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REDUCING PROCESS WASTES USING MACHINE LEARNING MODEL – A PERSPECTIVE OF INDUSTRY 4.0

Assistant Professor Dr Elango Natarajan

Sustainability is a world agenda. Success in global sustainability hinges strongly on the commitment of the entire world community, not just any individual country. Since the manufacturing sector can potentially negate sustainability, it is seen as a key player in the success of global sustainability. A key factor which is working against sustainability in manufacturing is the rising amount of wastage. Reducing wastage in manufacturing is therefore one of the ways to support the global drive for sustainability. These include wastage in energy, labour, material and the other critical resources of manufacturing, including water. This article highlights the issue of waste in manufacturing, and proposes a technical approach to reduce such wastage, clearing the way to achieve sustainable manufacturing.

There is no denying that the prime aim of any business is to increase productivity and make the company profitable. The wastage of materials, labour, and machine time during production is a major contributor to low productivity and reduced profit. The big challenge in sustainable manufacturing is how best to reduce waste from the production without undermining the effectiveness and efficiency of the process. The waste in production include the excessive consumption of energy, high usage of materials and labour, rejection of products in the inspection, and operational failure during product use. The wastage, also known as 'muda' in lean manufacturing terminology includes over-production, long waiting time, non-optimised transportation, inappropriate processing, excess inventory, excess motion, and defects. The solution to these issues lies in understanding the production process well and designing the product accordingly.

Content

Manufacturing essentially involves the assembly of parts. The parts are manufactured closest to the net shape through various manufacturing processes such as drilling, milling, turning and shaping. The operator decides the operating conditions for any machining process based on his past experience or the data provided in the operations manual. The parameters include speed, feed, depth of cut, cutting tool selection, and coolant condition. They are decided and set beforehand at the start of production. These parameters play a vital role in the quality of the finished product. The machined part is accepted, when checked for quality, only when it fulfils the limit of acceptance prescribed. Otherwise it is rejected as waste. The cutting conditions influence the energy consumption. The setting of the best cutting parameters will therefore assist the company to avoid the rejection of machined parts, as well as reduce energy consumption. Industry 4.0 has been hailed by manufacturers as a valuable tool to achieve their overarching business goal of high productivity and lucrative profit. One of the core technologies driving IR 4.0 and this new wave of ultra-automation is Industrial AI and Machine Learning.

Machining is known to be a highly nonlinear element. Distributed Process Planning (DPP) can be adopted to segment the machining process planning into supervisory planning, execution control and operation planning. In the supervisory planning, the generic processes are obtained based on machining features and machining knowledge. In execution control and operation planning, the resource-specific processes including machine tool selection, cutting tool selection, optimum machining parameters and machining conditions are carried out. Each of these processes involve precise decision making that leads to the success of production.

My suggestion for smart and sustainable manufacturing is to develop a machine model for the operations such as tool selection, cutting or machining processes, etc. The model can be built by gathering the data sets from past experiences. The user can select the optimum conditions for cutting from the predictive model through which the exactness of the required surface finish can be achieved with no waste. The predictive Machine Learning (ML) model can be updated using the recent data sets as well.

Given a scenario over here:

For machining of a part in CNC lathe, one has to select the appropriate tool, and set appropriate cutting condition (speed, feed, depth of cut, coolant, etc). We will build a model which can predict the cutting conditions based on the requirement of the surface finish of the part. If there is a new task that is to be carried out, the operator can take the predicted cutting condition with respect to his expected surface finish of the part. He can then use such optimum cutting condition to produce the part to the exact expectations. Meanwhile, the machine model related to tool monitoring would suggest to the operator the condition of the tool and predict the right tool to be used for the operation. This step is important for any company as the use of precision tool for simple operation leads to waste.

The challenge in building the machine model is to collect enough data sets for training and validation. So, we may start the training with at least about 100 data sets, which are experimentally determined. Once the model is built, we may validate the predicted data experimentally and input the new data set into the model for tuning. This iterative way of tuning the model will prepare more effective ML models.

We now know that wastage in manufacturing stands in the way of making manufacturing more sustainable. Recent developments in IR 4.0 technology, especially machine learning and artificial intelligence, offer new opportunities to reduce such wastage. Research to develop such technologies is the way forward if we are to make manufacturing smarter and more sustainable. Smart manufacturing will contribute effectively to support the global agenda on sustainability.

