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Machine learning for medical gas systems

SHJ Medical Gas Specialists has developed a real-time machine learning system for optimal operations of medical gas systems, which uses big data analytics with edge and cloud computing to save energy costs.

Compressed air is essential to a wide range of industries and highly specialised applications such as medical gas systems (MGS), where it is a particularly critical resource. Hospitals rely on air compressors and dryers as well as traditional gas alarm panels for a host of functions ranging from facility operation to patient care. However, compressed air is the most expensive service on site, costing many times the price of electricity, and is often generated inefficiently and then subsequently wasted.[1]

This may be attributed to the fact that there is no available technology or method that can be applied to allow real-time monitoring and intelligent control of MGS, particularly the energy-efficient and reliable operation of medical air plant. The current control systems available, which mostly use fixed speed compressors, tend to operate inefficiently and without optimisation.

Research has indicated that significant energy costs can be made through optimisation of both the production facility and system level.[2] However, that can only be achieved by considering the compressed air system as a whole and deciding whether current alarm and monitoring methods can be upgraded to an intelligent system to suit next-generation needs. Enhanced energy efficiency will depend on system automation, which is in the process of undergoing a major transformation.[3]

Advanced computation and communications technologies are reaching such a level of maturity that designers can make dramatic changes in the way they design their automatic control systems. A major shift from dedicated mechanisms to cyber-physical systems means that we are no longer constrained by the mechanical and electrical design of a machine. Instead, machines in which the mechanism's motions are defined by sensors/actuators and control software provide significant opportunities for flexible manufacturing, adaptive throughput, energy management and an increase in machine lifetime value.

The resulting cost savings and competitive advantages are essential as the evolution and convergence of many new technologies - mechatronic systems, controllers, edge and cloud computing, big data, machine learning and the Internet of Things (IoT) – develop. They provide the basis for increasing the self-awareness of the machine, allowing it to optimise its own performance for given duty cycles, diagnose and compensate for non-catastrophic faults, and coordinate operation with other machines with minimal input from the operator.

The need to modernise MGS through a greater focus on technological innovation to improve reliability and security, to maximise operating profits and productivity, and to minimise energy consumption, has now been established. To meet the emerging challenges and opportunities, developing expertise in data storage, communications, IoT, energy efficiency and healthcare will help to supercharge a compound technological breakthrough to build a new design method. Its implementation is being supported by pioneering work in the prototyping and production of real-time machine learning systems over IoT networks.

These machines are enabled to understand and learn from the data so that, by real-time processing of measurement data provided by dedicated sensors installed in the machine, the system can enable autonomous decision making based on online diagnosis. This leads to ever-increasing machine reliability, with the goal of achieving zero defects, together with higher productivity and efficiency.

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Development of a real-time machine learning system for MGS

At SHJ Medical Gas Specialists, based in Chesham, UK, we have developed a real-time machine learning system for the optimal operation of MGS, utilising a set of emerging IT technologies including 4G/5G , artificial intelligence (AI), the IoT, blockchain and cloud and edge computing. It uses real-time big data analytics to enhance productivity and efficiency and to optimise decision making and performance, creating an opportunity to apply real-time AI techniques for advanced control, management and maintenance by collecting data from sources on the IoT networks.

Qualitative and quantitative data analysis builds a next-generation decision support system that can also action changes to optimise the efficient operation of MGS. This is a new data-driven model that is dramatically changing the landscape of the healthcare sector by providing digital solutions with innovative measures. Experimental results have demonstrated that up to 30 per cent of energy costs can be saved through real-time AI optimisation.

Optimum performance of system operations is achieved by leveraging the trained deep neural network (DNN) with edge computing and distributed cloud over the IoT communication networks, where the sensing capabilities and the computational power are provided by the designed controller, transmitter and distributed cloud to track everything that is relevant to operations.

Through such deep learning and big data analysis, we can develop a knowledge base from which to correct errors and perform focused maintenance procedures without unnecessary interruptions, thus improving efficiency and maximising profitability. It has been shown that the real-time machine learning system can be used to provide fault detection and isolation capabilities and can be integrated within an optimal control framework (trained by AI) to respond to the changing conditions of medical air plants. This optimal controller is enabled to provide its own monitoring capabilities which can be used to identify faults within the process and also within the controller itself.

As discussed previously, compressed air currently costs many times the price of electricity and MGS are often operated inefficiently. IoT and blockchain technologies can be used to modernise medical gas alarms, improve reliability and security and reduce networking costs. Remote monitoring, fault detection and isolation tasks can be performed to achieve the maximum life and efficiency from MGS using fibre-optic/industrial bus or wireless (or both for redundancy), designed and built for real-time data collecting and analysis.

