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ARTIFICIAL INTELLIGENCE AND COMPUTER VISION – A MATCH MADE IN HEAVEN?

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ABSTRACT

After becoming independent in 1957, Malaysia continued as an agricultural country but quickly grew into a manufacturing nation in a relatively short time. Literally from nowhere, the manufacturing sector now commands more than 38% of the nation's GDP overtaking the agriculture sector which commands just slightly above 7%. In addition to the multinational manufacturers who are mainly in the electrical and electronics sectors, there are also other smaller producers who produce for the rest of the world. Nevertheless in order to compete, they cannot just rely on manual labour whether local or foreign, to produce high volume and high quality goods at a competitive price. With intense competition, even the old way of making many products to satisfy the global appetite for good products from both the brick-and-mortar shops to your huge online shops is no longer adequate. Manual operations in the manufacturing process can come in various forms, ranging from the very simple but monotonous and repetitive to the highly complex or sophisticated. In the quality department many of the local manufacturers have chosen to use human labour to ensure their quality is maintained. For many of these highly repetitive but relatively simple tasks, the human operators need to be properly trained for an appropriate length of time before they can perform effectively. Other than the intelligence of these operators, their ability to detect deviations from the desired patterns are also utilised. And this is where artificial intelligence and computer vision can help. This paper shows how artificial intelligence combined with computer vision can be used to improve productivity and effectiveness in three different areas within a typical supply chain to make each of this production processes more efficient, namely in the production of edible bird's nest, retail ecommerce and finally the recognition of cancerous cells.

Keywords: artificial intelligence, computer vision, image processing, automation, quality control, healthcare, ecommerce

1.0 INTRODUCTION

Malaysia's humid tropical climate and seasonal monsoonal weather have produced conducive conditions for plant growth. Hence for a long time after independence, agriculture forms the backbone of the Malaysian economy where the agriculture sector contributed 37% of Malaysia's GDP [1]. In those early years, the economy was supported by a range of primary products (e.g. tin, rubber, palm oil, timber, oil, liquefied natural gas, etc.) before the Government embarked on an industrialisation programme to transform it into a manufacturing-based economy, with electronics and electronic components as the mainstay [2]. The manufacturing sector's contribution stood at 38.3%, over a third of the country's GDP in 2018 but by now the contribution by the agriculture sector is just slightly over 7.3% [3]. Manufacturing fulfils an important need where handcrafted or manual production cannot handle, i.e. more consistent quality, cost reduction and overall reduction in production time.

Compared with mass production, manual production does not produce goods with consistent quality. This is especially true when we use human operators to do quality checks as both boredom and fatigue can cause lapses in concentration leading to defects escaping detection and inadvertently sent to the customers. While there is demand for hand-crafted products, however if the demand is high this mode of production is not efficient. However depending on the complexity of the product manufactured as well as other factors, the manufacturing process may not be fully mechanicalised. Moreover, there are still many of the repetitive processes in the Malaysian manufacturing sector that are still handled by humans.

Because of today's very short time-to-market deadlines, demanding customers, and a rise in the complexity of products, manufacturers are finding it increasingly harder to maintain high levels of quality. And this is where artificial intelligence and computer vision can help. Prior to 1955 when there was no such term, intelligent systems were either known as thinking machines, cybernetics, automata theory, or complex information processing [4]. The term artificial intelligence was first coined at the *Dartmouth Summer Research Project on Artificial Intelligence,* a 2-month, 10-man study of artificial intelligence initiated by John McCarthy in 1956. While there are many definitions, Ray Kurzweil, an American inventor and futurist defines it as machines that perform functions that

require intelligence when performed by humans [5]. A well known global media company did a survey on the importance of artificial intelligence (AI) in the automotive and manufacturing sectors. They found that while 44% classified AI as *"highly important"* in improving the manufacturing function in the near term, just lightly less than half of them believed that this is *"absolutely critical to success."* [6]. Hence this reaffirms that artificial intelligence holds the key to future growth and success, especially for those industries in the manufactur ing sector.

Computer vision (CV) as the name suggests, fundamentally deals with how computers can gain high-level understanding from digital images or videos [7, 8]. It seeks to understand and imitate the capability of the human visual system which includes the acquisition, processing, analyzing and understanding digital images to help make better decisions. This is illustrated in Figure 1.

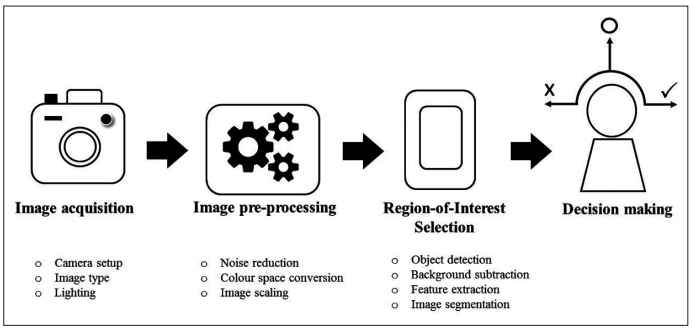

Figure 1: Traditional computer vision pipeline

This is especially true when it comes to quality control and inspection. Even the most eagle-eyed human inspector would fail at finding defects that are either very small or can only be seen at a certain angle. However a machine equipped with a powerful camera that is many times more sensitive than the naked eye will not fail. It starts with getting the human expert to identify the defects and then train the machine to perform the same task based on the results from the human expert. However, for many of these manual quality inspection, it is neither easy nor simple as it requires a huge amount of resources to properly train the humans before they can handle the task effectively.

A major driver for the industry to adopt these new technologies has been the huge improvements in image acquisition devices making them very affordable and attractive to adopt and the same goes for computing power. In tandem with these two major developments has been the intense work into the development of powerful algorithms.

For a typical product supply chain, it usually starts with the sourcing of the relevant raw materials after which these are then combined to manufacture the product before eventually reaching the consumers or customers through the appropriate distribution channel which can now be via the internet. The supply chain would generally be the same for each industry, whether it is for the production of tee shirts or medical devices. To illustrate both the flexibility as well as the power of AI and CV working together in a particular intelligent system, we have identified three key areas within such a supply chain.

Edible bird's nest (EBN) are nests formed from the saliva of swiftlets commonly found in South East Asian and is a multi-billion dollar industry. Trained operators are currently used to sort these natural products into the correct grade for eventual sales. In the next section we shall look at how AI working together with CV can be used to correctly grade EBN.

Breast cancer is a group of diseases in which cells in breast tissue change and divide uncontrolled, typically resulting in a lump or mass. What makes it deadly is that there are usually no symptoms when the tumour is small and most easily treated. Regular screening is important as it can help in early detection. Breast cancer is the most common cancer affecting women, with about 2.1 million cases reported per year, as communicated by the World Health Organisation (WHO). Moreover, breast cancer is also the main cause of cancer-related deaths in women. For example, it is estimated that in 2018, 627,000 women died of breast cancer, corresponding to about 15% of cancer-related deaths in women [9]. In Malaysia, breast cancer tops amongst the various types of common cancer. When cancer is suspected, a sample of the tissue for microscopic analysis is usually obtained. However, lack of trained experts, time consuming process, difficult in identifying the tumours, etc, are some of the challenges which can slow this process down. In the second part we will show some of the results of the collaboration of AI with CV to detect breast cancer using the concept of artificial teachers to help train such an intelligent system to help the medical experts. And lastly we will illustrate some of our work in using a combination of AI and CV to perform visual fashion understanding which is of huge interest for the industry, motivated primarily by the needs of electronic commerce in clothing retrieval, fashion recommendation, etc. A fundamental driver for this is to identify fashion landmarks which are functional key-points defined on clothes, such as corners of neckline, hemline and cuff.

2.0 IDENTIFYING THE RIGHT EDIBLE BIRD'S NEST

EBN are nests formed from the saliva of swiftlets commonly found in South East Asian countries of Malaysia, Indonesia, Thailand, and Vietnam [10] and is a multi-billion dollar industry. They are especially popular among some Asian communities due to their high-protein nutrients [11] and sialic acid which is believed to improve brain function.

To cater to the various customer preferences, EBNs are sold either in the unprocessed or raw form or they can also be sold after cleaning, further processing and then graded. The price of EBNs solely depends on the grade. Among the various grades, Grade AA nests are the most expensive as it is the highest quality, followed by Grade A, B and C. The grades of EBNs are normally based on their shape, size, colour, and level of contaminants. Conventionally, trained human operators would grade EBNs based on these features. However, the consistencies of the grading results can be unreliable as the manual grading process is prone to the subjectivity of the human operators [12]. Thus, such a tedious grading process leads to production costs, subjectivity in the end results, as well as low efficiency as huge amounts of time are spent on the inspection. Furthermore, hiring and training new operators to inspect the nests are unavoidable for such a conventional approach to grading. Notwithstanding the conventional method, with the technological advancement in recent decades some aspects of identifying EBNs have improved dramatically in terms of speed, accuracy, and reliability [10].

In this section, we will describe a novel and fast multi-features neural fuzzy approach using a set of unique features to automatically grade EBN and the results compared with several state-of-the art AI (artificial intelligence) techniques. Unlike other popular approach our contributions are as follows:

1) a novel application of a neural fuzzy approach, based on an intuitive multi-feature set to accurately grade EBNs,
2) unlike other more popular AI techniques, our proposed approach does not need huge amounts of training data - which would require huge amounts of human effort and time to compile,
3) training is fast and it does not need special high performance computing platforms.

Grading of the EBN that is practised by the industry is based on the size, amount of contaminants, and the overall shape. A common method adopted by the industry to assess the size is by comparing it with the three fingers of the human hand where the three fingers are the index finger, middle finger and the ring finger of an average adult [13]. Clearly this can be very subjective when the operators are trained to assign the correct grade to each specimen as the size of their fingers would vary. A more scientific approach would be to measure the width and length of each specimen of the EBN but obviously this would be very time consuming.

Moreover, the grade of the EBN also heavily relies on the amount of contaminants in each sample. These contaminants or impurities can range from feathers, sand particles, bird droppings, etc. EBNs with lesser amount of contaminants will fetch a higher price compared to those with more contaminants. Finally, the shape of the harvested nests will have a significant effect on the grade. Deformed EBNs that are significantly different from their accepted shapes will have a lower commercial value [13]. What this means is that specimens when placed evenly on a horizontal surface that exhibit a perfect half cup shape would be a good grade. Lower grades, would also have a similar shape as their better counterparts but these will not be even when placed on a horizontal surface, as shown in Figure 2.

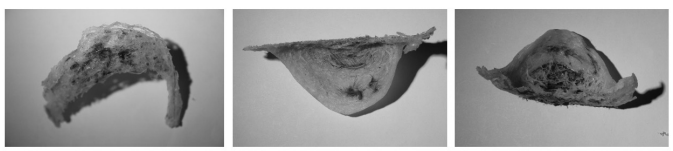

Figure 2 Examples of EBN for Grade AA, Grade A and Grade B. Adapted from [Introduction to Birds Nest 2018]

An important element for any successful autograding system is CV. For example, to identify the correct grade of mangoes is to correlate it to the fruit's maturity level. In such an intelligent system when used to auto grade and sort agricultural produce like mangoes, CV would again play a very important role as a core component. Nandi *et al.* first obtained sample images of unsorted mangoes for five different varieties of mangoes. Human experts were then used to predict the maturity of mangoes from these images. In their study, the Gaussian Mixture Model (GMM) was used to predict the maturity level of the mangoes based on the set of relevant features of the mangoes. They showed that the classification accuracies of the Gaussian Mixture Model (GMM) in their system were as good as those of human experts [14].

Diseases of fruits like apples, palm oil fruits, mangoes, dates and strawberries can also be correctly identified with the appropriate classifier working on the extracted features of the fruit. In order to correctly identify the disease, a unique set of features were used for each different fruit. Solanki *et al.* applied such an approach involving the right classification technique with an effective set of extracted features to identify the diseases [15]. They segmented the images of the fruits in order to identify and segregate the healthy and infected parts on the fruit. With these results, the system was then able to correctly grade the fruits based on the amount of infections found on the fruits. To improve the system's performance various segmentation techniques to identify the region of interest were also investigated and these include histogram matching, region based segmentation, edge detection and fuzzy segmentation.

Automated classification and grading of agricultural products have been extensively implemented using a variety of different classification techniques [16, 17, 18, 19, 20, 21]. Other than agricultural produce, Han Yan *et al.* developed an Adaptive Neuro-Fuzzy Inference System (ANFIS) to classify water quality status of river based on a total of 9 weeks data (845 observations consisting of 3 water quality parameter) collected from 100 monitoring stations in all major river basins in China [22]. They were able to report good classification accuracies with such an approach. Other than water quality identification, B. Ari Kuncoro and Suharjito investigated ANFIS to classify the texture of crumpled aluminum foil, corduroy, cotton and orange peel from the images using a combination of Discrete Cosine and Gray Level Occurrence Matrix (GLCM) methods on the set of extracted features [23]. Other areas where ANFIS was used includes the work by Alireza et al where ANFIS is now used to detect and diagnose breast cancer based on a set of risk factors [24]. In their work, they chose to use ANFIS to see if it can correctly identify breast cancer patients using nothing more than a set of 22 features from the standard data sets and then on real data. They were able to obtain satisfactory results with the ANFIS they developed.

2.1 Auto Grading of EBN

The EBN images were collected from a centralised EBN processing facility with modern and hygienic facilities. This is a more cost-effective way of processing the EBN. The EBN when harvested is sent for processing by the individual EBN farms which are usually managed on a small scale. They would not be able to provide either the facilities or the human personnel to process the raw EBN and grade the EBN efficiently and consistently.

To test the auto grader, we used the EBN of 3 different grades, AA, A and B which had been carefully graded by the trained operators. A total of 63 samples were collected and photographs were taken with a standard Digital SLR camera fitted with a macro-lens.

Table 1 shows a selection of the 4 extracted features for each class of EBN. Notice the different range of values for each feature. Both the size and the estimate of the impurities are in their thousands whereas curvature and colour are less than one.

Classification of the EBN grades has been investigated with several powerful and popular AI techniques, namely the

Adaptive Neuro Fuzzy Inference System (ANFIS), k-Nearest Neighbour (kNN), Naive Bayesian (NB), Support Vector Machines (SVM), as well as Artificial Neural Networks (ANN). Because the values of the extracted features are of different ranges, we need to normalise them to the range [0, 1] to avoid the larger numerical values from any of the features dominating the auto-grading process. Hence we investigated several different data preprocessing methods that converted the raw data into an effective and efficient form before the data were processed. Z-score normalization, decimal scaling, linear normalization, min-max normalization and a non-linear normalization based on the sigmoid function were investigated. The results showed that the classifiers are sensitive to the pre-processing schemes used and they performed better for some of these normalisation schemes. kNN was not able to match the accuracies of the others managing only 61.54%. On the other hand, NB was able to match the accuracy achieved of the more modern SVM classifier. In addition, if we just look at the lowest performance of ANFIS, it still outperforms most of the other classifiers as shown in Table 2.

Table 1: Features extracted for various grades

grade	curvature	size	contiminants	colour
AA	0.3560	5784956	1148060	0.6824
AA	0.7969	2646064	2370178	0.6784
	-	-	-	-
A	0.2403	6333746	133551	0.7608
A	0.4217	5075468	416805	0.7765
	-	-	-	-
B	0.3537	5361693	518880	0.6784
B	0.7216	5084135	4971157	0.6980
	-	-	-	-
	-	-	-	-

Table 2: Maximum and minimum classification accuracies (%)

Classifier	Min	Max
kNN	54.19	61.54
NB	72.09	89.70
ANN	68.32	89.28
SVM	74.97	89.52
ANFIS	81.34	94.09

Finally, the Convolutional Neural Network (CNN) was also tested to auto-grade EBN. The MVGG-19 [25] which is based on the VGG-19 CNN and uses the same number of convolutional layers and max pooling layers was chosen.

The MVGG-19 used here has 19 layers, with 32 input filters in the first layer. However, the MVGG-19 has a smaller number of parameters compared to the VGG-19. The MVGG-19 was integrated with Keras library and TensorFlow backend. Moreover as it is computationally intensive, the NVIDIA GeForce GTX 1070 GPU was used to speed up the computation. Since the EBN dataset images have large dimensions, the computation time is much longer. Hence, the dataset images were scaled down before they can be processed by the CNN model. Squashing was adopted to resize the images. Furthermore, as such computation methods thrive on large data sets, data augmentation in the form of random transformations were applied to the existing EBN dataset such as horizontal/vertical flipping, clockwise and anti-clockwise rotation. Table 3 summarises the best classification accuracy extracted from the various pre- processing schemes.

Table 3: Best Classification accuracies obtained

Classifier	Accuracy
kNN	61.54
NB	89.70
ANN	89.28
SVM	89.67
ANFIS	94.09
MVGG-19	88.89

With 4 features presented to the classifiers, ANFIS performed better than kNN with the kNN able to only achieve 62% whereas ANFIS was able to achieve 94%. Neural nets, SVM and NB were able to achieve about 89%, some 5% less accurate than ANFIS. We have also evaluated a non-feature based approach that does not require any feature extraction as it uses the images. However, as the data set is relatively small, a significant amount of preparatory work needs to be done before the MVGG-19 CNN was able to learn the various grades and then autograde the remaining images not used in the training. The CNN was able to produce an average accuracy of 89% with this non-features approach.

A major advantage of our features-based approach is that it is less time consuming as the system developed here was able to achieve satisfactory results without requiring a huge set of data nor any additional computing hardware. In the future, we would like to extend the work to look at EBNs from a different source where the grading may be different as well as to investigate a better imaging system to further improve the accuracy of the system.

3.0 ARTIFICIAL TEACHERS FOR BREAST CANCER CLASSIFICATION

The field of Artificial Intelligence is particularly compatible with the overall approach adopted by the field of Natural Computation, where researchers aim to solve computational problems by getting inspiration or adapting mechanisms from nature [26]. One of the earliest examples, pioneered by McCulloch and Pitts [27], corresponds to a family of techniques, which form the foundation of the current AI explosion, i.e. deep learning, also known as artificial neural networks, more generally. The process of obtaining inspiration or adapting mechanisms from nature is however, far from complete. In fact, it could be argued that it has barely begun. Other examples of neural network breakthroughs associated with bioinspiration include convolutional neural networks [28], and the usage of attention-based mechanisms [29], all of which have been particularly prominent in targetting CV problems.

When seeking bioinspiration for Artificial Intelligence, it is natural to focus on the biological organism that exhibits the highest level of general intelligence so far, i.e. humans. When we compare arguably the most common learning paradigm in the field of neural networks (i.e. supervised learning with a single dataset) with how teaching/learning occurs in humans, the constraints and limitations of the former become very evident. For example, humans learn a diversity of different fields and skills, in carefully structured stages, with different kinds of assessments, involving

a variety of teachers and teaching methods. In other words, the simplicity of neural network learning paradigms is currently no match for the richness and complexity of the educational approaches and pedagogical techniques practised by humans. Having said this, researchers have gradually been making some progress in this direction. For example, in curriculum learning Bengio *et al.* [30] divide the learning process into several stages of increasing complexity, which partially addresses the approach of learning in "carefully structured stages" mentioned above. Furthermore, and in direct connection with this section, Hinton *et al.* [31] have improved the classification accuracy of a "student" model by employing an additional "teacher" model, which partially addresses the "variety of teachers" limitation mentioned above.

The approach introduced by Hinton *et al.* building upon the work of Rich Caruana and his colleagues [32] is generally referred to as knowledge distillation. The approach hinges on the key insight that crucial knowledge regarding generalization can be transferred (distilled) from a larger teacher model (e.g. an ensemble of many models or a large single model) to a smaller student model, by making the student learn the teacher's full set of output/label probabilities rather than just the single winning output/label. The full vector of output/label probabilities contains rich information not necessarily obtainable by the small model when trained from scratch on the same training set. For example, in the classic digit classification dataset MNIST, if the input pattern is the digit "8", then the probabilities of the output nodes corresponding to "8", "3" and "1", might be 0.6, 0.2, and 0.05 respectively. These relative probabilities contain useful information about digit similarities (i.e. the similarity between 3 and 8 is higher than the similarity between 1 and 8), which in turn is useful for generalization. The information contained in the full vector of probabilities is often called *"dark knowledge"* because it represents the hidden/implicit knowledge learnt by an ensemble, or a large regularized model. If we relate back to the human educational domain, an intuitive but loose analogy would be to equate the traditional approach of directly training on the dataset as *"learning facts"*, and the knowledge distillation approach as additionally learning the attitudes, soft skills, relative emphasis, and indirect implications of the teacher. We can also see that the artificial assistants also need to *"go back to school"* - using the concept of teacher and student to learn the key details to be effective. In this case, the neural networks have to go back to school!

As mentioned in the introduction, breast cancer is the most common cancer affecting women, and is also the main cause of cancer-related deaths in women. In Malaysia, breast cancer is the top cancer amongst the various types of common cancer [33] as shown in Figure 3. In the period between 2012 and 2016 the following were the 10 most common cancers diagnosed in Malaysians: ovary, uterus (cervical), liver, prostate gland, leukaemia, nasopharynx, lymphoma, lung, colorectal, and breast cancer.

