# Smart ports: towards a high performance, increased productivity, and a better environment

**Hayder Ali Al-Fatlawi, Hassan Jassim Motlak**
Department of Electrical Engineering, College of Engineering, University of Babylon, Babylon, Iraq

**Article Info**

***Article history:***

Received Nov 21, 2021
Revised Oct 6, 2022
Accepted Oct 25, 2022

***Keywords:***

Automated guided vehicles
Internet of things
Smart container
Smart port
Smart ship

**ABSTRACT**

Ports are currently competing fiercely for capital and global investments in order to improve revenues, mostly by improving performance and lowering labor costs. Smart ports are a fantastic approach to realize these elements since they integrate information and communication technologies within smart applications, ultimately contributing to port management improvement. This leads to greater performance and lower operational expenses. As a result, several ports in Europe, Asia, Australia, and North America have gone smart. However, there are a lot of critical factors to consider when automating port operations, such as greenhouse gas emissions, which have reached alarming proportions. The purpose of this study is to define the most essential tasks conducted by smart ports, such as the smart ship industry, smart gantry and quayside container cranes, transport automation, smart containers, and energy efficiency. Furthermore, it gives a model of the smart port concept and highlights the critical current technologies on which the ports are based. Each technology's most significant contributions to its development are noted. This technology is compared to more traditional technologies. It is hoped that this effort would pique the curiosity of fresh researchers in this sector.



*Corresponding Author:*

Hayder Ali Hassoon
Department of Electrical Engineering, The University of Babylon
Hilla-Najaf Road, Babylon, Iraq
Email: hayderalialiali@gmail.com

## 1. INTRODUCTION

Maritime logistics services are of great importance in contributing to the increase in international trade, which is for more than 85% transported through sea ports [1]. To accommodate this quantity of goods, it has become necessary to develop these ports to be more efficient and productive. This goal can be reached through the use of smart ports, in which all operations are automated. Smart ports depend in their work on the use of modern information technologies to reach the best level of planning and management both within and among ports, thus easing administrative procedures and enhancing the management of freight traffic [2]. Currently, many researchers are concerned with how to find smart logistics services and propose solutions to achieve them [3].

Many academic or practical research projects have provided new solutions to reduce the complexity of the port operation, an example of these projects is Erasmus smart port in Rotterdam, the Netherlands [4], and the smart port of Hamburg in Germany [5]. The concept of a smart port means the automation of all operations performed by the port, as well as the communication of all port activities through the auto transmission of mobile data in real-time. This leads to doubling the ability of ports to complete and integrate port operations [6]. Therefore, the smart port saves time in documentation and money as a result of reducing manpower, as well as facilitating tracking and traffic, which helps reduce congestion, increase productivity, and maintains the safety of workers [6].

Any smart port consists of a combination of sensors, actuators, wireless equipment, and database processing centers. This makes the services provided by port authorities more efficient and resilient in a more sustainable way. Among the most prominent sensors that are used in the smart port to collect appropriate data are eddy current sensors, ultrasonic sensors, imaging sensors, inertial sensors, radio frequency identification (RFID), and radar [7].

To work on transforming traditional ports into smart ports, it is necessary to be aware of the most important operations that take place in ports. As shown in Figure 1(a) and 1(b), the port areas can be divided as: i) the terminal consists of several berths. Each berth deals with a specific type of goods, such as containers, oil and gas tankers, and cruises; ii) the quay is the ship's anchorage to unload their cargo, where dock container cranes unload containers from ships to horizontal transport systems, which eventually transfer them to the container yard; and iii) a yard is an area where containers are unloaded from horizontal conveyor systems into a container yard for temporary storage until distribution to customers. The yard has gantry cranes that stack containers. Each container has a height of 2.62 m. The container is placed on top of another with a height of up to 16 m according to ISO standards [8]. To provide a sufficient path for transport movement, the container piles are separated by 25-30 meters; iv) trucks enter through the port gates to transport containers from the container yard. The gantry cranes load the containers onto trucks, which exit through the port gates and transfer the containers to the customers. As shown in Figure 2, five main applications of smart outlets can be identified, which are as: i) smart ships; ii) smart gantry and quayside container cranes; iii) automation of transportation; iv) smart container; and v) smart energy management.

