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Artificial Intelligence for the Environment-Research and Policy Directions for Bahrain

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Abstract: Bahrain has had unique environmental challenges given its high rate of population increase and its fast growing industries within a small land size. The main environmental challenges according to the Bahrain Supreme Council of Environment include: sea water pollution from wastewater treatment projects, ground water pollution from sea water intrusion and air pollution from oil refineries, aluminum manufacturing and power plants. This has had a significant impact on marine life and the quality of life of inhabitants. Traditional solutions to these problems have proven unfeasible and sometimes non-practical given the uniqueness of Bahrain and its environment. This paper attempts to discuss the potential use of AI technologies for environmental applications in Bahrain and to identify major research directions in this area. It is seen that complex environmental problems in Bahrain where traditional approaches could fail can be the subject of AI research and technology development.

Keywords: Artificial Intelligence, Knowledge-based systems, environmental protection, air pollution, wastewater management, water pollution, marine life.

I Introduction

The population growth and the extensive industrial development in the Kingdom of Bahrain have resulted in several environmental challenges. Bahrain's principal environmental priorities as indicated in a report by the *Supreme Counsel of Environment of the Kingdom* [1] has been focused on wastewater treatment and management specially that from desalination of sea water, ground water pollution given the continuous rise in water consumption and seawater intrusion, marine life and biodiversity given the land dredging, reclamation projects and climate change which results in rising sea levels, and finally air pollution from oil refineries, aluminum manufacturing and power plants. A recent study of the Public opinion on the most important environmental issues in Bahrain showed that pollution from industries and hazardous waste, ground water contamination, waste management, pollution of the sea are the top environmental challenges that face the country [2].

The uniqueness of these challenges come from the fact that the kingdom has a relatively small size, is an island and is potentially fast growing in population and industrialization which all may result in very challenging environmental problems. For example, wastewater treatment has been a big challenge to Bahrain and continues to be a source of threat to the sea water and marine life. With more than 100,000 m^3 of waste water overflowing the water treatment plant and dumped in the sea, continuous monitoring of effluent characteristics on continuous basis is required, for finding yearly pollution load to the marine environment specially that of aluminum plants, water desalination plants and oil refineries [3]. With regards to ground water pollution of the water table with sea water resulted in salinity of the soil, which has reflected negatively on agricultural environments and reduced the area of the agricultural land [1]. Air pollution due to extensive gas emission from cars and industries is causing increased temperatures and degradation in air quality in a small land size promising a significant issue to the inhabitants of the kingdom.

Although several measures and policies have been adopted by the government to address the above challenges, significant problems still arise everyday as the country is expanding both geographically, demographically and industrially. Therefore, all of the above challenging problems to the environment in Bahrain require non-traditional solutions as traditional solutions may not be able to track the exponential growth of pollution to sea, water and the air due to the exponential growth of population and industries in a fast-developing country.

Recent developments in Artificial Intelligence (AI) have motivated researcher to look into non-traditional solutions to challenging environmental problems [3]-[7]. AI has been the enabling technology to many developments in environment

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protection technologies. AI is based on machine intelligence where machines mimic cognitive functions that humans have such as learning and problem solving. AI is classified into a number of types based on the complexity and the problem-solving ability of the system. Weak (Narrow) AI Machines are made to respond to specific situations but cannot think for themselves while strong (general) AI machines are able to think and act just like a human and to learn from experiences [4]. Examples of narrow AI include machine-based deduction systems of formal statements from logical expressions, knowledge-based systems which deal with methods to model and gather expertise; software to simulate human expertise and to support experts, pattern analysis and pattern recognition: inductive analytical processes in general, machine learning in particular; robotics: autonomous control of robotic systems, i.e. autonomous systems; smart multimodal human-machine interaction: analysis and "understanding" of language (in conjunction with linguistics), images, gestures and other forms of human interaction [5].

