Big Data and Industrial Internet of Things for the Maritime Industry in Northwestern Norway

Hao Wang*, Ottar L. Osen*, Guoyuan Li†, Wei Li†, Hong-Ning Dai‡, Wei Zeng§
* Big Data Lab, Faculty of Engineering and Natural Sciences,
Aalesund University College, Norway.
† Mechatronics Lab, Faculty of Maritime Technology and Operations,
Aalesund University College, Norway.
‡ Faculty of Information Technology,
Macau University of Science and Technology, Macau
§ Connecticut Transportation Safety Research Center,
University of Connecticut, USA

***Abstract*—*Big Data Analytics* (BDA) and *Internet of Things* (IoT) are rising quickly. The recent emerging *Industrial IoT* (IIoT), a sub-paradigm of IoT, focuses more in safety-critical industrial applications. Studies showed that the adoption of BDA increase companies' output and productivity; IoT enables companies to have more information and control in physical resources, processes, and environments; BDA and IIoT complement each other and develop as a double "helix". In this position paper, we briefly review the opportunities and challenges in this era of big data and IoT for the Møre maritime cluster; then we propose a new framework integrating BDA and IIoT technologies for offshore support vessels (OSVs) based on a hybrid CPU/GPU/FPGA[1] high performance computing platform. We believe that such a framework, when implemented, can help maritime companies increase their output and productivity, and hence enable the whole cluster to continue to be a leader in the global maritime industry.**

I. Introduction

It is commonly agreed that we are in the era of *big data* (BD), and it is highlighted in a statement from the United Nations that "the world is experiencing a data revolution" [1]. BD is changing all aspects of human society, esp. the business world. Large amount of data has been collected for decades and data analysis is not a new idea, but "what sets the current time apart as the big data era is that companies, governments, and non-profit organizations have experienced a shift in behaviour. . . they want to start using all the data . . . to improve their business" [2]. Through an extensive scientific business survey done by MIT and IBM, it was detected that top performing companies are more likely to be sophisticated users of analytics than low performing companies and more likely to see their analytics use as a competitive differentiator [3]. Another study [4] from MIT, after surveying 179 large companies, showed that companies that adopted "*data-driven decision making*" have output and productivity that is 5-6% higher than what would be expected given their other investments and IT usage. A 5% increase in output and productivity makes a significant difference of winning the fierce competition in most industries. This quantified study confirmed that the effective adoption of BD can enhance a company's decision making, insight discovery, and process optimization.

The Internet of Things (IoT) [5], [6], [7] is a new paradigm that covers technologies including ubiquitous computing, pervasive computing, wired/wireless sensors, networks, and embedded systems, forming a communicating-actuating network of a large amount of *things* including Radio-Frequency IDentification (RFID) tags, mobile phones, sensors, actuators and etc. In this way, physical environment and resources could have presence in the digital world. IoT is included by the US National Intelligence Council in the list of six "*Disruptive Civil Technologies*" with potential impacts on US national power [8]. Very recently, *Industrial IoT* (IIoT) emerges quickly as a sub-paradigm which focuses more in *safety-critical* applications in industries like aerospace, energy, and healthcare. Defects and failures in such applications would often result in dangerous situations even loss of lives, so principles of safety-critical systems must be included and stricter criteria must be enforced. Safety and security are the first-class citizens in the design, an approach (completely) different from that of a domestic IoT application. The result of rapid development of IoT/IIoT is that the enormous amount of collected data from different sources will have to be processed, analysed, and visulized in a timely manner, and that is where big data analytics (BDA) will fit in. In fact, BDA and IoT complement each other and develop as a double "helix".

The northwestern Møre region of Norway is one of the leading clusters in the global offshore support vessel (OSV) shipbuilding and shipping (ship service) market, consisting of almost 200 companies with a total turnover in excess of NOK 50 billion. As pointed out in [9], this cluster consists of companies representing all stages from upstream suppliers to downstream customers and this geography proximity plays an important role in the value creation process in the whole supply chain. However the globalization is counteracting the

Corresponding addr.: Hao Wang, hawa@hials.no, Aalesund University College, Postboks 1517, 6025 Aalesund, Norway

[1]FPGA is short for field-programmable gate array.

impact of this proximity. Production and operation in the maritime industry have strong safety-critical aspects and BDA and IIoT have a lot of opportunities along with challenges. It is the current focus of the Big Data Lab (BDL) here in Aalesund University College (AaUC) to develop applied R&D projects based on our existing strong collaboration with the Møre cluster.

