality Kerian River after filtration and 5 hours of UV disinfection was summarized in Table 4.4
- According to DOE, the treated water is still categorized as slightly polluted where its parameters lie within the classification of Class III of Malaysia water reuse standard, suitable for irrigation.
- Membrane filtration alone cannot remove Total coliform, but UV can further reduce it to meet the US and Vietnam standards.

Table 4.4 Results of the treated water quality parameters

Parameter	Unit	Average concentration	Index range	Water class
pH	-	7.75	6-9	Class I
Turbidity	NTU	4.14	5	Class I
BOD_5	mg/L	4.27	6	Class III
E. coli	CFU/mL	2	0	-
Total coliform	CFU/mL	26	50	Class I

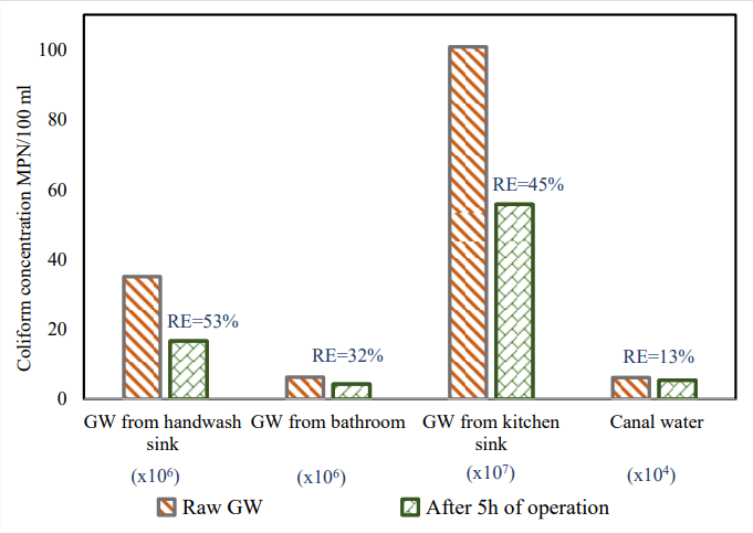
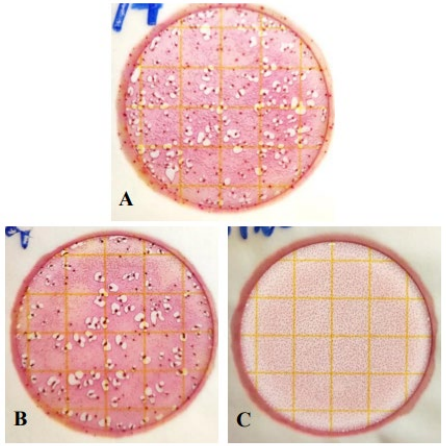


Figure 5. Coliform found in different greywater after 5 hours of filtration processes



re 6. Formation removal in the case of washing basins water samples

) Before treatment; (B) Treatment without UV; (C) Treatment with UV

Table 2 Water characteristics and removal efficiency of pollutants from washing basins with and without UV disinfection as compared to current standards for water reuse in irrigation.

Parameters	Without UV		With UV		Current standard	
	Mean value	RE (%)	Mean value	RE (%)	US EPA EPA/600/R-12/618 [(a)]	TCVN 12180-2:2017 [(b)]
pH	7.57	-	7.60	-	6.0 – 9.0	-
Turbidity (FTU)	4.56±1.41	86	5.63±1.93	83	-	-
BOD_5 (mg/L)	18.81±2.15	88	19.57±2.31	87	≤30	≤20
COD (mg/L)	112.88±3.95	66	116.2±4.05	65	-	-
Coliform (MPN/100ml)	22.10×10^6	63	0	100	≤200	≤1000

[(a), (b)] *Suggested guidelines for water reuse in restricted urban areas (USEPA 2012; STAMEQ 2017)*