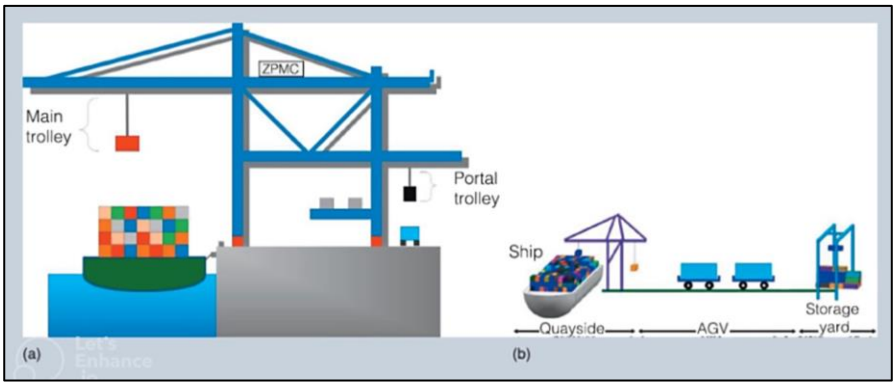


Figure 1. Port operations (a) loading and unloading the ship and (b) the process of transporting goods from the quay to the yard [7]

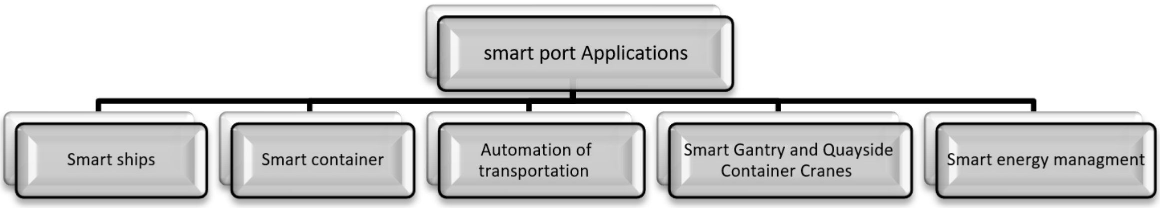


Figure 2. Main smart port applications

This work presents the most important modern technologies that were used as a basis for building the smart port, with mention of the most significant previous works that contributed to the development of each technology. The second section deals with building smart ships, whereas the third section deals with smart bridge cranes and container cranes. In the fourth section, the automation of transport operations in the port is discussed. The fifth section addresses smart containers, followed by the use of modern technologies in the field of energy to raise the efficiency of the port in section six. The seventh and eighth sections shed light on the use of modern communication systems in port operations, and the connection and management of the port through the internet of things (IoT). Finally, the conclusions drawn are stated in section nine.

## 2. SMART SHIP

Since ancient times, ports have played a prominent role in the prosperity of cities and thus the economic growth and prosperity of all coastal cities around the world. In Europe, for example, about 74% of goods are imported or exported by ship [9]. During the past two decades, the movement of ships increased, which led to the occurrence of congestion in the sea lanes as a result of the remarkable development of global maritime trade. This caused the number of ships, and eventually the amount of greenhouse gas emissions and environmental pollution, to increase [10]. In order to avoid marine accidents and other undesirable problems such as delays in the process of departure and arrival of ships, there was a need for effective navigation systems that enable communication among ships as well as ports.

Saxon and Stone [11] presented a study which stated that about 48% of ships arrive at least 12 hours later than the scheduled time due to congestion. This leads to more fuel consumption and consequently an increase in cost and pollution. To exemplify, reducing one hour of ship waiting time could save up to $80,000 [12]. The smart management of ships helps minimize the waiting time, the mooring of ships, and helps them to commit to their arrival schedule, by means of selecting the paths and ports, based on their location and the traffic rate. To develop the system monitoring and control of ships, a satellite system of smart sensors and monitoring devices were provided, which increased the amount and reliability of information sent and received to the port. These systems help smart ships to connect to smart ports and organize the berthing process, thus facilitating the loading and unloading process [6], [13].