In this position paper, we briefly review the opportunities and challenges in this era of BD and IoT for the Møre maritime cluster; then we propose a new framework integrating BDA and IIoT technologies for OSVs based on a hybrid CPU/GPU/FPGA high performance computing (HPC) platform. We believe that such a framework, when implemented, can help maritime companies increase their output and productivity, and hence enable the whole cluster to continue to be a leader in the global maritime industry.

II. Literature Review

A popular definition of BD is that big data is high *volume*, *high velocity*, and/or high *variety* information assets that require new forms of processing to enable enhanced decision making, insight discovery and process optimization [10], [11].

The above definition is coherent with the 3Vs model for describing BD. IBM introduced a fourth 'V' – *veracity*, concerning about the quality of data, because biased data can only produce wrong answer. Very recently, it has been argued that a fifth 'V' - *value* might be even more important than the previous four V's, because it is only sensible for a business to adopt big data strategy if it could generate value considering the costs.

Nowadays data are collected from all aspects in business, but the large volume of data would be of little use if it has not been effectively analysed so that insightful information can be extracted and applied in the decision making and business processes. Davenport and Harris argued in their seminal book [12] that it is vital for business to compete on analytics, which means "the extensive use of data, statistical and quantitative analysis, explanatory and predictive models, and fact-based management to drive decisions and actions".

In the seminal paper of [13], big data analytics is considered in the wider context of business intelligence and analytics (BI&A). With several decades' development of BI&A, we have many successful database-based technologies for structure data and web-based technologies for unstructured data. The Economist expected that the number of mobile devices, surpassing the number of laptops and PCs in 2011, will reach 10 billion in 2020. The overwhelming and fast-increasing number of mobile devices and sensors has inspired a lot of innovative technologies and created new businesses. At the same time, this new development brings a lot of value-adding opportunities to existing business sectors. E.g., the RFID technology with real-time data visibility brings instant location-awareness to commodities, vehicles, personnel and etc., which could fundamentally change how a supply chain is operated. Another example is that FedEx collects and processes data from airlines, connections hubs, location of assets, weather forecasts, and traffic information, which allows for real-time routing information to be pushed out to individual drivers and optimization of pickup delivery and asset utilization [14]. We can see that real or near-real time information delivery is one of the defining characteristics of BDA.

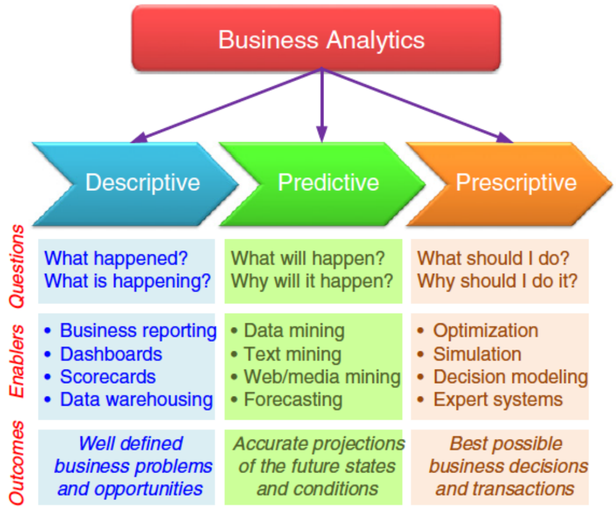

Figure 1. Categories of Analytics [15, Fig.3]

From the point of view of analytics-as-a-service [15], there are three categories of analytics: *descriptive analytics*, *predictive analytics*, and *prescriptive analytics*. They are depicted in Figure 1: (1) descriptive analytics reports on "what is happening or happened", which could help the business identify opportunites and challenges; (2) predictive analytics uses technologies like data/text/web mining to make probabilistic predictions on future happens; (3) prescriptive analytics uses technologies like simulation, decision support and expert systems to explore different alternatives and provide recommendations on the course of action of a decision maker.