Water Reuse standard Malaysia http://www.nahrim.gov.my/

PARAMETER	UNIT	CLASS					
		I	IIA	IIB	III	IV	V
Ammoniacal Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	> 2.7
Biochemical Oxygen Demand	mg/l	1	3	3	6	12	> 12
Chemical Oxygen Demand	mg/l	10	25	25	50	100	> 100
Dissolved Oxygen	mg/l	7	5 - 7	5 - 7	3 - 5	< 3	< 1
pH	-	6.5 - 8.5	6 - 9	6 - 9	5 - 9	5 - 9	-
Colour	TCU	15	150	150	-	-	-
Electrical Conductivity*	μS/cm	1000	1000	-	-	6000	-
Floatables	-	N	N	N	-	-	-
Odour	-	N	N	N	-	-	-
Salinity	ppt	0.5	1	-	-	2	-
Taste	-	N	N	N	-	-	-
Total Dissolved Solid	mg/l	500	1000	-	-	4000	-
Total Suspended Solid	mg/l	25	50	50	150	300	300
Temperature	°C	-	Normal + 2 °C	-	Normal + 2 °C	-	-
Turbidity	NTU	5	50	50	-	-	-
Faecal Coliform**	count/100 ml	10	100	400	5000 (20000)[a]	5000 (20000)[a]	-
Total Coliform	count/100 ml	100	5000	5000	50000	50000	> 50000

Notes :

N : No visible floatable materials or debris, no objectional odour or no objectional taste
* : Related parameters, only one recommended for use
** : Geometric mean
a : Maximum not to be exceeded

WATER CLASSES AND USES

CLASS	USES
Class I	Conservation of natural environment. Water Supply I – Practically no treatment necessary. Fishery I – Very sensitive aquatic species.
Class IIA	Water Supply II – Conventional treatment required. Fishery II – Sensitive aquatic species.
Class IIB	Recreational use with body contact.
Class III	Water Supply III – Extensive treatment required. Fishery III – Common, of economic value and tolerant species; livestock drinking.
Class IV	Irrigation
Class V	None of the above.

Evaluation of turbidity measurement using IOT

by Dr Yu Kok Hwa and Mr. Nguyen Thanh Quang

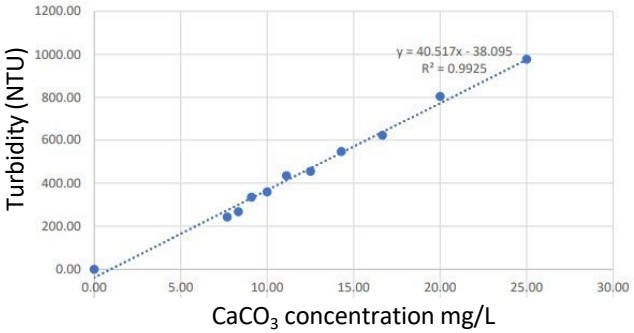
The turbidity measurement using IoT water quality monitoring system was studied to identify the difference from the standard method.

The gravity arduino turbidity sensor measures turbidity or opaqueness using light transmittance and scattering rate, which changes with the amount of total suspended solids (TSS) in water.

A new voltage-turbidity conversion equation was derived for the turbidity sensor and then applied in the measurement of turbidity caused by $CaCO_3$ nanoparticles, oil emulsion, and dye.

The turbidity measurement on calcium carbonate solution was strongly affected by the sensor selection, ranging between 1.10 and 15.99%. As for the time-based turbidity measurement, the liquid solutions used are calcium carbonate solution, oil emulsion, dye solution, and protein emulsion. The dynamic measure of solution turbidity was affected by the settlement of $CaCO_3$ and the separation of oil emulsion.

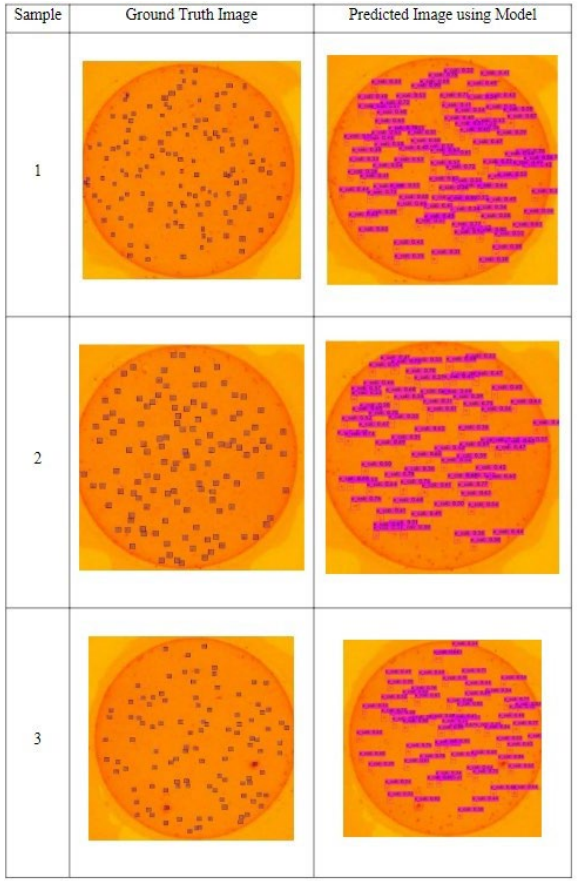
In conclusions, the limitation of sensor should be studied before implementing.



