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Application of robotics in offshore oil and gas industry— A review Part II

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HIGHLIGHTS

- We present technical review of robotics used in offshore oil and gas industry.
- Site survey, production structure and inspection require assistance from ROV.
- Underwater inspection, welding and manipulation are critical areas in offshore.
- Remote sensing, prevention and cleaning of oil spill require robotic surveillance.
- For safety and productivity teleoperation robotics is the future of this industry.

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ABSTRACT

Demands for oil and gas are increasing with urbanization and industrialization of the world's increasing population. Giant oil fields are declining in their production worldwide and this situation is creating need for search of new conventional and non-conventional fossil reserves. With steep depletion of major onshore and shallow-water-offshore oil fields new search of fossil fuel is moving towards deep-water and ultra-deep water offshore fields. Obviously new reserves are located in extreme, hostile and hard-to-reach environmental conditions. Exploration, development and production of oil from such difficult offshore fields have many serious challenges to health, safety and environment (HSE) therefore, require sophisticated technological innovations to support increasing energy demand. Biggest oil spill accidents in explosion of Deepwater Horizon offshore oil platform are burning example of such challenges which human society cannot risk to repeat. Therefore, development of advance drilling system, more accurate and intelligent inspection mechanism, faster responsive system in cases of unfortunate incidence and efficient damage control system is need of the safer future. Successful implementation of robotics, in space and manufacturing industry, is an critical example of how robotic assistance and automation is the only option for safe and cost-effective production of oil in foreseeable future. Teleoperation of unmanned drilling and production platforms, remote operated vehicles (ROVs), autonomous underwater vehicles (AUVs), under-water welding, welding robots for double hulled ships and under-water manipulator are such key robotic technologies which have facilitated smooth transition of offshore rigs from shallow waters to ultra-deep waters in modern time. Considering the sensitivity of product and difficulty of environment, most of these technologies fall under semi-autonomous category, where human operator is in loop for providing cognitive assistance to the overall operation for safe execution. This paper summarizes the key robotic technologies currently used in offshore oil and gas facilities.

1. Introduction

With ever increasing demands for energy to keep the pace of industrialization newer sources of fossil fuels are required. Non-conventional energy sources are either inefficient or insignificant to meet real energy challenges as of now, therefore around 80% of our current energy demands are fulfilled by fossil fuels and out of which 50%–60% comes from oil and gas alone [1,2]. Transportation industry is the biggest consumer of fossil fuel because alternative power sources fuel-cell, battery and solar cells have very low energy density in comparison to it. With fast depletion of easy resources new fields for petroleum products are found in more extreme conditions such as deep-water, hot deserts and arctic zone etc. [3]. With downhill onshore production, offshore crude oil pro-

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duction has grown from 1 Mboe/d (million barrels of oil equivalent per day) in 1940 to nearly 24 Mboe/d in 2009 [4]. With shrinking supply and increasing demands, now oil and gas companies are also trying for new non-conventional petroleum reserves such as heavy oil, tight gas, shale gas and coal-bed methane etc. Modern economy is highly sensitive to quality, quantity and cost of crude oil as it can be clearly observed in phenomena of falling crude oil prices leading of fall in other non-oil commodity prices world wide [5–7]. This fall in crude oil prices came due to increasing production of gasoline, by hydraulic fracturing, mostly in USA [7]. Though hydraulic fracturing poses serious challenges to environment by ground water pollution, noise pollution, degradation of air-quality and potential danger of future earthquakes. But counter argument is that fracking technology is swiftly getting advance and matured to deal with above mentioned challenges. Overall essence is that demand for higher energy cannot be ignored, therefore advancement of technology for better management of existing resources and safer exploration of future difficult resources hold the key for success.

