Efficient Soft Sensor Modelling for Advanced Manufacturing Systems by Applying Hybrid Intelligent Soft Computing Techniques

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***Abstract* - Data-driven soft sensor are inferential models that use on-line available sensor to predict quality variables which cannot be automatically measured at all, or can only be measured at high cost, infrequently, or with high cost and delay (laboratory analysis or on-line analyzer). In soft sensors development, the main issues should deal with treatment varying data, selection of input variables, model training, validation, and soft sensor maintenance to adopt the heavy duty of oil refineries in the aim to improve products and increase yield. In this research improvement on virtual sensor on hybrid soft computing methods fuzzy logic system and neural network which employ to construct the modelling and use rough set theory and differential evolution. This study will work on data of refining of crude oil for two different sources and combine database of them to improve the quality of data discover the knowledge inside the data pattern. The contribution of this study will help to break the barriers of privacy between manufacturers and improve the adoptability of soft sensor modelling to the changes of data sources.**

Keywords - soft sensor; advanced control systems; neural netwrok; fuzzy logic; oil refinery, Industry4.0

I. INTRODUCTION

Industrial processing plants are usually heavily instrumented with many sensors. However, there are fewer dependable and precise sensors available for accurate online measurement of quality variables especially related to composition. The primary purpose of the sensors is to deliver data for process monitoring and control. [1]. In this ongoing paper our aim to study and discuss the improvement of data quality and reduce the redundant information in manufacturing data. Data mining techniques and its methods have been used in knowledge discovering. Each technique has its own advantage and disadvantage. Soft computing used to perform and recruit data mining projects.

Most industrial processes are well equipped with on-line process sensors, such as temperature, flow rate, and pressure sensors, and in some cases analysis sensors. Data historian that collects and stores historical data usually linked to the process computer. Some variables, especially, the quality variables do not have on-line sensors or available sensors are cost effective or reliable. The foundation of building intelligent sensors is that the product quality variables have a functional relationship with other process variables that can be measured on-line.

Accelerated development of modern process control method influences all aspects of process monitoring and control. New challenge is constantly being brought into focus by development in control theory, new regulatory methods, modern actuators, intelligent sensors, and

application of advanced methods. At the same time, industrial plants are expected to show more efficiency and law obeying that set firm boundaries in products quality and polluter's emissions.

There are three main terms working as controllers of field equipment or the processes of oil refineries industries which are: PLC, DCS and SCADA. A supervisory control and data acquisition, and programmable logic control system is always used to control small industries like water treatment station; electrical power station; and irrigation systems. Oil and gas refineries mostly rely on a distribution control system. [2]

A programmable logic controller, is basically a computer-based control system that continuously monitor the state of inputs devices and makes decision based upon a custom program stored in it to control the output devices. PLC is a computer-based control system which is controlling field element or a process through a particular sequence of instruction which is nothing, but a logic and this particular set of instruction is stored inside the PLC in form of a program.

Distributed control system (DCS) refers to a control system or manufacturing system, in which the controller elements are distributed throughout the system with each component sub-system controlled by one or more controllers. DCS is a control system where the total process is divided in a number of sub-system and each sub-system is being controlled its own controller, and basically in DCS a large process is being controlled through a number of controllers each controlling its own sub-system, so the whole control will be distributed and employing the number of controllers.

Supervisory control and data acquisition is a kind of control system architecture. It is not exactly like PLC and DCS. SCADA is a software package and doesn't include any hardware package, which is used for monitoring and issuing commands. SCADA uses other peripheral devices like PLC/ DCS/ PID controllers to interface devices. The control systems and its types will be discussed in our research for the purpose of getting on the real time data for the refinery or any industry processes. This paper will be divided into five sections; first section will review the process control in oil refinery. Second section is going to define the soft sensor, where is the third section go through some literature papers and previous researches. The fourth section explain the challenges of soft sensor modelling. And the last section give in details the scope of the research study and the proposed method to solve the problem of varying of data in manufacturing and complex processes in oil refineries.