We witnessed a widespread adoption of RFID technology, from which the concept of IoT was originated. However, because IoT covers so many stakeholders and aspects, many visions arise from industries and academia [5]. In essence, there are mainly three perspectives: (1) "Things oriented", which focuses in improving object visibility, i.e., the traceability of an object and the awareness of its status, current location, etc; (2) "Internet oriented", which aims at promoting the network protocols, e.g., the Internet Protocol, as the network technology for connecting smart objects around the world; (3) "Semantic oriented", which focuses on issues on how to represent, store, interconnect, search, and organize information generated by the extremely large (and ever-growing) number of smart objects.

As mentioned in Section I, very recently, the quickly-growing notion of IIoT is attracting a lot of attention. IIoT is originated based on the differentiation between more general domestic IoT and more safety-critical-focused industrial IoT. As pointed out by [16], compared to domestic IoT, IIoT has long product cycles, often operating in extreme conditions; IIoT generally needs to integrate with other industrial systems from different vendors, while domestic IoT normally is a vertically integrated, single-vendor solution; IIoT must prevent unauthorized access while domestic IoT is more concerned with users' privacy issues; IIoT must be fault-tolerant and cannot assume continuous access to Internet or cloud, therefore, IIoT has to be autonomous and able to function during network interruptions.

III. MØRE MARITIME CLUSTER OF NORWAY

As mentioned in Section I, the Møre cluster has a complete value chain with many leading international OSV companies like Rolls-Royce Marine, VARD, Farstad and Bourbon, who all have their own development and design divisions in this region. The core actors involved in contracting OSVs are ship operators, ship designers, and the shipyard. Figure 2 shows the various functions found in the OSV maritime network.

Companies in the cluster have benefited from the close geographical proximity [9]. A relatively long history of previous collaboration within the cluster facilitates cooperation and effective information and knowledge exchanges, improves ship quality, and shortens lead times. However, globalization is counteracting the impact of this proximity. The turnover of contracts from shipping companies in the cluster for local design companies was reduced from 56% in 2006 to 25% in 2009. To an increasing degree, vessels now are being built at foreign locations such as Brazil, China, and Dubai. Advanced components produced in the cluster are assembled in a shipyard in Brazil or China. Shipyards constructing OSVs are becoming increasingly global, working with shipyards overseas. The largest Norwegian OSV operator now has 75 percent of its vessels in Asian and Brazilian waters. It is observed that international customers are less involved in the predesign process but more financially oriented, contrary to many local customers that are concerned about getting the best technological solutions. In addition, the North Sea and new oilfields in the Barents Sea, outside Brazil, and in the South China Sea present new deep-sea challenges like harsh weather conditions and deep sea levels. Deep-sea challenges pose new great difficulties to both ship production and operations.

A long-standing challenge for operating an OSV is its maintenance management [17]. The maintenance of an OSV is complicated and expensive: (1) a vessel being out of service is considered a big loss, amounting to 0.5 to 1 million NOK per day; (2) an all-around maintenance is a big project by itself, one example in [17] showed that a 5-week project was budgeted to 25 million NOK. A maintenance project typically involves dry-docking the vessel, pre-ordering parts, hiring a large number of different facilities and personels. In addition, such a project is apt to be delayed because its scale and complexity, the same example in [17] was delayed and overspent by 100%; (3) unexpected failures of key components will result in more severe risk in operations and more expensive cost in maintenance.

IV. A NEW BDA-IIOT FRAMEWORK FOR MARITIME

Recently, with the intention of remote ship monitoring for better services for shipping customers, vessel builders started to adopt new sensor technology by installing different sensors for different components on board an OSV and transmit data using satellite communications to land-based service centres, e.g., HEalth MOnitoring System (HEMOS) by Rolls Royce Marine. After a while, builder companies realized that the collected sensor data could also help improve vessels' maintenance and future design. This has motivated the collaboration between the BDL of AaUC and different maritime companies on developing a systematic framework integrating BDA and IIoT technologies for OSVs. We expect that such a framework can help obtaining: (1) real-time analytics results to support vessel operations; (2) analytics results to support diagnosis of vessels, prediction for maintenance needs, and allocation of maintenance facilities and resources, especially for OSVs operating in different international locations due to globalization; (3) analytics results on operation challenges in different waters and weather situations so as to facilitate and prioritize new components and designs. In addition, as pointed out by [14], from the aspect of regulators, BDA on sensor-enabled operation data can improve energy efficiency and environmental performance, safety verification and assessment, and the monitoring of accidents and environment risks, and help regulators introduce more quantified regulations for the administration of ships and seas.