Detection and counting of E. coli on petri film using YOLO v4

by Ir. Dr. Yen Kim Sam

- The presence of Escherichia coli limits the water reuse purposes and the safety of water is measured by colony forming unit per 100mL (CFUs/100mL).
- Since the manual counting by a laboratory personnel is time-consuming, there is a dire need for vision automation in the count of E. Coli bacteria.
- The study includes the usage of machine learning capabilities to detect and count the colony present on the commercial petri film.
- The sample images obtained from the analysis of lake, drainage and river samples was captured under the selected lighting condition before augmentation.
- The processed images are then annotated using Label Studio and later trained using YOLO v4, an object classifier network that employs Convolutional Neural Network (CNN).
- The network is being trained to pick up presence of E. Coli on petri film in the unit of CFU.
- The results showed that with only 50 test piece sample images, the model achieve amAP accuracy of approximately 75%, IOU score of 0.82 and an average loss of 3.6555.
- During the test phase, this work recorded a precision of 0.9087±0.00737, recall of 0.0.9468±0.00573 and F-score of 0.9273±0.00577.

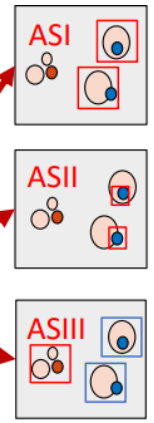


Detection and counting of E. coli on petri film using YOLO v4 and v7 by Ir. Dr. Yen Kim Sam

With small sample size, we have demonstrated: ASII – stringent annotation
promotes true positive detection.

- Model (YOLOv4) trained with ASII performed 4.37%, 5.37% and 4.82%
higher in terms of precision, recall and F1-score in hold-out testing images
respectively compared to model trained with ASI.
- With a smaller sample size, specific and stringent annotation is important

RESULTS ON ANOTATION STRATEGIES – 50 IMAGES



Training

Model	mAP (%)	Precision (%)	Recall (%)	F1 – Score (%)
ASI	68.88	77.00	70.00	73.00
ASII	79.76	85.00	78.00	81.00
ASIII	86.31	81.00	85.00	83.00

Testing

Over-detection *Under-detection*

Model	Ground truth	TP	FP	FN	Precision (%)	Recall (%)	F1-score (%)
ASI	149	139	44	10	75.96	93.29	83.74
ASII	149	147	36	2	80.33	98.66	88.56
ASIII	149	117	6	32	95.12	78.52	86.03

RESULTS ON ANOTATION STRATEGIES – 100 IMAGES

Training

Model	mAP (%)	Precision (%)	Recall (%)	F1 – Score (%)
ASI	90.55	87.00	91.00	89.00
ASII	89.26	86.00	90.00	88.00
ASIII	88.17	83.00	90.00	86.00

It's comparable!

Testing

Model	Ground truth	TP	FP	FN	Precision (%)	Recall (%)	F1-score (%)
ASI	249	221	15	28	93.64%	88.76%	91.13%
ASII	249	210	14	39	93.75%	84.34%	88.79%
ASIII	249	219	14	30	93.99%	87.95%	90.87%