For ships, the global positioning system (GPS) is an essential tool for navigation in and out of the port area. The importance of real-time data increases during port operations, do as to identify the location and condition of objects for planning and coordinating activities with high efficiency [14], [15]. The retrieved positioning data can be used for prediction (e.g., route prediction, arrival times), as well as being combined with other data sources to achieve contextual data about individual objects and points of interest [16]. Figure 3 represents the process of ships collecting information and exchanging it with other sources through satellites or 3G/4G communication technologies. The ships can communicate with the port and its departments to know the traffic of ships and the docking times. This also enables the port to track goods and identify their status and location [17].

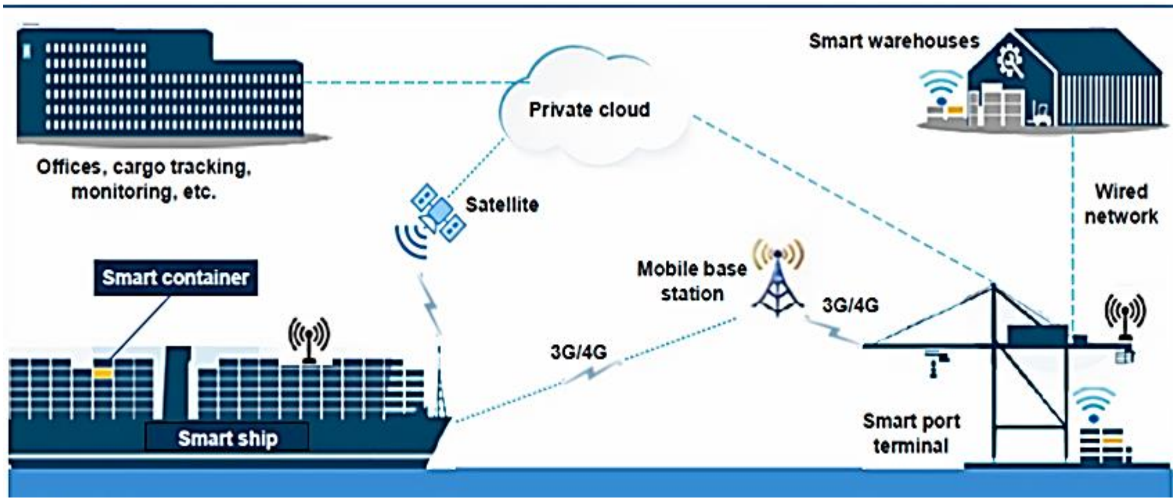


Figure 3. Communication systems types in smart ship at sea [17]

Table 1 draws a comparison between smart ships and traditional ships, where it is noted that smart ships have advantages that help them outperform their traditional counterparts. It is possible to obtain more accurate information about the paths of ships and possible congestion in marine traffic. Through this, it is possible to estimate the time of arrival and delivery for ships, eventually reducing waiting time for ships, as well as the emission of greenhouse gas emissions (GHG) and the carbon footprint resulting from the continuous operation of ships during the waiting period. It can be stated that it mitigates the negative effects on the climate and the environment, and improves the clarity of the air. From the aforementioned points, it can be noted that the use of smart ships allows for more efficient and productive planning of port operations [17]–[19].

Table 1. Comparison between smart ships and conventional ships

| Smart ships | Conventional ships |
|---|---|
| Less fuel consumption | More fuel consumption |
| More accurate information on ship movements | Less accurate information on ship movements |
| Improved ship scheduling and time of arrival of ships | Congestion in sea traffic and more delay time of arrival of ships |
| Increase in ports' efficiency | Less efficient ports |
| Reduction in greenhouse gas emissions (GHG) | Increase in greenhouse gas emissions (GHG) |

## 3. SMART GANTRY AND QUAYSIDE CONTAINER CRANES

The increasing demands of customers for low cost and fast shipping have led to the competition of the global economy. To enter that competition, the automatization of the loading/unloading of equipment has the potential to dramatically improve the performance of port operation, as it becomes efficient and high-tech. The most important aspect is ship-to-shore container cranes (STS), which make up the bulk of the investment (70% of total costs in ports). It is used in the cargo loading and unloading system. It is a factor affecting the efficiency of port operations [20].