II. Refinery Process control Overview

Petroleum Refining process can be classified into three major groups: separations, conversions, and blending. And separated into five basic area: fractionation (distillation); conversion processes; treatment processes; formulating and blending; and other refining operation include (light-end recovery; sour water stripping, solid waste; process water and wastewater treatment; cooling, storage and handling and product movement; hydrogen production; acid and tail gas treatment; and sulfur recovery. Distillation is the most common separation process in refining. And conversion include different types of reaction process, such as cracking, hydro processing, reforming, isomerization, and alkylation. Cracking reactions break large molecules into smaller ones, while isomerization and alkylation reactions rearrange and combine smaller molecules into larger, more valuable molecules. Reforming reactions rearrange the structure of molecules without changing the number of atoms to create higher value gasoline blending components for example. Hydro processing reaction use hydrogen to remove contaminants such as Sulphur and nitrogen from the hydrocarbons. Most of these reactions require a catalyst and carried out in a variety of different reactor configuration including fluidized bed reactor, fixed-bed reactors, and liquid-contacting reactors.

Petroleum refinery process control is carried out using control technologies such as conventional control technology and modern control technologies. The conventional method uses microcontrollers which are used for small scale control applications and for limited control parameters. The modern control technologies like programmable logic controller (PLC), Supervisory control and data acquisition (SCADA) and Distributive control system (DCS) are used for large geographical area spread process control with multiple process parameters. [3]

Most of the process control system in refineries are achieved by distributed control system (DCS). Processes are then subdivided into smaller portions, which are locally controlled by low-level computing units, called boxes, or process manager (PMs). Any control system has certain degree of fault and these type fault has tolerance range. The fault portion of the plant will be isolated from the process control. Process operators interact with boxes via suitable interface, and boxes are able to manage the flow of information between processes, sensors and actuators, involved with A/D and D/A conversions. Boxes are connected via a local control network(LCN), which is also connected to a server, called the plant information system (PIS), where the historical data will be store in this system of oil refinery and perform high- level control and optimization activities. [4]

Crude oil distillation tower is the heart of any crude refinery because it is the process element in charge of the separation of petroleum cuts. These cuts then being process in other commercial products. The separation is made in distillation tower with side extraction. The economic goals of operation a distillation tower is based on obtaining the maximum amount of product with the highest quality within the specification. [5]. In our research, we will emphasis about the industries processes for petroleum productions and develop the modelling of soft sensors especially in oil

refinery since this industry has more effective on the local revenue of our country and other oil countries.

The modern petroleum processing is separation (distillation, solvent refining); conversion (carbon removal, hydrogen addition); reforming (catalytic reforming, steam / hydrocarbon reforming); rearrangement (isomerization); combination (catalytic polymerization); Alkylation); treating finishing, blending (gasoline, kerosene and diesel, lubes and waxes, Asphalt); Protecting the environment (waste water treatment, disposal of solids, sulfur recovery).

Integrating the whole product and process development chains by communicate between design, manufacturing, marketing and management in chemical industry should be adjust on modeling and simulation. [6]. The operation of each industrial plant is based on the reading of a set of sensors. Their reliable functioning is essential as the output of sensors provides the only objective information of the process. [7] Oil refinery industries integrating is the start point to flight toward and industry 4.0 concept in this field.

III. SOFT SENSOR

A. Virtual Sensor Classification

Soft sensor is valuable tool in many different industrial fields of application, including refineries, chemical plants, cement klinks, power plants, pulp and paper. Soft sensor offer a plenty of property: low cost can be replace the hardware devices for the purpose of monitoring and prediction; SFD (sensor fault detection, PFD (process fault detection) are the most properties for soft sensor to work in parallel with physical sensors and industrial processes; there easy implementation with plant hardware; the real time estimation of data are the properties that has crucial part instead of laboratory testing and online analyzer.Well designed soft sensors are cheap and precious tools able to work in parallel with, and eventually replace a real sensor when it is affected by fault or taken off for maintenance.

The performance of soft sensors models relies on the quality of data that are process to extract knowledge during identified procedures. Data are stored in historical plants databases, which are generally required for purposes other than modeling the soft sensors. The aim of soft sensor is to deliver additional on-line information for the process control system. Where the soft sensors based control system can calculate control action with adaptive model adjustment [1]

To measure the quality variables in real-time, one can use computational intelligent methodologies to build intelligent computational sensors to infer the value or the quality target variables from other on-line measured variables. The basis for building such intelligent sensors is that the value of target variables, or the product quality, have a functional relationship with other process variables that can be measured on-line.