In the context of environment monitoring and protection, significant research has been done on application of AI to a variety of environmental problems. AI has been used in developing Environmental Decision Support Systems where AI knowledge-based techniques has been integrated with tasks such as monitoring, data analysis, communication, information storage and retrieval [6]. AI technologies help overcome the problem of huge amount of environmental data and their dynamic nature when these are used in making decisions about the environmental protection strategies. AI has also been used in modeling of waste water treatment plants in order to enhance their efficiency and capacity. Intelligent trashcans and waste sorting robots in Garbage dumps have been a revolutionary concept in the waste management sector [7].

2 Research Method

The objective of this paper is to develop a framework for research in the area of using AI in solving environmental problems in Bahrain. The methodology used to develop this framework includes identification of environmental problems in Bahrain and their priorities, Mapping possible AI solutions to environmental problems and exploring potential research directions.

The following sections present the main environmental challenges unique to the kingdom of Bahrain and attempts to propose AI-based solutions to these problems shedding light on research directions in this field. These environmental challenges are based on a number of sources such as the report on the "State of the environment in the kingdom of Bahrain" published by the Directorate of Environmental Assessment and Planning -the supreme council of environment [8] as well as other individual research articles on the most significant issues that face the environment in Bahrain. The last section provides conclusions and directions for future research.

3 Environmental Issues in Bahrain

Bahrain has unique environmental issues for many reasons. The uniqueness of Bahrain is that it is an island with a small land size and at the same time a very fast growing population and industries which imposes very challenging environmental issues. The "*Public Commission for the Protection of Marine Resources, Environment and Wildlife"* in the kingdom of Bahrain is the main body that is responsible for the environment and the implementation of relevant national environmental strategies in the kingdom [1]. The commission has published a number of reports on the state of the environment in the kingdom as well as annual communications under the "United Nations Framework Convention on Climate Change". In the 2009 report on the state of the environment in the Kingdom of Bahrain [8], the commission outlines the main environmental challenges that the kingdom is facing.

Fast growing industrialization has also had significant impact on the sea, air and groundwater. One of the major environmental issues in Bahrain is the pollution of the sea water which results from a number of sources including pollution by waste water, disposal of desalination stations outcomes into the sea, and oil spills. The increased sea water pollution in addition to sand dredging, land reclamation and rise of water temperature, has resulted in major challenges in protecting the marine life especially sea grass, coral reefs and mangroves. The harmful effects of industrialization and the resulted pollution of the sea will continually result in a shortage of fish stock which requires non-traditional approaches to management of the coastal regions [8]. On the other hand, fast growing industrialization has also had significant impact on air pollution due to extensive gas emission which resulted in increased temperatures and degradation in air quality in a small land size. Another major environmental challenge in Bahrain has been the pollution of ground water by seawater intrusion which resulted in increasing its salinity. Therefore, the uniqueness of the state of the environment in Bahrain requires non-traditional environmental measures and solutions that are customized to the country which is aspiring to achieve its national goals of prosperity and economic and societal development stated in the Bahrain Economic Vision 2030 [9].

The following subsections explore the four major drivers for these challenges where AI can have a potential use and hence can result in significant impact on solving the environmental problems of Bahrain.

3.1 Wastewater Treatment

Bahrain has been investing in waste water treatment plants and sludge incineration plants since the early 80's of the last century. However, the significant increase in population and the expansion of industries has resulted in a significant problem to the capacity of wastewater treatment plants. These plants discharge considerable quantities of treated wastewater which has high concentrations of Ammonia and heavy metals into the marine environment. The main plant for domestic waste water is the Tubli wastewater plant which receives over 190,000 m^3 per day of domestic wastewater from all over Bahrain of which 40% are treated to the secondary level and 60% to the tertiary level. A sizeable fraction of the treated wastewater is discharged into the sea. Treated wastewater discharged into the sea reaches approximately 130,000 m3 per day. Other wastewater plants were installed to address the wastewater from industrial and sea water desalination sources but all these use traditional approaches to wastewater treatment [8]. Treatment of waste water has imposed several challenges on the government of Bahrain. The main challenge has been the high cost of waste water treatment expansion projects and their need for large areas of land which is a scarce resource in Bahrain [8].