The control systems in traditional STS cranes depend on placing the load in the required place quickly and safely, which are determined by the personal skill of the workers and can be rather time-consuming. To increase the lifting speed and reduce the time, the cranes need to be fully automated to achieve high productivity. The higher the operating speeds of the lever, the more difficult the control task [20].

In the traditional crane, the crane operator from the top of the cabin looks down to transport containers from one place to another. Over a long period of time through which the work is repeated periodically, it may cause fatigue and exhaustion for the operator. This could eventually lead to accidents in addition to delays in completing work [21]. Two types of cranes frequently used in ports are rail-mounted gantry (RMG) and rubber gantry (RTG). To operate one crane for 24 hours a day, three operators are required to work alternately, implying the need for hundreds of workers as crane operators [22].

To switch from conventional cranes to robotic cranes, advanced sensors are installed on the crane chassis to detect the position of carriages and containers. These sensor systems consist of encoders for reading container data, laser rangefinders, cameras, and programmable logic controllers (PLCs). The PLC collects the location data and compares it to the desired position provided by the yard computer, and in turn directs the crane motors [23], [24]. The automation of cranes contributes to a significant reduction in labor costs, as one operator can operate three to six cranes remotely from the console room via video surveillance. It also helps to ensure operational safety [23]. Table 2 presents the comparison between smart cranes and traditional cranes. It is noted that the use of smart cranes significantly increases the productivity and efficiency of the port, as a result of reducing the cost of labor and speed in carrying out the work, as well as preventing human errors as a result of accuracy in loading and unloading [7], [19].

Table 2. Comparison between smart cranes and traditional cranes

| Smart cranes | Traditional cranes |
|---|---|
| No need for much labor | Requires much labor |
| No human errors | Human errors occur |
| Accuracy in loading and unloading | Less accuracy in loading and unloading |
| Speed in handling loads | Delays in the handling of loads |
| More efficient and productive | Less efficient and productive |

## 4. THE AUTOMATION OF TRANSPORTATION

At the port, the horizontal transportation of containers consists of two separate logistic operations, as outlined below [24]: i) land transport (LS): it is the process of transporting containers from the port gate to the yard and vice versa; ii) waterside transportation (WS): the process of moving containers from ships after unloading by quay cranes (QCs) to the yard and vice versa. The process of road transport is performed by trucks through the main gate of the port to the yard. Since those trucks are non-automated and the truck drivers are off-street labor entering the station driven by outside labor, and not familiar with unmanned cranes, special attention must be paid to ensure the safety at those stations [24]. As for the transport on the waterside, it can be done either by conventional means of transport such as tractors and trailers or by automated platform-type vehicles automated guided vehicles (AGVs). Horizontal transportation on the waterside of the harbor with traditional gantry cranes was done by tractors and trailers. However, the use of conventional transportation appeared to be waning with the use of unmanned cranes due to safety issues while the driver was in the cabin of those vehicles [24].

With the automation of the processes that occur in the smart port, such as storage and cranes inside the port, traditional trucks also ought to be automated and replaced with electronically guided transport platforms. Smart ports prefer the use of AGV to reduce operating costs. However, there are several problems associated with using AGV such as positioning, route planning, obstacle avoidance, and route tracking [25].

The problem of positioning can be solved by using the differential GPS (DGPS) system as a navigation system for unmanned vehicles and systems, especially for AGVs, given that it has robustness and accuracy [26]. It can also be used as a collision warning system. The work in [26] proposed a system to automate entire container transportation operations using unmanned trucks with DGPS and a set of sensors, whereby [26] used optical-based systems, especially laser and radar systems, instead of DGPS systems [13]. Pratama *et al.* [25] proposed an algorithm for the positioning and obstacle avoidance of AGV using laser measurement systems. As for [27], a new technology is proposed for fusion positioning of ground vehicles that combines a virtual sensor and an electromechanical-based micro-inertial measurement unit. In [28], the distance from the ground to the marked points on the vehicle is measured by using ultrasonic sensors. The path tracking of AGV dumps is done using several technologies including a camera sensor [29], laser navigation system [30], inductive guidance using underground electric wire [31], wall tracking algorithm [32], and semi-guided navigation method using magnetic tapes [33]. From the aspects stated above, it is concluded that transportation automation has many benefits, including reducing labor costs and reducing safety and collision accidents, as well as contributing to improving the environment by reducing gas emissions.