Most widely reported and studied tragedy of Deep Horizon oil spill in the Gulf of Mexico [8] has created severe crisis for countless sea species, dozens of company employees lost lives, livelihood of local fishermen are destroyed permanently and operating company British Petroleum (BP) has got embroiled in to many law suits [9]. Investigators have found that there was a recurring pattern of ignoring warning signals, failure to share information, and a general lack of appreciation for the risks involved [10]. This accident was a huge setback for oil and gas industry being biggest environmental crisis of known human history while severely affecting countless lives for decades. But this unfortunate event has also triggered the most serious debate not only in governments, academia and environmentalists but also among the major players of the oil and gas industry for the future strategy of safer exploration and production of the fossil fuels [11]. Deepwater drilling exploration is very challenging because drilling takes place at deep, cold, distant and extremely high-pressure environment. And in the case of Deep Horizon oil spill, extreme pressure of natural gas under sea-bed had created a crack in recently built concrete core, through which gas traveled to rigs riser and then to the platform, where it ignited, killing 11 and injuring 17 workers. Attempt to close the well failed miserably when efforts to activate rigs blowout preventer (BOP), a safety mechanism designed in the cases of failure to close the well from which oil was drawn, did not succeed at the last minutes of crisis. In this accident almost 200 million gallons of oil was spilled in deep water creating terrible pollution for marine lives [12]. Almost 2.9 million liter of dispersant chemicals were poured in sea water to treat water which was polluted by oil and gas plumes [13,14]. This oil spill became even more critical because leak happened in deep water at the depth of 1511 m and for which there was no readily available technology to control the such spill immediately at such a deep subsurface level. Advanced industrial ROVs (Remotely Operated Vehicles) from Schilling Robotics, AUVs (Autonomous Underwater Vehicles) and UAVs (Unmanned Aerial Vehicles) were employed to do sea-floor survey and remote sensing of subsurface submerged oil respectively for accurate analysis of the pollution caused by oil spill [13,15]. In their internal report itself BP has given glimpse of the extent of damage and herculean efforts involved in overall cleaning operations by stating that "at its peak in 2010, the response effort involved the mobilization of approximately 48,000 people, the coordination of approximately 6500 vessels and the deployment of approximately 2500 miles (13.5 million feet) of boom to contain or absorb the oil. As at the end of December 2014, BP has spent more than 14 billion USD and workers have devoted more than 70 million personnel hours on response and clean-up activities. The US Coast Guard ended the remaining active clean-up operations in the Deepwater Horizon area of response in April 2014" [16,17]. 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].

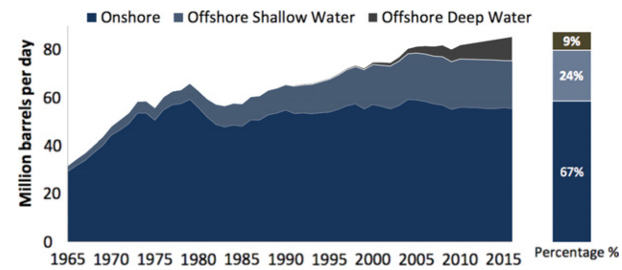

Fig. 1. Onshore versus offshore oil production map [20].

Since, most of the giant onshore oil fields are in declining production and overall supply of crude from onshore reserves are leveled-out now [4,21], required thrust to match the soaring demands of supply chain is coming now from offshore productions. Currently almost 30% of the world's oil production is coming from developing offshore field and deep-water reserves are also contributing around 9% as shown in Fig. 1 [4,20]. Since 2002 now even offshore oil production is also on decline due to saturation of shallow water oil wells. Oil reserves found in depth $d \leq 400$ m from sea level are called as shallow, deep-water when $400 < d \leq 1500$ m and ultra-deep-water when $1500 < d$ m. As of now almost 80% of the total offshore production comes from shallow water oil reserves. First offshore drilling is tracked back to as early as 1869 to the first patent for offshore drilling rig design of T.F. Rowland but first commercially developed field started in 1896 off the coast of Summerfield, California. These early offshore fields were very shallow only few feet deep from sea level. Deep-water production became commercially feasible from year 1990 and started with production rate of 1.5 Mboe/d and now scaled up to three times. In a same spirit of finding new oil reserves, from year 2005 onwards oil companies have also started exploring ultra-deep water territories of sea. Contribution of offshore production is critical for the world economy but somehow overall offshore production is also showing leveling off around 23 Moeb/d from years 2002 onwards, mostly due to shrinking shallow water reserves and inability to find new big offshore reserves in recent time. And most of the new offshore oil and gas fields are found in extreme environmental conditions such as deep under and frozen arctic zones etc.

Sensitivity of the product coupled with harshness of the environment now leading to critical HSE challenges, therefore, continuous inspection and maintenance of the oil and gas facilities are extremely important tasks. Extraction of oil and gas from deep water conditions is an impressive engineering feat but it also require equally capable technologies to prevent accidents and ensure safety of human and marine lives. While increasing demand of oil and gas with advanced technologies have made difficult oil fields economically feasible but in case of accidents cost is catastrophically unaffordable as clearly demonstrated in Deep Horizon oil spill case. Human limitations and their capacity to operate in intensively extreme environment is really critical, therefore, robotic assistance in such situations will be immensely valuable [22]. In such human–machine cooperation model, most of the cognitive ability to take decisions will come from human operator and access to critical objects, data collection, inspection, manipulation and feedback comes from robotic device equipped suitable sensors. Therefore, it can be said that overall automation of the oil and gas facilities can be further divided in to many specific subproblems such as human–machine interface [1,8,23–25], data-signal transmission [26–29], resource allocation and task scheduling [30–33],