Fig. 1: Tubli Waste Water Treatment Plant [8].

3.2 Desalination Stations

The population increase in Bahrain has placed a high demand on water. With the limited sources of ground water, Bahrain has invested heavily in desalination plants (the Sitrah desalination plants) to meet the increasing domestic water demand. The desalination technology used in these plants consists of the Multi-Stage Flash (MSF), Multi-Effect Desalination (MED), and Reverse Osmosis (RO). However, the increasing capacity of the desalination stations has placed a great concern on the environment as the disposal of the desalination brine with certain physical and chemical characteristic into the sea has led to a negative environmental impacts especially the sea water pollution and hence the marine life [11].

A study on the impact of the disposal of the concentrated brine in the Bahraini coast on the marine environment through collection and analysis of water samples from the surrounding areas of the brine outlets showed that Heavy metals of Copper and Iron levels at the outlets were much higher than their baseline values and thus exceeded Bahrain standard. In addition, the study indicated that the brine discharged temperature was much higher than the sea ambient temperature which imposes great concerns on the marine life [12].

3.3 Oil Spills

In 2003, the coasts of Bahrain suffered from a severe oil spill where an oil slick was detected 20 miles north of Bahrain northern coast which inflicted serious damage to the marine environment. In response to this incident as well as other oil spill incidents, the government established the National Oil Spill Response Command Centre in the fishermen's harbor in Sitra. The center is equipped with ICT technologies to facilitate combating slicks, including telephone The Supreme lines, fax machines, internet network, and display screens that broadcast live images from the spill site [8]. The Government of Bahrain has developed the National Contingency Plan to Combat Oil Spills in order to maintain readiness for combatting oil slicks in the territorial waters of the kingdom [1]. Furthermore, The Supreme Council for Environment has also provided a reporting system for Individuals, Businesses, Governmental Entities, and NGOs to report on oil spill accident in the Kingdom of Bahrain [13].

3.4 Ground Water Pollution

Ground water has been the main source of irrigation in Bahrain and hence, deterioration of the water quality has resulted in a significant decrease in the portion of agricultural land leading to severe desertification. The major problems that face the water sources of Bahrain is the seawater intrusion to groundwater and which results in increased salinity levels rendering it not suitable for drinking. The groundwater salinity in Bahrain ranges from 2,000 to 10,000 ppm

which is much higher than international levels. This has severely affected wildlife habitats, plants and animals, and the biological diversity of such habitats. Furthermore, the increased salinity of ground water has driven many agricultural lands out of production leading to desertification [8], [11].

4 Environment Applications of Artificial Intelligence

The broad range of AI technologies and their applications have made it hard to find a unified definition for the concept. According to [4], AI refers to "agents' (programs running on computer systems) able to learn, adapt and deploy themselves successfully in dynamic and uncertain environments". AI technology represents the convergence of three trends: Big Data, machine learning and cloud super-computing. AI is classified according to its capabilities into narrow, general and super intelligence where each category uses various levels of complex technologies for a range of narrow to wide variety of applications. Fig. 1 shows the classification of various types of AI technologies [14].

AI has had numerous applications in the recent years promising solutions to complex problems facing human lives. From healthcare, transport, finance, entertainment to military, government and space applications, AI is going to be a game changer on the problems that face humanity especially with the advent of enabling technologies such as high-speed communications and high speed-small sized processers [16].