The fibre-optic communication thus has been developed to increase data rates without electromagnetic or radio frequency interference (EMI/RFI), and to provide a cost-effective way to transmit more information with guaranteed safety. The wireless communication network based on self-developed protocol by an ultra-high frequency (UHF) radio frequency (RF) can achieve up to a two kilometre wireless link. With the IoT communication network built, real-time monitoring and intelligent control of MGS can be achieved, so that we can have an eagle-eye view of every event while it is happening.

The IoT networks developed will require greater capacity to support sensors that monitor and control a wide range of industrial processes and equipment, reporting back into a central console. Not only is the IoT driving more bandwidth, it is also driving a consolidation of IT systems to better process valuable production data and enable faster decision making based on this information.

Coupled with emerging technologies such as 4G/5G and blockchain resistant to modification of the data to connect people and business processes, the IoT allows objects to be sensed or controlled remotely across the network. This creates opportunities for more direct integration of the physical world into computer-based systems, and results in improved efficiency, accuracy and economic benefit as well as reduced human intervention.

It also creates an opportunity to improve the efficiency of intelligent MGS by applying machine learning and AI techniques for advanced control, management and maintenance. This allows the upgrade of current systems by collecting data from all sources on the IoT networks for real-time big data analytics. Such next-generation decision support systems will optimise the efficient use and operations of MGS.

SHJ's Empower plant control system provides real-time diagnostics, alerts and fault detection on their medical gas plant.

With the development and implementation of remote monitoring and intelligent control of MGS through the integration of advanced data communication technologies for industrial IoT networks with combined edge computing and distributed cloud for machine learning, a new optimal, energy-efficient operation of medical compressed air plant has been developed. Massive data, such as from vibration and acoustic measurements, is remotely collected through the newly-built supervisory control and data acquisition (SCADA) and IoT networks.

The complex processes are modelled and trained by a DNN using multilayer perceptron (MLP) with adaptive learning rate and wavelet activation function. This rapidly identifies network coefficients for minimising energy consumption by Bayesian optimisation with Gaussian processes, and allows higher accuracy of fault detection and prediction (such as leakage), and condition monitoring-based predictive maintenance (using AI algorithms to predict the next failure of a component/machine/system). This leads to a highly efficient and reliable operation of MGS.

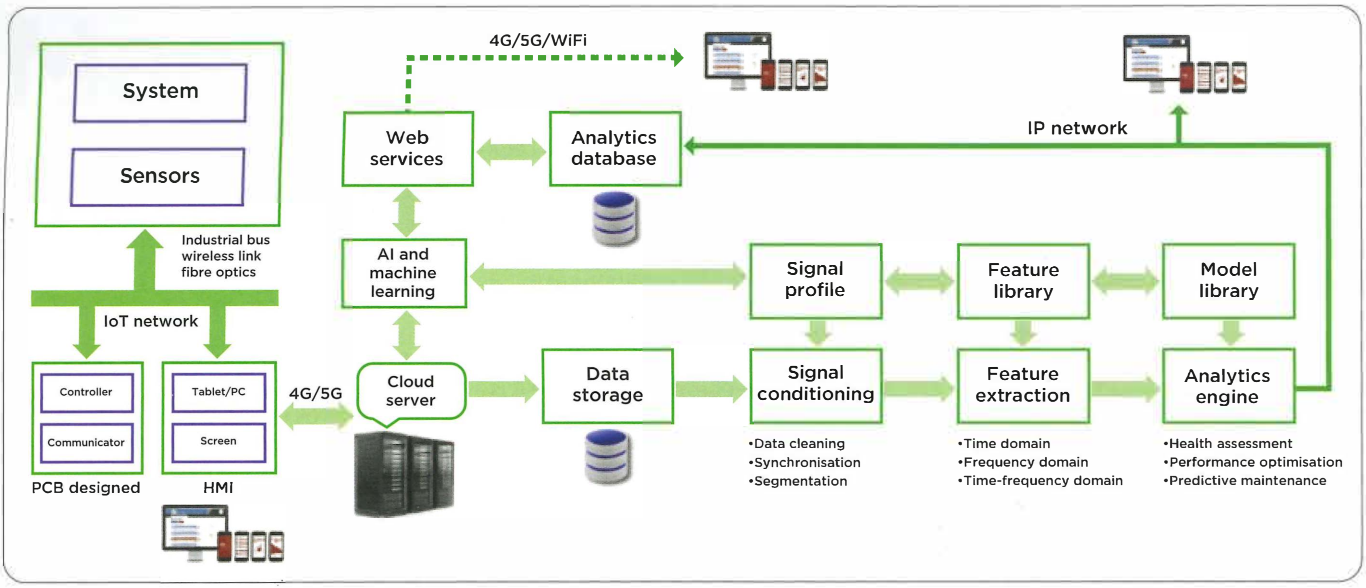
System Implementation

SHJ has developed and implemented a real-time machine learning system from product design to customised production, through feasibility studies, innovative technologies development and system prototype testing. Using printed circuit boards (PCBs) as machine controllers, signal collectors and transmitters and developing IoT communication networks for real-time monitoring, control and AI optimisation, we have constructed an intelligent plant control and predictive maintenance system for the highly efficient operation of MGS.

