Industrial Internet of Things for Oil and Gas Industry

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Abstract:

Deployment of internet connected assets and sensors in oil and gas applications has been around for decades but the recent technological developments are promising for more. The use of industrial internet of things (IIoTs) for oil and gas applications has attracted a great deal of interests today. There are several technologies that are enabling the implementation of IIoT. In this paper, we present a survey of IIoTs for oil and gas applications. The state-of-the art technologies and case studies for different IIoTs applications that encountered in oil and gas are discussed. More importantly, we identify the trends, opportunities and open challenges in the oil and gas industry-based internet of things solutions. This survey is intended to serve as a guideline for IIoTs technologies used in oil and gas industry .

Keywords : IIoTs, Radio frequency identification (RFID), Wireless sensors networks (WSN), Big Data/Analytics, Cloud/Fog computing,

I. Introduction:

The applications of the internet of things (IoTs) to the manufacturing industry is called the industrial internet of things (IIoTs) (or industrial internet or industry 4.0). IIoTs have a wide spread among various industries[1], as it enables the acquisition and accessibility of greater amounts of data, at greater speeds, with better analytics, and more efficiently than before.

Never the less, oil and gas companies should consider implementing IIoTs to overcome both the current low oil prices and the increased difficulty of environmental regulations. As the OPEC oil crude prices fell toward around $50 per barrel; their lowest since 2005[2], see Fig. 1, beside further signs of weakening prices in futures market with no significant increase in demand expected, investing in IIoTs solutions is the best option to lower drilling, operational and maintenance costs. Furthermore, the increasing compliance costs of worker safety and environmental new standards, the new partial bans and restrictions due to environmental concerns; such as groundwater concern, and the greenhouse gas/Methan reports on the wellheads leaks, all could be avoided and enhanced with IIoTs predictions and

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early detections management systems leading to conformance to low-carbon and health, safety, and environmental (HSE) regulations.

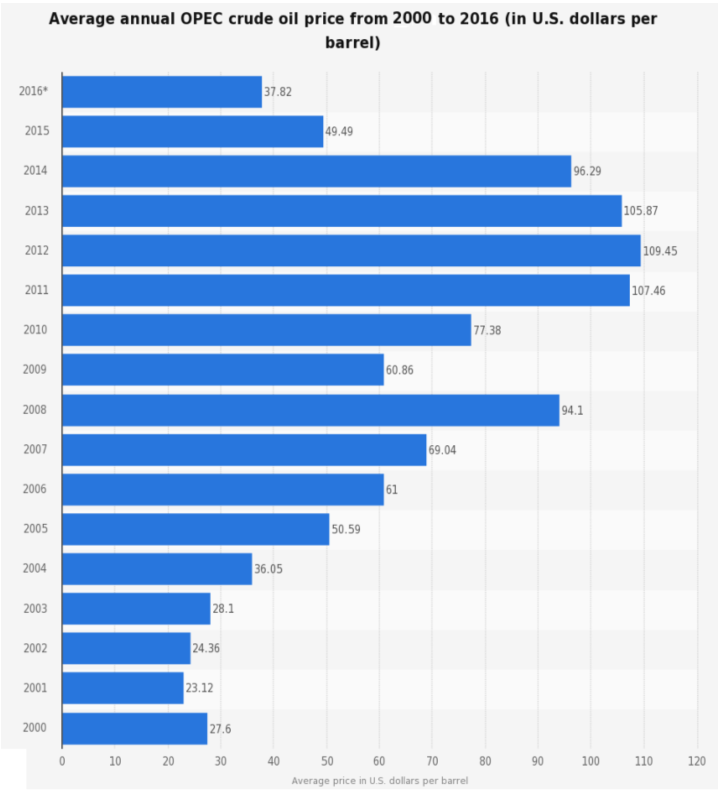

Fig. 1: Average annual crude oil prices for the last 17 years, OPEC IEA [2]

Today's IIoTs wide adoption in oil and gas industry with its very sophisticated applications are all due to the recent technology evolutions. As more and more computing power, storage, and battery capacities become available at relatively low cost and low size. This trend is enabling the development of extreme small-scale electronic devices with identification/ communication/ computing capabilities, which could be embedded in other devices, systems, and facilities[3]. IIoTs should have three characteristics [3] as shown in table.1 below.