CLEAN AND HALAL: THE FIRST PROCESS OF QUALITY FOOD PREPARATION

Assistant Professor Chef Mohamad Fadzly Che Omar

Halal refers to all good (clean and pure) food that can be eaten, has high quality, and is clearly good for our health. Good food must come from good sources, and all the processes to make it and the ingredients used must follow guidelines provided by Islam. In Malaysia, the Department of Islamic Development Malaysia (JAKIM) is the responsible body appointed to conduct halal certification, working together with the states' Islamic Religious Department. All matters related to halal certification are fully conducted by JAKIM including product and premise auditing, halal monitoring and enforcement, and others in order to maintain the quality of halal products.

Halal is very much connected with hygiene especially when it involves food because food is closely related to our body. When hygiene is neglected, humans are unable to control their body because they are prone to get food poisoning due to unhygienic food. All daily activities will then be affected including worshiping Allah. If we refer to various books of fiqh, cleanliness is always the earliest topic discussed. This shows how important cleanliness is in Islam. We are ordered to eat only good food (clean and nutritious) provided to us on earth. The advantage of eating clean food is that it can make our body healthy and energetic.

People all over the world are beginning to acquire awareness towards clean food. They are mostly starting to prefer halal food because the level of hygiene and nutrition in halal food is more reliable. The demand for halal food is high worldwide due to the quality, and also the thorough research and process. Certification of halal products has made halal food in great demand especially in countries with high Muslim populations.

The term 'halal' is not subjected to the prohibitions clearly mentioned in the Quran (carcass, blood, pork, slaughtering animal without saying Bismillah) only but also involves some basic food processing procedures including personal hygiene, premise cleanliness and food hygiene in order to produce quality food which is beyond doubt clean, healthy and halal.

Personal Hygiene

The first step in food processing is personal hygiene. Personal hygiene is essential because the quality of food substantially relies on the ones handling the food. Food handlers must first ensure their own cleanliness by cleaning themselves before working and by wearing clean attire in accordance with the premise's SOP. They need to be neat in order to work with ease to ensure tasks run smoothly. They too need to ensure that nails are cut short and hair is trimmed in order to maintain food hygiene. After using the restroom, hands need to be washed thoroughly as taught in Islam. These steps must be cautiously practised by all parties involved in food processing in order to protect food from exposure to unhygienic matters which can then ruin the food and affect others.

Cleanliness of Processing Premise

Islam forbids acts that bring harm to other people whether to our family or others in the society. Therefore, precautionary features must be made available such as different entrance and exit doors, and windows that allow good ventilation during food processing to avoid hazards for the workers.

Everything that can invite harm to our life is strictly prohibited in Islam and must be avoided at all cost. This is in accordance to security formula in Islam, Jilbu al-Maṣōliḥ Wa Dar'u al-Mafāsid (creating good, rejecting bad and eliminating harm). The premise or any food processing area must be clean, free from any impurities. The floor and walls must always be in good condition. The place must be free from oil and flour spills, dust and others. This is to avoid cockroaches, flies and so on. Drains need to be clean to prevent clogging which will be a breeding ground to mosquitoes. Knives, spoons, forks, ladles, pots and pans, plates, and cutting boards must be clean and washed with detergent after every usage. Otherwise, it can cause a disastrous effect if food becomes contaminated when cockroaches, flies, other insects or animals disturb food ingredients such as flour and milk. This can make them spoilt or the water supply may be contaminated with bacteria. Other than that, ensure that all kitchen utensils are not used to cut or is not touched by swine or dog. All garbage bags need to be tied before throwing them in the garbage bin.

Unhygienic surroundings not only affect workers but also customers. This is emphasised in Islam through the method of Qawaid Fiqh that was taught by Rasulullah PBUH which is Lā Ḍarār Wa Lā Ḍirār (there should be no harm and cannot be harmful).

Food Hygiene

The next step is to ensure ingredients are in good condition. Good condition means permissable animals are slaughtered according to Islam. The discussion about animal slaughtering can be found in 'Fiqh 4 Mazhab' book, chapter 1, 2 and 3 or any other Fiqh books.