In recent work, we have experimented with extensions to the above knowledge distillation ideas and have applied these to the domain of cancerous breast tumour classification in mammograms [34] which serves as another example of the fruitful marriage between CV and AI. In particular, images from the Digital Database for Screening Mammography (DDSM) were used. This is a database to facilitate research into AI techniques for breast cancer screening. The database was built

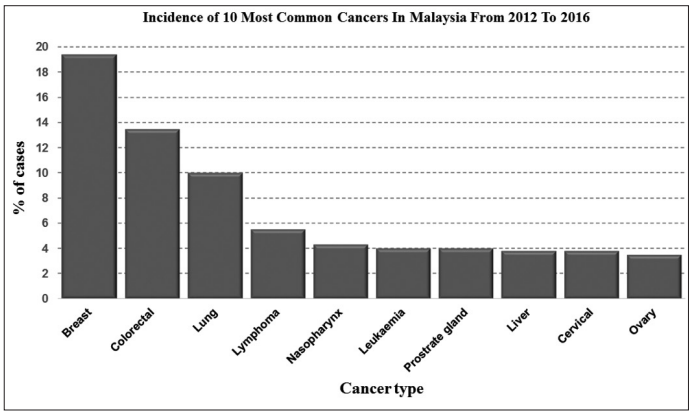

Figure 3: Incidence of 10 Most Common Cancers In Malaysia From 2012 To 2016

from about 2,500 studies, each one consisting of two images of the breast, one from the cranial-caudal (CC) view and the other from the mediolateral-oblique (MLO) view. The images are classified into the following labels: *normal, cancerous, benign or benign without callback.* The images are also accompanied by corresponding pixel wise segmentations of the lesions [35, 36]. To the best of our knowledge there are currently no other research works that explore knowledge distillation questions in the context of the DDSM dataset.

In particular we have sought to extend the knowledge distillation (KD) approach by looking into two key ideas: (1) the introduction of assistants between the teacher and student, and (2) reversing the direction of distillation. The first idea involves distilling from the teacher to one or more intermediate assistants before distilling from the final assistant to the student. This idea was initially proposed by Mirzadeh *et al.* [37], based on the observation that a student's performance deteriorates as the gap between the teacher and the student increases. Motivated by this observation, the authors recommended to place assistant models in between the teacher and student to more effectively transfer the required information. The authors showed that student model performance is positively correlated with the number of assistant models used. Regarding the second idea, distillation traditionally occurs from the more complex (larger) model to the simpler one, so a reversal here implies distilling knowledge from a smaller model and applying this to a larger model. The idea of KD reversal is somewhat related to the idea of curriculum learning [30], except that instead of implementing gradually increasing complexity at the level of datasets, this is implemented at the level of models, whereby the output probabilities of simpler models are used to help the representation learning of larger models.

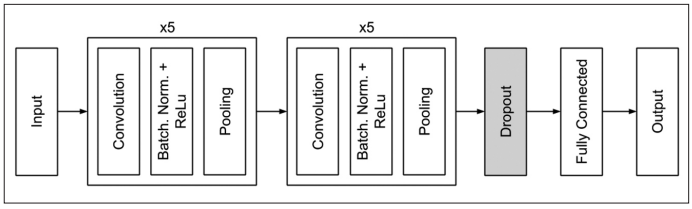

Figure 4: Our baseline model consisted of convolutional, batch normalization, pooling, dropout and fully connected layers

In our main experiment, we set up a series of conditions to test the performance of different numbers of assistants (i.e. 0, 1, or 2), and different distillation directions (i.e. the standard

flow from a more complex teacher to a simpler student, or the reverse). Our baseline model, depicted in Figure 4, consisted of ten 2-dimensional convolutional layers, each with batch normalization, ReLU activation functions and max pooling layers, and one final fully-connected layer.

All of the remaining models consisted of standard residual networks [38], adapted from the standard ResNet models provided by PyTorch in their torchvision package, adopting varying numbers of layers (i.e. 18, 34 and 50), applying dropout, and limiting the number of outputs to 3. For the performance metric reported here, we adopt the area under the curve (AUC) metric, computed relative to the malignant class. The AUC performance values for models trained in the traditional manner (without KD) for the baseline, ResNet18, ResNet34, and ResNet50 models, were 0.7684, 0.8792, 0.8810, and 0.8876 respectively, and can be found in the "Base AUC" column.

Table 4: AUC of class 2 (malignant) against class 0 (normal) and 1 (benign) for models with knowledge distillation

KD Flow	Teacher	Assistant 1	Assistant 2	Student	Base AUC	KD AUC
D→S	ResNet50			Baseline	0.7684	↑ 0.7706
S→D	Baseline			ResNet50	0.8876	↓ 0.8871
D→I→S	ResNet50			ResNet34	0.8810	↑ 0.8818
D→I→S	ResNet50	ResNet34		Baseline	0.7684	↑ 0.7726
S→I→D	Baseline			ResNet34	0.8810	↑ 0.8850
S→I→D	Baseline	ResNet34		ResNet50	0.8876	↑ 0.8893
S→I1→I2→D	Baseline			ResNet18	0.8792	↑ 0.8810
S→I1→I2→D	Baseline	ResNet18		ResNet34	0.8810	↑ 0.8891
S→I1→I2→D	Baseline	ResNet18	ResNet34	ResNet50	0.8876	↑ 0.8902

Legend: D = deep network, S = shallow network, I = intermediate-sized network compared to D and S, I1 = smaller network than I2. The knowledge is distilled from the Teacher to Assistant 1, then to Assistant 2 and lastly to the Student. The "Base AUC" column refers to the baseline performance of student models without KD (in the "Student" column) and is portrayed for the sake of easy comparison with corresponding KD variants. Arrows in the rightmost column denote whether the KD conditions improved the AUC of corresponding non-KD (base) conditions. All cases showed an improvement except for the reverse non-assistant condition (i.e. S→D).

Changing the conventional knowledge distillation method of ResNET50 to a shallower network seems to be able to boost the performance of the student based as shown here in Table 4. The reverse knowledge distillation method (i.e. S→D case) however did not improve the performance of the deeper student model. However, when one assistant was added, both KD flows (i.e. D→I→S and S→I→D) showed an increase in AUC relative to their non-KD conditions. The usefulness of assistants and reverse KD was also observed when two assistants were used, as seen in the S→I1→I2→D condition, which exhibited the best performance across all conditions (i.e. 0.8902 AUC), indicated by bold typeface in the table. Overall these results clearly show the positive effect and potential of combining assistants with reverse KD. Both techniques are motivated by the need to decrease the complexity/knowledge gap between models, and presumably both are effective for the same reason, although a detailed and insightful explanation into the effectiveness of the techniques is an open question for future work.

The techniques discussed here clearly highlight that even within the relatively narrow scope of extending learning paradigms with multiple artificial teachers and teaching flows, the bioinspired approach to AI in general, and AI for Computer Vision in particular, still has a lot to offer.

4.0 IMPROVING EFFECTIVENESS OF ECOMMERCE

In getting an overview on how big ecommerce is we turned to a report by a global business data platform which conducted an extensive study in 2019 focusing on both sales and revenue of ecommerce. They concluded that retail ecommerce sales stands at USD3.53 trillion in 2019 but growth of revenue from e-retail would nearly double that number by 2022[39]. Online shopping would remain as one of the most popular online activities worldwide.

Among those, online clothing shopping has seen immense growth in popularity in recent years. According to Rusell [40], fashion retailers have had a 38% increase in online orders even during the Covid-19 pandemic.

However, the issue with online clothing shopping is the inconsistent sizing across different brands and manufacturers [41]. Various studies have shown that 50% of returns are caused by sizing issues [42, 43]. Furthermore, fit of the garments may vary as body proportions do not conform entirely to standard sizing. A Kurt Salmon Associates study reported that 50% of women have difficulty finding apparel that fits. To make a custom-fit garment, customers would have to manually provide their measurements, which may not be readily available or accurate. Custom-fit garments are also usually costly and inconvenient to purchase due to the need for multiple fittings to achieve the desired fit. This is where the need for virtual tailoring arises.

Deep learning techniques have been widely applied to industries where a large amount of labelled data can be collected/acquired, e.g., in wireless communication [44], industrial robotics [45], smart manufacturing [46], and quality control in printing industry [47], to name a few. However, data labelling process can be tedious, time-consuming, and prone to human errors. This is particularly so in the case of labelling accurate landmark positions on object/subject of interest for a large number of images [48, 49, 50, 51, 52]. It thus poses us a critical question, i.e., is it still possible to address industrial problems where the labelled data sample size is small?

The literature suggests that such problems may be addressed by appropriately transfer-learning from existing Deep Learning models on similar problems and with data augmentation. A recent study on smart buildings has shown that a deep neural network trained with building source data in Beijing has been successfully adopted and re-trained to predict ventilation control for buildings in Shanghai with just 15 days' of data [53]. On the other hand, for data such as images that have much higher dimensionality than that of a smart building, data augmentation has been playing significant role for boosting up small samples [54].

In this section, we report a case study on body landmark detection with an extremely small dataset. Figure 5(a) shows a typical example of the frontal image of a customer and the expected body landmarks, including five landmarks along the shoulders ('Shoulder.A' to 'Shoulder.E'), two landmarks on the right and left side of the chest ('L.Chest' and 'R.Chest), two landmarks on the right upper arm ('Arm.A' and 'Arm.B'), and finally one landmark on the left wrist ('Arm.E'). To the best of our knowledge, there is no public dataset that is similar to the

body landmark dataset shown in Figure 5. As there are currently only 99 sample images with their corresponding landmarks, it is far from being adequate to train any deep neural network from scratch.

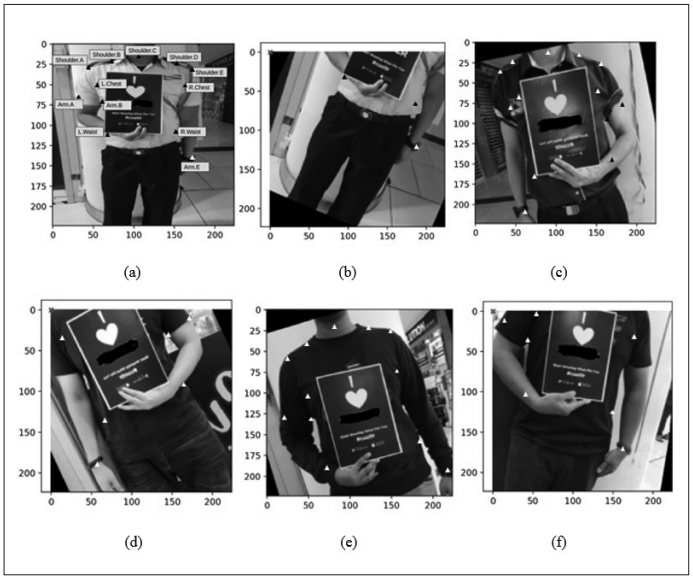

Figure 5: Examples of augmented training images with ground truth body landmarks (triangles). (a) Labels of body landmarks. (b)-(f) augmentations through rotation, translation, cropping, flipping, etc. of different training images and their corresponding ground-truth body landmarks.

However, there do exist public datasets in related domains, e.g., DeepFashion [55], Pose [56, 57], etc. Therefore, by leveraging on the concept of transfer learning, we explore architectural modification to an existing Deep Fashion Net that was trained for fashion landmark detection [58], and re-train the modified deep convolutional neural network for body landmark detection. We divided 99 samples into 79 training samples and 20 validation samples. Due to the extremely small sample size, we applied heavy online augmentation where each sample is augmented 100 times with random rotation, translation, cropping, and left-right, leading to a total sum of 7900 training samples and 2000 validation samples, respectively. Figure 5(b)-(f) show some examples of augmented images and their corresponding landmarks (triangles).

The DeepFashionNet in Figure 6 contains a base network (i.e., VGG16) for extracting image features and classifying clothes to different attributes and categories, a landmark branch for predicting fashion landmarks (see the circles in Figure 8), and an attention unit that focuses the classification on the area of fashion landmarks.

The proposed Fashion-to-Body Attention Network adopts the VGG16 feature extractor, fashion landmark branch, and the attention unit in the DeepFashionNet, but replaces the classification branch with a body landmark branch (see Figure 7). The body landmark branch has identical architecture to the fashion landmark branch, except that the output heatmap has 12 channels corresponding to 12 body landmarks, instead of 8 channels corresponding to 8 fashion landmarks. The loss function is defined as the mean squared error (MSE) between the output heatmap and the ground-truth heatmap.

To train the proposed model, the weights for VGG16 extractor and fashion landmark branch are loaded from the trained DeepFashionNet [59] and are frozen. The weights of the attention unit are initialised with uniform distribution on [0, total number of weights in the network]. The body landmark branch are initialised according to Kaiming He method [60]. The learning rate is set as 0.0001 with decay. The optimisation method is the Adam optimiser [61]. The training would run for 20 epochs in total.

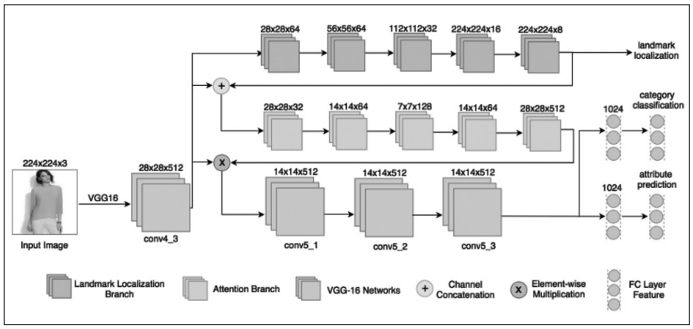

Figure 6: Deep Fashion Analysis [52]. The architecture contains a base network of VGG16, a fashion landmark branch, and an attention unit.

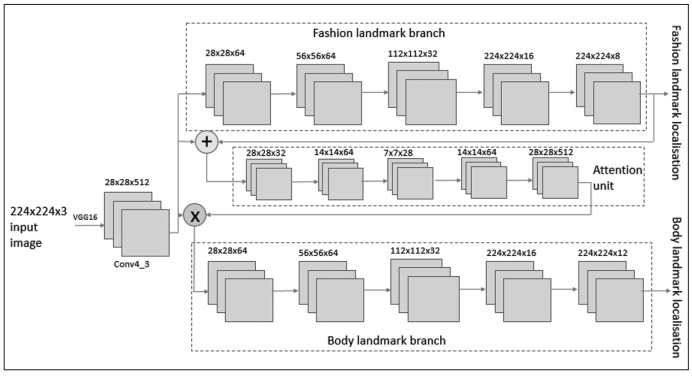

Figure 7: The proposed Fashion-to-Body Attention Network for body landmark detection. It replaces the classification branch in the base network with a body landmark detection branch. The idea is to use fashion landmarks detected by the fashion landmark branch to provide the attention for the body landmarks.

Figure 8 demonstrates the body landmark detection results of several testing images by applying our proposed model. The crosses are the detected landmarks whilst the triangles are the ground truth. In comparison, the fashion landmarks detected by the base network, DeepFashion Net, were also plotted as circles. Notice the semantic difference between the ground-truth body landmarks (i.e., triangles) and the fashion landmarks (i.e., circles). Visually it is clear that the predicted body landmarks (i.e., crosses) are much closer to the ground-truth body landmarks than to the fashion landmarks. Table 5 has shown that the testing error in terms of normalised average landmark distance between the predicted landmarks and the ground-truth, is 0.0284 for the proposed model. It is around 47% lower than that was reported for the Fashion landmarks (0.0534) by [52]. It demonstrates that the proposed model has successfully transferred fashion landmark detection to body landmark detection through the attention mechanism.

Nonetheless, the preliminary experimental results also revealed several drawbacks of the proposed model as well as some intrinsic problems with the dataset. As shown in Table 5, the mean individual body landmark localisation error varies from landmark to landmark. The largest individual landmark localisation error occurs with the landmark 'Arm.E' and

'L.Waist'. There is a large variation of local image features around the area where the landmark 'L.Waist' would be marked in different images, due to the fact that customers were holding an A4 paper with their right hands, sometimes blocking the waist. On the other hand, even if the waist is not blocked, the variation of labelling a waist landmark is still larger than other landmarks. This is reflected as the landmark localisation error for 'R.Waist' is the second largest (see Table 5).

The large mean localisation error for 'Arm.E' over all the testing images is mainly skewed by the large error of the wrongly detected landmark in image e.g., Figure 8(c). In fact, the landmark 'Arm.E' in Figure 8(c) was not detected but instead a

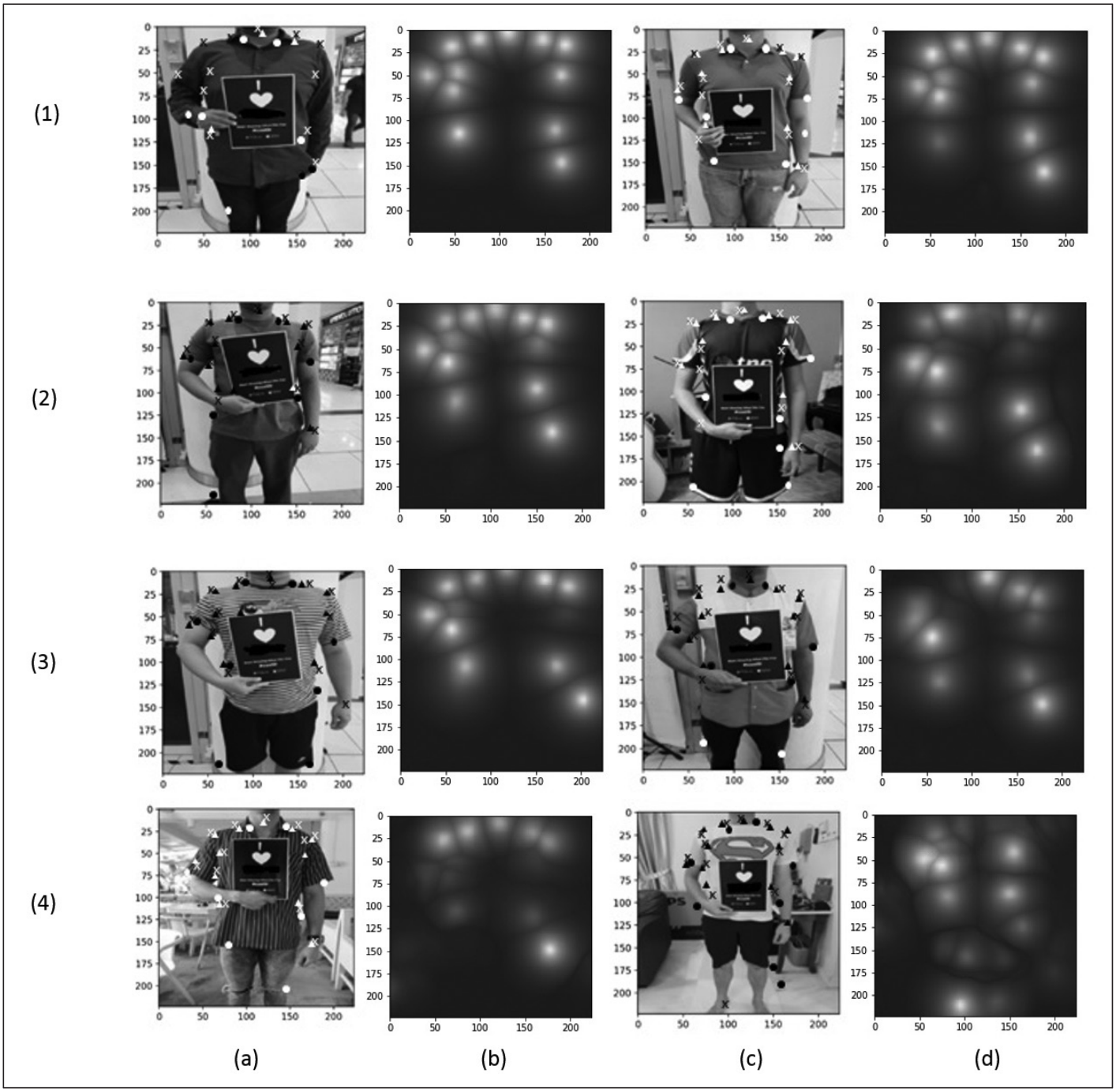

Figure 8: Columns (a) and (c) are frontal images of customers with their respective body landmarks and fashion landmarks. Triangles (∆): ground-truth body landmarks (i.e., manually labelled); Crosses (X): body landmarks detected by the proposed model; Circles (O): fashion landmarks detected by the base network, DeepFashion net. Columns (b) and (d) are the landmark heatmaps for the images in columns (a) and (c), respectively.

Table 5: Mean body landmark localisation errors of testing images

L.Che	R.Che	Sho.A	Sho.B	Sho.C	Sho.D	Sho.E	Arm.A	Arm.B	Arm.E	L.Wai	R.Wai	Average
0.0188	0.0262	0.0221	0.0226	0.0162	0.0246	0.0135	0.0279	0.0122	0.0632	0.0634	0.0302	0.0284

point around the right ankle was detected. A close examination of its corresponding heatmap (Figure 8(d)) shows that there are more than 12 landmark responses. This is possible since the convolutional layers' receptive field is small and therefore local features that excite the relevant neurons will be detected and returned as a candidate landmark. The right ankle has similar local features as that of a wrist and thus had very high response. As the current model does not incorporate any structural constraints on the body landmarks, it returned the largest response in each channel of the output heatmap which contains the right ankle.

Observing carefully the heatmaps in Figure 8, we notice some of the detected landmarks have very weak and/or wide responses and resulted in relatively large visual localisation error compared to the rest of the landmarks, e.g., 'Shoulder.A' and 'Shoulder.B' in image (3)(c), 'R.Chest' in image 8(a). These problems may be attributed to the lack of texture variation around the landmarks in concern, i.e., the foreground looks similar to background. In such cases, it is important for the model to pick up the structural/shape constraints among the landmarks to counter the lack of texture information. This is, however, not the case with the proposed model.

We also observe that when the localisation error of individual landmarks is high, it does not necessarily mean the landmark has large semantic deviation from the ground-truth landmark, particularly in the case of 'L.Waist' and 'R.Waist'. It suggests that it is important to have a different evaluation metric that would better capture such characteristics than the current MSE error for individual landmarks.

The current dataset is small, lacks variations in poses, clothing styles, clothing texture, background, etc., and suffers from high interpersonal variation of manual landmark labelling. These issues should be addressed during the course of further data collection.