It enables remote monitoring and control, risk reduction and shorter response times and provides essential management data for predictive maintenance purposes. This has been achieved through changing the current way of designing, installing and running MGS. The next-generation SCADA and IoT networks and the products and intelligent energy-saving systems developed use a three-level process and data specification framework:

SCADA and IoT networks with data communication assured by blockchain

1 UHF (RF Wireless, product deliverable) to on-site remote monitoring station/tablet PC screen.
2 Hardwired (RS485/Optical Fibre,



Real-time machine learning system.

product deliverable) to on-site remote monitoring station/tablet PC screen.
3 4G/5G (mobile network) primarily for off-site remote monitoring.
4 Ethernet (IP network) primarily for off-site remote monitoring.

Real-time data acquisition, analytics and remote monitoring

1. PCB boards (product deliverable) as machine controllers, signal collectors and transmitters.
2. Software for processing real-time operational data and display in a variety of formats, e.g. mimic diagrams, graphs, charts and histograms (edge computing and distributed cloud).
3. Web services with a database management system developed for real-time data remote view, alarms and historical trending analysis (cloud computing).

Intelligent control and predictive maintenance by real-time AI analytics and optimisation

1. Intelligent compressed air system developed by the real-time AI algorithm for optimal control with fixed/variable speed compressor (product deliverable).
2. Algorithms to process real-time data for controlling and real-time AI optimisation (edge computing and distributed cloud), where a DNN using an MLP model is trained to identify network coefficients and then the trained DNN is used as intelligent control for medical air plants.
3. Web services with a database management system and computerized maintenance information management system (CMIMS) developed for real-time AI analytics and optimisation, by creating and transmitting the program to the controller. Data is transmitted to enable the operator's control of the technologies (cloud computing, blockchain technique) and predictive maintenance planning and scheduling, so that we can have a knowledge base from which to correct errors and improve efficiency (software deliverable).
4. Intelligent systems to provide full site history, training records, breakdown records, site closures, equipment replacements, secure data communication and optimal control strategies with energy-saving, predictive maintenance planning and scheduling, and everything else required to enable hospitals fully to meet health and safety reporting requirements.

The intelligent system using advanced technologies could be used in hospitals to operate existing fixed speed medical air compressors more economically than variable speed compressors, thus (i) generating significant energy savings from existing plants, (ii) avoiding the need for capital investment in new variable speed compressors, and (iii) saving operational costs as fixed speed compressors have lower running costs.

A fixed speed compressor can be designed to achieve similar performance to a variable speed compressor in terms of energy saving and to overcome the drawbacks of variable speed drive. With blockchain resistant to modification of the data, the real-time intelligent system can also secure data transfer over IoT networks for remote control optimised by deep learning. Our innovative technologies have been used to design a new integrated system to allow remote monitoring, intelligent control and predictive maintenance to optimise the efficient use of MGS and meet next-generation needs. Hospitals can now be equipped with cutting-edge products, systems and services which will improve productivity and profitability.

Conclusion

Insights provided by real-time data from various sensor networks and intelligent systems can offer ways to optimise the operations and maintenance of the physical assets, systems and processes of MGS. SHJ's development of real-time machine learning systems using big data analytics with edge computing and distributed cloud will help enhance and expand their application widely and allow continuing delivery of the latest technological innovations.

This is a new data-driven model that is dramatically improving the landscape of the healthcare sector. In particular, these advancements will work to alleviate the effects of the health crisis sparked by the outbreak of novel coronavirus. The modern MGS created by such extensive research and development efforts will undoubtedly benefit the healthcare industry and increase our collective expertise, allowing us all to serve the public better. IFHE

References

1 Li G, Kong J, Jiang G, Xie L. Research of intelligent control of air compressor at constant pressure. *Journal of Computers* 2012; **7** (5): 1147-54.
2 Rice AT, Li PY, Sanckens CJ. Optimal efficiency-power tradeoff for an air compressor/expander. *Journal of Dynamic Systems, Measurement, and Control* 2017; **140** (2): 021011.
3 Ellahia RM, Khanb MUA, Shah A. Redesigning curriculum in line with Industry 4.0. *Procedia Computer Science* 2019; **151**: 699–708.