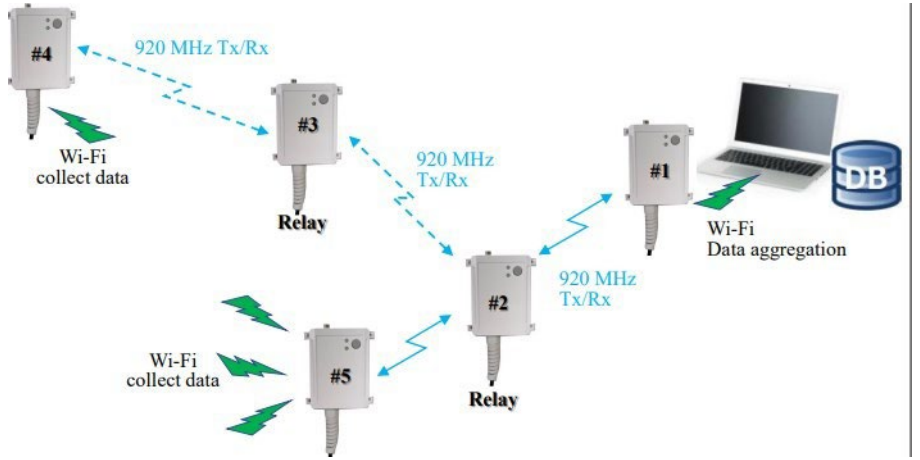
Coincidence in sums, individual predictions are different

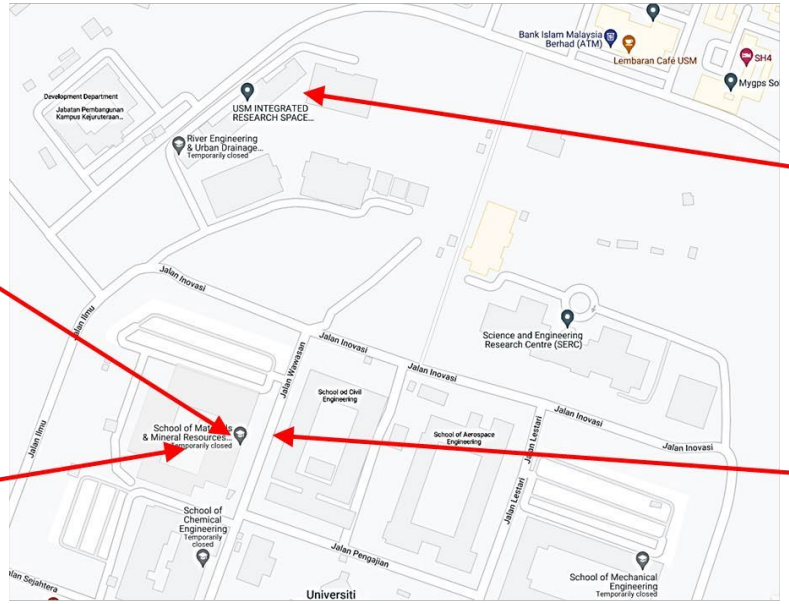
YOLOv7

Model	Ground truth	Predicted	TP	FP	FN	Precision	Recall	F1 - score
ASI	249	253	228	25	21	90.12%	91.57%	90.84%
ASII	249	253	228	25	21	90.12%	91.57%	90.84%
ASIII	249	240	225	15	24	93.75%	90.36%	92.02%

D2D Wireless System for Water Reuse System by Dr Huang-Bang Li and Dr. Takeshi Matsumura

For data transfer, 4 units of antennas were successfully installed in USM for the development of D2D wireless system.
It encloses 920 MHz radio module and CPU with build-in Wi-Fi as interface for senser data and image/picture transmission and aggregation.
Manual of operation was developed and pass down to USM team.
USM team will study the transfer of data from IoT sensor into the D2D wireless system.





Scientific Contribution:

Presentations at International Conferences:

No:a	Paper title:	Author names	Affiliation	Conference name	The date of the conference	The venue of the conference
1.	Optical Segmentation on E. coli colonies formed on E. coli test piece (Petrifilm) - for the development of IoT devices for water quality monitoring	Teoh Mynn Wei, Yen Kin Sam, Yap Jia Xin, Leo Choe Peng, Namal Arosha S. Senanayake Mudiyanselage	Universiti Sains Malaysia, Universiti Brunei Darussal am	ASEAN IVO Forum 2021	18/11/2021	Virtual
2.	Development of IoT Water Quality Monitoring System	Tay Ying Keat; Yu Kok Hwa; Yen Kin Sam; Leo Choe Peng; Hong Chia Huey	Universiti Sains Malaysia	ASEAN IVO Forum 2021	18/11/2021	Virtual
3.	Optimization of deep learning model for E. coli detection based on annotation strategies	Khairul Firdaus Mohd Talib, Mohamad Syahmi Johar, Jia Xin Yap, Choe Peng Leo, Kok Hwa Yu	Universiti Sains Malaysia	IEEE International Conference on Artificial Intelligence in Engineering and Technology (IICAIET 2023) (http://iicaiet.ieeesabah.org/)	12-14/9/2023	Sabah, Malaysia