B. Data of Industrial Processes

Common usage of computers and networking technologies and introduction of new data acquisition system in manufacturing companies has created large electronic databases in which the manufacturing process, product, equipment related data is stored. These data can be analyzed to identify potential pattern in the parameters that control a manufacturing process or the quality of the products produced. [9] Good quality data are not uniformly available. Inaccurate samples in process variables, as well as analyzer and lab measurements occur due to poor calibration, measurement error, computer interface error etc. where is the data sometime quite noisy with outlier or even measurement failures. These complexities must be taken into account during both modelling development and real time use of the sensor. [10]

Some industrial processes like refiners, fermentation, polymerization, has process stages, critical and have environment to be monitored or measure values, where variables shape crucial value in the production line of the processes. There are many stages of operations and many variables related to each operation in each stage. System and process engineers always try to understand the relationship between parameters variables of the system and processes.

IV. LITERATURE REVIEW OF SOFT SNESOR IN MANUFACTURING AND OIL REFINERIES INDUSTRIES APPLICATIONS

Mathematical models of processes, designed on the basis of experimental data, by system identification procedures, can significantly help, both to reduce the need for measuring devices and to develop rigid control policies. Soft sensors, inferential sensors or virtual sensors, are the mathematical models designed to embodied the computing devices for crucial cases in industries. [11]

The Estimation of Octane number in the gasoline formed by refineries is presented. This type of virtual instrument was designed with the aim of replacing measuring hardware during maintenance tasks. This virtual instrument was based on nonlinear moving average model, applied by using multilayer perceptron neural networks. Stacking approaches are adopted to improve the estimation of instrument performance. The implemented method that based on neural combination of a set of first-level neural estimators, was compared with classical linear algorithms of model aggregation. This comparison had been done to approve the validity of the proposed approach. [12]

Injection noise into the available data or using the bootstrap resampling approach was used to improve the generalization capabilities of neural network based soft sensors with the aim to solve the difficulties with small data sets by manipulating of trial training data sets. The new method based on aggregation of neural models, teaching on

diverse training data sets, which are obtained by the noise injection and bootstrap resampling. [13]

An adaptive soft sensor instrument based on neural network technology which was three layer back propagation neural network (BP NN) technology which adopt to build a soft sensor model to be as an alternative for the physical sensor, where this type of soft sensors was correctly applied to an advanced control system and run successfully on DCS equipment. Multivariate linear regression model to show a linear relation among variables. The results for this research had shown that better estimation precision was gained through on-line correction, and the calculation values of the model can keep in step with the change of product quality watchfully. [14]

Auto-Associated Neural Network (AANN) based soft sensor design which used to keep the control system keep working normally and work efficiently by indicate the faulty sensors in water treatment plant control system. Principle component analysis (PCA) is used to reduce the dimension of the input vector and to show the correlated relationships among the parameters. Intelligent soft sensor concept is developed to improve the diagnosis of faulty sensors or drift in sensors reading in robust and reliable way where the analysis of input parameters will simplify the way to process the data in soft sensor models. [7]

Another Soft sensor application in cement industries for prediction quality purpose of parameters, where soft sensor based on back propagation neural has been settled for rotatory cement kiln in cement industry, production capacity of this plant 10000 ton per ton of clinker. This type of model had been developed to predict the content of free lime, C_3S, C_2S, and C_3A of the clinker quality.[15]

Sharma and et al. show that so many soft computing techniques like Genetic Algorithm (GA), Artificial Neural Network (ANN), Particle swarm optimization (PSO), fuzzy logic controller (FLC) had been used to improve the performance of PID controller of water tank system which consist of numerous sensors/ transducers used for measurement of process variables such as level, flow, pressure and temperature. Sharma in his paper used Genetic algorithm and particle swarm optimization. The last algorithms tune the PID controller by reducing the fitness function which is error function and improved the parameters which is the performance parameters (rise time, settling time, steady state error and overshoot). [16]