## 5. SMART CONTAINERS

To transform traditional containers into smart ones, they need to be equipped with a number of sensors that track containers by collecting data on their geographical location, as well as remote monitoring of events and conditions (such as temperature) for containers throughout their journey. Examples of events that can be noted include whether or not containers have been opened, changes in temperature, emergency situations such as vibrations and falling of fragile goods, and floods and fires that occur during container transport. This technology allows sending immediate alert messages to investors to take the necessary measures [19]. The smart container sends continuous feedback throughout its journey in real-time, helping to plan maintenance or report damage [34]. The smart container technology reduces the berthing time of the ship in the port; thus, it reduces the operating cost by about 10% [12], [35].

At container terminals, DGPS technology has been used. This system extends GPS through the use of fixed reference stations that detect the difference between a known exact location and GPS positioning data [13]. Thus, the exact location of the containers can be determined along with the tracking of container movements within the terminal [36]. There are a number of relevant works found in literature. One of these is the work of [37], wherein RFID seals are used to track commercial container from the point of origin until they reach their destination, thus helping protect goods from damage, theft, and terrorist threats. Figure 4 shows a container with a security seal that reveals any unauthorized attempt to open or tamper with the contents of the container.

Figure 4. A container with RFID seal

In study [38], electronic locks, sensors, and alarms are used to send their information by an radio frequency (RF) communication unit to the base station to know the status of the smart container. The GPS unit is linked to determine its location. As for [39], they suggested wireless sensing networks (WSN) technology to obtain the data of the container and then send it over large areas. The work in [40] proposes

WSN as a technique but created a wireless connection that connects containers with a cellular network, i.e., an additional container connection and an in-container connection to communicate from inside to outside the container and vice versa.

Table 3 shows the comparison between smart containers and traditional containers. Through smart containers, physical locations can be identified and tracked. Alerts can be created and important information can be sent to the information center. Employees, suppliers, and consumers can also view particular information or get email notifications. Because smart container data is electronically created and end-to-end secured, it is safe and reliable [6], [19].

Table 3. Comparison between smart containers and traditional containers

| Smart container | Traditional container |
|---|---|
| Locate the actual places and keep track of them. | Employees must look for containers |
| Alerts can be set up to shed light on essential information | Not possible |
| Allow employees, suppliers, and customers to view specific information or get email notifications. | Not possible |
| The data is produced electronically and encrypted from end to end, thus it is safe and reliable. | The data can be tampered with because it is generated manually. |

## 6. ENERGY EFFICIENCY OF SMART PORT

Due to the increasing rise in energy prices, as well as to preserve the climate from environmental changes, many ports seek to enhance energy efficiency by adhering to environmental regulations issued by the authorities for reducing pollutants and greenhouse gas emissions from energy stations [41]. Equipment electrification, alternative fuels, and renewable energy sources, together with operational efficiency, dramatically cut hazardous emissions and constitute the port’s future generation [42]. The energy efficiency of a port is proportional to its operational efficiency. The automation of smart port devices and equipment reduces energy consumption and consequently improves energy efficiency [43]. There are a variety of technical solutions that may be used at the port to improve energy efficiency and enhance the environment. Electricity can be used as a source of energy for numerous equipment, electric vehicles, renewable energy, energy storage systems, reefer cooling systems, lighting technologies, and alternative fuels are just a few of these options [41].

While docked, most ships turn off their main engines, and turn on auxiliary engines to supply power for lighting and cooling activities. These engines burn fuel (diesel oil, heavy fuel oil, or liquefied natural gas (LNG)) at idle and emit greenhouse gases. Cold ironing, or the so-called beach card, is the use of electricity supplied through the grid or renewable sources in order to provide the energy required for such activities in ships [44]–[46]. The use of cold ironing in ports has contributed to reducing toxic emissions. On average, 29.3% of carbon dioxide is reduced in port areas [47].