IIoT Characteristics	**Includes**	**Technology**
1- Comprehensive perception	- Identification - Sensing - Localizing	- 2D barcode, u-Code, IPv6 - Sensors Networks, WSN - RFID tags
2- Reliable transmission	- Within the Oilfield - Between the Oilfield and the headquarter	- WiFi, Bluetooth, ZigBee - Satellite, Fiber Optics, Cellular - M2M, LPWAN - Gateway, Switching, Networking
3- Intelligent processing	- Cloud/Fog Computing - Data integration - Data analysis - Machine Learning	- Hadoop platform, etc - 3rd party analytics

Table.1 : IIoTs characteristics and their enabling technologies

In this paper, we surveyed the literature and company profiles to list out IIoTs applications in the oil and gas industry. Our survey is based on the different state-of-the-art technologies enabling IIoTs. Moreover, we list out the challenges facing IIoTs in this mission-critical industry. The paper is organized as follows. In section II, a brief background on IIoTs for oil and gas industry is introduced. Then, the surveyed list of the enabling technologies of IIoTs for oil and gas industry is introduced in section III. In section IV, main challenges with discussion on how to target them are presented. Finally, the paper is concluded in section V.

II. IIoTs for Oil and Gas:

IIoTs are connecting the physical world of sensors, devices, and machines with the internet. Moreover, by applying deep analytics through software is turning massive data into powerful new insight and intelligence. The oil and gas industry is using scalable architectures that consider possibilities for plug-and-play methods combined with (sensing/actuating) integrated with IIoTs infrastructure and integrate the wireless monitoring of petroleum personnel in critical situations (onshore/offshore), container tracking, tracking of drill string components pipes, monitoring and managing of fixed equipment.[4].

The oil and gas industry include : exploration, extraction, refining, transporting, and marketing petroleum products, based on the business value chain, it’s usually divided into three segments; upstream, midstream, and downstream. Each segment has its own information, communication and technologies (ICT) challenges[5], and can find the greatest benefit from its initial IIoTs efforts in one of these business objectives [6]:

- *Improving reliability*: Minimize the risks to health, safety, and environment by reducing disruptions.
- *Optimizing operations*: Improve the cost and capital efficiency of operations by increasing productivity, optimizing the supply chain, and lowering maintenance cost.
- *Creating new value*: Explore new sources of revenue and competitive advantage that transform the business.

Table. 2 below explains these three segments in more details, along with their challenges, targeted IIoTs business objectives and some IIoTs applications.

	Upstream	Midstream	Downstream
Segment Includes	- Exploration - Visibility studies - Extraction - Production	- Transporting - Storage	- Refining - Marketing - Gasoline retailing
O&G assets	- Wellheads - Off-shore oil field - On-shore oil field	- Pipelines networks - Pump stations - Gathering systems - Storage tanks	- Refiners - Gasoline stations
Challenges[5]	- Remote, shifting, dispersed: locations. - High cost of drilling new wells - Acquisition , storage, sharing: field data. - Analysis, modeling, matching: field data. - Centralized: control, management, decision making.	- Harsh, remote, long: geographic environments - Communication - Remote control - Security monitoring	- Acquisition, control: refiner's data - Production dispatching - Emergency command - Security, safety: monitoring - Distribution scheduling management: of oil and gas - Communication, management: of multiservice to headquarter
IIoT Applications Examples	- Drilling monitoring - H2S monitoring	- Remote pipeline monitoring - Leak detection system - Pump stations monitoring - Block valve monitoring - Tank storage monitoring	- Natural gas compressor monitoring - Meter station monitoring - Corrosion real-time monitoring - Fueling stations managements
IIoT Business Objectives [6]	- Optimizing operations	- Optimizing operations - Improving reliability	- Optimizing operations - Create new value

Table.2: Oil and gas segments (upstream, midstream, downstream)'s challenges, IIoTs business objectives, and some IIoTs applications.