New BDA and IoT/IIoT technologies are emerging quickly, but most of them are targeted to land-based applications. An OSV is a special environment in that it operates in different (difficult) situations for an extended period of time and relies mostly on satellite communication, which is very expensive. Therefore, it is unrealistic to use cloud-based BDA solutions and to install powerful computing facilities onboard an OSV. As the frequencies and formats of data vary a lot by different sensors, semantics-based data integration [18] would be inevitable. However, the computational need for such real-time data integration and analytic tasks is challenging to local computing facilities on an OSV.

Furthermore, compared to land-based applications, OSV has specialized and strict safety and security regulations and guidelines [19]. Deployment of the framework shall not interfere the safety and security of operations; regulations and guidelines are important inputs to predictive information meant to assisting operations. All these aspects must be considered when designing the specialised framework. In particular, security and privacy issues of IIoT [20] and certification of analytics software [21] are two important topics in such a domain-specific framework.

In general, BDA requires heavy computational power. As to building a HPC platform, CPU, GPU, and FPGA have their own specific advantages and disadvantages, nowadays increasing number of HPC platforms/projects are exploring different combinations and report comparison results for different algorithms and applications. As we have observed in the HPC community, super computers have already been built with a hybrid CPU and GPU architecture to make use of the large pool of processing units in GPUs, e.g., Titan, a super computer built in Oak Ridge with a combination of GPUs and traditional CPUs, was ranked No. 1 in the Top500.org November 2012 list [22]. In addition, we have seen in recent years fast develop-

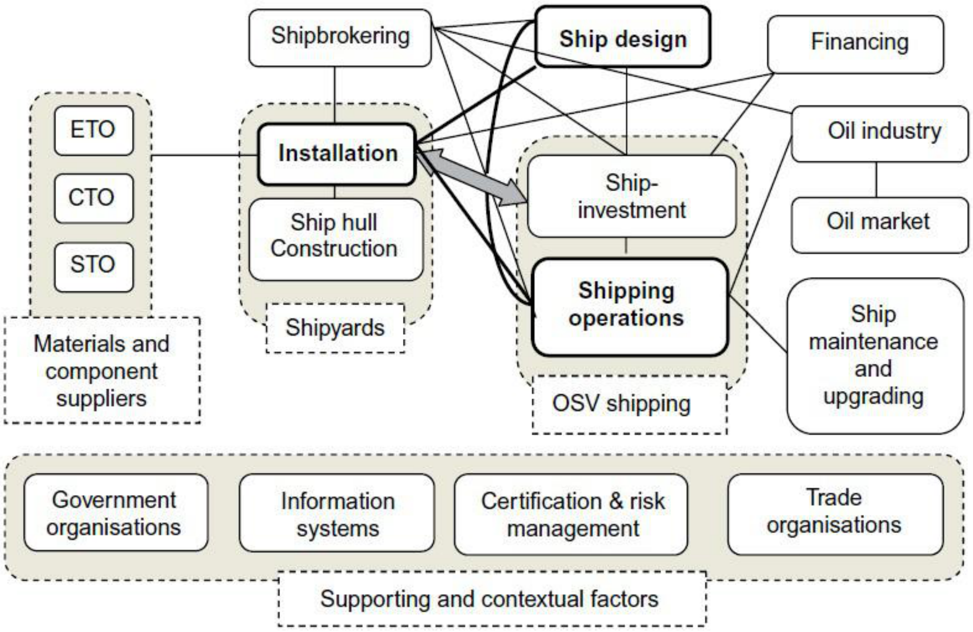

Figure 2. Maritime Network [9] (The focal ship design – shipping operations – installation triad unit of analysis, indicated by bold interconnecting line; interconnectivity between ship investment and installation at a shipyard represents the functional basis for contracting an OSV ship, indicated by a double-headed arrow)