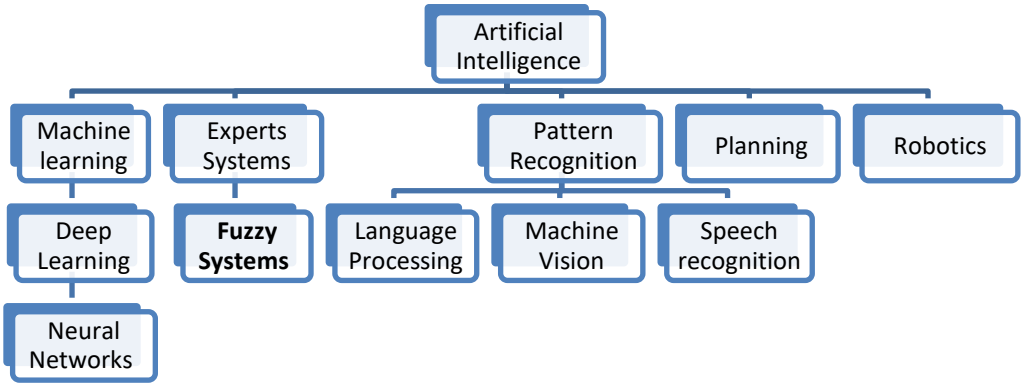

Fig. 2: Various types of AI [14].

In the environmental sector, AI research has been focused on several environmental problems which promise new solutions to ill-defined problems relating to environmental protection, reducing air pollution, wastewater management, water pollution, preserving marine life and many other problems. The AI technologies in this area are developing every day and thousands of companies that utilize human and machine intelligence to perform various tasks exist. The following subsections discuss the various environmental applications of AI [15]-[19].

The main enabler for research in this area in Bahrain is the governmental support to research and technology in ICT and the environment. The research strategy of Bahrain places Information and Communications Technology (ICT) and Environmental research among the main research priorities of the country [20]. The main research base is at higher education institutions which are required to dedicate 3% of their revenues for research in the main research areas stated in the research strategy. On the other hand, the country has paved the way for IT and Hi Tech companies to start their business and provided support to investment in this area which paves the way for any future investment in AI in the country. Another main enabler for using AI in many areas nonetheless the environmental applications in Bahrain is the advent of 5 G technologies to Bahrain recently which can be a main driver for any future investment in AI solutions [21].

4.1 Waste Water Treatment

The problem with the performance and efficiency of waste water treatment plants is that the process is highly complex as it is composed by several operational units- which make it difficult to implement an automatic process control over the wastewater treatment plant. This is because of the lack of understanding of the biochemical process and the interrelationships between different characteristics of the system. In general, the process is ill structured as there is a lack of understanding of the biochemical process and the interrelationships between different characteristics of the system. Performance and efficiency of the plant operation can only be enhanced if the supervisory control system is able to react to the changes and deviations of the inputs to the system which are highly varying. Furthermore, the sludge process used in the treatment plant is highly dependent on the unforeseen changes experimented by live beings (microorganisms). Therefore, the performance and efficiency of the plant operation can only be enhanced if the supervisory control system is able to react to the changes and deviations of the inputs to the system which are highly varying [16].

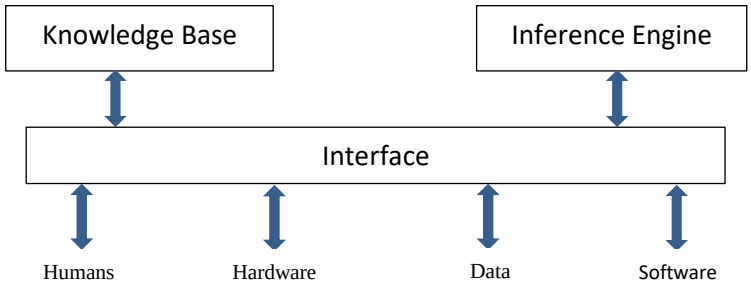

Fig. 3: Knowledge-based systems [18].