Because direct current may minimize peak demand and average power usage, using direct current (DC) instead of alternating current to operate port cranes is more energy efficient [48]. Energy can also be stored in supercapacitors for later use [49]. Adopting new technologies in improving port lighting instead of traditional lighting (which represents about 3-5% of total energy) improves energy efficiency. The use of light-emitting diode (LED) bulbs instead of high-pressure sodium lamps to light the outlet storage facilities and administration building is an example of this technology [50]. The use of lighting levelling techniques can also save electricity [51].

Renewable energy resources include solar panels, windmills, tidal movement, waves, and underground heat [52]. In [53], it is proposed to cover the surface of the cooling area with solar panels to shade the containers, thus reducing the energy consumption required for cooling, as well as the use of the energy generated from it in operating the port equipment. The Jurong Port in Singapore has generated an annual electrical power of 12 million kWh by using solar panels to cover the warehouse’s rooftop, as shown in Figure 5 [54], [55]. Hamburg’s Port also covered the roofs of warehouses with solar panels and generated electric power of 500 megawatts per hour annually [56]. As for the latter, it was able to generate 25.4 megawatt using wind energy by installing more than 20 turbines [41]. In the ports of Valencia and Hamburg, the consumption of lighting energy has been reduced by up to 80% through the use of motion-sensitive lights that illuminate when vehicles pass [57]. As can be seen from the above, the smart port makes a substantial contribution to reducing gas emissions and global warming by continuously improving its energy efficiency and incorporating renewable energy into all of its operations. Furthermore, the efficiency of automated port systems and equipment provides for cost savings in energy, and the usage of automated guided vehicles has a substantial environmental impact.

Figure 5. PVs covered on the warehouse roof space [53]

## 7. COMMUNICATION SYSTEMS OF SMART PORT

In automated ports, the use of wireless communication systems has become an urgent necessity due to its unique advantages. However, there are some difficult problems faced by these systems during implementation. The biggest challenge is that it is affected by the large metal parts that make up the containers and most of the port equipment. The second challenge is that it is affected by high-energy electrical equipment. Some of these problems can be solved through the development of anti-jamming (antenna) techniques so that the use of wireless communications becomes more widespread [7].

WSN is one of the most promising technologies due to its size, cost-effective nature, less energy consumption, and its ability to easily deploy in the target environment, as well as for its entry into many sensitive applications. WSN is widely used for many applications such as military, medical care, environmental monitoring, smart agriculture, ground earthquake monitoring, control lighting, smart cities, and monitoring electric grids [58]–[62]. Many port areas employ a WSN, which is comprised of linked wireless sensors installed at a point of interest to monitor physical or environmental parameters including location, temperature, and humidity [63]. These sensors can contact one another as well as with a base station linked to a remote system for storage, processing, and analysis [64]. Ngai *et al.* [65] proposed an intelligent context-aware decision-support system to facilitate vertical and horizontal container transfers. As for [15], RFID, WSN, and mobile technologies are used to create a cloud-based system service-oriented (SOA) architecture that combines context-aware data about transportation vehicles and containers.

The WSN is built with ZigBee. It is simple, utilizes lower data rates, low cost, small size, and is energy efficient, allowing ZigBee-based devices to function for six to two years on two Mignon batteries. Furthermore, ZigBee supports a lot of nodes (up to 65,000) and may thus be utilized to construct a large-scale WSN [66], [67]. ZigBee is used for short-distance radio networks, telemetry systems, various types of sensors, and surveillance devices [68] .With regard to its application in smart port operations [69], a ZigBee sensor network has been proposed that allows for increased security of container shipments by detecting door openings, temperature and humidity, photometry, and by tracking the location of containers via GPS. ZigBee can also be used in structural health monitoring. A pressure gauge sensor is placed on critical parts of port equipment (for example, a yard crane). ZigBee sensors send sample data to the base station in order to monitor equipment status and decrease maintenance expenses [7].