The Traditional Chinese medicine was one of the fields that soft sensors has been applied. Soft sensor based on least square vector machine (LS-SVM) used to predict and investigate the impact of the process parameters on the extraction rate in the extraction processes. LS-SVM converts the inequality constraints in SVM to equality constraints. The outcomes of using this method successfully improves the regression accuracy, and the training error was smaller. The characteristics of LS-SVM method are less computation, less training time, provides faster convergence speed, and high real time efficiency. The LS-SVM method can find better model accuracy in case of small samples. The experimental results compare with other methods, LS-SVM method presented higher model accuracy, less time consuming, feasibly analyzing the influence of the dynamic parameters on the extraction rate. [17]

One of the soft sensor applications is fault diagnostic, soft sensor based on neural network developed and applied on FCCU in oil refinery to detect the fault in control system, actuator, and process. The outlet temperature of the riser reactor is the most important process variables and is controlled by manipulating the catalyst rate. The input variables for this model had been pre-processed by using feature extraction in a moving time window to track dynamic data. A wavelet transform and a qualitative interpretation are adopt to extract the feature of dynamic trends. This model proved its efficiency to predict and investigate single and multiple faults successfully. [18]

Improving product quality monitoring and control in oil refinery by estimating the stabilized gasoline concentration (C5) in the top flow and the butane (C4) concentration in the bottom flow of debutanizer column had been implement by applying soft sensor models based on neural networks. Nonlinear autoregressive moving average models were used to fit real input/ output data. Trial and error approach, expert knowledge and physical insight used to obtain the number of lagged samples. Multilayer perceptron neural network with one hidden layer and sigmoidal activation function were used to implement the unknown functions. The number of neurons were decided by trial and error approach. Compare with gas chromatograph, the designed soft sensor defeat the great delay and gave on-line estimation that were suitable for monitoring and control purpose where the experts could monitor the plant performance in real time. And the quality of soft sensor performance suggests the possibility of using the real time estimation of the presented model in control loop to improve the debutanizer distillation column performance. [19]

Luo and Shao proposed hybrid soft computing model, neurofuzzy system based on rough set theory and genetic algorithm, the purpose of the suggested model was to predict the freezing point in Fluid Catalytic Cracking unit (FCCU). Soft sensor based on neurofuzzy system was implemented to combine the qualitative reasoning of fuzzy logic with the quantitative numeric processing of ANNs. RST used to generate reductive rules set of the neurofuzzy system while GA used to get the optimal discretization value. The trend of this paper had been reached by combining the synergistic constituents methodologies which include fuzzy logic systems, ANN and others. [20]

A fuzzy model based expert optimization control strategy in industrial processes has been developed. The control system involve of knowledge base and reasoning with control, optimization, and coordination rules and fuzzy model-based optimization search. The proposed model had been applied in FCCU control system of oil refinery. The purpose of fuzzy logic optimization system was to predict

numerical prediction of cracking product distribution. Real time optimization of cracking product distribution through hybrid method of optimization rule and fuzzy model-based was searched. The result show prediction output with little different between the real output and virtual output of fuzzy modelling and expert optimization control. [21]

Developing data- driven soft sensor in oil refinery industries had been deployed and discussed, Liu et.al. had discussed in his paper developing soft sensor based on neural network and process knowledge in crude distillation unit in oil refinery to predict the refinery D90 quality variables. Standard back propagation used to train the neural network offline which is consider as limitation of this work. The soft sensor had been executed by using Visual C++. The prediction output of the soft sensor tracks the analyser movement pattern well and match lab measurement better than the online analyser. [10]

This section review data mining techniques in manufacturing and study applications of soft sensors techniques in different industries. Most of the literature show the advantages of using soft sensor as virtual sensor to predict or monitor the hard to measure variables what is called primary variables from easy to measure variables. There are many techniques and method were using during the different applications. Although the good results and efficient using of soft sensors models but still there is a gap either from the method itself that modelling soft sensor to deal with different type of data from different resources, or from the industries operations that effects on the functions of soft sensor modelling and how soft sensor adapt and reconstruct itself with the changes of sensors and processes data.

V. CHALLENGES OF SOFT SENSOR MODELLING

The challenge of soft sensor to adopt changing data of various feedstock, change the process conditions, and changing work environment.