Scientific Contribution:

Published Journal Papers:

No:	Paper title:	Author names	Affiliation	Journal name:	The publisher of the Journal	The volume number and Pages
1.	Porous cellulose beads intercalated with calcium carbonate nanoparticles for dye adsorption	Jia Xin Yap, Wei Chee Gan, C.P. Leo	Universiti Sains Malaysia,	Desalination and Water Treatment	Taylor & Francis Online	doi: 10.5004/dwt.2022.28938
2.	Electrochemical cleaning of superhydrophobic polyvinylidene fluoride/polymethyl methacrylate/carbon black membrane after membrane distillation,	N.A. Zakaria, S.Q. Zaliman, C.P. Leo A.L. Ahmad, B.S. Ooi, Phaik Eong Poh,	Universiti Sains Malaysia, Monash University	Journal of the Taiwan Institute of Chemical Engineers	Elsevier B.V.	2022, 38, 104448
3.	3D imprinted superhydrophobic polyvinylidene fluoride/carbon black membrane for membrane distillation with electrochemical cleaning evaluation	NA Zakaria, SQ Zaliman, CP Leo, AL Ahmad, BS Ooi, PE Poh	Universiti Sains Malaysia, Monash University	Journal of Environmental Chemical Engineering	Elsevier B.V.	2022, 10 (2), 107346
4.	Extended use of greywater for household irrigation purposes in a developing country	Ngo Anh Dao Ho Choe Peng Leo, Anh Tuan Ta, Thanh Quang Nguyen	Universiti Sains Malaysia, TDTU	Water Practice and Technology	IWA Publishing	WPT-D-23-00188, under review.

Societal Impact:

- 2 chemical engineers, 2 mechanical engineers, and 3 electrical and electronic engineers improved their engineering competence through the interdisciplinary collaboration.
- USM (2 final year students, 1 MSc. Student) and TDTU students (2 undergraduate students) learned on IoT and water reuse technologies in the experimental works.
- >100 participants, including representative from local universities, industry and professional society enhanced their knowledge on ASEAN IVO Project, NICT, IoT and water reuse technologies in Knowledge Transfer Workshop I, II and talks.

- Invited talks

Water reuse and recycling, Economic, Environmental, and regulatory Considerations, IChemE, Virtual, 17/06/2023. https://www.icheme.org/knowledge-networks/communities/special-interest-groups/water/events/17-06-23-water-reuse-and-recycling-economic-environmental-and-regulatory-considerations/

- Technical Sharing Session on Greywater in Malaysia, National Water Research Institute of Malaysia Virtual,16/3/2023. https://www.nahrim.gov.my/hebahan-penghantaran-abstrak-sesi-perkongsian-teknikal-e-poster-produk-dan-teknologi-inovasi-rawatan-greywater-di-malaysia/
- Water Security in Sustainable Development, Applied Science Private University, Jordan, 14/3/2023.
- Natural resources: Water efficiency for sustainable living, Virtual, MalaysiaGBC, Natural resources: Water efficiency for sustainable living, 13/08/2022 https://www.mgbc.org.my/malaysiagbc-natural-resources-water-efficiency-for-sustainable-living-13-august-2022-virtual-via-zoom/

- Undergraduate education:

WSU 101 Sustainability: Issues, Challenges & Prospect https://www.openlearning.com/courses/sustainability-issues-challenges-prospects/homepage/?cl=1







Conclusion:

- Water reuse requires improved treatment technology, and sensors to meet the local standards.
- Image analysis enhanced the analysis of water quality for reuse.
- Data collection is essential to gain
  in insights from water quality, reusability and use behaviors in ASEAN countries.

Future works:

USM:

- Purchase sufficient items to sustain the water reuse system.
- Study the data transfer between IoT sensor and D2D wireless system.
- Arrange training at NICT.

TDTU:

- Conduct Knowledge Transfer Workshop
- Prepare manuscript for submission to indexed journal.

NICT:

- Study the stability of D2D wireless system.
- Arrange training at NICT.