5.0 CONCLUSIONS

In this paper we have illustrated what the *marriage* of artificial intelligence which Kurzweil has conveniently compared to just a *"a bag of tools"* with CV can accomplish. The first section introduced how AI working together with CV can revolutionize the multi-billion dollar EBN industry by providing better efficiency and productivity. As the price of EBNs solely depends on the grade it is the current practise in the industry to use trained operators to sort the raw EBNs to the correct grade. While the human visual superior system is much better than the current cameras however, humans even trained ones can become tired easily and even inconsistent occasionally. By combining AI with CV we investigated 6 different AI techniques to autograde EBNs with ANFIS achieving an accuracy of 94.09%. Breast cancer is a major disease around the world and because it does not show any symptoms unless it is too late, early detection through regular screening is necessary for successful treatment. In the second part we showed the results of the use of CV with AI to detect breast cancer using the concept of bioinspired AI help train such an intelligent system in order to help the medical experts. Using two assistants and reverse KD, a maximum performance across all conditions of 0.8902 was obtained. And lastly we illustrated how a combination of AI and CV was used to perform visual fashion understanding which is of huge interest for the industry, motivated primarily by the needs of electronic commerce in clothing retrieval, fashion recommendation, etc. A fundamental driver for this is to identify fashion landmarks which are functional key-points defined on clothes, such as corners of neckline, hemline and cuff. Unlike conventional AI approach on such a technique, our DeepFashionNet was trained only on an extremely small dataset, something is unconventional and challenging to do. With such an approach we were able to achieve mean body landmark localisation errors of the testing images from a low of just 0.0122 (Arm.B) to 0.0634 (L.Wai).

With AI trending at the moment and the spotlight turned on it, many in the industry wants to believe that this is the silver bullet that they have been waiting to solve all their woes. However, those working in the field will tell you that while many of the success stories published are very encouraging, there are certain limitations to AI's ability. However this is not to say that AI does not work but while progress is being made in pushing the boundaries on those which work and those which do not, new(er) applications are being announced almost on a daily basis. In this paper we have combined the "intelligence" of AI with CV to show how it can work on several different problems, as we believe the brain needs to *"work with the eyes"* - just like what humans normally do when we try to interpret what our eyes tell us. Many of the current approaches in using AI requires large amounts of data (EBN grading, breast cancer identification for example) where more is preferred. A major challenge will be the collection of these data as it can be challenging, time consuming and costly to assemble a large amount of data. On the bright side, with the cost of both computing power and sensors coming down it will now be more cost effective for industries to adopt such technologies. Finally we hope that the results from using this combination of AI and CV on three different areas have clearly shown they are a match made in heaven - with the potential to help produce a better world. ■

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PERFORMANCE EVALUATION OF ASPHALT CONCRETE USING WASTE BLISTER PACK AS ADDITIVE

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ABSTRACT

Disposal of non-decaying wastes, including blister packs, has become a significant concern in developed and developing countries. Blister pack waste materials were used as an additive to in this to enhance the performance of asphalt concrete mixes. Four different asphalt concrete combinations were produced using shredded waste blister packs (WBP) at distinct proportions to achieve research goals, including 0.25%, 0.50%, and 0.75% by weight of total aggregate. Afterward, Marshall properties (i.e., density, stability, flow value, air void, voids in mineral aggregate, voids filled with asphalt, and retained stability) were evaluated to check the performance of asphalt concrete and later on to determine the optimum asphalt content. It was investigated that the specimens made with 0.25% and 0.50% (by weight of total aggregate) WBP satisfied all Marshall criteria including significant stability and retained stability value. The percentage of optimum asphalt content was lowest for the mixes with 0.75% WBP content, followed by 0.50%, 0.25% and 0%. Meanwhile, highest stability was found for the mixes with 0.50% WBP content. All the properties at 0.25% and 0.50% WBP content showed better results than the control mix (i.e., 0% WBP).

Keywords: Waste blister pack, Marshall properties, Optimum asphalt content

1.0 INTRODUCTION

Asphalt concrete (AC) is the most widely used paving material around the world. It contains 92 to 95% mineral aggregate and 5 to 8% asphalt binder [1]. Construction of pavements should be done as it is strong and durable for their design life. Asphalt pavement performance is affected by several factors, e.g., the properties of the components (binder, aggregate, and additive) and the proportion of these components in the mix. The performance of asphalt mixtures can be improved with the utilization of various types of additives, these additives include polymers, latex, fibers, and many chemical additives [2; 3]. El-Saikaly (2013) used waste plastic bottles (WPB) as an additive and suggested that WPB can be conveniently used as a modifier for asphalt mixes for sustainable management of plastic waste as well as for the improved performance of asphalt mix. The stability value of this mixture is 24% higher than the conventional mix and shows lower bulk density [4]. Modified asphalt with the addition of processed plastic waste of about (5-10)% by weight of asphalt as a modifier and found that the value of Marshall stability strength, fatigue life, and other desirable properties of the asphalt concrete mix has been improved [5]. Prasad *et. al.* (2013) added (1-9)% plastic waste by the weight of the recycled asphalt in hot mix asphalt concrete, and the mixtures showed better binding property, stability, density, and more resistance to water [6]. By adding the fine size of the shredded plastic waste particle (passing sieve #16 (1.18mm)) to the asphalt mixture increases Marshall stability and index of retained strength by 18% and 12% respectively, as compared with the conventional mix [7]. The use of these technologies not only strengthens the road but also enhances the durability of the road as well as helps to improve the environment and generate revenue.

Various types of waste materials are produced due to industrial growth with a growing population. Blister pack is one of them. The use of blister packs has been increasing day by day. Blister packs are used for packaging products such as toys, hardware, medication, etc. It was reported that in 2016 [8], the world created 242 million tons of plastic waste, 12 percent of all metropolitan solid waste. This waste has begun from three locales, 57 million tons from East Asia and the Pacific, 45 million tons from Europe and Central Asia, and 35 million tons from North America. Another report was mentioned that in 2019 [9], the world's cities created 2.01 billion tons of solid waste, summing to an impression of 0.74 kilograms per individual per day. With quick populace development and urbanization, the yearly waste era is anticipated to extend by 70% from 2016 levels to 3.40 billion tons in 2050. Disposal of the massive sum of waste, particularly non-biodegradable waste has made different sorts of issues and produces a destructive impact on the environment. So, these tremendous sums of plastic waste are destructive for the city. Researchers and analysts, the world over

have put themselves to the assignment to investigate the reusing of waste material to the advantage of the environment as well as the economy. Most critically, the authors endeavoured to see into the possibility of the re-use of solid waste material within the development of streets. According to [10], the best way to get rid of the excessive solid wastes accumulating in urban and industrial areas is to implement the re-use of waste material. Using recycled materials in road pavements is nowadays considered not only as a positive option in terms of sustainability but also, as an attractive option in means of providing enhanced performance in service [11]. It's proven that the addition of certain polymers to asphalt binders can improve the performance of road pavement [12]. The addition of polymers typically exhibits greater resistance to rutting and thermal cracking. Besides, it decreased fatigue damage, stripping, and improved temperature susceptibility. Polyethylene is an extensively used plastic material, and it is one of the most effective polymer additives [10; 3].

It is important to note that most of the previous studies used either plastic bottles or polyethylene as additives considering environmental issues. None of the prior research considered waste blister packs as additives in the asphalt concrete mixes. Considering this, this study focused to explore the performance of waste blister pack (WBP) as additive including optimum percentage in asphalt concrete mixes that will eventually reduce the disposal problems of the blister packs.

2.0 MATERIALS

2.1 Aggregate

Stones are most commonly used in asphalt concrete as aggregate. The different properties of aggregate have a large impact on the stability, flow, and different Marshall properties of asphalt concrete. Locally available aggregate was used in this study. The properties of the used aggregate are shown in Table 1.

Table 1: Physical properties test results of aggregate

Test Name	Test Standard	Result (%)	Standard Value
Los Angeles Abrasion (LAA)	AASHTO T 96	19.12	≤30
Aggregate Impact Value (AIV)	BS 812: Part 112: 1992	19.30	≤25
Aggregate Crushing Value (ACV)	BS 812: Part 110: 1992	22.81	≤30
Elongation Index (EI)	BS 812: Section 105.2: 1990	22.42	≤30
Flakiness Index (FI)	BS 812: Section 105.1: 1990	22.50	≤30
Specific Gravity (Coarse Aggregate, Fine Aggregate)	AASHTO T 85	2.65, 2.74	-

2.1.1 Gradation of Dense Graded Aggregate

Aggregates of various sizes are used in asphalt concrete. The particle size distribution of aggregate is termed gradation. The sieve analysis is conducted to determine the particle size distribution. In this study, and aggregates were screened by AASHTO T27 specified sieve ¾ inch to # 200. The combined gradation of aggregate and filler is shown in Table 2.

Table 2: Selected combined gradation of aggregate and filler

Coarse Aggregate (C. A) = 52%, Fine. Aggregate (F. A) = 42% & Mineral Filler (M. F) = 6%				
Sieve Size	**% Passing**	**Specified limit (AASHTO T27)**	**Cumulative % Retained**	**% Used**
3/4"	100	100	0	0
1/2"	97.4	90-100	2.6	2.6
3/8"	80.76	76-90	19.24	16.64
#4	61.52	44-74	38.48	19.24
#8	47.14	28-58	52.86	14.38
#40	33.30	8-27	66.70	13.84
#80	16.92	5-17	83.08	16.38
#200	06	5-8	94	10.92
#200 (Retained)			100	6
			Total	100

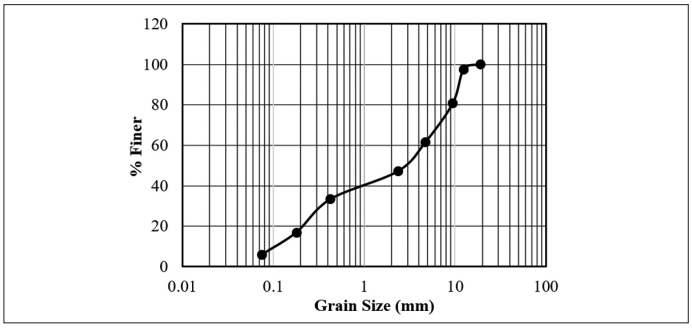

Figure 1: Grain Size Distribution Curve

2.2 Mineral Filler (M. F)

The fillers are sieved through No. 200 sieve. It offers permeability, stiffens the binder, and fills the voids in aggregates. In this research work, dust is used as filler whose specific gravity was 2.57.

2.3 Asphalt

Asphalt is used in the aggregate as binding materials and it also acts as a filler and stabilizer in asphalt mixture. It offers impermeability and particle adhesion cause asphalt fills the void. The properties of used asphalt are shown in Table 3.

Table 3: Physical properties test results of asphalt binder

Test Name	Test Standard	Test Value	Standard Value
Penetration grade	ASTM D 5-86	66	60-70
Softening Point	ASTM D 36-70	51ºC	30ºC to 80ºC
SG	ASTM D 70-76	1.02	0.97 to 1.02
Ductility	ASTM D 113-86	100+	100+
Flash point	ASTM D 92-90	308ºC	Minimum 175ºC
Fire point	ASTM D 92-90	337ºC	Minimum 200ºC

2.4 Waste Blister Pack

Waste Blister packs (WBP) were collected from locally available sources including hospital and pharmacy. It is one kind of Polyvinyl Chloride (PVC) plastic [13] and most PVC sheets for pharmaceutical blisters are 250µ or 0.25 mm in thickness [14]. The specific gravity of WBP used in this study was 1.25 and melting temperature of WBP with asphalt was 150°C. First, the collected WBP cleaned by water then dried in sunlight. Next, the cleaned WBP was cut into small pieces, i.e., approximately 10 mm length and 1 mm width sizes. The photo views of WBP before and after shredded have been shown in Figure 2. Three different percentages of WBP 0.25%, 0.50%, and o.75% (by weight of total aggregate) were selected for this study.

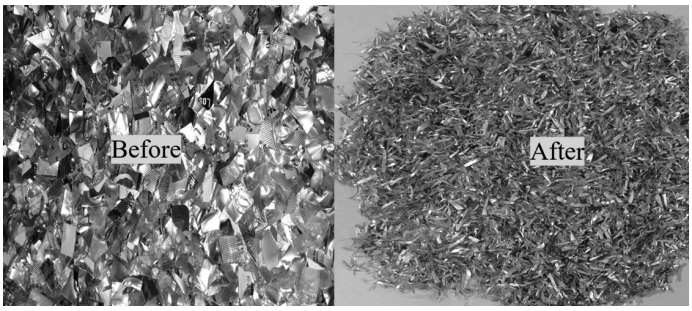

Figure 2: Waste Blister Pack (Before and After)

3.0 EXPERIMENTAL WORK

3.1 Preparation of Marshall Specimen

The samples for bituminous concrete mixtures were prepared as per ASTM D1559 at different asphalt contents. As a first step in the procedure, the aggregates with the proper graduation were thoroughly dried and heated. A sufficient mixture was generally prepared at each asphalt content. Each specimen has been required approximately 1.2 kg of mixture. Then the asphalt with WBP and the aggregates were heated separately and then mixed. Next, the mixture was placed in the mold, mixed by hand with a trowel, and compacted. After compacting the mould was placed in air to cool for 30 minutes and removing the specimen from the mould after a predefined time. After removing the sample, the required dimensions were taken and then submerged into the water bath at 60ºC for 35 minutes.

3.2 Marshall Stability, Flow and Marshall Quotient

After finishing the required time in a water bath, the sample was placed in a Marshall stability tester machine to determine stability, flow value, and the Marshall quotient (MQ). All samples were tested under the Marshall stability tester machine.

4.0 RESULTS AND DISCUSSION

This research evaluated the performance of asphalt concrete mixtures with different percentages of WBP. After completing the stability and flow tests the Marshall properties of asphalt concrete mixture specimens have been explored to achieve research goals. Then evaluated the optimum asphalt content (OAC) for each WBP content. The results that were obtained were presented in detail in the subsequent section through Figure 3.

4.1 Density Void Analysis

Figure 3(a) shows the Marshall Stability curves of different percentages of waste blister pack (WBP). Stability is the maximum load required to produce a failure of the specimen when the load is applied at a constant rate. Stability values increase with the asphalt content increase till it reaches the peak and then it started to decline gradually with higher asphalt content. But at 5% asphalt content, all specimens show better stability. It was also observed that the stability of the modified asphalt mixture increases as the WBP content increases up to 0.50%, but it started to decline at higher WBP (0.75%). A similar study conducted by Awaeed et al. (2015) reported that using (2-10%) waste plastic bottles (WPB) by weight of the optimum asphalt percent (5.0%) as a modifier to enhance the properties of asphalt mixtures. The authors found that all the values of stability for different modified asphalt percentages were higher than the stability of conventional mixture value (10.318 KN), while the maximum stability value was found nearly (14.489 kN) at 8% WPB content [15]. Figure 3(b) shows the relationship between flow value and asphalt content with different percentages of WBP. The flow of the modified asphalt mixture was lower than the conventional asphalt mixture value and the flow decreased continuously when increasing WBP content.

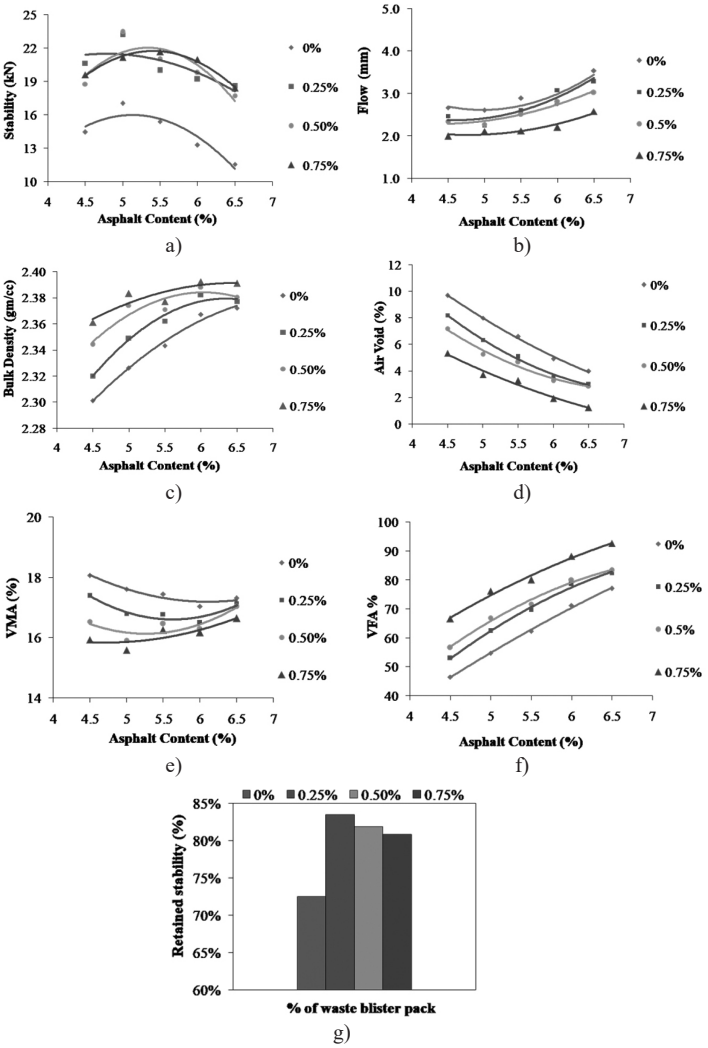

Figure 3: Marshall Properties Curves (i.e (a) Stability, b) Flow, c) Bulk Density, d) Air void (%), e) VMA%, f) VFA%, and g) Retained Stability Curves

Figure 3(c) shows the relationship between bulk density and asphalt content for different percentages of the WBP. Bulk density increased with the increasing of asphalt content for all types of specimens. The bulk densities of all specimens using waste blister pack modified asphalt mixture were higher than the conventional asphalt mixture value. The maximum bulk density was (2.39 gm/cc) at waste blister pack content (0.75%). This is due to the fact that the addition of high concentrations of waste blister packs into the mixtures. Figure 3(d) shows that the air void (%) of Marshall Specimen at different asphalt content for the different percentages of the WBP. The air void (%) has been decreased with increasing asphalt content for all cases. The air void proportion of the modified asphalt mixture was lower than the conventional asphalt mixture. The air void (%) of the modified asphalt mixture decreased gradually as the waste blister pack content increased up to highest content (i.e. 0.75%).

In general, as shown in Figure 3(e), the voids in mineral aggregate (VMA) % percentage of the modified asphalt concrete mixtures was lower than the conventional asphalt concrete mixture, the (VMA) decreases continuously as the WBP modifier content increases. Besides, It is seen from Figure 3(e) that the VMA values of all specimens decrease as the asphalt content increases to 5.0%, and then it started to go gradually up to higher asphalt content. When the binder is applied in a mixture, the aggregate first absorbs the binder, then the binder fills the void of the mixture. As a result, the VMA value has been decreased initially and then increased because the void space available includes air voids and the effective asphalt content not absorbed into the aggregate. Figure 3(f) shows that the voids filled with asphalt (%) of Marshall specimen at different asphalt content for the different percentages of the waste blister pack. The VFA value increased with increasing the asphalt content for all mixtures. Besides, the VFA percentage of the modified asphalt concrete mixtures was higher than the conventional asphalt concrete mixture. Figure 3(g) shows the percentage of retained stability for different percentages of WBP. The values of retained stability have been increased by adding of waste blister pack used as an additive. All the retained stability values of Marshall mixes with different percentages of a blister pack are greater than the conventional mix. The graph shows that maximum retained stability was found when 0.25% WBP was added with the conventional mix. Maximum retained stability value for the conventional/control mix was found 73% and for modified mixes with 0.25%, 0.5% and 0.75% of WBP were found 83%, 82%, and 81% respectively.

4.2 Optimum Test Results

The summary of optimum test results is summarized in Table 4. It is evident from Table 4 that the use of waste blister packs gives better results as compared to the control mix. Also, a higher percentage of WBP content shows lower values of flow value, OAC, air void %, VMA, and higher values of stability, density, VFA, and retained stability. It is also seen that all the values are within the specified limit in exception of 2 or 3 cases. Besides, the Marshall quotient values are within the limit. The permanent deformation, shear stresses, and rutting characteristics of asphalt concrete can be measured by MQ value, and the high MQ values indicate a high stiffness mix and resistance to creep deformation [16].

It is also observed from Table 4 that when increasing WBP, the OAC values had been decreased. It was explained that an increased amount of WBP content in the mixture fills the voids in the aggregate. Besides, it acts as a binder, as a result, lower space is available for asphalt. This, subsequently, decreases the voids in the mineral aggregate and air void (%). Marshall stability also increases up to maximum then decreases. This is because at lower WBP content, it contains higher voids. So, when increasing WBP fills the voids, it may make dense-graded mixtures as a result, higher the stability. As can be seen from the table that the values of VFA for samples have been increased when increasing WBP content. This is because with increasing WBP more voids are filled with waste. From the table, it is also seen when increasing WBP contents increase the density. That is why increasing this reduces the void as a result of increased density.

Table 4: Results summary concerning optimum asphalt content

Properties	Waste Blister Pack (WBP)				
	0	0.25%	0.50%	0.75%	Standard Values AASHTO T 27
OAC (%)	6.03	5.93	5.80	5.63	-
Stability (kN)	13.68	20.5	22	21.5	5.34 kN (minimum)
Flow (mm)	3.0	2.8	2.6	2.2	2-4
MQ (kN/mm)	4.56	7.32	8.46	9.77	2-5
Density (gm/cc)	2.36	2.376	2.38	2.384	-
Air Void (%)	4.8	4	3.8	2.8	3-5
VMA (%)	17.2	16.6	16.2	16	-
VFA (%)	70	76	78	82	65-78
RS (%)	73	83	82	81	70% (minimum)

However, it's far seen that all the mixes satisfy the minimal retained stability value requirement, i.e., 70%. It indicates that each one mix with these fillers has excellent moisture resistance caused damages.