Animals which are slaughtered or do not need to be slaughtered (fish, squid, shrimp, crab and so on) need to be clean from blood, the internal organs must be removed, then rinsed and drained before storing them in the freezer or cooking. Meat and poultry (chicken, duck, cow, goat, buffalo, etc.) slaughtered according to Shariah Law must not be put together with unlawful (haram) butchery which eventually will make it difficult to differentiate between halal and haram. This is because when halal and haram are mixed together, automatically all are considered haram, based on a Fiqh method Iẓa Ijtama'a al-Ḥalāl wa al-Ḥarām Ghuliba al-Ḥarām (when halal and haram mixed, they are considered haram). The same goes for food mixed with alcohol; it is considered haram.

Oil used for cooking must not be exposed and must be covered after every use and not be used too many times. Ingredients used in cooking such as spices, soy sauce, milk, sauce, flour and so on must be used before expiry date so that it would be safe to consume. Selecting fresh fruit and vegetables is very important in ensuring food produced is at the maximum level of quality for customers who want nutritious food. It is a good practice to choose nutritious food over junk food for our customers' well being.

Conclusion

Halal is a long process which considers many factors in food processing. Good personal hygiene, clean premises and hygienic ingredients are some essential basics which all parties involved must adhere to whether the product is to be exported, distributed at local market or served at home. Today, the food industry is growing widely and rapidly. As the food industry grows, so does technology and more food products are being produced hence the application of studies, interpretation of fiqh method and scholars' view as reference are extensive in the effort of ensuring quality and accuracy of halal products.

FROM BIOTECHNOLOGY TO MANGROVES

Associate Professor Dr Eric Chan Wei Chiang

The case for Mangrove conservation

Conservation versus exploitation is a decade old debate. This year, the debate has shifted to focus on mangroves. A call has been made in the New Straits Times to ban the conversion of natural mangrove reserves for commercial purposes on the eve of 26 July 2020, the International Day for the Conservation of the Mangrove Ecosystem. More than 95 per cent of the world's mangroves are in the tropics, and 40 per cent lie within Southeast Asia, which is acknowledged as the global hotspot of mangrove species diversity.

Calling for an indefinite ban on mangrove conversion may sound like a radical sentiment. However, it must be remembered conversion of mangrove land for commercial purposes have not yielded good results. Mangroves along the Straits of Malacca have been converted into oil palm estates. Doing so requires building a coastal bund and protecting it against erosion. Coastal bunds in many cases have burst causing seawater intrusion and subsequent loss of the oil palm estate.

Rhizophora apiculata

Rhizophora stylosa

Avicennia rumphiana

Sonneratia alba

Mangroves are more valuable retained as they provide a myriad of ecosystem and socioeconomic services. The main threat to mangroves is that they do not have many charismatic species and perceived to have a lower biodiversity and carbon sequestration than tropical rainforest. The latter is untrue as the amount of blue carbon sequestered by mangroves has been shown to be comparable to tropical rainforests. Furthermore, despite having fewer species than tropical rainforest, mangroves trees are good candidates for bioprospecting.

Involvement in mangrove research

Dr Eric Chan Wei Chiang is a biotechnologist by training, but his interest in mangroves started early as his father, Dr Chan Hung Tuck, a former senior director in the Forest Research Institute Malaysia was a prominent mangrove researcher. It was not an easy shift for his research focus from bioactive properties to mangroves but he started by studying the bioactive properties of coastal plants and mangrove trees. These early studies were aimed at giving additional economic incentives to conserve mangrove.

Dr Eric was publishing on a regular basis but being in his comfort zone, his research still had a minimal impact on mangrove conservation. He jumped at the chance when Academician Senior Professor Dato' Dr Khalid Yusoff, Vice-Chancellor and President of UCSI University called for a taskforce to apply for research programme grants in 2015 aimed at the remediation of Putrajaya Lake and in 2017 aimed at the conservation of ecosystems along the Straits of Malacca.

Despite not being successful in procurement of any research programme grant, the discussion resulted in his first Fundamental Research Grant Scheme (FRGS) which was entitled, "Creation of a Root Targeted Delivery Vehicle for fertilizers using cellulose from duckweed and other agricultural waste biomass". This allowed him to start a small research team.