Wi-Fi can also be used in the field of smart ports due to its wide range and broadband advantages. It uses specific frequencies, such as 2.4 or 5 GHz channels [68]. Wi-Fi is mostly utilized for video surveillance and AGV remote control [70]. For example, using video recognition technology, the camera installed in front of the yard crane will make it simple to determine the encoding information of containers. For standard Wi-Fi, the maximum range is 100 meters, but the common range is 10-35 meters [68].

RF communication is a wireless point-to-point communication method. The benefits of RF communication include long-distance communication up to 5 km and the ability for users to connect with one another directly through radio frequency stations without the need for extra infrastructure support. Communications between ships and ports, as well as between workers in remote places, are carried out in the smart port utilizing RF applications with no extra infrastructure support [7]. Table 4 includes a comparison list of common wireless technologies and pertinent applications used in smart ports [7].

Table 4. Comparison of wireless communication systems [7]

| Wireless Technologies | ZigBee | RF | Wi-Fi |
|---|---|---|---|
| Bit rate | 250 kbps | 9.6 kbps | 300 Mbps |
| Range (outdoor) | 100 m | 20 km | 100 m |
| Frequency | 784 MHz | 433 MHz | 2.4 GHz/5 GHz |
| Cost | $ | $$ | $$ |
| Popularity | + | ++ | +++ |
| Public Access | - | + | + |

## 8. INTERNET OF THINGS IN SMART PORT

According to the IEEE, the internet of things (IoT) is "a combination of sensors and embedded devices linked together to form a network for collecting and sharing data and connected to the internet" [71]. The IoT has been used in most areas of life, including smart farming [72], [73], smart cities [74], healthcare sector [75], smart home, smart river monitoring system [76], smart street lighting [77], and intelligent transport [78]. Some of the primary IoT applications at smart ports include real-time route planning and tracking of smart ships [79], container surveillance [80], transportation applications [81], storage capacity optimization [82], and e-navigation [83].

## 9. CONCLUSION

Information and communications technology may be used to boost the performance and operation of smart ports, including smart ships, containers, cranes, AGV, and energy management, which helps increase revenues for the national economy of countries that has seaports. Furthermore, information and communication technology may be used to minimize greenhouse gas emissions in order to soften the atmosphere and make the air purer, which has been a pressing issue in recent years and creates a variety of difficulties such as forest fires, melting ice, and so on. Today, with the use of modern technology, smart ports have become a reality where smart sensor systems improve performance associated with various terminal tasks. The use of wireless network systems in the port station is one of the main factors that contributed to the construction of smart ports, as it was a means of linking between sensors, as well as collecting information and sending it to the data center and vice versa. Various communication solutions currently in use in the automated terminal are mentioned.

Recent technological developments are opening new doors for improvement in performance and efficiency as well as providing a high level of safety and reliability in ports, but they also involve huge demands on the IT/IS core landscape. This work offered a classification of the most recent enabling technologies and information systems used in seaports. Thus, it is important for a better understanding of smart port operations.

Finally, the automation of port equipment and port terminal operations and their transformation into a smart port improves fluidity, reliability, security of information exchange, and real-time decision-making. These approaches also increase the smart port's production and efficiency, lower labor costs, and eventually are of benefit to the environment. As a result, smart technology plays a significant role in port development today and in the future.

## REFERENCES


[1] UNCTAD, *Review of Maritime Transport 2016*. United Nation Publication, 2016.

[2] S. Bessid, A. Zouari, A. Frikha, and A. Benabdelhafid, "Smart ports design features analysis: a systematic literature review," *13ème Conférence Francophone de Modélisation, Optimisation et Simulation (MOSIM'20)*, 2020.

[3] M. Hermann, T. Pentek, and B. Otto, "Design principles for Industrie 4.0 scenarios," in *2016 49th Hawaii International Conference on System Sciences (HICSS)*, Jan. 2016, pp. 3928–3937, doi: 10.1109/HICSS.2016.488.