5.0 CONCLUSIONS

Through this experimental investigation, an effort has been made to improve the state of knowledge on the effects of WBP as an additive material in the asphalt concrete mixes. So, Marshall properties of AC containing WBP as additive has been evaluated and compared with the standard specification. In this regard, the physical properties of the raw materials (i.e., aggregate, asphalt and additive) were ascertained. After that, prepared Marshall specimens containing WBP were evaluated for several Marshall properties, including stability, density, air void (%), flow value, VMA (%), and VFA (%) for different WBP contents (0, 0.25, 0.50, and 0.75%).

In this study, asphalt concrete mixes containing 0% WBP were considered as control mixtures. Evidently, the specimens made without WBP satisfied all Marshall criteria (Table 4). But, 0.25 and 0.50% WBP containing AC mixtures show better results than the control mixture. However, 0.50% WBP

containing specimen showed highest stability (22 kN) and the value is 60.81% more than the control specimen stability value. The OAC (%) decreased while increasing additive content and 0.75% WBP containing specimen showed the lowest value (5.63%). Also, 0.75% WBP containing specimen satisfied all Marshall criteria in exception of air void (%) and VFA (%). The results of 0.25% and 0.50% containing WBP specimens are near to each other. Therefore, mixes containing 0.25% and 0.50% WBP additive content may be effectively used in AC to enhance the properties of mixtures.

It can be concluded that by using WBP in asphalt concrete mixture gives a better result than conventional mix. Moreover, the plastic is made of good bonding with aggregate and asphalt. It is expected that this study gives information to the professional's engineers and academicians for using WBP as an additive in asphalt concrete. Using WBP in asphalt concrete mixture not only improves the properties of asphalt concrete but also solve the solid waste disposal problem in the environment. Further experimental investigation on properties including resilient modulus, rutting, fatigue test should be carried out before using WBP as an additive material on the pavement.

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SIMULATION AND OPTIMISATION OF A SWRO SYSTEM IN CAPE TOWN, SOUTH AFRICA

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ABSTRACT

A SWRO system was designed to fulfil 50% of the population water demand in Cape Town, South Africa, which can lead up to 383,353 m^3/day in the next 15 years. The total dissolved solid (TDS) within the product (i.e. drinking water) must be lowered than 600 ppm by referring to standard guideline stated by the World Health Organization (WHO). The design flowrate was set at 766,704 m^3/day and the parameters such as feed, permeate, concentrate flowrate, number of vessels, number of membrane elements, number of stages, seawater chemical composition, temperature, pressure, and system configuration were considered in this study. Reverse Osmosis System Analysis (ROSA) 2017 software was used to determine how different parameters affect one another in the SWRO system. The TDS product concentration obtained from ROSA pre-optimisation simulation results was 74 ppm, which was too low compared to the standard set. Therefore, a ROSA post-optimisation was done to increase TDS value to 181 ppm, which was closer to the standard. The efficiency of the SWRO system recovery rate was 76% and specific energy consumption (SEC) was 6.18 kWh/m^3, greater than the previous value of 50% and lower than 9.7 kWh/m^3 in terms of recovery percentage and SEC respectively. The a lower amount of feed and energy resulting in major savings in terms of operating cost for the SWRO system.

Keywords: Seawater reverse osmosis (SWRO) system, Reverse Osmosis System Analysis (ROSA), Optimisation, Energy consumption

1.0 INTRODUCTION

2.1 billion people (i.e. 29% of the population) does not have the privilege to access safe drinking water that are free from contamination [1]. Without clean water, diseases will be likely to linger, illness and death caused by cholera, polio, typhoid, and others are inevitable. The chaos caused by unclean water will not only stop at diseases, but development of agriculture will also be on a standstill and economy of the country will eventually plummet in the long run.

With the effect of climate change not in favour, water will be more valuable than ever in the next decade. And from there many scientist and engineers have been trying to figure out ways to deal with water scarcity. Over the years, technologies to fight water crisis or to obtain clean water have been invented. Some of them are solar powered water filtration, fog catchers, the life straw, etc. These technologies are extremely innovative and have helped many people around the world. However, they have limitations such as low water production, expensive, unreliable, and unfriendly to the environment.

Cape Town, which is located at the Southwestern most part of South Africa has experienced many water shortages before with an average of at least once per year. Between 2015 and 2018, the town was hit by the worst water crisis the nation has ever faced. During the early 2018, its dam was below 25% of its capacity due to less rainfall at the end of 2017 and 2018 [2]. With 4 million residents relying on water to survive and the approaching of 'Day Zero', the government had issued a statement where each person has only a limited amount of water that can be use per day [2]. Consumers have to reduce their household water usage from 540 L to 280 L per day for more than 36 months [3]. The water crisis was then eliminated not due to the efforts of people from Cape Town or the government, but because of heavy rainfall in the next few weeks. The water level of the dams had risen and 'Day Zero' was delayed until an indefinite time. However, many people speculate that if heavy rainfall did not happen the worst is yet to come. Incidents like this may happened again with a few very persuasive reasons, climate change, every increase of population in the area and limited fresh water supply. Hence the idea of desalination plant may help the community from ever going into another water crisis again.

Desalination is the process of removing minerals from a volume of water. The objective is to turn highly salt contaminated water into a safe useable water. It can be achieved using the membrane filter based desalination (e.g. nanofiltration, electrodialysis) and non-membrane based filters (e.g. multistage flash, multieffect distillation) [4]. Nanofiltration was one of the methods to desalinate seawater into drinking water. However, even with today's technologies nanofiltration has a few

limitations of which it usually desalinates 5000 ppm of saline water under 9 bars with an excellent salt rejection rate of 95%. However, as the salt content in the water increases to 25000 ppm, it is close to impossible to turn it into drinkable water as the rejection rate is only 41% at the same pressure [5]. According to the World Health Organization TDS guidelines level for a good palatable drinking water is around 600 ppm (mg/L), hence nanofiltration could not serve the purpose of desalinating seawater into drinkable water. Since False Bay has a saline range of 34% to 35%, nanofiltration is not being considered as the main filtration system due to the fact that the cost and effort to achieve drinkable water from high salinity of water is unrealistic. Another way to turn sea water into drinkable water is through filtration via reverse osmosis. The objective of this study is to simulate and optimise the reverse osmosis membrane filter system and model using the Reverse Osmosis System Analysis Software (ROSA) that further improved using Excel software to assess how the parameters changes affect one another.

2.0 METHODOLOGY

2.1 Selection of Saline Water Source

Cape Town of South Africa is close to many water sources within a 50 km radius, such as the Berg River, Palmiet River, mountain dams, ground water, reservoir, etc. False Bay has been chosen as the location for desalination to be taken place because part of Cape Town of South Africa lies beside False Bay, which is partially in contact with the southern part of the Atlantic Ocean and the Indian Ocean. Salinity of False Bay lies between 34 % (34 ppt) and 35% (35 ppt) [6] which is around the average of an ocean salinity. The contamination ranges from short term nutrients enrichment, organic matter and microbial contamination to long term heavy metal (i.e. cadmium, lead and zinc) contamination. Heavy metal contamination is mainly caused by sewage effluent, agricultural, commercial, urban development and marine transportation such as fishing boats and yacht [7]. Estimated seawater characteristics and chemical composition of False Bay are shown in Table 1.

Table 1: Seawater Characteristics and Chemical Composition

Parameters	Values	References
Depth of Seawater	40 m to 120 m	[7]
Average temperature	17 °C	[6]
Salinity	3.45 % (34.5 ppt)	[6]
Chemical Oxygen Demand (COD)	1410 mg/L	[6]
pH	8.9	[6]
Fats and oils	17 mg/L	[6]
Suspended solids	6 mg/L	[6]
Glycerol	0.14%	[6]
Nitrogen	25 mg/L	[6]
Nickel	0.24 mg/L	[6]
Chloride	19545.24 mg/L	[8]
Sodium	10892.58 mg/L	[8]
Magnesium	1303.56 mg/L	[8]
Sulphate	2779.70 mg/L	[8]
Calcium	417.79 mg/L	[8]
Potassium	403.21 mg/L	[8]
Carbon (inorganic)	28.15 mg/L	[8]
Bromide	67.63 mg/L	[8]
Boron	4.49 mg/L	[8]
Strontium	0.09 mg/L	[8]
Fluoride	1.33 mg/L	[8]
Barium	0.005 mg/L	[9]
Phosphorus	52.02 mg/L	[10]
Nitrate	1.53 mg/L	[11]

2.2 Water Demand

The basis of water demand for Cape Town of South Africa used in this study was targeted for 50% population excluding agricultural, commercial, and industrial usage. Referring to the Standard Country Report 2017 [12], the water consumption per person per day are shown in Table 2, where estimated 130 L of water needed per day for each person.

Table 2: Estimated Water Consumption Rate per Person per Day from year 2013 – 2017 extracted from Standard Country Report: 26 utilities in South Africa, 2017 [12]

Year	Water Consumption per Person per Day (L)
2013	112
2014	112
2015	176
2016	136
2017	114
Average	130

For 4.7 milliion people, desalination plant estimated product output as per 2021:

Total Water Consumption (litres) = 611,000 m^3 per day
Estimated Desalination Plant Capacity: 50% of Cape Town Population = 305,500 m^3 per day
12,730 m^3 per hour or 3.5 m^3 per second
Estimated population of Cape Town in 2035: 5,900,000
Total Water Consumption (litres): 130 x 5,900,000 = 766,705,000 litres per day
Total Water Consumption (m^3) = 766,705 m^3 per day
Estimated Desalination Plant Capacity: 50% of Cape Town Population
766,705 m^3 x 0.5 = 383,352 m^3 per day
15,973 m^3 per hour or 4.43 m^3 per second

2.3 Coagulations and Flocculation

Due to high turbidity of water around the False Bay water are high in turbidity with brown discoloration and milky white green appearance. It was due to the present of diatom *Anaulus australis*. The surf zone blooms present due to high concentration of nutrients presence in nearby rivers which passes through agricultural sectors [13]. As for the milky white-green appearance in some bodies of water, it is studied that plankton community composition were presence in these body of waters causing a rise in turbidity [13]. Further to this, the body of water were warmer, less saline and contains unusual amount of nitrate, silicate, chlorophyll α and calcium [13]. Hence process of coagulation and flocculation were used to remove these suspended solids hidden in the seawater feed.

Coagulant and flocculants water treatment chemicals were added into the stream to remove iron, suspended solids and hardness of water through the effect of bridging mechanism:

dispersion, adsorption, compression and collision [14]. After the effect of bridging mechanism takes place, suspended solid will join together in the form of a bigger solid and sediment at the bottom of the sediment tank. A pump was designed to transfer the solids/sludge for further treatment. Figure 1 shows the overall flow of the first pre-treatment process.

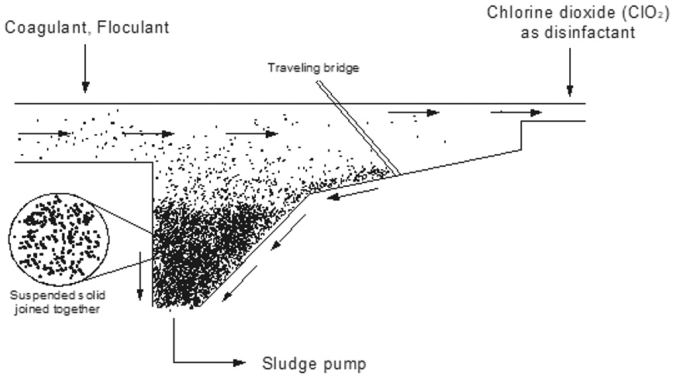

Figure 1: Illustration of Settling Tank process

Water inlet flow: 800,000 m^3 / day
Detention time: 1.5 hours
Estimate tank holds 80% of water inlet flow at any given time
Tank capacity = 40,000 m^3

2.4 Reverse Osmosis System Design Simulation

Recovery ratio of seawater desalination has an average value of 50% or 0.5, hence this value was used to balance energy consumption concerns and avoid accelerated membrane fouling. Based on the recovery ratio, many parameters such as flow of feed water, brine and concentration of brine were calculated. The feed water flow, concentrated water flow, permeate water flow, percent rejection and concentrate water concentration are show in equations (1) to (4).

$$Q_f = \frac{Q_p}{RR} \tag{1}$$

Where Q_f is feed water flow (m^3/day), Q_p is permeate water flow (m^3/day), *RR* is recover ratio.

$$Q_c = \frac{Q_f}{1-RR} \tag{2}$$

Where Q_c is concentrate water flow (m^3/day).

$$Q_p = Q_f - Q_c \tag{3}$$

$$PR = \left[1 - \left(\frac{TDS_p}{TDS_f}\right)\right] x\ 100\% \tag{4}$$

Where *PR* is percentage rejection, %, TDS_p is product total dissolved solids and TDS_f is feed total dissolved solids.

$$C_c = C_c\left(\frac{1}{RR}\right) \tag{5}$$

Where C_c is concentrate water concentration, mg/L and C_f is feed water concentration, mg/L.

2.5 Osmotic Pressure

The osmotic pressure of the feed, π was determined by measuring the concentration of total dissolved salts in the feed solution. The osmotic pressure of feed was obtained from the following equation while obeys a law that resembles the ideal gas equation:

$$\pi = \frac{nRT}{V} = RT\sum X_i \tag{6}$$

Where, π is the osmotic pressure (kpa), R is the universal gas constant, 8.314 kPa m^3/kg mol K, T is temperature (K), $\sum X_i$ is the concentration of all constituents (Table 4) in a solution (kmol/m^3).

2.6 Specific Energy Consumption (SEC)

Recovery ratio of seawater desalination has an average value of 50% or 0.5 based on Seawater desalination power consumption data 2011. It was used a reference for RO energy system configuration. Qiu and Davies (2012) developed different specific energy consumption equations for different configuration. RO system configuration are shown in equations (7) to (11). [15]

Single stage without energy recovery

$$P_{osm}\frac{1}{r(1-r)} \tag{7}$$

Single stage with energy recovery

$$P_{osm}\frac{1}{(1-r)} \tag{8}$$

Two stage without energy recovery

$$\frac{P_{osm}}{r}\left[\frac{2}{\sqrt[2]{(1-r)}} - (2-1)\right] \tag{9}$$

Single stage with energy recovery

$$\frac{P_{osm}}{r}\left[\frac{2}{\sqrt[2]{(1-r)}} - (2)\right] \tag{10}$$

BO batch-RO

$$\frac{P_{osm}}{r}\left[ln\frac{1}{1-r}\right] \tag{11}$$

Where, P_{osm} is π obtained from equation (6)
n is the number of stages.
r is the recovery ratio which is equivalent to 0.5.

2.7 Membrane Specifications

SEAMAXX was selected because it resembles closely to polyethylenimine (FilmTecTM SeamaxxTM-440 Element). Number of membrane elements of SEAMAXX membrane and number of vessels required were determined using equations (12) and (13).

$$Ne = \frac{Qp}{Qe} \tag{12}$$

Where *Ne* is number of membrane elements, *Qp* is permeate flow and *Qe* is membrane element flow capacity.

A typical number of membrane elements per vessel is set at 6. Number of vessels needed for desalination process:

$$Nv = \frac{Ne}{6} \tag{13}$$

Where *Nv* is number of vessels and *Ne* is number of elements.

2.8 Selection for Number of Stages

In reverse osmosis, the number of stages was defined as how

many pressure vessels the seawater feed passed through until it exists as a concentrate. For each stage, the elements were arranged in parallel. From the number of stages specification sheet provided by (Dupoint, 2020), the 8 number of serial element and 2 number of stages were selected.

The relation of the number of pressure vessels in the subsequent stages was determined as staging ratio. The staging ratio, R of a system was calculated using the equation (14):

$$R = \left[\frac{1}{(1-r)}\right]^{\frac{1}{n}} \quad (14)$$

Number of pressure vessels in the first stage, *Nv*(1) and second stage, *Nv*(2) was calculated in terms of staging ratio) using equations (15) and (16):

$$Nv(1) = \frac{Nv}{1+R^{-1}} \quad (15)$$

$$Nv(2) = \frac{Nv(1)}{R} \quad (16)$$

2.9 Charge Balance for Seawater Feed

Charge balance was to make sure the validity of the amount of chemical substance in the feed water. An overall charge balance was performed by converting the unit mg/L to meq/L (milliequivalent per litre). Milliequivalent is define as the chemical activity or combining power of an element relative to the activity of 1.0 mg of hydrogen. Molar mass of the chemical entity was multiplied by the number of free electron charges it has, regardless of whether it is positive or negative were determined using equation (17):

$$M_m \text{ x } \frac{number\ of\ valance\ charge}{mol} = \frac{mg}{meq} \quad (17)$$

$$\frac{mg}{L} \div \frac{mg}{meq} = \frac{meq}{L}\ (milliequivalent\ per\ litre)$$

Where M_m is molar mass, $\frac{g}{mol}$.

3.0 RESULTS AND DISCUSSION

3.1 Simulation Results

The estimated values and simulated results were compared in this study (Table 3). It was found that optimisation change the feed flow rate and made the energy requirement of 9.7 kWh/m^3 lowered compared to the pre-optimized value of 14.14 kWh/m^3 and lower recovery ratio of the overall system. The duty of the pump decreased as a result of lower energy usage. The feed, reject and product flow rate for both manual calculations and ROSA calculations are slightly different because optimisation has been done to increase the recovery ratio and lower down the pressure requirement of the process. This results in a greater RO system efficiency hence a change in flowrate. The product total dissolve solid (TDS) are significantly different. 600 mg/L is a WHO safe drinkable water guideline hence the value was estimated as a benchmark. However, the results on the ROSA software exceeds the expectation of a high purity water with a value of only 73.76 mg/L. Therefore, further optimisation was carried out to increase the product TDS value so that it is close to benchmark standard while at the same time able to lower the energy requirement to achieve a more economical RO system using Excel software. While the TDS of the product is lowered, naturally, TDS of the reject will increase. The specific energy consumption from ROSA software is lower (9.7 kWh/m^3) than the calculated value which is 14.14 kWh/m^3, due to lower recovery rate and optimization. However, the value could be lowered if there is an implementation of ERD [16].

Table 3: Comparison of results between estimated value and ROSA simulation

Properties	Estimated value	ROSA simulation	Percentage difference (%)
Feed flow rate (m^3/day)	766,704	786,705	2.61
Product flow rate (m^3/day)	383,353	378,010	1.39
Reject flow rate (m^3/day)	383,353	408,695	6.61
Recovery ratio (%)	50	48.05	3.90
Product TDS (mg/L)	600	73.76	87.00
Reject TDS (mg/L)	71,091	68,258	4.00
Specific energy consumption (kWh/m^3)	14.14	9.7	31.4
Number of elements required	5,961	6,144	3.07
Number of vessels in 1st stage	583	512	12.18
Number of vessels in 2nd stage	413	512	23.97
Operating pressure (bar)	69	80	15.94
pH value	7	5.37	23.29

Figure 2 shows the feed flow data section of the ROSA software and the seawater quality of False Bay. It includes chemical composition, temperature, pH value. It was found that the TDS value around 35,000 mg/L. The seawater charge was balanced out between the cations and anions.

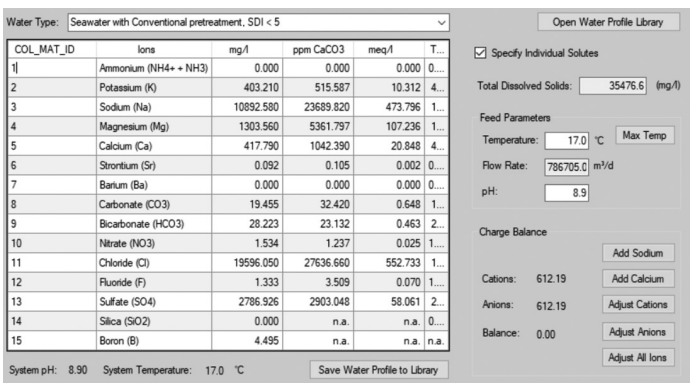

Figure 2: ROSA simulation water feed section

Stages and temperature was set as 2 and 17 °C, respectively for the vessels and element was set to the calculated number (Figures 3a and 3b). The RO process details, chemical compositions, stages and scaling reports are shown in Figures 4 and 5.