Dr Eric (2nd from the right) and Dr Wong (left) with their research team preparing for their presentation at the Green and Sustainable Chemistry Conference in Berlin, Germany. Their presentation won the Top 5 Finalist of the Elsevier Green and Sustainable Chemistry Challenge 2015.

Reaching out to others

No man is an island and to make a difference, Dr Eric had to engage like minded individuals. With the FRGS funding, he formed a nascent research group with fellow biotechnologists, Associate Professor Dr Wong Chen Wai and two of his postgraduate students. In 2015 they were selected as the Top 5 Competitors of the Elsevier Green and Sustainable Chemistry Challenge 2015, out of 500 proposals submitted globally. In April 2016, they had presented the proposal on the "Sustainable Fertilizer Delivery Systems and Biosorbents" at the Green and Sustainable Chemistry Conference in Berlin, Germany. The team had also presented their findings at the Green Chemistry New Zealand 2019 Conference where two of his students won prizes.

This year, despite the global pandemic, Dr Eric and his team are spreading their wings even further, by linking up with external partners in Universiti Malaya, Universiti Teknologi PETRONAS and Sabah Forest Research Centre to apply for research programme grants aimed at engaging coastal communities in rehabilitating mangroves, measuring the blue carbon sequestered by rehabilitated mangroves, using wood from rehabilitated mangroves to produce fuel, and studying the life-cycle and sustainability of this technology. Together with his research team, they are committed to realising Senior Professor Khalid's vision to, **"Go beyond; Be Profound: Make a difference"**.

Dr Eric (left most) and Dr Wong (2nd from right) with their postgraduate students at the Green Chemistry New Zealand 2019 Conference hosted by the University of Auckland. Two of their postgraduate students won awards at the conference.

CANCER BIOLOGY AND DRUG DISCOVERY
Associate Professor Dr Cheah Shiau Chuen

Associate Professor Dr Cheah Shiau Chuen is a cancer biologist who have placed great interest in cancer biology and drug discovery. Dr Cheah's interest mainly focuses on understanding the cancer physiology and targeted treatment, which include apoptosis; NF-KB, Wnt and Notch targeted pathway; metastasis, angiogenesis and cancer stem cell in tumour microenvironment and cancer nanoparticles drug delivery using in vitro and in vivo models.

Dr Cheah graduated from Universiti Kebangsaan Malaysia (UKM) with First Class Honours in Bachelor of Science (Hons) Biochemistry as well as a Doctor of Philosophy (PhD) in Biochemistry. Being trained in cancer biology, Dr Cheah has rapidly excelled in the field after obtaining her PhD in 2006. In her profession, she serves as a member of the European Association of Cancer Research and the American Society for Biochemistry and Molecular Biology.

Dr Cheah was a National Science Fellowship scholarship recipient and a two-time FRGS grant recipient. In 2003, she was awarded with the High Impact Research Awards. Subsequently, she was awarded with the UCSI Top Researcher Award and Promising Researcher Award in 2016 for her research achievements and contributions. Owing to her achievement as a young academician, she was awarded the Trialect Fellowship that allowed her to be attached to the Institute of Pascale, Italy. Dr Cheah has been invited as a speaker for GE Healthcare's Cellular Imaging Symposium and Annual University Research Performance Forum on Effective Institutional Research Performance Management.

Dr Cheah made substantial contributions to the understanding of pathophysiology of complex diseases. As a principal investigator in FISH detection on Gene Rearrangement of Malaysian Lymphomas in her 2014 FRGS, she studies the correlation on genetic profile and gene expressions on malignant lymphoma which can throw light on the utility of these results in delineating poor prognostic malignant lymphoma subtypes, and failure to respond to chemotherapy. Lymphoma is a common cancer occurring in Malaysia, ranked 4th as reported in 2019 Malaysia National Cancer Registry, which concurs with worldwide incidences.

Recent studies indicated that cases with myc, BCL-2 and BCL-6 gene rearrangements are associated with poor prognosis, and failure to respond to chemotherapy. Additionally, myc gene translocation is also seen in transformed tumours. Her team aims to elucidate the incidence and pattern of double- (2 genes rearrangements) and triple-hit (3 genes rearrangements) of c-MYC, BCL-2 and BCL-6 gene translocation profile in Malaysian cases of B-cell non-Hodgkin lymphoma. It is also to determine if myc gene expression can be a surrogate marker for the presence of above gene translocation and investigate the role of EBV in initiating gene rearrangement and downstream pathway alterations.