The diverse nature of oil and gas industry IIoTs applications needed two IoT network connections with interoperability and compatibility among the different applications supported. The two IoTs network connections are: 1)'*Mesh networks'*, which is a closed system with protocols defined for group of connected machines, used with local control system; and 2)'*Telemetry networks'* that uses existing telecom infrastructure to send information back to central control location. Both network connections are used among oil fields with open standards IP based infrastructure to provide flexible and open architecture for all services. The "*Cisco wireless refinery solutions*" [7], "*Huawei digital pipeline solution*" [8], and recently proposed "*Aljeel smart oil and gas solutions*" [5] are good examples of IIoTs networks.

There are several initiatives working toward standardized architecture for IIoTs to facilitate interoperability, simplify development, and ease implementation[9]. Reference architectures are evolving in close collaboration between research and industry. The major three models (which are used as other names for IoTs: Industry 4.0, Industrial Internet) are:

- Reference architecture model *industry 4.0* (RAMI 4.0)[10]
- *Industrial internet* reference architecture (IIRA)[11]
- *Internet of Things* - architecture (IoT-A)[12]

IIoTs reference architecture handles all the requirements needed to implement the different technologies to a business case. For the sake of demonstration, a simplified open architecture model is presented in Fig. 2 to show the case of an intelligent oil field (IOF) [3].

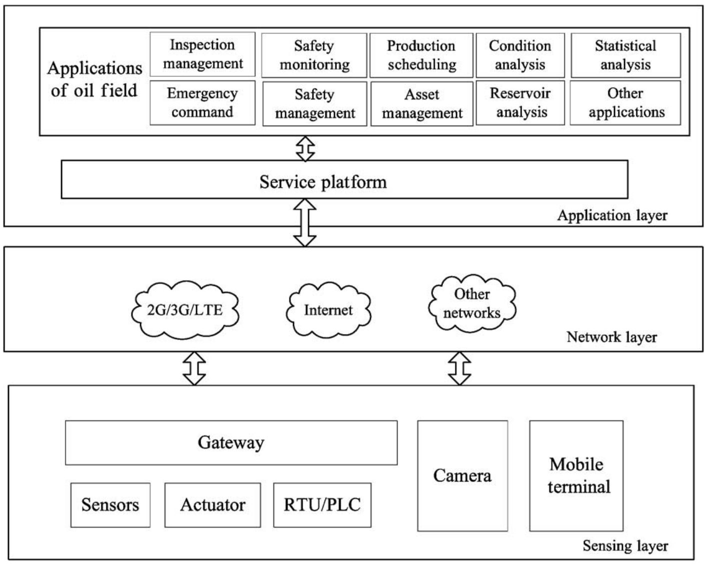

Fig. 2: IOF using CCSA open standard model [3]

III. IIoTs enabling technologies for Oil and Gas industry:

Incorporating IIoTs solutions requires using several compatible and interoperable technologies to seize and capture all possible data needed to revolutionize oil and gas industry. According to recent publications [13-14], digital technologies such as the cloud, big data analytics and mobility are recognized as adding value to upstream oil and gas companies by helping reduce costs, make faster and better decisions, and increase workforce productivity. Oil and gas companies are increasingly leveraging the cloud to more rapidly unlock the value of other digital technologies, specially for enabling : Mobility, big data analytics and IoTs.

Therefore, this section is devoted to review the latest industrial and research advances in IIoTs systems through these three enabling technologies: wireless , oil big data/ analytics, cloud/fog computing.

A) Wireless technologies:

Deploying wireless technology is the first and fastest way to use IIoTs in oil and gas industry. Allowing for more- smart sensors and instrumentations added to the network easily, facilitate tracking asset and personnel locations for safety and security measures, promote for collaborative work between oil fields worker and experts back in headquarter- leading to more efficient decision making.

The mobility aspect of wireless connectivity makes it possible to have more efficient worker. This enables the workforce to bring wireless tablets and handheld bar code readers into the field to do regular and simple tasks in an online and automatic manner instead of using the 'pen and paper' way of working[7], also allow worker to contact the headquarter instantly in case of emergency to ask for a second opinion, deliver real-time video reports or enter the database of a fault asset[15].

Wireless mobility and connectivity in oil and gas industry is not a one-size-fit-all solution. There are different and sometimes disparate locations - offshore, onshore- and depending on the application needed or already existing systems in case of upgrading. But the most foundational technologies within oil fields and the ones that shapes current IIoTs applications are :

- Wi-Fi: (IEEE802.11a/b/g standards) for wireless local area networking.
- RFID: Radio frequency identification for tracking locations.
- WSN: Wireless sensor networking for sensing, monitoring and control.