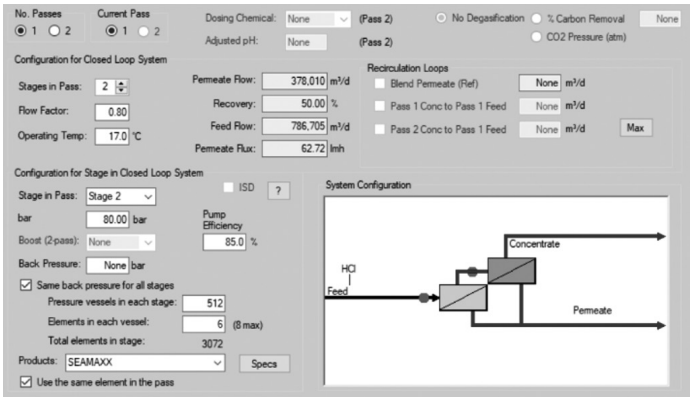

Figure 3 (a): System configuration section

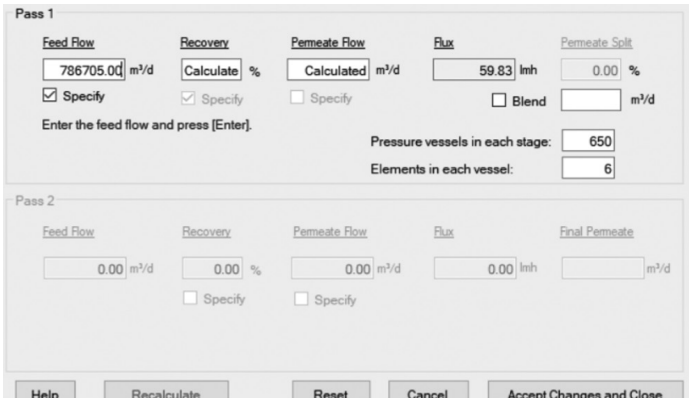

Figure 3 (b): Flow calculation matrix of ROSA software

Reverse Osmosis System Analysis for FILMTEC™ Membranes — ROSA ROSA_Desalitech ConfigDB u399339_356
Project: Lu Hock Chee Advance Design — Case: 1
Lu Hock Chee, — 18/1/2021

Project Information:

Case-specific:

System Details

Feed Flow to Stage 1	786705.00 m³/d	Pass 1 Permeate Flow	378009.75 m³/d	Osmotic Pressure:	
Raw Water Flow to System	786705.00 m³/d	Pass 1 Recovery	48.05 %	Feed	24.34 bar
Feed Pressure	80.00 bar	Feed Temperature	17.0 C	Concentrate	48.29 bar
Flow Factor	0.80	Feed TDS	35493.41 mg/l	Average	36.31 bar
Chem. Dose (100% HCl)	14.01 mg/l	Number of Elements	6144	Average NDP	62.54 bar
Total Active Area	251142.14 M²	Average Pass 1 Flux	62.72 lmh	Power	152827.27 kW
Water Classification: Seawater with Conventional pretreatment, SDI < 5				Specific Energy	9.70 kWh/m³

Stage	Element	#PV	#Ele	Feed Flow (m³/d)	Feed Press (bar)	Recirc Flow (m³/d)	Conc Flow (m³/d)	Conc Press (bar)	Perm Flow (m³/d)	Avg Flux (lmh)	Perm Press (bar)	Boost Press (bar)	Perm TDS (mg/l)
1	SEAMAXX	512	6	786705.00	79.66	0.00	615992.37	54.29	170712.63	56.65	0.00	80.00	61.19
2	SEAMAXX	512	6	615992.37	133.95	0.00	408695.25	117.28	207297.12	68.78	0.00	80.00	73.76

Figure 4 (a): RO process details

Pass Streams (mg/l as Ion)							
Name	Feed	Adjusted Feed	Concentrate		Permeate		
			Stage 1	Stage 2	Stage 1	Stage 2	Total
NH4+ + NH3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	403.21	403.21	514.70	775.23	0.90	1.07	0.99
Na	10892.58	10892.59	13905.38	20945.37	21.34	25.73	23.75
Mg	1303.56	1303.56	1664.66	2508.63	0.59	0.73	0.67
Ca	417.79	417.79	533.52	804.02	0.19	0.23	0.21
Sr	0.09	0.09	0.12	0.18	0.00	0.00	0.00
Ba	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO3	19.45	0.41	0.66	1.51	0.00	0.00	0.00
HCO3	28.22	43.98	55.47	82.25	0.36	0.40	0.38
NO3	1.53	1.53	1.95	2.93	0.02	0.03	0.02
Cl	19596.05	19616.28	25042.83	37723.36	35.32	42.61	39.32
F	1.33	1.33	1.70	2.56	0.00	0.00	0.00
SO4	2786.93	2786.93	3559.14	5364.07	0.51	0.64	0.58
SiO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Boron	4.53	4.50	5.65	8.30	0.34	0.41	0.38
CO2	0.02	2.62	2.94	3.43	2.62	2.91	2.78
TDS	35476.60	35493.41	45312.43	68257.59	61.19	73.76	68.09
pH	8.90	7.00	7.04	7.22	5.38	5.37	5.37

Figure 4 (b): Chemical compositions

Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	8.90	7.00	7.22
Langelier Saturation Index	1.09	-0.62	0.15
Stiff & Davis Stability Index	0.13	-1.58	-1.04
Ionic Strength (Molal)	0.73	0.73	1.46
TDS (mg/l)	35476.60	35493.41	68257.59
HCO3	28.22	43.98	82.25
CO2	0.02	2.62	3.43
CO3	19.45	0.41	1.51
CaSO4 (% Saturation)	20.51	20.52	46.03
BaSO4 (% Saturation)	0.00	0.00	0.00
SrSO4 (% Saturation)	0.18	0.18	0.46
CaF2 (% Saturation)	98.74	98.74	702.10
SiO2 (% Saturation)	0.00	0.00	0.00
Mg(OH)2 (% Saturation)	28.19	0.00	0.02

To balance: 0.01 mg/l Na added to feed.

Figure 5 (a): Stage details

Stage Details

	Element	Recovery	Perm Flow (m³/d)	Perm TDS (mg/l)	Feed Flow (m³/d)	Feed TDS (mg/l)	Feed Press (bar)
Stage 1	1	0.05	71.97	44.00	1536.53	35493.41	79.66
	2	0.04	65.61	49.91	1464.57	37235.08	74.77
	3	0.04	59.01	57.17	1398.95	38979.14	70.19
	4	0.04	52.30	66.18	1339.94	40693.35	65.88
	5	0.04	45.58	77.54	1287.64	42343.45	61.82
	6	0.03	38.95	92.23	1242.06	43894.43	57.97
Stage 2	Element	Recovery	Perm Flow (m³/d)	Perm TDS (mg/l)	Feed Flow (m³/d)	Feed TDS (mg/l)	Feed Press (bar)
	1	0.06	74.89	56.15	1203.11	45312.43	133.95
	2	0.06	71.69	62.41	1128.22	48316.26	130.49
	3	0.07	69.70	68.67	1056.54	51590.22	127.33
	4	0.07	66.80	76.61	986.84	55229.03	124.45
	5	0.07	63.10	86.59	920.04	59233.39	121.83
	6	0.07	58.70	99.12	856.94	63588.62	119.45

Figure 5 (b): Scaling calculations

3.2 Further Optimisation

To further optimise the process, an excel sheet was used to compare different parameters such as SEC, recovery rate, cost and temperature. Assumptions made during comparison were cost of each RO membrane was $769 (FILMTECTM MEMBRANES, 2020), efficiency of the pumps were set at 85%, product flow rate 383352.5 m^3/day, number of passes was 1, no back pressures and number of stages was compared with recovery and SEC. At each stage, the ROSA simulation was used to calculate its respective recovery % and SEC value while pressure, flowrate, temperature, number of elements and vessels were kept constant. Percentage ratio was obtained by dividing the respective recovery percentage with achievable recovery percentage. The last recovery stage was stage 5 and the optimum values are shown in Table 4. The optimum number of stages was roughly 2.5 stages ≈ 3 stages (Figure 6). Table 5 shows the pre and post optimisation results and technical drawing of the design membrane elements and vessels are shown in Figures 7 and 8.

Table 4: Number of Stage Optimisation using Excel

No. of stages	Recovery percentage	Percentage ratio	SEC (kWh/m^3)	% ratio
1	21.71	26.93	12.05	100.00
2	48.06	59.62	9.70	80.50
3	69.81	86.60	8.62	71.54
4	80.59	99.98	8.45	70.12
5	80.61	100.00	9.08	75.35

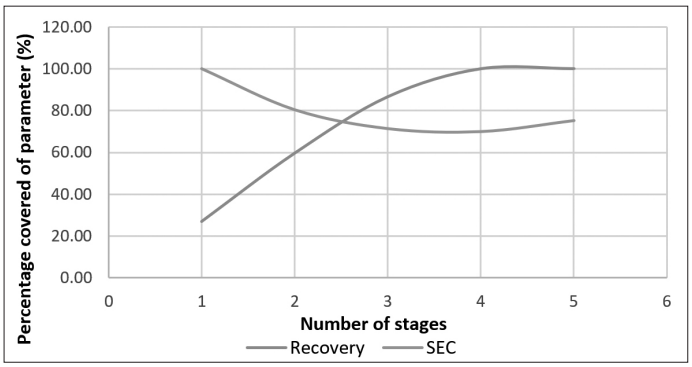

Figure 6: Optimal number of stages

Table 5: Pre and post optimisation results

Properties	ROSA simulation (pre-optimised)	ROSA simulation (post-optimised)	Changes
Number of stages	2	3	+1 stage
Operating pressure (bar)	80	66.5	-13.5 bar
Feed flow rate (m^3/day)	786,705	506,705	-280,000 (m^3/day)
Product flow rate (m^3/day)	378,010	384,417	+6,407 (m^3/day)
Reject flow rate (m^3/day)	408,695	122,288	+286,407 (m^3/day)
Recovery ratio (%)	48.05	75.87	+ 27.82%
Product TDS (mg/L)	74	181.13	+107.13 (mg/L)
Reject TDS (mg/L)	68,258	146,429	+78,171 (mg/L)
Specific energy consumption (kWh/m^3)	9.7	6.18	-3.52 (kWh/m^3)
Number of elements required	6144	8100	+1956
Cost of membranes ($)	4,7242,736	6,228,900	+41,013,836 ($)
Power (kW)	152585	98970	-53,615 (kW)

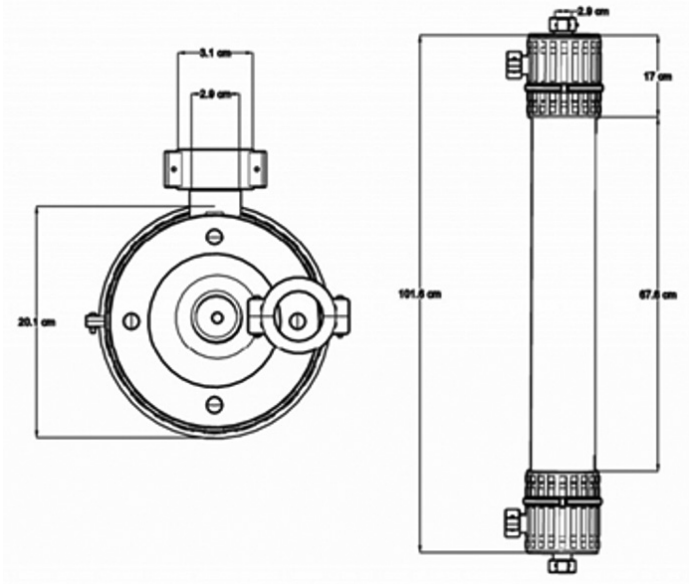

Figure 7: Technical drawing of a RO membrane element

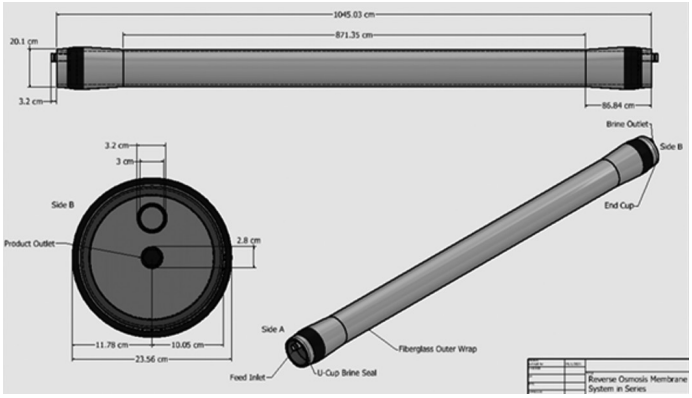

Figure 8: . Technical drawing of a RO vessel

4.0 CONCLUSIONS

A configuration of 3 stages, 1 pass and 6 elements in a vessel achieved an optimum efficiency using the ROSA software after post optimisation. Approximately 8,100 membrane elements were used so that the seawater feed flow of 506,705 m^3/day can achieve a production rate of 384,417 m^3/day and brine flowrate of 122,288 m^3/day. The recovery rate was 75.87 % and the final product TDS simulated was 181 mg/L. In addition, the specific energy requirement was as low as 6.18 kWh/m^3 and the total membrane active area was 251142.14 m^2 at an optimum temperature of 22.5 °C. ■

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COMPARISON OF PISTIA STRATIOTES AND LEMNA MINOR PLANTS POTENTIALS IN BIOREMEDIATION OF DOMESTIC WASTEWATER

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ABSTRACT

Phytoremediation is an eco-friendly and cost-effective biotechnological method of wastewater treatment that involves the use of plants. In this research work, the potentials of Pistia stratiotes and Lemna minor aquatic plants in the treatment of wastewater were examined. The two plants were cultivated in the wastewater sample for 10 days. Water quality parameters (turbidity, chemical oxygen demand (COD), phosphate, ammoniacal nitrogen and nitrate) tests were conducted on the untreated (influent) and treated water (effluent) samples at a detention time of 24 hours. The outcome of the analysis demonstrates that P. stratiotes effluent achieved a reduction efficiency of up to 91.9%, 68%, 79.6% and 71% for turbidity, phosphate, ammoniacal nitrogen and nitrate, respectively. Whereas for L. minor treated water samples, the highest reduction efficiency for turbidity, COD, phosphate, ammoniacal nitrogen and nitrate was found to be 87.2%, 46%, 48.7%, 83% and 56%, respectively. Hence, the overall outcome obtained indicated that P. stratiotes improved the domestic wastewater quality than L. minor plants.

Keywords: biological wastewater treatment; retention time; nitrate; phosphate; turbidity

1.0 INTRODUCTION

The menace of water pollution has become a global crisis around the world. This is due to increase in population, industrialization, inefficient management of water resources and poor treatment technologies (Shah *et al.,* 2014). One of the environmental issues that impact the lifetime maintenance of water resources in Malaysia is water pollution (Afroz *et al.,* 2014). In Malaysia, freshwater from natural sources contributes 97% of the overall water demand and consumption (Gasim *et al.,* 2009). Unfortunately, there is a high chance that the broadly available sources of natural water endowed in the country cannot guarantee adequate water supply due to water pollution (Afroz *et al.,* 2014). Management of water pollution is one of the most critical aspects of environmental pollution. However, phytoremediation can be used to curb environmental pollution (Raju *et al.,* 2010). Additionally, aquatic plants (free-floating, emergent and submerged macrophytes) and algae have been used to remove nutrients and contaminants from wastewater. Phytoremediation of wastewater using aquatic plant systems has been recognized as an alternative means of wastewater remediation. Aquatic plants such as *Pistia stratiotes, Lemna minor, Azolla filiculoides, Hydrilla verticillata, Azolla caroliniana, Spirodela polyrhiza, Salvinia cucullata, Lemna gibba, Azolla pinnata, Eichhornia crassipes* and *Typha domingensis* has been used as bioaccumulator agents in recovering and recycling of wastewater (Mustafa and Hayder, 2020). Pistia stratiotes is a free, noxious and stoloniferous herb with short stem found floating in stagnant shallow ponds (Pavithra and Kousar, 2016). Similarly, *Pistia stratiotes* aquatic plant was selected as the test plant in this research because it has the ability to enhance microbial activity, absorb nutrients and remove suspended solids (Fonkou *et al.,* 2002). On the other hand, duckweed (*Lemna minor*) belongs to the *Lemnaceae* family. *L. minor* is effective in removal of heavy metals, organic matter, suspended solids and soluble salts from wastewater (El-Kheir *et al.,* 2007; Radic *et al.,* 2010). Furthermore, Hanafiah et al. (2018) reported the effectiveness of *P. stratiotes* and *S. molesta* plants in removal of total suspended solids and ammoniacal nitrogen from wastewater. Hayder and Mustafa (2021) evaluated the performance of three aquatic plants in biofiltration of domestic wastewater. The outcome of the study indicated that the aquatic plants reduced the turbidity, ammonia, phosphorous and nitrate concentration in the wastewater samples. Hence, this study investigated and compared the efficiency of two selected plants; *P. stratiotes* (water lettuce) and *L. minor* (duckweed) in bioremediation of secondary treated domestic wastewater. The novelty of this study included the applications of aquatic weed plants in wastewater treatment. Furthermore, it involved the design and development of a sustainable hydroponic systems for investigating, comparing and ascertaining the potentials of *P. stratiotes* and *L. minor* in bioremediation of wastewater.

2.0 MATERIALS AND METHODS

2.1 Experimental Setup

The experiments were conducted in the premises of the campus and fed with sewage treatment plant (STP) effluent. Two rectangular acrylic tanks connected to an inlet and outlet pipes of known dimensions were used as the wastewater treatment system. The inlet pipe was connected to the exit point of the secondary treated domestic wastewater, which supplies the influent water directly into the constructed treatment tanks. These tanks served as a shallow pond system for the cultivation of the aquatic plant samples and tertiary treatment of the wastewater. Figure 1 illustrates the schematic diagram of the treatment tanks used in this research.

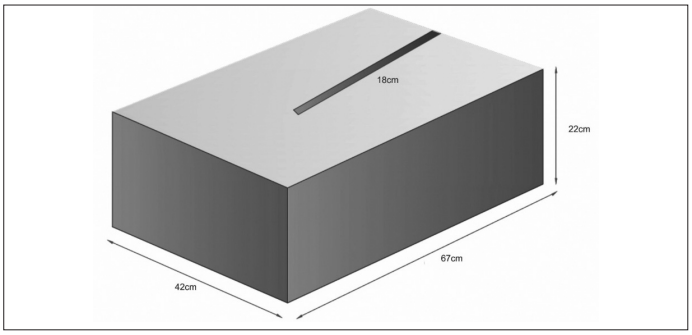

Figure 1: Schematic diagram of the treatment tank

2.2 Collection of the Plant Samples

The selected plant samples (*P. stratiotes* and *L. minor*) were obtained within the vicinity of the campus. Approximately 80g of the plant samples were used for the cultivation process. The plant samples were rinsed and acclimatized for 7 days in plastic bowls before transferring into the constructed treatment tanks filled with the influent water samples.

2.3 Collection and Analysis of the Influent and Effluent Water Samples

The influent water samples were collected at the secondary treated water discharge point in the STP. Whereas, the *P. stratiotes* and *L. minor* treated water samples were regarded as the effluent samples. Physicochemical analysis such as turbidity, chemical oxygen demand (COD), phosphate, ammoniacal nitrogen and nitrate of the influent and effluent water samples were monitored every 2 days at a retention time of 24 hours for 10 days. The turbidity of the water samples was assessed using a HANA HI 93703 turbidimeter with a range of 0-1000 NTU and 890 nm peak. COD level was determined using the reactor digestion method (8000). The phosphate test was analyzed using the ascorbic acid method (HACH method 8084) and the concentration of nitrate was determined using the cadmium reduction method (HACH method 8039). The tests were repeated thrice and the average results obtained were recorded. Furthermore, the percentage reduction efficiency was calculated using equation 1 (Mustafa & Hayder, 2020). Additionally, analysis of variance (ANOVA) was used to assess the significance of difference. The flowchart of the methodology and the summary of the experimental process is presented in Figure 2 and Table 1, respectively.

$$\text{Percentage reduction efficiency (\%)} = \frac{Wi-We}{Wi} \times 100 \quad (1)$$

Where Wi = influent concentration

We = effluent concentration

The flowchart of the methodology is presented in Figure 2 and Table 1.

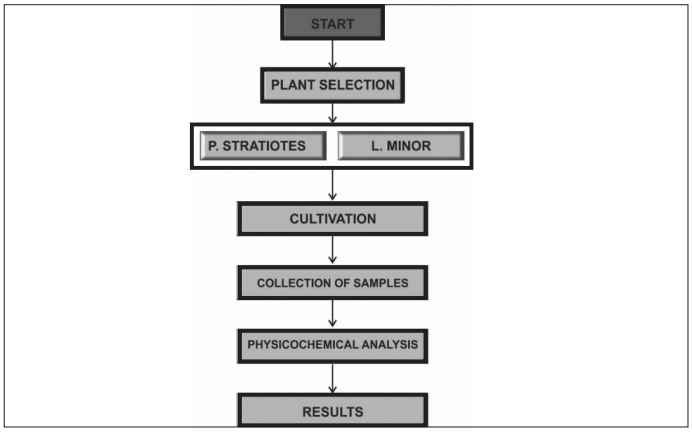

Figure 2: Flowchart of the methodology

Table 1: Summary of the experimental process

Weight of plant	Type of aquatic plants in the constructed treatment system	
	a) Pistia stratiotes	*b) Lemna minor*
80 g 0 day of the treatment process	 *Figure 3: P. stratiotes samples*	 *Figure 4: L. minor plant samples*
10th day of the treatment process	 *Figure 5: P. stratiotes on the 10th day of the sampling period*	 *Figure 6: Action of duckweed pests in L. minor cultivated treatment system*

3.0 RESULTS AND DISCUSSION

This research work was conducted to investigate the efficiency of *P. stratiotes* and *L. minor* plants in the phytoremediation of domestic wastewater. Water quality parameters such as turbidity, COD, phosphate, ammoniacal nitrogen and nitrate were analyzed according to the methods described above. The results obtained are presented in the graphs below.

3.1 Determination of Turbidity Concentration

The potentials of *P. stratiotes* and *L. minor* aquatic plants in improving the clarity of the influent samples were studied. The outcome of the turbidity analysis are presented in Figure 7.