In collaboration with Sunway University, Monash University, Duke-NUS Graduate Medical School, Singapore General Hospital, Singhealth Tissue Repository as well as Institute of Cell and Molecular Biology (IMCB), they proposed a new hypothesis to the clinician on the markers towards prognosis and response to chemotherapy. Furthermore, her team's investigation has led to identify genetic profile and gene expressions that are associated with poor prognosis. Hence, this provide further hints and failure to respond to chemotherapy. To date, several publications were produced from this work, and another manuscript is currently under preparation.

Dr Cheah's recent involvement in Nasopharyngeal Carcinoma (NPC)

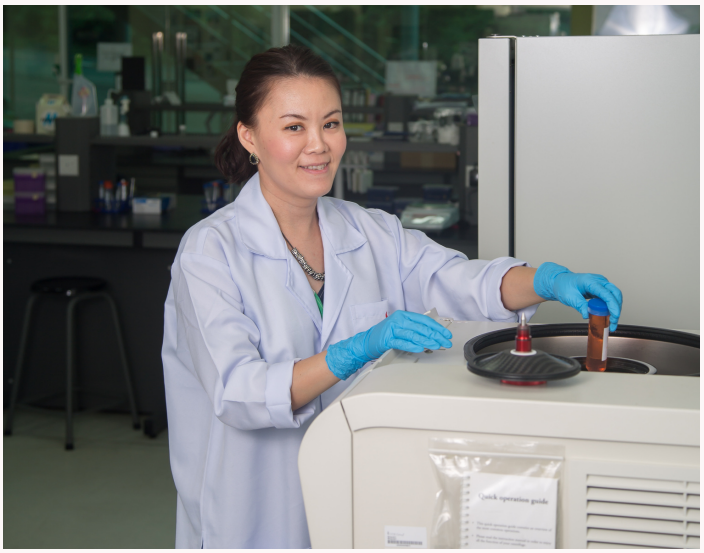
Dr Cheah recently has shifted her interest to Nasopharyngeal carcinoma (NPC), one of the most aggressive head and neck cancers and frequently metastasises to distant lymph nodes and organs. NPC is a unique endemic to Southeast Asia, hence not adequately studied by most of the large-scale international cancer initiatives. The collective rationales hence urge the need to comprehensively investigate the fundamental mechanism of metastatic NPC in this country. She is currently working with numerous groups of renown cancer scientists both locally and globally, attempting to map the genomic and epigenomic landscape of nasopharyngeal carcinoma. On top of that, Dr Cheah's team is also identifying the signature biomarker of early metastasis event in NPC using heterotypic multicellular tumour spheroid (MCTS). NPC and its complex tumour microenvironment (TME) are essential for various aspects of macroscopic tumour growth, maintenance, invasion, metastasis and angiogenesis.

Dr Cheah has close collaborations with universities, research institutions, hospitals and the industry. She works closely with Professor Rais Mustafa from the Faculty of Medicine, Universiti Malaya on a MOHE-High Impact Research Project that focuses on Molecular Mechanisms of Drug Action. Her team targeted natural compounds towards few diseases and study the efficacy and mechanism of action. Few conclusions were drawn from their findings. Collectively, the findings from her team provide novel understandings of the natural compounds, which is crucial for the development of therapeutic agents. Their collaboration led to publications in reputative journals, several high impact factors have been cited and referred by numerous groups of scientists of the field.

On a separate note, Dr Cheah also sought international collaboration with the University Medical Center of Groningen (UMCG), Netherlands. She is currently supervising a PhD student with Professor Frank from Groningen Medical School. The study focuses on cancer stem cell as a therapeutic target. The research on cancer stem cell as a therapeutic target has led to several manuscripts which are currently under preparation.