The complexity, nonlinearity, data quality of industries processes, all together configure as challenge for the modelling of soft sensor. Building a robust and efficient soft sensor models need to share data between industries and breaking the privacy barriers and cooperation between manufacturing.

Soft-sensing in crude oil distillation towers and other units of oil refinery with varying feedstock typify difficult problems because the relationship between easy to measure process variables and difficult to measure quality variables varies with the type of crude oil processed. The type of crude oil change with suppliers. Even the crude oil from the same supplier may also vary in Hydrocarbon content. Furthermore, many refineries operate with mixed sources of crude oil with varying blending ratio. Further there is a lake in literature that studying soft sensors in oil refineries and cooperation the data between manufacturing represent obstacle to going through the trend of industry 4.0 in this field.

VI. SCOPE OF WORK AND METHODS OF THE STUDY

Based on the problem statement and challenges of the study of soft sensors. We will emphasis on some studies that been applied soft sensors in its processes of production. Petroleum, chemical, thermal power plants and study their control systems and find either industry has used soft sensors and has database in its production systems or doesn't have. We will improve and evaluate the modelling of soft sensors. The main issue is the adoptability for the model of soft sensor to keep its performance equal with the changes of daily process data to keep the stability of process control systems.

The scope of study will work on some important units in petroleum refinery, crude distillation units and isomerization processes. Where these units play important role in the overall economic performance of oil refinery. The focusing in these units are the quality of gasoline and other cuts.

Main data (temperature, pressure, and flow rate) as well as the additive hydrogen ratio. These data will be collected from these units from two different refineries, one of Malaysia oil refineries and other one from Iraqi oil refineries (Middle refineries company / Aldora refinery-Baghdad).

Expert knowledge from the two different refineries will configure in fuzzy rules set to support and improve the quality predictions.

A. Method of the Study

Soft sensors are mathematical models that allow us to infer relevant variables on the basis of their dependence on a set of influential variables. This definition for soft sensor draws the map for our methodology. The important criteria and factors that should be take into account for any soft sensor modelling are: Size, quality, and nature of data; available computational method; Urgency of the task; what we want to do with the data of a specific process.

The method steps of this study in details: first defining of manufacturing issue in accurate statement and classify the variable of input and output; defined the data model and data requirement; source the data from all repositories (refinery (1) and refinery (2)) either from DCS, PLC or SCADA and preparing the data (the data should be relational or in flat, files, stored in a data warehouse, computed created on site or brought from other party). The data should be selected and filtered from redundant information; Evaluating the data quality; Choosing soft sensor model (Hybrid soft sensor model Fuzzy Logic System (FLS) combine with Neural Network (NN) based on Rough Set Theory (RST) and Differential Evolution (DE) ; Interpreting the results and detecting new information

(prediction) of product quality; Deploying our results and the new knowledge into manufacturing fields. Fig. (1) show the flow chart of our research method.

Data will be collected from two different sources (in this study from two different refineries), where the type of the data are process variables data; secondary variables (temperature, pressure, flow rate) and expert knowledge. The data set should be split into two parts the training or generalization data and the validation or testing data. The classic split of the dataset ether divided on four or five based on the data size. The purpose of using two different resources to avoid the overfitting and fill of the proposed modelling.

The suggest model that will be used here hybrid soft computing fuzzy logic system combine with neural network based on rough set theory and differential evolution. The membership function that is going to be used here in FLS is Gaussian distribution curves. A simple Gaussian curve and a two sides composite of two different Gaussian curves. The main difference between our suggestion model and other models is dealing with very complex processes in oil refinery with changing of data pattern to achieve the stable of control system and linked with other oil refineries to share soft sensor modellings adoptability.

B. Control Systems of Oil Refineries

Most of the control system of the studied oil refineries Distribution Control System (DCS) where the recorder data will be store and process in this data to monitor and control processes in petroleum product. Plenty of data store in this control system. In manufacturing process analysis at the process level, operation level, the distribution control system (DCS) promise nearby the secure and safety operating of the technology. The measurement assists the values of the process variables (PV's) to DCS which forward the information to the graphical user interface (GUI). Operators of the technology can get information about the system via GUI and they can control the process by changing the set points (SP's). An advanced model-based process control (process computer) calculate among others the operation set points (OP's) to DCS. The data stored by DCS have the potential to provide information for product and process design, monitoring and control. The data could be defect because of measurement failure and restored inconsistently. Process data warehouse (DW) is a data analysis decision support and information process unit which operate separately from the database of DCS.