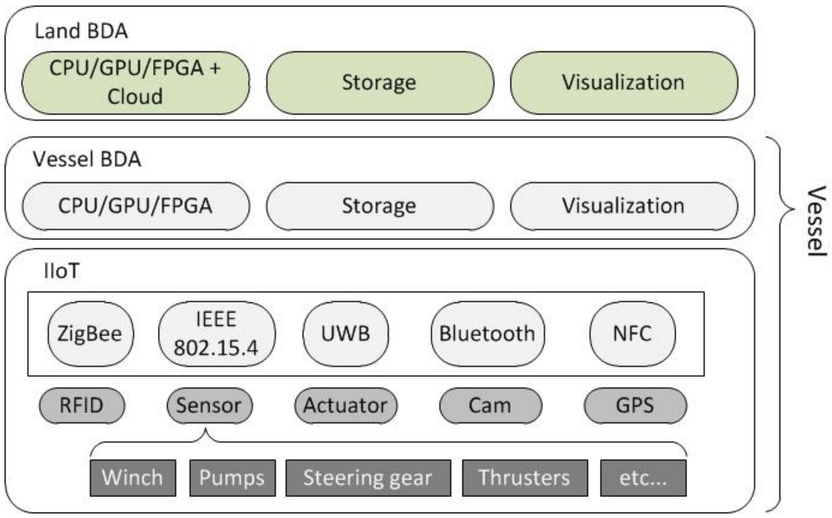

Figure 3. Conceptual 2-layer BDA-IIoT Framework for OSV

ment of FPGAs, the performance of which starts matching that of GPUs with much less power consumptions [23]. For this reason, FPGAs are being adopted in new HPC architectures. More importantly, the new OpenCL 2.0 standard makes it much easier to program across different CPU, GPU, and FPGA architectures [24], [25], [26]. These new development enable us to experiment with different configurations considering the advantages and disadvantages of CPU, GPU, and FPGA and develop a smaller (in terms of costs, size, and power consumption) but more powerful BDA platform on an OSV.

Considering the domain-specific requirements in the OSV setting, we propose a two-layer BDA-IIoT framework as depicted in Figure 3: the vessel BDA layer and the land BDA layer. The vessel BDA layer consists of the vessel's local data processing and analyzing facilities for real-time BDA needs. Because of the limited computing resource available onboard, this layer focuses on real-time decriptive, predictive, and prescriptive analytics tasks to mainly support the ship operations. This layer could be further decomposed as the IIoT components and the BDA modules. The IIoT components include a variety of monitoring/sensing and actuating equipment such as RFID readers, sensors, actuators, cameras, and GPS.

They are used to collect real-time data for BDA, monitor and control different (critical) parts like winch, thrusters, and etc. The IIoT components use different protocols (e.g., ZigBee, UWB, Bluetooth, and etc) to communicate with the BDA modules. They send the collected data to BDA and obtain the real-time analytics results for operations. The BDA modules consist of the hybrid CPU/GPU/FPGA platform mentioned above, the data storage, and the visualization module displaying all the analytics results. The land BDA layer focuses on analytics tasks of large batch historic vessel data for maintenance and future ship design and development. In this layer, a more powerful setting of the hybrid CPU/GPU/FPGA platform could be combined with mature cloud-based BDA solutions to provide efficient and effective analytics results. In particular, advanced simulation [27] technology can be applied to achieve better outcome.

V. Conclusions and Future Work

In this paper, we review the challenges and opportunities for the northwestern Møre maritime cluster of Norway, including deep-sea and globalization challenges. Based on an analysis on the domain-specific requirements from the OSV setting, we propose a new BDA-IIoT framework based on a hybrid HPC platform.

Currently there are strongly increasing awareness and interest in BDA and IIoT technologies among the companies in the local cluster. To address this, we are planning relevant education for maritime industrial leaders and professionals as well as bachelor/master level courses for students. We are collaborating with more local companies setting up R&D projects on different topics based on the proposed BDA-IIoT framework.

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