Dr Cheah's partnership with the industry - MediPearl Pte Ltd, Singapore on various Traditional Chinese Medicine efficacy and formulation resulted of 11 filed patents for medicaments from plant materials and herbal medicine for osteoporosis and related conditions in Great Britain, China, United States, Spain, Europe, Taiwan, Singapore, Malaysia, Australia, Hong Kong. Furthermore, her collaboration with Dr David Ross Appleton, Principal Scientist in Sime Darby Technology Centre since 2009 had led to establishment of phytochemicals library and few publications in ISI Tier 1 and Tier 2 thus far.

As a cancer biologist, Dr Cheah hopes that one day in the near future she would be able to make significant contributions to the science through uncovering the targeted therapy specifically on cancer stem cell and tumour microenvironment and that the discoveries could be applied to the bedsides eventually.



Dr Cheah handling sample extraction during her research analysis.

INVERSE PROBLEMS IN IMAGE PROCESSING: A GATEWAY TO UNDERSTANDING MACHINE LEARNING MODELS

Dr Tarmizi Adam

Introduction

Image processing has been a long-standing field and has attracted numerous researchers for several decades. Image processing can be seen as an off-shoot of a wider class of field called signal processing. Image processing uses both advance and classical techniques in signal processing to acquire, store, and manipulate images.

Image restoration is a popular research within image processing where it aims to restore corrupt images. Most image data is captured with certain degrees of corruption especially in image data that is captured by an imaging device. Image restoration may not be necessary for image capture via personal handheld imaging devices as multiple snaps of the image can be captured to compensate for the corruption until an uncorrupted image is obtained. However, recapturing an image may be too costly in certain applications such as satellite imagery of astronomical images. Therefore, there is a need for restoring the captured corrupted image employing fast and efficient algorithms. The restoration of these corrupted images can be modeled as an inverse problem. What is an inverse problem in the context of image restoration?

Imagine arriving at a crime scene where a dead body with a pool of blood and broken spectacle on the floor were observed. The chairs and tables in the room were also turned and moved in odd positions while the windows were broken. The walls in that room were also marked with several bullet impacts. The crime scene investigator task is to gather and examine as much information as possible from the crime scene to be able to have an idea on whatever happened before the crime started.

Information such as how many people were involved? How many shots were fired? Trajectories of the bullets, The true positions of the tables and chair before the crime happened, who was the owner of the broken spectacles? and so on. All this information are pertinent to "reconstruct" or "create" the original scene before and during the occurrence of the crime. Then a "solution" to the crime is needed which would probably result in the capture of those involved in the crime. The "solution" for the above situation mainly involves three steps i.e., observations, processing, and results. The observations from the crime scene with limited information and clues, an estimation of what would have happened during and before the crime will yield results (the capture of the murder suspect). In mathematical science and engineering, this process is called inverse problems.

General overview of a very popular inverse problem in image restoration known as the total variation (TV) image restoration model and the importance of the TV models and how does it relate to understanding other machine learning models will be discussed here. The term "modern" here does not mean that the ideas are novel and new. These "modern" techniques are built upon classical results, but interest in these "modern" techniques has only been re-surging in the past decade due to the celebrated compressed sensing theory.

Inverse problems: A more technical view

How to restore or reconstruct an observed a blurry noise corrupted image **y** back to an uncorrupted image **x**? A mathematical equation below was construed:

$$\mathbf{y = Hx + n} \qquad \textbf{(1)}$$

This equation shown that the corrupted observed image **y** is assumed to be obtained by adding a noise **n** to an uncorrupted image **x** and **H** is the operation that makes the image blurred. This image degradation model is illustrated in Figure 1.

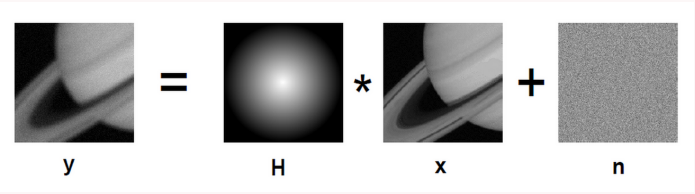


Figure 1: An illustration of the forward inverse problem model (1). Usually, only one observed corrupted image y is presented. The objective is to infer the clean image x with some or limited knowledge of the blur H and noise n. The symbol ∗ in the picture is the convolution operator and usually models blur in images

Again, the question is by only having the observed noisy and blurry image **y**, some information about the blurring operator **H** and the noise statistics of **n**, can we get back or at least have a good estimate the original uncorrupted image **x**? This inverse problem at hand is known as image restoration in the image/signal processing community and has been studied for decades.