1) Wireless sensing, monitoring, and control:

Wireless sensor networks (WSN) mainly uses interconnected intelligent sensors to sense, monitor, and control. This technology is composed of a number of sensing stations transmitting wirelessly the information they capture. WSNs are a key investment area across the oil and gas supply chain including refineries/petrochemical plants, pipelines, exploration & production, and transportation. By providing secure and reliable two-way wireless communications, WSN enables automation and control solutions that are not feasible with wired systems.

This technology is supported by low-cost, low-data rate, low power wireless mesh/star networking standards and protocols, as shown in Fig.3 and table.3 below:

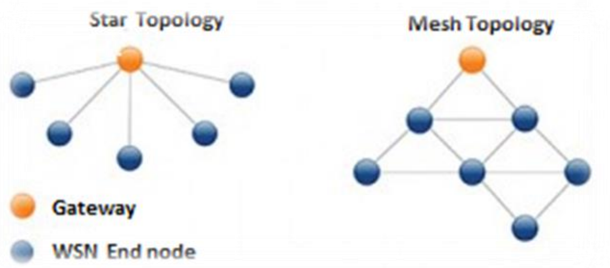

Fig. 3: Wireless sensors networks topologies [16]

Standard/ protocol name	**Type**	**Objectives**	**Interoperability** [18]
IEEE 802.15.4	Low rate- Wireless Personal Area Networks Standard (LR-WPAN)	Define PHY and MAC layers only	- 802.15.4 devices
ZigBee	Standard protocol stack	Wireless mesh networking layers (Network and application layers) over IEEE802.15.4 standard.	- Other ZigBee devices only - Use Complex application layer gateway.
ZigBee PRO[17]	For industry		
6LoWPAN	Protocol	Integration of low-power IEEE 802.15.4 devices into IPv6 networks	-other wireless 802.15.4 devices - Devices on any other IP network link - Use simple bridge device
Wireless HART [17]	Open wireless communication standard for industry	Definition of protocols for self-organizing, self-healing and mesh architectures over IEEE 802.15.4 devices	-other WirelessHart registered devices only, from any vendor.
ISA 100 [17]	Wireless systems standards for industrial automation	Use IEEE 802.15.4 PHY and modified MAC layer	- other ISA100 devices only

Table.3 : WSN standards and protocols

A sensing station is generally composed of [19]: a power unit, processing unit ,sensing unit, communication unit. Based on the WSN application these units varies [16] , some of them are shown in table.4 below.

Power Unit/ batteries	**Sensing unit**	**Processing unit**	**Communication unit**
-Non-rechargeable -Rechargeable -Energy harvesting[16]	-Level sensor -Pressure transducer -Flow-meters -Resistance temperature detector (RTD) -Emergency shutdown (ESD) valves	-Collect and process signals captured from sensors. - Microcontroller	-Wirelessly transferring the sensor measurements to the gateway. -Ad-hoc communication between sensing stations.

Table.4: Examples of different sensing station units

This type of technology was very useful in the industry environment, table.5 below show some of the solutions to oil and gas industry environment.

Applications	Capability	Benefits
Remote monitoring [20]	-Pipeline integrity monitoring -Tank level monitoring -Equipment condition based monitoring (CBM) -Pipeline and refineries pressure relief valve monitoring (PRV) -Wellhead automation and monitoring.	-Allows for energy management and savings. - Improve security and regulations compliance. - Reducing or eliminating down times. - Reducing repair and maintenance costs. - Limit damage and potential danger. .
Condition monitoring and maintenance [20]	-Preventive and predictive maintenance -Post-fault diagnosis is improved - Real-time corrosion monitoring	
Production performance [20]	- Hopfield network: Unsupervised Self organizing map (SOM) that perform data pre-processing. - Prioritize key sensor values and classify operational performance	Enhance operational visualization, foresight, forecasting and maintenance schedules
H_2S/ MG (multi-gas) monitoring systems [20]	- Monitoring H_2S/MG release during oil exploration and refinery. - Monitoring H_2S/MG pipelines leakages - Correlate reports from spatially distributed sensors	- Reduce its sever impact on humans and the environment - Detect and localize a leakage - Differentiate actual leakages from single source gas diffusion.

