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Application of robotics in onshore oil and gas industry—A review Part I

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HIGHLIGHTS

- We present review for application of robotics in onshore oil and gas industry.
- Robotic automation used in all the five stages of petroleum industry is described.
- Pipe and tank inspection are two most important areas of robotics application.
- Aviation robotics and Wireless Sensor Networks are also becoming popular.
- For safety and productivity teleoperation robotics is the future of this industry.

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ABSTRACT

With ever increasing global demand and depleting resources for fossil fuels, oil and gas industry is now positively looking for advanced robotic solutions to increase their productivity and safety. With time easy resources of the fossil fuels are shrinking and newly searched reservoirs, to feed supply demands of global consumption, are mostly located in extreme environmental conditions such as hot deserts, deep water and arctic zone etc. Production of the fossil fuels, in such inhospitable environmental conditions, poses difficult challenges to health, safety and environment (HSE). Tragic incidents like Exxon Valdez and Deepwater Horizon oil spills are examples of such challenges. Therefore, oil and gas industry has lot to learn from successful implementation of robotics and automation for dull, dirty and dangerous (3D) tasks of manufacturing industry. Most of the robotics technologies, currently used in the oil and gas industry, are mainly focused on inspection, maintenance and repair (IMR) of plant facilities with higher frequency and accuracy. Fundamental idea, involved in the automatization of these processes, is based on the principle of teleoperation with skilled operator. Automation of 3D tasks not only improves HSE standards but also lead to much needed economic efficiency by reducing production cycle, floor space and number of staff members required for continuous inspection and manipulation of plant facilities. Considering the risks involved in this industry usage of completely autonomous robots, first without achieving very high reliability, is still a far fetch choice. Therefore, semi-autonomous robots, where actions are performed by robots but cognitive decisions are still taken by skilled operator, is an excellent choice for this industry as a near future solution. In the onshore oil and gas industry robotic solutions are used both in upstream and downstream processes, such as site survey, drilling, production and transportation, mainly focused in the form of in-pipe inspection robots (IPIRs), tank inspection robots (TIRs), unmanned aerial vehicles (UAVs) and wireless sensor networks (WSNs) etc. This paper presents the state of art robotic solutions currently used in onshore oil and gas facilities.

1. Introduction

With rapid growth in world's population demands for additional share of industrialization which eventually leads to higher demands for natural resources. With annual depletion rate of 8% oil and gas industry is pressed to add new stream of production to meet soaring demands [1]. Around 80% of our energy demands are fulfilled by fossil fuels out of which 50% to 60% comes from oil and gas alone [2,3]. Fossil fuel combustion is responsible for almost 78% of the greenhouse gases in the USA alone [4]. Though this increasing consumption of fossil fuel is creating severe environmental crisis by unwanted emissions but at present there is simply no equivalent substitute to this magical fuel called oil and gas in terms of energy density, ease of transportation and developed infrastructure. With this ever increasing pace of oil consumption, at present

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it is 142 Mboe/d (million barrels of oil equivalent per day), conventional resources of petroleum products are shrinking very fast and remaining oil and gas fields are characterized by adjectives such as arctic, deepwater, cold, heavy, high in water content, high sulfur content, to name but a few [5]. Further this scarcity of conventional resources forcing oil companies to go for exploration of new non-conventional petroleum reserves such as heavy oil, tight gas, shale gas and coalbed methane etc. Modern economy is highly coupled with oil prices therefore cost-effectiveness of the production is an important key factor to the future of this industry and global economy. Most of the production fields are not exploited fully because after certain level of recovery, production cost does not justify further investments of stakeholder's moneys. This increasing supply demand and difficult oil fields have not only increased the cost of production, but also compounded the risks related to human security and environmental safety.

Fossil fuels are hydrocarbons trapped in porous rocks and sediments in underground conditions [6]. Extraction of fuel from early onshore resources only required shallow drilling in highly pressurized free flowing wells. Although there are many historical instances for usage of oil in ancient times but first professional oil well in modern time was developed in 1859 by Edwin Drake in northwestern Pennsylvania, USA [7]. Over the period of time as natural pressure of crude oil reduces due to extraction its become difficult to recover complete volume of fossil fuel due to technical and economical challenges. But with increasing prices and dependence on fossil fuels, many advance technology such as water injection, gas lift and steam injection, as secondary and territory recovery methods, have become economically viable to increase recovery rate and extract more crude from non-free flowing resources [8]. According to [6] we now consume four barrels of known reserves for every barrel of newly added reserve. Therefore, most of the giant oil fields (roughly 500 around the world) which currently contributing 65% of the world's oil supply are almost now 50 years old and fast declining in production capacity keeping world oil production relatively flat [9]. With almost stagnant conventional onshore production, compensation for deficiency between demand and supply coming from either increasing offshore fields and non-conventional petroleum reserves such as shale oil, shale gas, tight oil, heavy oil, tar sands coal bed methane and methane hydrate etc. Revolution in production of these non-conventional resources of oil and gas in USA by newly advanced technology has generated an economic shock wave in international oil and gas market. For an example in the USA most part of unconventional fossil fuel supply is coming from horizontal drilling and hydraulic fracturing of shale gas and tight oil [10] as shown in Fig. 1. In the US alone production of shale gas has grown from 12 million m^3 in 2002 to 275 million m^3 in 2012, which accounts for almost 40% of the total natural gas production [11]. There are pros and cons of production of shale gas as opponents warn for water pollution, earth quake and methane emission, supporters show reduction in emission of green house gases as usage of coal gets reduced due to usage of more cleaner natural gas in electricity production [10,11].