In such scenarios, A Knowledge based systems acts as the master in a supervisory set point control (SSC) scheme which is fed with monitored data (pH, T, DO, ORP, aeration and flows, nitrate, nitrite and ammonium ions, etc.) using the data server and continuously decides the optimum control required to achieve the required nitrogen and organic matter removal efficiency. Control actions are then transmitted to the process computers that actuate on each element of the plant [22][23]. A knowledge-based system allows deriving new knowledge based on reasoning system though a knowledge base and an inference engine [25]. Therefore, knowledge-based control system can address usual abnormal situations and unusual abnormal situations in wastewater treatment plants.

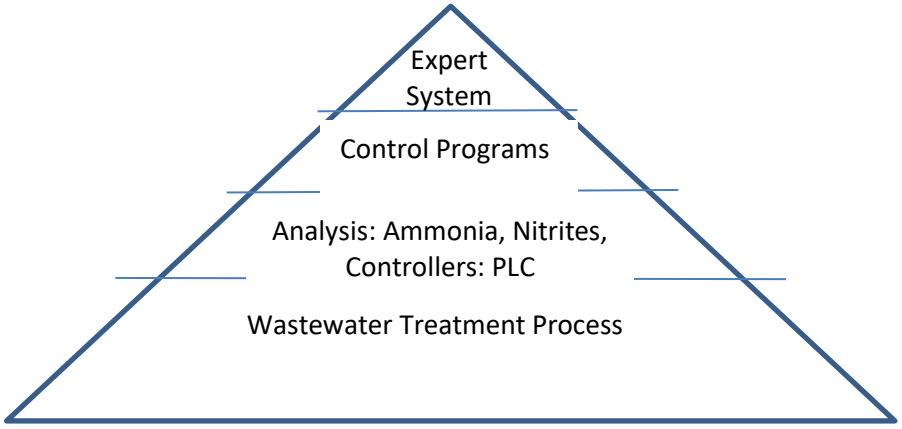

Fig. 4: A distributed system for supervision and control in wastewater treatment process [26].

Research in this area has been focused on utilizing Knowledge-Based control systems in the modeling and design of wastewater treatment plants to enable the different elements of the process to learn from previous cases (specific experimental knowledge) and to acquire the domain knowledge (general expert knowledge) in order to overcomes some of the main drawbacks of classical control techniques [19]. Another direction in research in this area is the use of artificial neural networks, and adaptive network based fuzzy inference system in wastewater treatment plant modeling and control such as pump station control, optimization of energy use, control of additives in treatment, control of an activated sludge plant, control of non-linear pH neutralization, optimization of nitrogen removal and aeration energy consumption in wastewater treatment plants [19], [26].

4.2 Protecting Marine Life

In this area, AI can help predict the spread of invasive species, follow marine litter, monitor ocean currents, keep track of dead zones and measure pollution levels [30]. The main AI technology is this field is the AI -based Autonomous Underwater Vehicles (AUV's) and underwater robots which can be used to track and count fish in order to build an open living database of marine health and fish population, deep sea assessment and also real-time monitoring of pollution levels of the sea. Figure (2) shows an example of AUV's used for marine life monitoring [29].

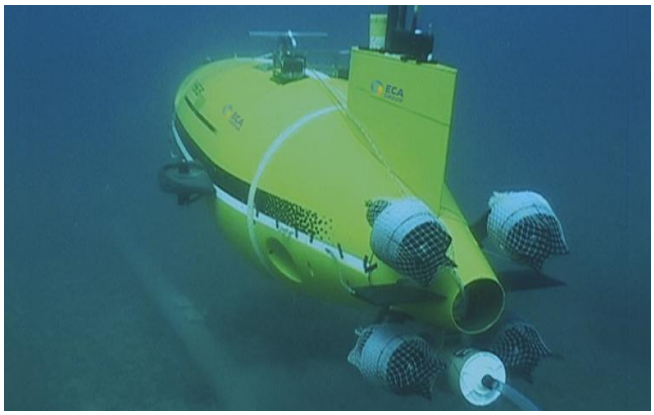

Fig. 5: The Alistar 3000 autonomous underwater vehicle [29].