Early and classical methods for solving the inverse problem **(1)** include the Tikhonov regularisation **(2)**, however, Tikhonov regularisation exhibit several limitations. For example, image recovered from this method are often smoothen out hence, hindering a sharp and crisp looking restored image. To resolve this issue, a very effective method called the total variation (TV) model was introduced.

$$\underset{\mathbf{x}}{\text{minimize}}\, F(\mathbf{x}) = \frac{1}{2}\|\mathbf{H}\mathbf{x} - \mathbf{y}\|_2^2 + \lambda\|\mathbf{x}\|_2^2. \qquad (2)$$

Total Variation (TV) Model

First introduced by Rudin, Osher, and Fatemi, TV denoising has played a significant role in image and signal processing. Unlike the Tikhonov model (2), the success has been due to the ability of TV in estimating piecewise constant images and jump discontinuities (corresponding to edges in images) which permits restoration of sharp images. Another factor that can be attributed to the success of TV is its convex property which permits fast convex optimisation algorithms to be used when solving the TV minimisation problem.

The TV model **(3)** is quite similar to the Tikhonov model. However, there is a slight change in the right most term **D**, a regulariser.

$$\underset{\mathbf{x}}{\text{minimize}}\, J(\mathbf{x}) = \frac{1}{2}\|\mathbf{H}\mathbf{x} - \mathbf{y}\|_2^2 + \lambda\|\mathbf{D}\mathbf{x}\|_1, \qquad (3)$$

The matrix **D** is called the first order difference matrix. To solve the optimisation problem **(3)**, one more component to understand which is the understanding of optimisation algorithms.

Optimisation algorithms: Alternating direction method of multipliers (ADMM)

Mathematical optimisation is a huge topic and has been a subject of research for several decades. The alternating direction method of multipliers (ADMM) is a very popular optimisation algorithm that has been used extensively for solving minimisation problems. TV model is formulated into ADMM form **(4)** which includes utilisation of augmented Lagrange functions to solve the TV image restoration problem.

$$\mathcal{L}_{\mathcal{A}}(\mathbf{x}, \mathbf{v}, \mu) = \frac{1}{2}\|\mathbf{H}\mathbf{x} - \mathbf{y}\|_2^2 + \lambda\|\mathbf{v}\|_1 - \mu^{\top}(\mathbf{v} - \mathbf{D}\mathbf{x}) + \frac{\rho}{2}\|\mathbf{v} - \mathbf{D}\mathbf{x}\|_2^2, \qquad (4)$$

Algorithm 1 needed to be programmed in a computer to solve (4) numerically. The programme implementing Algorithm 1 on a computer will run until some stopping criterion is satisfied. Examples of stopping criteria that are often used are the maximum number of iterations the algorithm should run or if the error between the current iteration and the previous iteration of the restored image has reached a certain value. For further details, please look into references 9, 10, 11, and 12 as below.

Algorithm 1. ADMM for minimization problem.

Initialize $\mathbf{u}^0$, $\mathbf{v}^0$, μ^0, $k = 0$ and $\rho > 0$
while some stopping criterion not satisfied
1. $\mathbf{x}^{k+1} = \arg\min_{\mathbf{x}} \frac{1}{2}\|\mathbf{H}\mathbf{x} - \mathbf{y}\|_2^2 + \frac{\rho}{2}\|\mathbf{v}^k - \mathbf{D}\mathbf{x} + \frac{\mu^k}{\rho}\|_2^2$
2. $\mathbf{v}^{k+1} = \arg\min_{\mathbf{v}} \lambda\|\mathbf{v}\|_1 + \frac{\rho}{2}\|\mathbf{v} - \mathbf{D}\mathbf{x}^{k+1} + \frac{\mu^k}{\rho}\|_2^2$
3. $\mu^{k+1} = \mu^k + \rho\left(\mathbf{v}^{k+1} - \mathbf{D}\mathbf{x}^{k+1}\right)$
4. $k = k + 1$