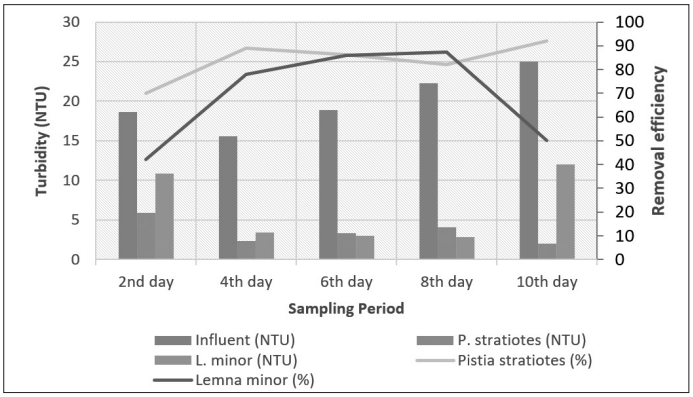

Figure 7: Graph of turbidity reduction against sampling period

From Figure 7, *P. stratiotes* and *L. minor* treated water samples showed a remarkable improvement in polishing the wastewater samples. Additionally, the effluent water samples indicated a constant reduction in the turbidity level when compared to the influent samples from the beginning to the last day of the sampling period. It was observed that on the 2nd day of the experiment, the turbidity level of the influent sample was reduced from 18.6±0.28 NTU to 5.9±1 NTU for *P. stratiotes* and 10.8±1.9 NTU *L. minor* treatment systems. Similarly, the influent samples were improved from 22.3±0.57 NTU to 4 ±0.52 NTU and 2.8±0.95 NTU by *P. stratiotes* and *L. minor*, respectively. The minimum and maximum reduction efficiency of 70% and 90% (*P. stratiotes*) and 42% and 87% *(L. minor*) were achieved. The findings obtained from the study demonstrated that a significant reduction (p< 0.0 5) was observed in the effluent samples. However, *L. minor* aquatic plants showed less effective treatment of the influent samples compared to the results obtained from the *P. stratiotes* plants. The highest reduction efficiency for *L. minor* effluent samples was obtained on the 8th day with a value of 87.2%. These findings indicated that *P. stratiotes* and *L. minor* are efficient in improving the influent water samples to the acceptable water standard of 5 NTU. Also, the results from obtained *P. stratiotes* effluent samples in this study corresponded with the work of (Aswathy, 2017), who reported that *P. stratiotes* significantly improved kitchen wastewater quality with 85.66% reduction in turbidity.

3.2 Determination of COD Concentration

COD is a water quality assessment parameter used for determining the strength of pollutants in wastewater. Figure 8 represents the results obtained from the COD concentration analysis carried out on the influent and effluent wastewater samples.

From the results presented in Figure 8, the trends in the COD concentration analysis demonstrated by the two test plants (*P. stratiotes* and *L. minor*) was almost the same. The COD values for *P. stratiotes* and *L. minor* decreased steadily as the contact time increases. On the 2nd day of the sampling study, *P. stratiotes* and *L. minor* reduced the COD from 152 ±0.5 mg/l to 121 ±0 mg/l and 115 ±0 mg/l , respectively. Additionally, in the overall experiments, the removal efficiency of COD was 49% for *P. stratiotes* and 46% for *L. minor*. The findings obtained from the study demonstrated that a significant reduction (p<0.05) was observed in the wastewater samples, but an insignificant change was observed between the two plants. Similarly, the outcome from the COD concentrated analysis is similar to the results reported by Ng and Chan (2017) in the phytoremediation of palm oil mill effluent wastewater using S. molesta plants. Furthermore, the mechanism by which aquatic plants decrease the concentration of the COD from the wastewater samples can be described in several ways. An increase in COD is caused by the assimilation of solid suspended nutrients attached to the plant roots in the treatment system (Ng and Chan, 2017). In other words, it may intensify the metabolic activity of microorganisms in the wastewater by utilizing available organic matter as a substrate (Mahmood *et al.,* 2005).

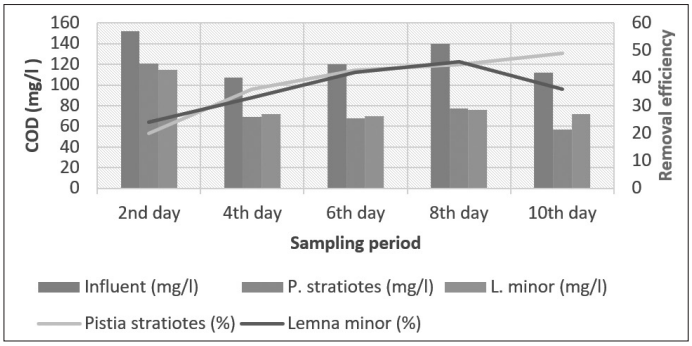

Figure 8: Graph of COD concentration against sampling period

3.3 Determination of Phosphate Concentration

The average phosphate concentration of the influent and effluent water samples are represented in Figure 9.

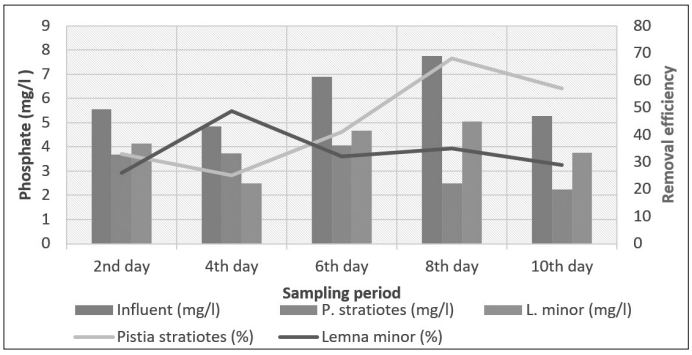

Figure 9: Graph of phosphate concentration against sampling period

From Figure 9, slight inconsistencies were observed based on the outcome of the experiment. The results indicated that the two plants reduced the phosphate level from 4.84 ±0.01 mg/l to 3.72 ±0.05 mg/l (*P. stratiotes*) and 2.48 ±0.01 mg/l (*L. minor*) on the 4th day. The highest reduction efficiency was 68% and 48.7% for *P. stratiotes* and *L. minor*, respectively. Furthermore, the ANOVA indicated a significant difference between the influent and the effluent samples, but an insignificant reduction was demonstrated between the two plants. Additionally, a higher phosphate removal by *P. stratiotes* was recorded in comparison to *L. minor* plants. The short roots of *P. stratiotes* played a significant role in phosphate uptake from the treatment system. Similarly, the built-in variation in macronutrient requirements for physiological processes could have been attributed to the differences observed by the two plants in the absorption of the nutrient. Likewise, an increase in phosphate concentration in wastewater after phytoremediation processes has also been reported (Akinbile *et al.,* 2015). Furthermore, Obek and Hasar (2002) reported a decrease in phosphate concentration from 15 mg/l to 0.5 mg/l in secondary treated effluents using *L. minor* on the 8th day of the treatment period.

3.5 Determination of Ammoniacal Nitrogen Concentration

The results for ammoniacal nitrogen analysis of the influent and effluent water samples are presented in Figure 10.

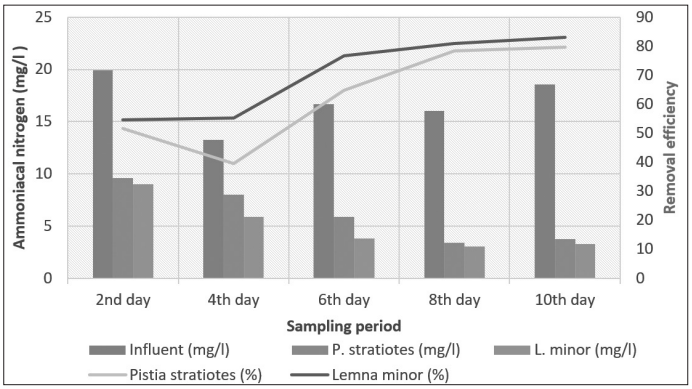

Figure 10: Graph of ammoniacal nitrogen concentration against sampling period

From Figure 10, the treatment system of the two test plants shows an invariable pace of reduction in the average ammoniacal nitrogen concentration of the effluent samples. The test plants reduced the ammoniacal concentration of the influent samples from 19.9±0.05 mg/l , 13.26±0.05 mg/l , 16.7 ±0.02 mg/l , 16.05±0.05 mg/l and 18.58± 0.08 mg/l to 9.6 ±0.1 mg/l , 8.01 ±0.02 mg/l , 5.86±0.05 mg/l , 3.44 ±0.02 mg/l and 3.78±0.17 mg/l (*P. stratiotes*) and 9 ±0 mg/l , 5.9 ±0.1 mg/l , 3.85±0.20 mg/l , 3.04±0.06 mg/l and 3.32±0.14 mg/l (*L. minor*). Similarly, this study indicated up to 79.6% (*P. stratiotes*) and 83% (*L. minor*) ammoniacal nitrogen reduction. Additionally, these findings demonstrated a significant reduction ($p<0.05$) between the influent and effluent water samples. However, the action of duckweed pests on the *L. minor* treatment system did not show a significant effect on the ammoniacal nitrogen concentration on the last day. Patel and Kanungo (2010) reported that the reduction of ammoniacal nitrogen was due to the absorption by *L. minor* plants.

3.6 Determination of Nitrate Concentration

The average nitrate concentration of the influent and effluent samples are represented in Figure 11.

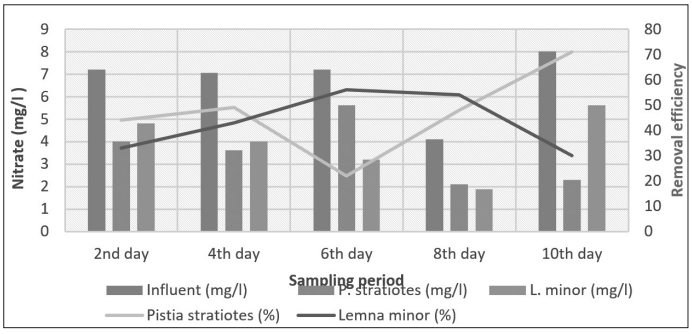

Figure 11: Graph of nitrate concentration against sampling period

From the results presented in Figure 10, it could be deduced that *P. stratiotes* and *L. minor* plants decreased the nitrate concentration of the influent samples within the 10 days sampling period. During the 2-day interval measurements, the nitrate concentration in the influent samples decreased with time, although the reduction was higher in the *P. stratiotes* effluent. Additionally, on the 4th day of the experiment, the test plants reduced the nitrate concentration of the influent samples from 7.04±0.26 mg/l to 3.6±0.1 mg/l (*P. stratiotes*) and 4.0±0 mg/l (*L. minor*). On the 6th day, decrease in the nitrate level of the influent samples from 7.2±0.11 mg/l to 5.6±0 mg/l and 3.2±0.02 mg/l was observed for *P. stratiotes* and *L. minor*, respectively. The slight reduction observed in the *P. stratiotes* effluent sample might be attributed to plant senescence caused by bacterial denitrification. While on the 10th day, a decrease of 2.3±0.17 (*P. stratiotes*) and 5.6±0.26 mg/l (*L. minor*) from 8±0.1 mg/l of the influent samples were observed. Furthermore, the outcomes obtained from this study demonstrated that a significant reduction ($p<0.05$) was observed in the effluent wastewater samples, which varied between 22%-71% for *P. stratiotes* and 30%-56% for *L. minor* plants. The increase in nitrate concentration observed in the *L. minor* effluent samples maybe due to the action of duckweed pests that fed on the *L. minor* plants prior to the final day of the sampling period. The results obtained in the *P. stratiotes* treatment system corroborates with the findings of Wickramasinghe and Jayawardana (2018). This study demonstrated that *P. stratiotes* plants exhibited high efficiency in nitrate uptake than *L. minor* plants. It is probable that the high growth observed by *P. stratiotes* plants enhanced the absorption of nitrate into the roots (Rivers, 2002).

4.0 CONCLUSION

The treated domestic wastewater used in this research work has passed through the preliminary stages of the STP before being subjected to tertiary treatment using *P. stratiotes* and *L. minor* aquatic plants. The outcome of the study indicated that more treatment is required on the secondary treated water samples before discharge into natural water bodies or use for drinking and irrigational purpose. Additionally, it was observed that the two selected plants showed a great tendency in polishing the influent water samples within a short period. Similarly, *P. stratiotes* plants exhibited better performance in comparison to *L. minor* plants. Additionally, *P. stratiotes* recorded reduction efficiency of up to 91.9%, 79.6%, 78% and 68% for turbidity, ammoniacal nitrogen, nitrate, and phosphate, respectively. In contrast, *L. minor* showed a better result than *P. stratiotes* plants in the ammoniacal reduction efficiency with 83%. Although, the constructed treatment system used in this study did not provide a conducive ecosystem for *L. minor* plants as poor growth and the actions of duckweed pests hindered its effectiveness in the tertiary treatment of the water samples. It can be concluded that phytoremediation using aquatic plants in our constructed treatment system is a depurative alternative method for low cost, energy-saving and eco-friendly techniques for tertiary treatment of wastewater.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. ■

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PROFILES

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THE THIRTY FIRST PROFESSOR CHIN FUNG KEE MEMORIAL LECTURE

Presented at Webinar on 31st July 2021

Professor Dr Mooi-Choo Chuah, FIEEE, NAI Fellow
Professor & Associate Chair,
Computer Science & Engineering Department,
Lehigh University, USA

Dr Chuah graduated with BEng (Honors) with 1st Class Honors from University of Malaya in 1984 and MSc and Ph.D. in Electrical Engineering from University of California San Diego in 1989 and 1991, respectively. She spent 12 years at AT&T Bell Laboratories and Lucent Bell Laboratories where she was a Member of Technical Staff, a Distinguished Member of Technical Staff and later a Technical Manager. She joined Lehigh University as an associate professor in Jan 2004. She is currently a Full Professor and the Associate Chair of the Computer Science & Engineering Department at Lehigh University, USA.

Her research interests include mobile health, computer vision, healthcare data mining, cloud security and security design for Cyber Physical Systems. She has authored/co-authored more than 150 papers in international journals and conferences. Her research hasbeen funded by major funding agencies in United States, e.g., National Science Foundation, DARPA, DOE and companies such as Qualcomm and FORD. She has served as Technical Co-Chairs for several top international conferences such as Technical Co-Chair for IEEE INFOCOM 2010, Symposium Co-Chair for Next Generation Networking Symposium for IEEE Globecom 2013, Technical Co-Chair for ACM/IEEE CHASE Conference and IEEE MASS 2019 Security & Privacy Track Co-Chair. She has also served as associate editors for several top IEEE transactions such as IEEE Transactions on Mobile Computing and IEEE Transactions on Parallel & Distributed Computing Systems. She has been awarded 63 US patents and 15 international patents based on her research work at Bell Laboratories in the area of wireless data system design, resource and mobility management design, MAC layer quality of service design etc. Based on her strong contributions in these areas, she was elevated to be an IEEE Fellow in 2015 and a National Academy of Inventors Fellow in 2017.

31ST PROFESSOR CHIN FUNG KEE MEMORIAL LECTURE

MY INDUSTRY TO ACADEMIA RESEARCH JOURNEY AND ENERGIZING INNOVATIONS AMONG MALAYSIAN ENGINEERS

(Date received: 20.08.2021/Date accepted: 30.11.2021)

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ABSTRACT

In this talk, the author would like to share her research journey from industry to academia, first in Malaysia and then in United States. She was fortunate to receive a strong science & mathematical education in Malaysia, trained as an engineer at University of Malaya, worked with a team of talented R&D engineers at Motorola Communication Sectors Sdn Bhd in Penang before she went to United States for graduate studies. In United States, again she was fortunate to have several mentors who helped to inspire her to conduct great research first in industry and then in academia. She will first share her research journal from Malaysia to United States. Next, based on her experience, she will share some main ingredients one needs to cultivate to conduct great research, e.g., curiosity, diligence, and perseverance. Subsequently, she will also share her thoughts on how industry leaders, academic leaders and Malaysian government can collaborate to energize innovations among Malaysian engineers as well as young generations aspiring to be our next generation engineers. Cultivating curiosity in STEM fields at young age, providing opportunities for high school students to appreciate science through solving real life problems with college students, and creating opportunities for faculty members in STEM fields to spend sabbatical semesters at top universities or industry R&D laboratories to horn their skills are necessary steps to energize innovations among Malaysian engineers.

Keywords: mobile computing, artificial intelligence, healthcare analytics, computer vision, project based learning, design thinking

1.0 INTRODUCTION

Ir. Professor Tan Sri Dato Dr Chin Fung Kee is one of the most respected and outstanding civil engineers in Malaysia, both in engineering practice and also in engineering research and education [1]. He was a renowned leader in geotechnical and structural engineering. He played a key role in the development of engineering education, research and practice in the country. For example, Prof Chin played a major role in the formation and development of the Faculty of Engineering, University of Malaya, Kuala Lumpur. Professor Chin's significant contributions benefited the engineering fraternity nationally, regionally and internationally and his success was recognized worldwide. In recognition of Prof Chin's outstanding achievements and contributions, the Prof Chin Fung Kee Memorial Lecture was inaugurated in 1991 and jointly organized by The Institution of Engineers, Malaysia (IEM) and the Engineering Alumni Association of the University of Malaya. Also a Prof Chin Fung Kee Gold Medal was established in UM to recognize the top engineering student with the best result in the final year common subject on Management (and later was changed to award for the best engineering graduate) [2].

The author was grateful for the honor of being invited by the Organizing Committee to deliver the 31st Prof Chin Fung Kee Memorial Lecture which was presented on 31st, July, 2021 and this paper is a write up of her presentation.

The author received her education in both Malaysia and United States. She was honored to be a recipient of Professor Chin Fung Kee Gold Medal in Management and Tunku Abdul Rahman Gold Medal in her final year electrical engineering study in 1984. After her bachelor degree, she worked as a R&D engineer and later as a senior R&D Engineer at Motorola Communication Sectors, Penang between 1984-1987.

Her undergraduate education, initial R&D engineer experience at Motorola Penang and encouragement from a caring mentor Prof. Tan Hong Siang of University of Malaya spurred her desires to pursue her graduate studies in United States. Initially, she secured a full scholarship to start her graduate study at MIT in United States but could not adjust to the cold weather so she took a leave of absence for a few months

and later started her graduate study at University of California, San Diego where she obtained her Master's Degree and later a Ph.D. in Communication Systems & Theory from its Electrical Engineering Department in 1991.

Upon completion of her PhD study in 1991, she was given the opportunity to work at AT&T Bell Laboratories, a top notch industry research laboratory in the world. She joined as a Member of Technical Staff, and was later promoted to be a Distinguished Member of Technical Staff in 1999, and Technical Manager in 2001. Based on her research work at Bell Laboratories with her colleagues, she was awarded 63 US patents and 15 international patents. Most of her patents are related to designing future wireless data systems.

Encouragements from her siblings spurred her to move from industry to academia. She joined Lehigh University in Jan 2004 as an associate professor and later was promoted to be a Full Professor in 2010. At Lehigh, she conducted research related to network security, disrupted tolerant networks, mobile computing and mobile vision. Her research was funded by major US funding agencies such as DARPA and National Science Foundations.

In recent years, she started to do artificial intelligence related research, e.g., computer vision and healthcare data mining research. Despite changing her research topics, she successfully secured funding from companies such as FORD, Qualcomm and National Science Foundation to pursue new research topics.

Her research works were published at top international conference venues such as IEEE INFOCOM (the top networking conference), IEEE SenSys (one of the top sensor network research related conferences) and top journal venues such as IEEE Transactions on Mobile Computing, IWMUT. She has served as Technical Co-Chairs for top international conferences e.g. IEEE INFOCOM 2010, Symposium Co-Chair for Next Generation Networking for IEEE Globecom 2013, Technical Co-Chair for ACM/IEEE CHASE (health care related conference) in 2017 and IEEE MASS Track Co-Chair for Security & Privacy in 2019. She has also served as associate editors for top journals such as IEEE Transactions on Mobile Computing, IEEE Transactions on Parallel & Distributed Systems etc. She was elevated to be an IEEE Fellow in 2015 and selected as a NAI Fellow in 2017.

In this paper, the author first described her own research experience that spans from industry to academia and factors that help prepare her to become a productive researcher in the international research community in different areas that she chose to get involved in. Life is not a bed of roses so was her research journey from industry to academia. Thus, she would like to share how she overcame different obstacles to become a successful researcher with encouragements from friends and colleagues. By sharing her experience in transitioning from industry to academia, she hopes that she can encourage others thinking about doing the same to have the courage to do so.

In addition, she shares some habits that effective researchers have in common based on what she has learnt as well as from her conversations with other effective researchers. Last but not least, she also presents some ideas on what professional bodies like IEM, university administrators and the Ministry of Education (MoE) can do to help train future engineers that can create novel and innovative solutions to solve complex problems that mankind will face in future in this fast moving technological society.

2.0 AUTHOR'S RESEARCH JOURNEY

2.1 Author's Research Journey in Malaysia

The author took pride in being trained as an engineer in Malaysia. She started her primary school in Hu Yew Siah before continuing her secondary school education at Penang Chinese Girls' High School (PCGHS) and sixth form in Methodist Boys' School (MBS) in Penang. She recalled that she and another friend were the only two that did not attend Penang Chinese Girls' Primary School (PCGPS) when they first showed up at PCGHS. PCGPS was a well known primary school with many talented students. These two young girls were not intimidated and ended up being the top 2 students in their remove class (1st year in Chinese High School). After MBS, she secured a Bank Negara scholarship to enroll into the Electrical Engineering degree program at University of Malaya (UM). She had a hard time adjusting in her first semester at UM especially in a class where she had to learn how to draw engineering diagrams that typically civil engineers had to draw because she was not used to having to imagine how a 3d object looked like from different viewpoints. She nearly quitted but received encouragements from a few young engineers (trained at UM) who were her eldest sister's friends.

After graduating from UM, she started her engineering career as an R&D engineer at Motorola Communications Sector Sdn Bhd in Penang. She was assigned to write assembly language software that provided control features for new series of transceivers that the Penang R&D Team was in charge of designing for the company in competition with another R&D Team in United States. Both teams designed similar series of transceivers for different governments. Facing a competitive team allowed the team she was involved in to work hard and eventually they were able to successfully produce a prototype ahead of their competitive team. While at Motorola, she noticed that her colleagues who were trained in United Kingdom and United States seemed to have better problem solving skills. That triggered her to have the desire to pursue graduate study overseas just to find out how they train engineers differently. At Motorola, she and her colleagues designed a new feature that allowed engineers to clone software from one transceiver to another easily. This feature involves transferring data from one device to another. Such work led her to be interested in conducting communication network related research in her graduate study.