Since Most of the new oil and gas fields are found in extreme environmental conditions such as harsh deserts, deep-water, frozen arctic zones and deep below ground level. Extraction, processing and transportation of petroleum products in adverse geographical and environmental conditions pose serious challenges to environment, marine lives and human health. Many serious accidents involving oil spills, leaks, fires, explosions, toxic emissions and water solution has taken past in future. Recently happened terrible offshore accident of Deep Horizon oil spill in the Gulf of Mexico [12] has shocked the world and warned us to be extremely careful of HSE related issues. Though this accident was in offshore conditions but many severe accidents has taken place in onshore facilities as well and one such accident that shook USA has happened in July

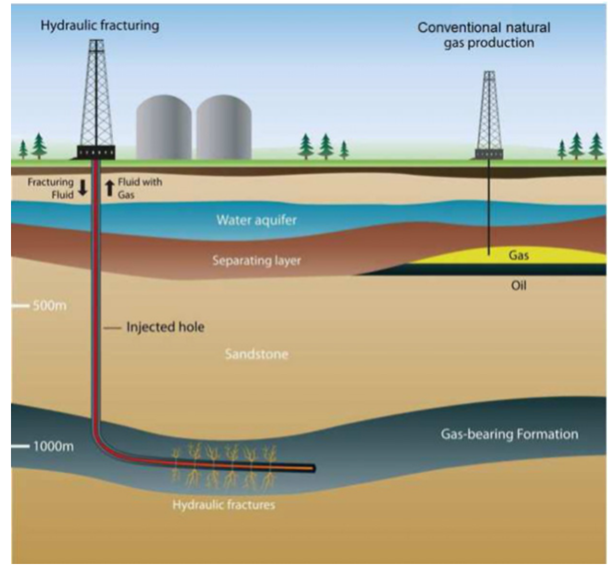

Fig. 1. Horizontal drilling and hydraulic fracturing [11].

2010 when a 30-inch carbon steel pipeline, operated by Enbridge Energy Partners, Canada's largest crude oil transporter, ruptured while carrying DilBit (short for Diluted-Bitumen extracted from oil sand [13,14]). These accidents went unnoticed for next 17 h until it released almost 3 million liters of DilBit into a tributary of the Kalamazoo River in Michigan. Whole clean-up operation costed company till now around 1 billion USD but even after 2 years of herculean efforts river is not completely clean while leaving permanent displacement of nearby communities [15]. Transportation of DilBit in to conventional oil pipelines is a very dangerous idea since it is by nature very corrosive, acidic and unstable mixture of volatile gases and thick raw bitumen [16]. And leak detection system across the industry is not yet reliable as mentioned in [17] that oil spill data maintained by federal regulators show that over the last 10 years, advanced leak detection systems identified only one out of every 20 reported pipeline leaks [15]. In the wake of several terrible oil spill crisis in Europe, European Commission has already funded several research projects with main objective of developing innovative intelligent robotic technologies for oil spill management [18,19].

2. Related research

With increasing energy demand for ever growing urban population of the world more pipeline networks are required for transportation of fossil fuels in different stages of its consumption cycle. Since petroleum products are sensitive and found in extreme environmental conditions extra efforts are required for continuous inspection and monitoring of the every component involved its extraction, production, processing and finally distribution. To work efficiently in such a intensive environment with all human limitations, robotic assistance to human cognition is extremely essential. Overall robotic assistive strategy for condition monitoring, inspection and control strategy of sensitive oil and gas industry can be break down in many subproblems such as human–machine interface [2,12,20–22], data-signal transmission [23–26], resource allocation and task scheduling [27–30], navigation technologies [31–33], localization of the mobile robots and workspace-objects [34–38], inspection technologies [39–45] and teleoperation [46] etc. Even after rightly an efficiently solving all these subproblems integration of all these subsystems is an another challenge [47].