end while

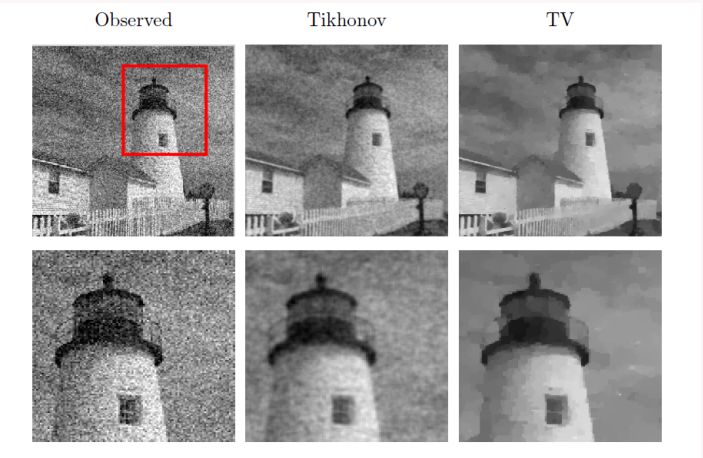


Figure 2: Denoised Light house. Compared to the Tikhonov denoising which still exhibits coarseness due to the noise, TV restoration manages to almost eliminate the additive noise.

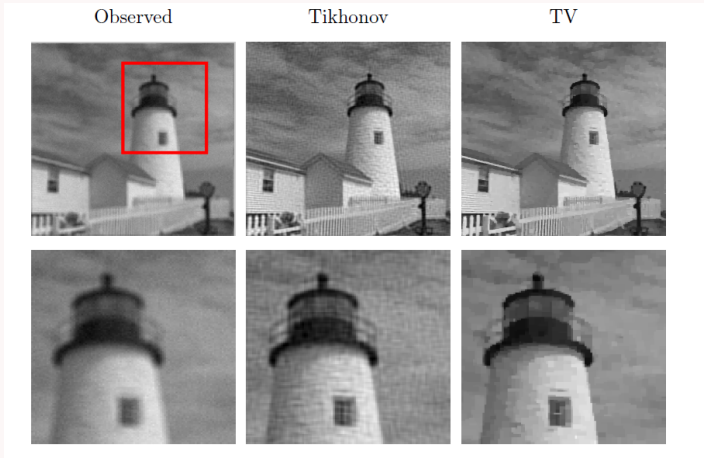


Figure 3: Deblurred Light house. Notice the sharp image obtained by TV restoration compared to the Tikhonov restoration.

Application

Figure 2 and 3 illustrates the superior denoising and deblurring capabilities of TV model when compared to the Tikhonov model. Results in Figures 2 and 3 were obtained by running Algorithm 1 on a computer. Note that the image restored by TV consists of sharp edges and the additive noise is almost eliminated totally. For the Tikhonov restoration, the restored image suffers from some coarseness and the image edges are softened out with some blurry effects. The results in both figures attest to the reason why the TV model is widely used in image restoration problems i.e., the ability to preserve image features and the effective elimination of additive noise.

Prospects

The TV model (4) generally falls into the following model where $\Theta(\cdot)$ is a fidelity term, $\varphi(\cdot)$ is called the regulariser and $\lambda > 0$ is the regularisation parameter.

$$\underset{\mathbf{x}}{\text{minimize}}\ \Theta(\mathbf{Hu}, \mathbf{f}) + \lambda\phi(\mathbf{v}), \qquad (5)$$

It turns out that many machine learning models can be captured by the general model (5) while the TV model being one of them. For example, regularised logistic regression, matrix completion, robust principal component analysis, and regularised least squares. Therefore, these models can be solved via the ADMM algorithm. As a consequence, having the ability to understand the simple TV model with the ADMM algorithm could be a first step in understanding more machine learning models presented in the literature.

Conclusion

TV image restoration problem and the ADMM algorithm are very popular in the image and signal processing community and have relations to other machine learning models. Therefore, understanding the TV model and the ADMM may serve as a starting point to understand other machine learning models. The mathematical concepts were purposely discussed in a very general and shallow manner without rigorous definitions and proofs. This is to give intuition and disseminate the general ideas of inverse problems for image restoration and its relation to other machine learning models. It is hopefully that this article gives some insights and interest to the signal/image processing, the machine learning community, and those interested in the topic especially in Malaysia to start looking into the mathematical aspects of image processing and machine learning.

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