Table. 5 : WSN systems used in oil and gas industry

For a detailed WSN system structure in Oil and Gas industry, refer to [20] where a case study of a “well remote monitoring system” is presented with details.

2) Asset and personal tracking:

A foundational technology for IIoTs is the radio frequency identification (RFID) technology, By using RFID readers, people can identify, track and monitor any objects attached with RFID tags automatically . RFID includes several tags and a very small subset of tag readers. Enclosed in an adhesive sticker, the RFID tag is a small microchip attached to a radio (utilized for receiving and transmitting the signal), with a unique identifier number (ID). The purpose of RFID tags is storing information regarding the objects to which they are attached. The basic process is that the information flow is triggered by RFID tag readers through transmitting a query signal, followed with the responses of nearby RFID tags. RFID characteristics [21] are shown in table.6.

Types	Frequency range	Transmission range
- Passive - Active	- Various bands -LF (124-135KHz) -UHF(860-960MHz)	Very low (few meters)

Table.6: RFID characteristics

Although the main purpose for using RFID technology is in tracking, there are multitude of applications across the oil & gas industry to effectively utilize it. By effectively installing both RFID readers throughout the oilfield site and RFID tags on objects, different applications were surveyed in [22], as depicted in table.7 below.

Domain	Uses
Operations	- Estimating drill lengths and drilling risers. - Drill pipe health and pipe corrosion detection - Laydown yards
Safety and security	- Search, rescue, incidence investigation and worker tracking - Worker safety equipment mandatory checklist system - Unauthorized personal detection - Mustering headcounts
Asset management	- Equipment identification and On-site critical information - Identifying unreachable assets and subsea applications. - Maintenance and workflow tracking
Administration	- Identification - Employee time logs and attendance - Activity logs and document tracking - Parking facilities and vehicle tracking

Table. 7: RFID applications in oil and gas industry [22]

B) Oil big data/ analytics:

Oil and gas exploration and production companies have been conducting complicated data analysis for decades. However, new startup oil data companies keeps coming by using new ways of analysis with less expanses for well drilling and stimulations such as: microbial DNA analysis [23] and physics based modeling[24].

On the other hand, real-time continuous analysis of large volumes of data is considered relatively new, as we surveyed couples of startup oil companies that have based their business on that aspect. There were several enabling technologies used by most of these companies, such as: data integration, big data analytics, and machine learning algorithms. Combination of these technologies allowed for modeling complex relationships between high resolution signals reveling new insights. Analyzed data come up from various different resources as: sensors data, geological data, semantic data, log-wells,…ect.

The applications and benefits of data analytics covered most of the oil and gas industry; in exploration, production, remote monitoring, maintenance, and even compiling to health, safety and environment (HSE) regulations. More details found in table.8 below.

O&G Application	Oil data companies	Year	Technology	Use Cases	Benefits
Well exploration	Biota [23]	2013	- Microbial DNA sequencing technology - machine learning - Not real time.	- Provide 4D snapshot along the life cycle of the well	- Maximize production in horizontal shale wells
	Tachyus[24]	2013	- Data integration -Physics based modeling - Machine learning	- Best place, way to drill new well - How stimulate oil wells -Predict equipment failure.	-Increase production. -More profit
Remote monitoring	BitStew [25] platform	2009	- Data integration - Software defined operations for IIoT - Machine learning - could/fog computing	- Semantic data modeling - Predictive automation for connected devices - Dynamic event management	- Mange risks -Improve asset performance -Increase uptime
Condition Monitoring And Maintenance	Ayasdi[26]	2008	- Topological Data analysis (TDA) - Machine learning	-Predictive Maintenance: correlating system status and failure modes to identify all possible failure modes.	- Avoid un necessary maintenance - Reduce down time
	OspreyData[27] (Sensor and analytic platform)	2013	- Mechanical assets sensors data analysis - Machine learning	- Predict and prevent artificial lift equipments failure.	- Performance optimization. - Reduce down time
HSE regulations	ExxonMobil upstream research company + Providence Photonics (Remote gas leak detection system)[28]	2013 (field test)	- Software to analyze infrared camera images.	Utilizing optical gas imagers and advanced computer vision algorithms to enable remote autonomous hydrocarbon leak detection.	Provides an early warning alert, even for small amounts of leaks.