2.2 Author's Research Journey in United States

While at Motorola, she occasionally still visited UM and Prof Tan Hong Siang, who was the Department Head of Electrical Engineering at that time, encouraged her to pursue her graduate study in United States. She applied to the two best engineering schools in United States and was accepted to one of them (MIT) with a full scholarship. Unfortunately, she was not able to adjust to the cold weather there and decided to take a few months leave of absence after one semester. Despite having this setback, she was determined to overcome this obstacle with tons of love and supports from her family especially her siblings. She later started her graduate study at the University of California San Diego (UCSD) where she completed her Master and PhD degrees in electrical engineering.

Even though her stay at MIT was very short, she learnt a few important lessons that influence how she conducted research and communicated with others about research subsequently. She learnt that one should be brave to ask questions when he/she does not understand new concepts in class. She also learnt that it is okay not to know much when one started doing research in a new topic as long as you work hard to learn fast. She also learnt that it is okay to rely on new friends for emotional support when you are far away from family members. She learnt Artificial Intelligence (AI) and some database concepts at MIT. Interestingly, when she was asked to indicate her research interests at MIT, she picked communication networks and artificial intelligence. Even though she took an AI course at MIT, she hardly knew what type of AI research she would like to do. You will see how life came to a full circle 32 years later when she started to do AI related research at Lehigh.

While at UCSD, she worked with a young but bright assistant professor. She was not very interested in the research topic that her advisor suggested to her but she continued to push herself to conduct research under him because of a very good advice that he gave her, i.e. "It does not matter what topic you conduct your research in but the whole PhD process helps you become a great thinker. Once you get your PhD, you are free to do whatever research you want". When she graduated in May 1991, technical jobs were hard to find since the job market happened to be down that year. She struggled with whether she wanted to go back to Malaysia/Singapore or remained in United States. She did apply for an academic position in Singapore because she learnt science in English and not in Malay. Unfortunately, her application was not successful. With God's grace, later she was given an opportunity to join Bell Laboratories, one of the top industry research laboratories in the world.

In the first few years at Bell Laboratories, she was not given any interesting research projects but that did not dampen her spirit of continuing to learn new knowledge to prepare herself to do interesting research. At that time, her research center was not keen in doing any internet related research while she was interested in such research. She spent weekends reading others' research papers in this area and conducted such research during her own free time. Eventually, she was given the opportunity to participate in a very high impact research project involving wireless LAN. At that time, there was no standard that allowed wireless LAN to provide quality of service. In addition, since wireless LAN is a broadcast medium, having security feature is important in wireless LAN data system but not much security features are provided in such systems. Their team was the first that designed MAC layer features that provide quality of service as well as designed network layer protocols for providing virtual private network features for wireless LAN systems. Multiple patents were awarded from the work they did in this project. Subsequently, she also designed mobility management features for future wireless data systems, MAC layer features for 3G systems, and MPLS related features for routers in the internet. All these work led to her being awarded 63 US patents and 15 international patents.

After 12 years at Bell Laboratories, encouraged by her brother to move to academia, she joined Lehigh in January 2004 as an untenured associate professor. By October 2004, she already secured a big grant from DARPA to get involved in disruption tolerant networking (DTN) research. Her team was the first that designed a DTN multicast delivery scheme and also the first that implemented security features for DTN. Her publications related to DTN can be found in [3-7].

Transitioning from industry to academia was challenging for she had to make sure that she could recruit high quality PhD, Master's and undergraduate students to build a research group. She had to work hard to build connections with faculty members both at Lehigh and outside of Lehigh. She was fortunate to have a bright undergraduate American student who was interested in doing security research for his MS degree and a new Chinese PhD student who did his MS in Singapore to help her in this DTN related project. Subsequently, she recruited 2 or 3 more but none worked out. They either had personal reasons that force them to quit their PhD programs or they did not have the right attitudes to pursue PhD degrees. She had to work extra hard to make sure that her team completed the deliverables that were originally planned in the funded project.

Despite the initial DARPA grant success, submitting research proposals turned out to be a challenging task for one may have great ideas but without preliminary results, reviewers of the proposals may not believe in your ideas. However, being at a smaller private university where you do not have a large research group may mean that you could not produce preliminary results fast enough to compete with larger research groups elsewhere. However, despite multiple proposal rejections, she persisted and worked harder until she succeeded in getting her research proposals funded by National Science Foundation (NSF).

One of the benefits that university faculty members enjoy is the ability to have a sabbatical semester or year every 7 years. During her first sabbatical semester, she tried to determine the next research topic she wanted to explore. At that time, she was troubled by the difficulties that her sisters had to deal with in moving her parents from upstairs to downstairs just to get them to a doctor's office for regular checkup. Thus, she started working on mobile health related research in the hope that using intelligent wearable sensors, caregivers of seniors can help collect useful sensor data to send to the doctor's office without having to transport seniors to his/her office. Subsequently, she and her collaborator at Steven Institute of Technology started two NSF funded mobile healthcare related projects (see Fig 1).

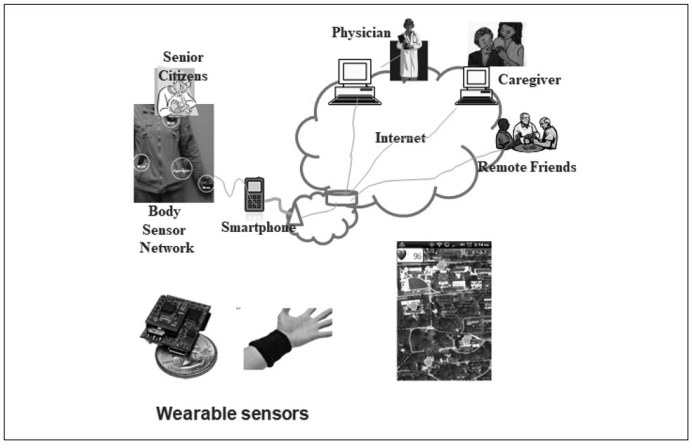

Figure 1: Mobile HealthCare Research

Funded by these NSF grants, she and her collaborators designed efficient schemes for monitoring gait patterns [8, 9] as well as using the Channel State Information extracted from WiFi

signals to infer human activities. Their work were published in several top conference and journal venues including IEEE Sensys [10] (one of the two top sensor network related conferences), ACM Ubicomp [11] (one of the top mobile computing related conferences). She also supervised undergraduate students to develop useful Android applications for healthy lifestyle and life-skill training for teenagers with autism disorder (Fig 2).

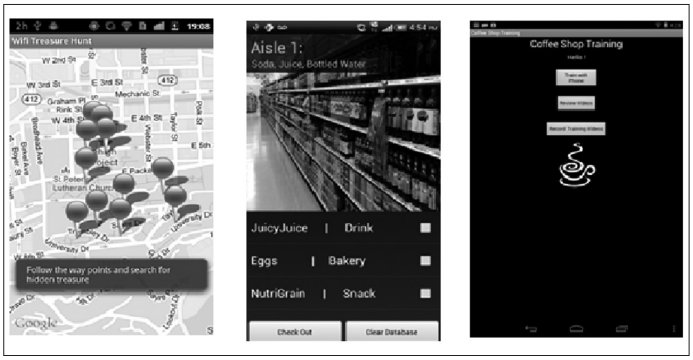

Figure 2: Android applications for healthy living and teenagers with ASDs

In addition, she was involved in designing a new internet feature called content centric networking feature and secured an NSF grant to develop a network prototype with such a feature. Since part of the goal of the project is to develop new application that can utilize large bandwidth, her research group started to explore how to support a video streaming feature in content-centric network. That project allowed her and her graduate student to travel to different locations within United States to give demos for their prototype during the GENI conferences. While touring some great places during off-times at these conferences, she thought of ideas for a new research project involving mobile vision that could allow tourists to retrieve interesting information about places of interests using images captured by tourists. Such thoughts eventually led her to start doing research in computer vision (Fig 3). This was the beginning of her Artificial Intelligence related research.

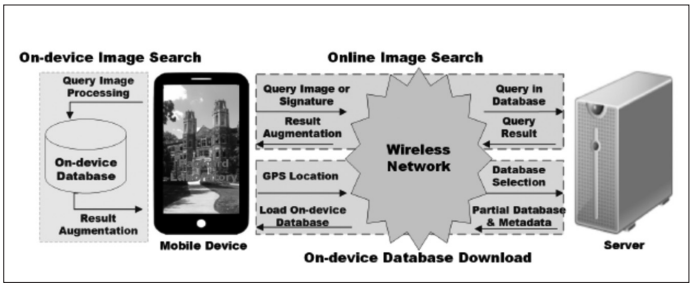

Figure 3: Mobile Vision Research

She started recruiting PhD students who are interested in doing computer vision related research. For the past 5 years, she has conducted research in topics such as object detection, tracking & trajectory prediction, few shot image/video segmentation. Such topics are useful in many application scenarios that affect our daily lives, e.g., analytics of videos collected during sport events, autonomous vehicles, video surveillance. Again, despite being new to these areas, she successfully secured funding from companies and NSF to conduct research in these topics. In order to conduct such research, she has to sharpen her knowledge by learning how deep learning models work and read many research papers. In addition, she has to find niche areas where she can contribute using her vast system research experience so that she can be competitive in securing research funding in a very hot research area where big name schools have large research groups to conduct such researches.

Furthermore, she became fascinated with the different domains that one can apply deep learning techniques to. Since she is always passionate about conducting research related to healthcare, she started exploring how she can apply such techniques for healthcare analytics. Since Lehigh is not a medical school which has access to tons of healthcare data, she had to work hard to see how she could get hold of some healthcare data to start her research in this area.

After not having any success in finding a publicly available healthcare dataset for nearly a year, she eventually found a data mining related challenge organized by a non-profit organization which is created to speed up research in ALS disease. This organization secured a dataset on ALS patients from two well-known hospitals that treat ALS patients and invited data mining researchers to participate in a challenge to develop the best data mining model that can predict ALS disease progression and ALS patients' survival rate. The challenge was over so she contacted the organizers to see if they were willing to share their dataset with her. Of course they were happy to share the dataset with her, and that was the beginning of her research in healthcare data analytics.

She and her PhD student conducted such research for several years. They designed an incentive mechanism which can encourage hospitals to share their datasets so that an aggregated model with better accuracy can be produced [12]. They also explored security issues related to deep learning models. Typically, healthcare data are often time series data and hence RNN models are often used to analyze such data. Unfortunately, one can attack such RNN models. She and her PhD student explored a new RNN attack that can affect the accuracy of RNN models [13] and suggest methods to detect and defend against such attacks. Recently, she started exploring how to use deep learning models to create an intelligent voice assistant to help college students deal with mental health issues [14].

To be a productive researcher, one has to proactively look for new research topics that one can contribute to. Security research has always been an important research topic. At that time, researchers have started to explore how to make power systems more scalable using intelligent monitoring devices that can be connected to the internet and such smart device enabled power system is referred to as smartgrid. Being a security researcher, she started brainstorming with an external young faculty to see if he would be interested in collaborating with her in smartgrid security related research. That young faculty was willing to provide a PhD student for this collaborative work. They ended up publishing both a conference and a journal paper in this topic. Later, she collaborated with another external faculty and her PhD student in another smartgrid security related topic. They also published a conference and a journal paper. Subsequently, there were two Electrical Engineering faculty who were interested in forming a team at Lehigh to collaborate with four other universities to submit a smartgrid security related to proposal to the Department of Energy. A young faculty at the leading institution was aware of the papers that she has co-authored and requested that she became a core member of the Lehigh team. They succeeded in getting a $3.2 million 5-year project in smartgrid security.

In summary, her research direction has always been influenced by her strong desire to use technology to solve real problems. Given an opportunity, she will work hard to learn new knowledge so that she can contribute innovative solutions to solve problems that society faces, e.g., healthcare domain, smartgrid security, autonomous vehicles.

3.0 FACTORS THAT HELP CULTIVATE INNOVATIONS

Over the years, she work with many talented researchers both younger and older than her. She learnt several useful lessons that help her to become a better researcher. Here, she summarizes what she has learnt in the hope that these suggestions may help future Malaysian engineers do well in pursuing their dreams of changing the world.

3.1 Right Training and Lifelong Learning

Before one can build a beautiful building, one first needs to learn how to build a strong foundation. Thus, before one can be a great engineer or STEM researcher, one needs to have a strong Math & Science foundation. She was glad that she was trained in Malaysian primary and high school educational systems that focus on training young children with a strong Math & Science background in her days and hope that such tradition continues to persist in Malaysia these days. Teachers cannot teach you everything so developing a curious mind while one is young does help. Her dad owned a small grocery store when she was young and she would spend time checking the invoices issued by employees since she liked Mathematics. She often caught mistakes made by employees. Her dad did not ask her to do this. She did it due to her interests in Mathematics.

In addition, having a lifelong learning attitude also helps. These days, technology changes take place rapidly. Thus, any STEM graduate should not think that he/she is done learning once he/she graduates but should have that passion to learn new technology that is of interests to them for we never know when such knowledge becomes handy.

She shared two testimonies from her own experience. When she was at MIT, she had no idea what types of research she wanted to do. She ended up working with a professor who did database related research. She knew nothing about database but she diligently read research papers and by the end of the semester she learnt something about database. Initially, she thought that she would not use that knowledge since her research at UCSD was related to communication networks. When she first showed up at Bell Laboratories, her supervisor remembered that she told him during her interview that she took a neural network course towards the end of her PhD study. He happened to have a database related problem that he wanted her to explore if she could come up with any new approach that could achieve higher accuracy in matching records from various databases with different data formats. That research resulted in her 1st US patent and she was told 5 years later by a PhD student they interviewed that it prevented Microsoft from filing a similar patent. The second example is related to her deep learning related research. When she took the neural network course at UCSD, she has never imagined that one day she will be involved in deep learning related research where neural networks are used to solve different problems in our daily lives, e.g., healthcare analytics, perception system for autonomous vehicles, etc.

Furthermore, one should develop a strong logical thinking skill at his/her young age. When she was at UM, she was a book worm that studied hard what the lecturers taught her but she seldom stepped back to think about bigger pictures and developed a strong logical thinking skill. Lecturers often quiz students based on what they teach. She recalled her Physics teacher in Form 6 behaved very differently from other teachers. He often tested his students using questions that students need to think hard about how to apply the knowledge he taught in his class. Students couldn't adjust easily to his teaching style. She got the lowest score in his class (despite still being top in the class) over all classes that she had taken over her years of education in Malaysia. Now that she looked back, she could appreciate deeply what he was trying to do. Students need to learn how to develop strong logical thinking skills so that they can have better problem solving skills. The college professors in United States often cultivate such skills by testing how well their students learn the concepts they teach in examinations and not how well they remember what they say in classes.

3.2 Motivation

The second factor that drives innovations is motivation. Often a researcher that has a strong dedication to a cause will drive himself/herself to create innovative solutions to solve real life problems that is related to the cause that he/she is passionate about. When this author was at UM, there were only 6 female students in her engineering class of about 200 students. Female students were not given any special privilege. They had to arrive at the lecture halls early so that they could occupy front row seats for they could hear the professors better at front row seats. At that time she was highly motivated to do well so that she could prove to others that female students could be great engineers too.

Another motivational factor for her to be successful in STEM careers comes from a healthy sibling competition. She has a younger brother who is also an electrical engineer and a professor in a Malaysian university. He was 2 years her junior at UM. Since Malaysia educational system often has national exams (LCE, MCE) for FORM 3 and FORM5 students, the two of them would compete with each other. She would do well in LCE and her brother would try to outperform her when it was his turn. When they were young (primary school), they often quarreled and argued, but when they grew up, they became great friends who encourage each other.

Since their parents came from families where both of their grandfathers passed away when their parents were very young, their parents were not given the opportunity to finish primary school education. However, their parents worked hard to provide for their children and encouraged their children to do well in their studies. They however do not exert pressures on this author and her brother to pursue graduate studies since they were already proud of them for finishing their college degrees. Her upbringing led her to have passions to help those that are less fortunate than them. It also led her to have passions to improve people's lives especially people's health. Her passion for doing research in mobile health and health analytics are motivated by such desires. For example she supervised undergraduate students to develop mobile applications that help train autistic teenagers

so that they could speak better and they could learn skills that allow them to function well in their daily lives.

3.3 Environment

No one can work alone. They need friends and supportive colleagues to nurture them along their way to become a successful researcher. Having a great relationship with your PhD advisor helps. Her PhD advisor conducted very theoretical researches when they first met but when she visited him 9 years after she graduated, he told her that he was doing a startup company with his current PhD student. He told her that what she told him inspired him to look at how to apply his research skill into solving more practical problems. Thus, having a great relationship with your MS or PhD advisor helps both of you to grow professionally.

Our technical communities can also provide supportive environments for young researchers to succeed. In United States, there are several funding agencies that fund faculty research. They are competitive but opportunities exist every year. For some important research topics, there are sometimes multiple opportunities every year. Within universities, university administrators also establish internal research grants to help to promote strong research.

Often, researchers need to read research papers published by other researchers to help trigger new ideas. However, subscribing to journal transactions, registration and traveling costs for attending top conferences can be expensive. Malaysian researchers can identify conference venues where strong researchers publish their researches on topics that are of interests to them. Then, they can see if such papers are shared by the researchers on arXiv using Google search engine. Thus, young researchers can still access the latest research papers without having to incur expensive costs. Often researchers also share their research codes on github and such codes can be used to train graduate students to conduct new research effectively.

3.4 Communication

Despite brilliant ideas you may have, such ideas are worth million dollars only if they can be communicated well to others. Since her PhD advisor was a young faculty, he did not spend much time training her how to write well. This author started learning how to write well technically at Bell Laboratories. She recalled that her first supervisor told her that he thought the technical report which she wrote was more like her reporting chronologically what she has done despite the fact that she spent much time in writing the report. However, she accepted his critiques and strived hard to improve her writing. She continued to learn how to write well from a faculty who is younger than her because that faculty writes very well.

STEM researchers are often asked to communicate their research to different audience. Sometimes, researchers give presentations to other researchers that are familiar with their research fields but sometimes researchers give presentations to those who are not familiar with their fields. Thus, researchers need to know how to communicate well and if needed, use non-technical terms to explain their research. They can use analogies and metaphors to help explain their concepts so that their targeted audience can understand better what they are trying to communicate across. One needs to be humble in order to be a good technical communicator. One of the lessons this author learnt at MIT was to witness a very famous Artificial Intelligence professor practicing his lecture in an open lounge for faculty and students. He was already a well-established researcher but he took every opportunity to improve his teaching. Such role models often motivate us to become better technical communicators.

We can also improve our presentation skills by watching how famous researchers present their ideas. Top conference venues often host presentation videos given by researchers so Malaysian researchers can benefit by watching such videos to understand better the research papers that these researchers publish. Malaysian researchers should also be brave to write to these researchers when they have questions related to the published papers. This author recalled that when she was a graduate student at UCSD, she read a Bell Laboratories researcher's paper and sent him an email to ask questions about his paper. Guess what, she ended up in the same R&D department with him when she joined Bell Laboratories.

3.5 Constraints

Whether we are industry or academic researchers, we face constraints all the time. Conference submission deadlines and bosses' deadlines in finishing the design of new products are not within our control. In addition, we only have access to limited human resources, e.g., the number of PhD students we have, the number of team members we have. Furthermore, we often have to work within limited budgets. Others may view these constraints as excuses why we cannot be competitive but effective researchers often work within their constraints.

For example, this author was only exposed to C programming during her final year study at UM but she used whatever knowledge she had and improved on it while she was at MIT. She was fortunate that a senior PhD student was very patient in helping her improve her C programming skill. Another example was related to her current computer vision related research. Compared to other top computer vision researchers that often have 10-20 graduate students to work with, she only has 2 PhD students who work in this area. Thus, they have to find a niche area that top computer vision researchers seldom look at and see how they can contribute. Eventually, they came up with more efficient schemes that can run faster but still achieve slightly better performance in video action recognition because others assume they have access to tons of GPU resources while her group faces the constraint of only having limited GPU servers in her research lab. She was very fortunate that her PhD student knew how to build GPU server from scratch and hence they were able to have 2 (eventually 3) GPU servers by building their own and getting a GPU donation from Nvidia.

3.6 Diligence & Illumination

Thomas Edison once commented that even genius relies only on 1% inspiration but 99% perspiration. Irrespective of how smart you are, if you are not hardworking, you will be left behind in this fast changing technological world. Thus, it is important that researchers work hard to improve their own skill sets so that they can have sharper minds to tackle new research problems. For example, this author was not familiar with computer vision research when she first started. That did not deter her from learning together with a PhD student that

had prior computer vision experience. Having a humble heart to learn from others especially those younger than you helps you to be able to accomplish more in your own research. Diligently and continuously sharpening one's skillsets allows a researcher to prepare himself/herself to get involved in new research areas when opportunities arise.

In addition, we also often need to change our routine and take vacations to give us opportunities to create new ideas for ideas can come from anywhere. Reading news articles about others inventions can sometimes inspire us to come up with new ones ourselves. For example, this author read a Yahoo news article about a startup company in United Kingdom that sold wearable products similar to FitBit which allow users to track their physical activities, e.g., their walking steps. Their business model is different in the sense that it works with companies that sell healthy products and entice users to continue to use their wearables by giving them coupons to buy these health products after they achieve certain milestones in the total number of walking steps that they take every week or every month. She thought that such a system can easily be manipulated by users by lending their wearables to friends to help achieve these milestones faster. Thus, she collaborated with another female faculty on how to design an efficient scheme that can infer if the walking steps are actually the owner's steps or others' steps. They ended up publishing their work in a top conference venue [8] and they also published a journal version at IEEE Transactions on Mobile Computing (one of the top journals in mobile computing) [9].