4.3 Oil Spills Detection

AI offers a number of solutions for detection and early warning of oil spills though the use of Artificial Neural Networks (ANN) in the classification of Synthetic Aperture Radar (SAR) images. SAR imaging has been extensively used for detection of oil spills in the marine environment as they are not affected by local weather conditions and cloudiness. The main problem with detection of oil spills from SAR images is that most detection techniques rely on detecting dark areas in the image. However, due to nonlinearities in the image data, the problem becomes very complex. ANN's can be used to simultaneously handle non-linear data of a multidimensional input space in the oil spill classification problem. Results of research in this area showed that ANN have been superior to other image classification approaches in detecting oil spills on SAR images [31]-[32].

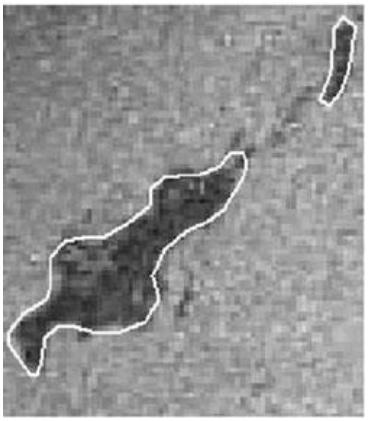

Fig. 6: Oil spill detection from SAR images using ANN [33].

4.4 Ground Water Pollution Detection

AI can play an important and useful role in this area. Significant research has been done on using AI for development of smart monitoring system that will enable quality control and detection of chemical and/or bio-contamination and a preemptive risk management [26]. The AI-based water contamination quality control systems are based on using advanced sensing technology coupled with pattern recognition techniques such as Support Vector Machines (SVMs), and Artificial Neural Network (ANN). The use of these technologies will help offer accurate severity level assessment of water quality [34].

4.5 Environmental Decision Support Systems

AI-based Environmental Decision Support Systems (EDSS) are intelligent information system that enable ideal and time-efficient decision making in environmental strategic management processes [35]-[37]. These systems use numerical and/or qualitative models which can produce estimates of the degree of potential environmental hazards, assessment of risks, judgment of the degree of concern about a certain hypothesis and eventually intervention decision-making regarding the appropriate methods for controlling or reducing environmental risks. The use of AI in EDSS enables complex environmental problems to be tackled as AI enhances the learning and decision-making processes in such problems [38].

An EDSS can understood as a multi-layered system where a user interacts with an environmental process at the top layer through a number of layers that include the knowledge acquisition and learning layer (from spatial (GIS) and temporal data base), AI, statistical and numerical models layer, the reasoning and integration layer which implements a predictive, planning or supervisory task over the environmental system [37].

5 Analyses of Results

The presented research has attempted to provide directions for researchers and decision makers in developing the future environmental strategies and to consider future AI solutions to address the environmental problems of Bahrain. It shown that AI can provide significant enhancements to wastewater treatment plants in Bahrain without increasing the land size needed for expansion. AI can also provide solutions to protection of marine life through AI operated autonomous underground vehicles. With ground water pollution, AI-based water contamination quality control systems can offer improvements to ground water quality which is also a scarce resource in Bahrain. Finally, AI environmental decision support systems can provide significant improvements to environmental monitoring activities at the governmental level and enhance the effectiveness of environmental solutions and monitoring activities imposed by the government on the various sectors that are involved in environment protection.

6 Conclusions

The most important challenges that face the environment of Bahrain has been presented and analyzed against possible solutions based on Artificial Intelligence technologies. The significance of this study stems from the fact that these problems are unique and require non-traditional solutions given the location, land size and the rapid growth of the country's population and industries. AI offers many solutions to these problems that face the environment in Bahrain and will potentially enable sustainable growth of the country in the future specially with the 2030 Economic vision of the country [9] which focuses on the continued development of the Kingdom's economy and building a better life for every Bahraini. It is with no doubt that achieving this vision requires solutions to the accompanying environmental problems which cannot be attained without utilizing future technologies such as AI technologies.

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