Table.8: Examples of oil data companies use cases

C) Could/Fog computing:

Wireless sensor networks (WSN) and internet of things (IoT) based services in oil and gas industry generate large amount of data from heterogonous devices and sensors that need real time processing, computing, storage , access, sharing and analysis, which creates big challenges for standalone IoT systems. Integration of IoT with Could computing is the solution, which is known as cloud of things (CoT)[29].

Cloud computing platform bring with its highly scalable, manageable, and schedulable virtual servers: storage, computing power, and virtual networking, according to user's requirements[29] The cloud provides Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) sets of capabilities for organizations that require elastic scale, security, compliance and improved economics [30-31]

Cloud computing provide many of advantages but it has also some limitations and challenges [31], which fog computing aims to resolve some of them. Proposed by Cisco[32], currently developed by "OpenFog"[30], fog computing is an extension of cloud computing to the edge of the network. It provides the ability to analyze data near the edge for stronger security and improved efficiency (where delays are critical or there is limited bandwidth), or to operate while disconnected from a larger network (autonomy). It also enables different fog instances to communicate with each other, enabling dynamic routing for resiliency and efficiency[30]. Fig. 4 below clarifies the differences between could and fog computing.

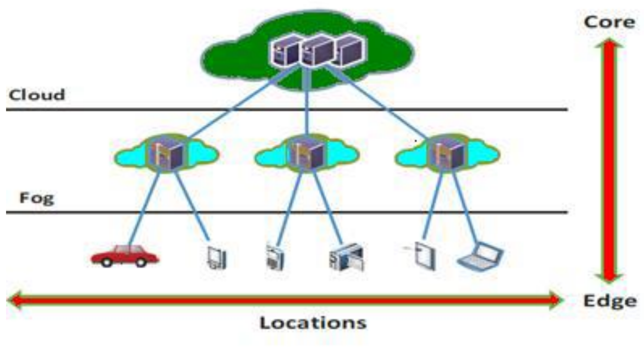

Fig. 4: Cloud and fog comparison on edge[31]

IV) Challenges:

Internet of things create a smart way to work in the industries and provide many new opportunities to them [3] and expected to be widely applied to the industries [1]. But there are a number of key challenges that remain in achieving widespread IIoTs adoption among oil and gas companies.

A)Standard and interoperability :

IIoTs applications use different technologies and these technologies use different standardization and protocols that made interoperability very difficult and required more of gateways to translate from one standard to another. Based on European commission recommendations it's important to develop technological standards to support IIoTs .[33][4]

B) Security concerns :

IIoTs are increasing the risk of cyber attacks and data spying. The massive data generated by the sensors and devices may be subjected to attack by cybercriminal and malicious hackers, because of the analysis code is directly exposed to open network environments or stored and managed in the cloud. Hence, companies should have a response plan to prevent losses from these threats as encrypting data may reduce the security risk, interconnectivity might helps proactively manage the risk of cyber attacks, and sensitive or private data must also be stored in a virtual storage server located inside the users country[30].Up to now there is no perfect solution!["The Internet of Things: Opportunities and Challenges for Distributed Data Analysis"][33].

C) Forced changes in business processes:

For established industries, IIoTs deployment requires fundamental transformation of business processes. This incurs high initial investment, where allocation of existing capital and equipment budget to support IIoTs adoption in existing and new operations will be difficult. Of course, the benefits are great. Cost of changes in existing infrastructure and manual business processes are hard to estimate. These changes to physical assets, people and processes cause an obstacle in acceptance of technologies such as IIoTs. Adoption by the large industries might serve as case studies to identify the pros and cons, as a positive network effect is needed [22].

V) Conclusion:

Oil and gas industry is benefiting from recent advancements in IIoTs enabling technologies and applications on fronts such as wireless sensor networks, radio frequency identifications, big data analytics and could computing. This paper listed the most important applications of IIoTs systems in this industry through their enabling technologies. Furthermore, this paper provides a list of major challenges that affect the adoption rate of IIoTs systems in such mission critical application and their possible solutions.

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