3.7 Opportunity & Perseverance

Often success in research occurs when you happen to be at the right place at the right time. Recalled that this author mentioned she was not given any interesting projects to work on when she first started at Bell Laboratories. Her dad became ill so she took a leave of absence to go to the wireless research center at National University of Singapore for a few months. During that time, she started building a simulator to evaluate new MAC features. She kept in touch with her US Bell Laboratories supervisor and he happened to just receive words from the upper management that they were going to have this new Wireless LAN project that needed an engineer to innovate on MAC features. Her dad recovered from his illness and hence she accepted her supervisor's invitation to go back to Bell Laboratories in United States to get involved in this project which ultimately resulted in her and her team mates being awarded multiple US patents.

Researchers also need to have perseverance in order to succeed in their research. This author encountered multiple obstacles in her research career but she did not give up easily. For example, when she was doing my undergraduate thesis, she ran into difficulties. The PCB board that she designed in the 1st round did not work. She was disappointed but she continued to work hard on improving it and she finally succeeded. She was given the best undergraduate thesis award. At UCSD, her PhD advisor was very young and sometimes not experienced in coaching her. When he told her that he couldn't help her further when she got stuck in a research problem, she did not give up. She prayed and sought guidance from above and was able to overcome her problem and finished off her thesis related research.

When this author first started her mobile healthcare related research, she also ran into obstacles. She was eager to design something to help the elderly but there was no faculty at Lehigh who is an expert in elderly care. However, she managed to start developing mobile applications to help autistic teenagers. There are a few autism experts in College of Education. She had to work hard in reading autism related papers that typically CS researchers do not read so that she could understand the typical jargons that researchers in this field used before she was able to convince her colleagues to discuss with her. Thus, when young researchers face obstacles, they should not just walk away. Instead they should work hard to see how they can remove such obstacles so that they can conduct certain research. Sometimes, we may have to change our direction a little bit to hit a gold mine of interesting research problems.

3.8 Additional Advice to Young Researchers

In this subsection, this author provides some additional advice to young researchers how they can improve their chances of becoming effective researchers. First, they need to set their priority right. Every one only has 24 hours per day. Some of us have to play multiple roles in our lives: faculty, researcher, mom/dad, care-givers to older parents, etc. Thus, it is important for young researchers to plan ahead to set aside some time where they can focus on just doing research. They should learn how to say no to service responsibilities that others can take care of. In addition, they should look for collaborators within and outside of their departments for research these days is often interdisciplinary. To make others more willing to be collaborators, young researchers should do their homework to show others that they are serious in doing the research that they are seeking collaborators' help. They should also make sure that they are aware of new research that others are doing in that particular topic and be able to educate their potential collaborators. Often brainstorming sessions need to take place before one can find a niche problem that the team can work on. Thus, they should cultivate patience when they start new research.

Young researchers should be aware of top conference venues in their fields. Reading most recent high quality conference papers allow young researchers to learn new problems and techniques that others propose to solve such problems. Often, one does not need to attend such conferences in-person if resources are not available to do so. They can watch online video presentations. If such conferences are held in nearby countries, e.g. Singapore or China, they can seek support to attend such conferences. They should read published papers ahead of time so that they can ask questions when authors are presenting their papers. Having in-depth technical discussions with authors that may have more knowledge than them help to improve their knowledge and eventually make them better researchers.

4.0 COLLECTIVE GOVERNMENT, HIGHER INSTITUTION & INDUSTRY EFFORTS FOR FUTURE MALAYSIAN ENGINEERS

The recent statistics in Malaysia has shown that fewer students are considering STEM education and STEM related careers. Efforts need to be carried out to reverse this trend for society needs young generations with creative ideas to come up with

innovations that can benefit mankind. Here, this author would like to share some of the efforts she knows various communities in United States are doing to ensure that they continue to instill creativity mindset among young children, high school and college students. Such efforts can be easily implemented in Malaysia if the government, higher institutions, professional bodies and industry join their efforts together.

4.1 Cultivating Creative Minds in Young Children

It is never too early to cultivate creative minds among young children. Instead of spoon-feeding students with information, young children in kindergarten need to be given toys, materials easily found at homes to create new things that are of interests to them. Children in primary schools should be exposed to interesting activities that can motivate them to learn science and mathematics. For example, students in elementary (equivalent to primary) and middle schools in United States are encouraged to use the MIT Scratch platform [15] to learn programming skill. With Scratch, one can program his/her own interactive stories/animated games, and share them with others in the online community. Scratch [15] is a free resource and enables young generation to learn how to think creatively, develop systematic reasoning skill, and work collaboratively. These are essential life skills in the 21st century.

There are also multiple websites with many interesting robotic projects using materials one can find at home for young children [16-18]. Typically, young children love to spend time doing interesting activities and having community centers organize small workshops where young children can do these robotic projects together help children cultivate creativity. Such activities not only allow them to learn how to work in teams early but also can excite them to learn more about science and consider STEM education.

4.2 Cultivating Creativity Among High School Students

To produce creative students, we must cultivate a classroom culture where students are allowed to let their minds roam around in an encouraging and supportive atmosphere. Typically, creativity happens not in exams where students are expected to spit out information that they memorize from what teachers say in class. Instead, having project based learning [19] helps high school students to flourish in creating new ideas. It gives students opportunities to build creative skills through exploration, creative thinking, brainstorming ideas with other students, evaluate feasible solutions and giving effective presentations to others about their solutions [19].

In project based learning [19], students work on a problem which allows them to solve a meaningful real-world problem over a period of time. Students conduct research to learn deeper relevant knowledge, develop critical thinking and communication skills. There are useful websites that provide information regarding how to incorporate project based learning into classrooms [20,21].

To encourage creativity, students at high schools can form different clubs which aim to solve societal problems in different domains. For example, students interested in solving climate change issues can form a club where they can seek donation support from communities to plant more trees, encourage students to bike to schools rather than drive. Students interested in ensuring every child has the opportunity to learn mathematics and science can form another club where they can organize weekend workshops to let primary school children in rural areas enjoy fun-filled activities involving solving mathematical problems that they encounter in their daily lives. Students interested in building things can form a club where they can help to build a community garden which allows others in urban community to enjoy greener scenery while they learn additional botany knowledge. Solving real life problems provide opportunities for cultivating creativity.

Middle and high school should have a maker space, equipped with varying tools and materials, where students can explore ideas and invent new things that are useful to their communities. In such a space, students can innovate, explore and build prototypes. Often our classrooms are set up too rigidly where students just sit and listen to what teachers say. Classroom should be redesigned to facilitate group discussions and have movable white boards for students to scribble their ideas and solutions.

Teachers in middle and high schools should be trained to encourage and support students in their creativity processes. Instead of teaching concepts by merely providing facts, teachers should use diverse daily life examples to motivate why students need to learn such concepts and also use different teaching formats, e.g., via having different teams conduct research about that topic and report back to class by creating posters of their research. Instead of merely testing students if they can memorize certain facts, teachers should evaluate if students know how to apply the concepts they learn in class. For example, instead of testing if a student remembers the equation for computing the volume of a cylinder, a teacher can test if a student knows how to solve a problem in a kitchen where he/she needs to pour fluid from a big cylindrical container into smaller containers.

Instead of merely relying on textbooks and lesson plans, teachers should introduce more unconventional learning material to encourage students to think outside the box and encourage them to dive deeper into the lesson. Teachers can google for free online resources that can help inspire them to come up with their own ideas. Teachers can also encourage students by having them watch Ted talks on interesting STEM topics. Role models plays an important role in the creative development of students in a class so arranging for them to listen to inspiring Ted talks can motivate them to pursue STEM education.

4.3 Cultivating Creativity Among College Students

Recently, several colleges and universities have started a variety of campus initiatives to teach creative thinking. Centers and institutions dedicated to creativity and innovation are formed. For example, Stanford University's d.school, Harvard Universtiy's i-lab, Lehigh University's Creative Inquiry Office. These initiatives hope to teach approaches to creative problem-solving, including design thinking, which is a core part of engineering education. Design thinking [22,23] is a methodology that leads students to break down complex problems into various stages to come up with creative solutions. Students go

through a discovery phase to understand the problems they need to solve, an interpretation phase to understand the constraints of possible solutions. Subsequently, they can brainstorm and explore the feasibility of their ideas during the idea formulation phase. Next, they create prototypes and solicit feedback during the experimentation phase, and refine them through a series of iterative designs during the evolution phase [22,23].

Universities and technical schools need to develop courses and programs devoted specifically to developing students' creativity. University of Michigan at Ann Arbor has an interdisciplinary creative-process course and Vanderbilt University has a program for creativity and innovation. Such courses help students develop the mindsets needed to approach ill-defined issues, understand different viewpoints, collaborate in interdisciplinary team settings to develop innovative solutions. Some universities such as Carnegie Mellon and Stanford now require students to take a course that develops creating skills before they graduate.

Lehigh's office of creative inquiry provides multiple opportunities for students to participate in project based learning projects throughout an academic year especially over summer. This office [24] supports a wide range of interdisciplinary initiatives that help students and faculty pursue new intellectual, creative and artistic pathways that lead to transformative new innovations, expressions and questions. One specific activity it organizes is the summer Mountaintop project experience. Mountaintop projects [37] are interdisciplinary deep dives where faculty, students, and external partners come together to explore a topic that they are passionate about, typically a project that creates new innovations with societal impacts. For example, in 2019, two professors from College of Education, Prof A. Bodzin and Prof T. Hammond partnered with Prof David Anasstasio from the Earth & Environmental Department to do an immersive virtual reality Lehigh River Watershed project. The project designed, developed and tested an immersive virtual reality application for STEM education to promote engagement and learning about spatial watershed features and environmental issues in the Lehigh River watershed. Team members learn Unity programming skills and developed immersive games for learning. Another project led by Prof Lori Hertz, a bioengineering professor, is related to fighting the malnutrition problem in Sierra Leone. Students designed several nutrition-dense foods at Lehigh which were then prepared and tested in Sierra Leone. The team consisting of students from bioengineering, financial engineering, psychology and health, medicine & society students work together to improve the recipes, investigate methods of preservation and packaging, analyze the products for nutrient levels and shelf-life and create a business plan on how to deliver such products at low cost to the populations in Sierra Leone that can benefit from such food products.

Engineering graduates have long been expected to have complex problem solving skills. Real life problems often encompass different aspects from technical to socio-economical to environmental. Any proposed solution needs to take into consideration various factors, e.g., scientific, financial cost effectiveness, etc. Often such factors are interdependent and trade-offs need to be made between ideal or practical yet affordable solutions. Developing creative minds at the early stage of their training help to build their confidence and cultivate better judgements while evaluating different solutions.

In the past, we typically arrange for engineering students to go to companies for internships where they can learn how to apply the knowledge they learn in class to real life problems in industries. However, internships need not just happen within companies. Practicing engineers can form non-profit organizations with support from the federal or state agencies to solve problems faced in different communities. For example, a rural community may need innovative solutions how to improve its agricultural productivity. Engineers can team up with engineering students to study the environment in that community, e.g., soil composition, weather to determine the type of crops the community can plant, how smart irrigation system can be deployed to ensure the crops are well irrigated, and how affordable technology can be designed to ensure the crops can be harvested efficiently and delivered to the right food markets. Another example is in the healthcare domain. Healthcare services may not be freely available in rural communities. Thus, engineering students can be charged with designing a smartphone application that allows residents in such rural communities to be seen by doctors far away and drones can be used to deliver medicines quicker to hard-to-reach areas.

4.3 Creating Intelligent Educational Tools for Personalized Learning

Typically students in a class come from different background. Thus, traditional classrooms with rigid class syllabus may not be suitable for all of them. In addition, in recent years, computing related majors such as computer science education has become very popular because young people realize that it helps to prepare them for better job opportunities. Universities are facing challenges to meet such increasing demand. Massive open online courses (MOCC) have been introduced to address this challenge. Such courses indirectly help students in countries which may not be that fortunate to have teachers with the right expertise to teach more advanced science topics.

However, there are challenges for teaching an effective MOCC class with diverse students' background. In 2016, Computing Community Consortium organized a workshop which brought together researchers developing educational tools based on technologies such as logical reasoning and machine learning, researchers in education, researchers with human computer interaction (HCI) and cognitive psychology expertize to brainstorm on what can be done to produce intelligent education tools which facilitate personalized learning. A copy of their report can be found in [25]. This author summarizes their findings in subsequent paragraphs for such findings help Malaysian educators see how they can develop innovative computer-aided solutions to provide personalized learning experience in big MOCC classes in Malaysia.

Recent technology advancements provide exciting opportunities to create more intelligent educational tools that can transform the manner in which students learn [25]. First, tutoring tools utilizing natural language processing, data analytics and logical reasoning have been created for automatic students' assessment, personalized instruction which includes targeted feedback and adaptive content generation for different groups of students with varying learning styles. Affordable cloud computing services have facilitated the large scale deployment of educational tools for data sharing and experimentation. Malaysian educators may want to explore if some of these

automated tutoring tools are publicly available and customize them to suit Malaysian local learning environments or develop similar tools themselves.

An example of an educational tool that can provide personalized learning is the AutoProf [26] which was developed to help students in a large introduction to programming course. Rather than having instructors grade students' programming assignments, this tool can execute a student's program on a properly chosen set of test inputs and then use the logical reasoning module to synthesize a variant of the student's program that works correctly if the student's submission does not work [25]. AutoProf then highlighted the lines of codes that need to be changed and provide hints to students on how to fix them. This tool has been shown to be effective by MIT researchers in its introductory programming course.

In addition, one can develop learning analytics tools utilizing machine learning to help students and instructors keep track of the learning progress and recommends the next best learning activity for a student based on his/her progress to date. For example, a tool described in [27] provides personalized predictions of a student's comprehension and predict his/her grade in the class. If a student's performance in a class is low, then he/she is referred to e-Tutor, an AI system [28] which provides personalized remedial help for the student.

Furthermore, researchers in Natural Language Processing (NLP) and HCI are developing tools and techniques which allow students to interact naturally in their personalized learning environments [25]. For example, NLP-based applications have been created to automatically generate factual-based questions in new subject matters, support group discussions of reasoning tasks and automatic grading of essays. Educational games involving virtual reality technology can also be developed to help motivate students to learn new concepts. Visual interactions are used in some programming tools to help students see what happens when a program executes different lines of codes, e.g. Python Tutor [29]. One can also solicit help from cognitive science researchers to identify effective education tools for personalized learning. Such researchers can deploy technologies to monitor if students are attentive or engaged in classes. They can also design experiments to evaluate what types of interventions are more effective in improving learning outcomes.

4.4 Creative Inquiry Activities Led by Industries and Professional Bodies

4.4.1 State/National Level Competitions

Industries and Professional Bodies can help to promote creativities through activities that they organize. For example, annual state and national robotic competitions at primary, high school and college levels can be organized to encourage our young generation to produce innovative solutions that are useful to society. For example, designing a low cost smart wheelchair that allows seniors with disabilities to be able to live more independent lives.

To promote data science related research, data mining related challenges such as those organized by Kaggle can be organized. Hospitals can pool together their healthcare data and professional bodies can organize a healthcare data mining challenge. For example, Amyotrophic Lateral Sclerosis (ALS) is a fatal neurodegenerative disease with significant heterogeneity that leads to muscle weakness and gradually impacts patients' body functions leading to eventual death. Though the average survival is 35 years from the onset of symptoms, ALS survival is markedly variable ranging from several months to over a decade. Because of this heterogeneity, ALS clinical trials typically require large number of participants with clinicians spending much time on analyzing the survival patterns and hence such a process is highly inefficient. Thus, the DREAM ALS Stratification Prize4Life [30] challenge was organized to better understand patients' profiles and seek mathematical tools to predict the ALS progression so that personalized ALS treatments can be given to ALS patients. The main goal of the challenge is to forecast disease progression more accurately based on 3 months data of that patient.

Similarly, Kaggle often organizes competitions in different business sectors where data mining researchers/students from all over the world can design models that address a particular topic and compete for a monetary award. For example, there is a Jane Street Market Prediction [31] competition in October that lasted 3 months where different data mining teams submit a model that can predict the financial markets. Such competition is organized to find a useful data mining model that can help to ensure that products would remain at "fair values", not undervalued or overpriced. Developing such a model is very challenging. Each team is given market data from a major global stock exchange and will develop their own quantitative trading model to maximize returns. Such competitions often motivate data mining researchers to come up with better techniques in a fun way. Another example is the multiple autonomous driving related challenges organized by companies such as Baidu Apolloscape [32]. Lyft [33] where multiple autonomous driving datasets are shared by these companies for researchers develop deep learning models for object detection, tracking and trajectory prediction tasks. Leaderboards for different tasks are created so that data mining researchers can boast about how good their developed models perform. Another site with similar ideas is the Kitti Benchmark Suite [34].

4.4.2 Partnership with Top Tech Companies & Non-Profit Organizations

Industrial engineers and researchers should play more active roles in shaping the curriculum at universities and technical colleges since they are more aware of what additional skills new graduates need to have in order to be effective at their workplace. Advisory councils with industry members and university alumni need to be formed at universities to provide constant feedback to universities on how they can improve their academic programs.

In Malaysia, we already have internship opportunities for engineering students. Such industry attachment in industry is important for it allows students to gain hands-on experience in applying the knowledge they learnt in classes. However, there are more industry sectors can do. The industry in different sectors can help to shape new programs that can meet their needs. For example, Boston University recently introduced a MS in Robotics & Autonomous Systems program where students can finish their degree in 2-3 semesters. Robotics & Autonomous systems have become a part of everyday life and an exponential job growth in multiple areas, e.g., medicine or transportation, are anticipated. Paid internship placements with industry partners is part of that MS program. Students complete advanced course

work and gain hands-on experience through paid internships. The all-rounded educational plan allows them to be ready to face challenges in real jobs upon graduation.

Besides exposing students to how engineers solve real problems, faculty members who educate students need to gain similar experience too. What is less common in Malaysia is to grant faculty members a sabbatical year or one semester to work at industry research laboratories so that faculty members can sharpen their knowledge and bring back more exciting and relevant topics to teach in their classes. Intel and Motorola used to have R&D departments in Malaysia and I hope they still have such departments. University administrators should have communications with them to see how to create new sabbatical leave opportunities for faculty at their R&D departments. A recent 2019 news article also highlighted the AI Park that Malaysia Ministry of Education (MoE) has spearheaded with partnership with SenseTime. SenseTime is a fast growing artificial intelligence related company with many talented engineers. If the Ministry of Education can strike a deal with SenseTime to provide internship opportunities for both engineering students and faculty, it will definitely help to jump start the artificial intelligence education and research among Malaysian universities.

Aside from internship opportunities, industry researchers and engineers are encouraged to give technical talks at universities so that students can be exposed to technical problems that practicing engineers deal with at work and solutions that they come up with. Having constant communications between the industry, professors and students at higher education helps to ensure that universities can produce graduates who can contribute to the industry immediately after they graduate.

Typically research partnerships between academia and industry can produce innovative solutions faster. A recent example at Lehigh during the pandemic period shows how useful such collaborations can be. A recent innovation was created by an ECE professor, Prof Nelson Tansu and his research team at Lehigh working together with his industry partner during the pandemic. In mid March, Prof Tansu were asked to find a safe and effective way to extend its existing supply of personal protection equipment (PPE) especially the N95 masks for their medical professionals by Dr. Christopher Roscher, an anesthesiologist at St Luke's University Health Network. Dr. Roscher was interested in exploring the use of UV light for PPE decontamination. Prof. Tansu and his colleagues collaborated with Dr. Roscher via Zoom meetings, phone calls and hundreds of emails and text messages. The collaborative team completed an initial prototype and installed it at St Luke in fewer than 3 weeks. They called their invention "Bug Zapper" [35]. In addition, industry researches are often short-term but during the process of solving short-term problems, industry researchers may identify longer-term problems that they need to solve. Thus, having MoE provide some research grant opportunities where industry and faculty can apply to work together will definitely help to promote innovations in Malaysia.

Besides government partnering with universities, this author hopes that philanthropists in Malaysia can also play important roles in shaping the future of young Malaysian engineers. There are many successful businessmen and business ladies in Malaysia. The hope is that they can collaborate to form a non-profit organization similar to the Gates Foundation that can give young or vulnerable population in Malaysia opportunities to have better lives through deploying affordable technology solutions. For example, the Gates Foundation [36] often work with partners worldwide to tackle critical problems in five program areas, namely (i) Global Health Division aims to reduce health inequities, (ii) Global Development Division focuses on improving delivering health products and services to the world's poorest communities, (iii) Global Growth & Opportunities division focuses on creating and scaling market-based innovations to stimulate inclusive and sustainable economic growth, (iv) the United States Division works to improve US high school and postsecondary education and support vulnerable children and families in Washington State, and (v) the Global Policy & Advocacy Division seeks to build strategic relationships and policy that can help advice their work. Non-profit organizations in Malaysia may not be able to replicate all the activities but having a few activities that incentivize young Malaysia engineers to come up with affordable technology solutions to solve local/regional problems will go a long way in encouraging them to come up with innovative solutions.

5.0 CONCLUDING REMARKS

In this paper, the author first shared her own research journey from industry to academia and from Malaysia to United States. She shared some testimonies about how she overcame some obstacles in life to become an effective researcher. Subsequently, she shared some of the factors that if young researchers can adopt to help them to become more effective researchers. Last but not least, she shared some of her thoughts on what educators, university administrators, Ministry of Education, engineering professional bodies and industry experts can collectively do to promote innovative thinking among young Malaysian engineers. ■

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Soon, F. C., Khaw, H. Y., Chuah, J. H., & Kanesan, J. (2018). Hyper-parameters optimisation of deep CNN architecture for vehicle logo recognition. *IET Intelligent Transport System*, 12(8), 939-946. https://doi.org/10.1049/iet-its.2018.5127.

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