Matlab software will be the platform of implementing the simulation of soft sensor modelling for FLS, ANN, and DE since it has great tools for analyzing and implementing the above-mentioned theories. For RST, we will use ROSETTA software as program for rough set theory where the script will be linked to Matlab to be complementary of the soft sensor modelling.

Industry 4.0 term is the trend for many industries. For oil refineries industry represent the next step in linking the oil refineries and sharing data between refineries to reach the stability status. Security purposes and confidentiality in petroleum productions is the obstacles of researchers to deal with analyzing data and study the soft sensors modelling in more details.

The results of proposed soft sensor mathematical will compare with laboratory results for product quality purposes and the errors between predictive results and actual results will be feedback to improve the control system performance in particular and manufacturing systems in general.

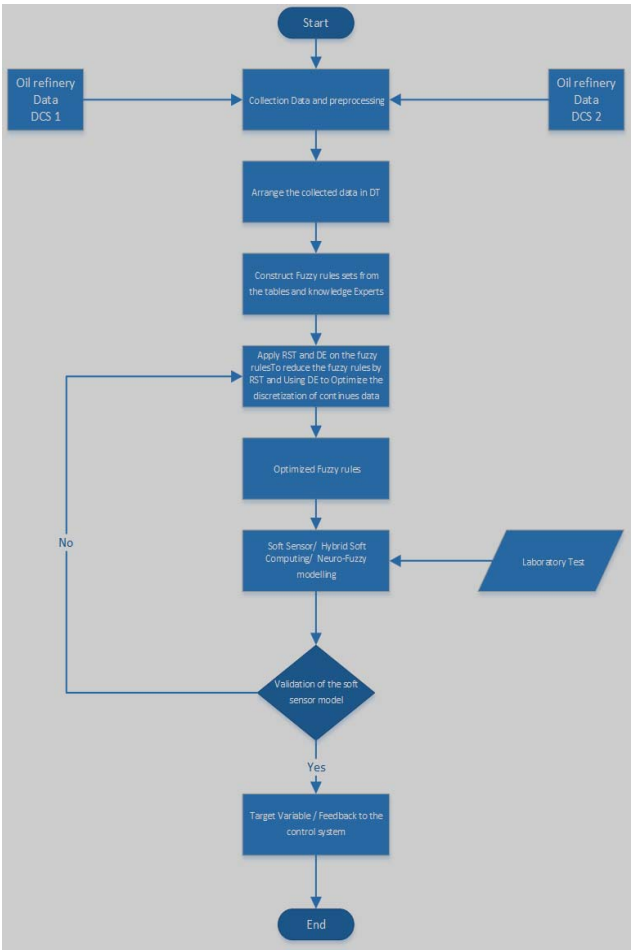

Figure 1. flow chart for the proposed method

VI. SUMMERY AND CONCLUSION

Potential application of soft sensors makes it the trend for many industrial fields of large plants, hard to measure process parameters, measurement delay, working environments harsh to measuring device survival, hard control requirements. Industry 4.0 is the target for many industries, in this research we tried to prove the validity of this term by combining same modelling of soft sensor for

different refineries to improve the project of global intelligent data mining techniques. Reviewing of literatures and conference papers, show that many limitations in the models that had been used in different industries.

The main problems for soft sensor in industries can be conclude in the adoptability of soft sensors modelling in harsh environment like oil refinery, and lake of high quality of raw data and change of the data following the changes in feedstock of deterioration in sensors and process operation. The future trends of manufacturing toward industry 4.0 and internet of things need more cooperation and break the barriers of privacy between industries to improve their products first and to enhance the automation level of their manufacturing operations.

The objectives of this study can be achieved by improve hybrid model neuro-fuzzy model based on rough set theory to reduce the fuzzy rule and differential evolution method to optimize and discretize the continues data of virtual sensor model. The suggest model will be compare with other closed models for the purpose of validation. The main objective of this study is to combine two of decision tables for different processes and sensors data to improve the quality of the data.

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