[4] R. Zuidwijk, B. Kuipers, and R. Morris, "Companies active in the port of Rotterdam are discovering the benefits of scientific collaboration-thanks to erasmus smart port rotterdam," *RSM Discovery-Management Knowledge*, vol. 18, no. 2, pp. 5–7, 2014.

[5] A. Botti, M. Grimaldi, A. Tommasetti, O. Troisi, and M. Vesci, "Modeling and measuring the consumer activities associated with value cocreation: an exploratory test in the context of education," *Service Science*, vol. 9, no. 1, pp. 63–73, Mar. 2017, doi: 10.1287/serv.2016.0156.

[6] K. Douaioui, M. Fri, C. Mabrouki, and E. A. Semma, "Smart port: design and perspectives," in *2018 4th International Conference on Logistics Operations Management (GOL)*, Apr. 2018, pp. 1–6, doi: 10.1109/GOL.2018.8378099.

[7] Y. Yang, M. Zhong, H. Yao, F. Yu, X. Fu, and O. Postolache, "Internet of things for smart ports: Technologies and challenges," *IEEE Instrumentation and Measurement Magazine*, vol. 21, no. 1, pp. 34–43, Feb. 2018, doi: 10.1109/MIM.2018.8278808.

[8] P. T.-W. Lee and J. S. L. Lam, "Developing the fifth generation ports model," in *Dynamic Shipping and Port Development in the Globalized Economy*, London: Palgrave Macmillan UK, 2016, pp. 186–210.

[9] P. de Langen, M. T. Calvet, M. Fontanet, and J. Caballé, "The infrastructure investment needs and financing challenge of European ports," 2018.

[10] E. A. Bouman, E. Lindstad, A. I. Rialland, and A. H. Strømman, "State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping-A review," *Transportation Research Part D: Transport and Environment*, vol. 52,

pp. 408–421, May 2017, doi: 10.1016/j.trd.2017.03.022.
[11] S. Saxon and M. Stone, "Container shipping: The next 50 years," *Travel, Transport and Logistics*, 2017.
[12] M. Jovic, N. Kavran, S. Aksentijevic, and E. Tijan, "The transition of Croatian seaports into smart ports," in *2019 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, May 2019, pp. 1386–1390, doi: 10.23919/MIPRO.2019.8757111.
[13] S. Vo, R. Stahlbock, and D. Steenken, "Container terminal operation and operations research - a classification and literature review," *OR Spectrum*, vol. 26, no. 1, pp. 3–49, Jan. 2004, doi: 10.1007/s00291-003-0157-z.
[14] G. Giuliano and T. O'Brien, "Reducing port-related truck emissions: the terminal gate appointment system at the Ports of Los Angeles and Long Beach," *Transportation Research Part D: Transport and Environment*, vol. 12, no. 7, pp. 460–473, Oct. 2007, doi: 10.1016/j.trd.2007.06.004.
[15] L. Heilig and S. Voß, "A cloud-based SOA for enhancing information exchange and decision support in ITT operations," in *Lecture Notes in Computer Science*, Springer International Publishing, 2014, pp. 112–131.
[16] D. Ashbrook and T. Starner, "Using GPS to learn significant locations and predict movement across multiple users," *Personal and Ubiquitous Computing*, vol. 7, no. 5, pp. 275–286, Oct. 2003, doi: 10.1007/s00779-003-0240-0.
[17] S. Aslam, M. P. Michaelides, and H. Herodotou, "Internet of ships: a survey on architectures, emerging applications, and challenges," *IEEE Internet of Things Journal*, vol. 7, no. 10, pp. 9714–9727, Oct. 2020, doi: 10.1109/JIOT.2020.2993411.
[18] A. Accetta and M. Pucci, "Energy management system in DC micro-grids of smart ships: main gen-set fuel consumption minimization and fault compensation," *IEEE Transactions on Industry Applications*, vol. 55, no. 3, pp. 3097–3113, May 2019, doi: 10.1109/TIA.2019.2896532.
[19] K.-L. A. Yau, S. Peng, J. Qadir, Y.-C. Low, and M. H. Ling, "Towards smart port infrastructures: enhancing port activities using information and communications technology," *IEEE Access*, vol. 8, pp. 83387–83404, 2020, doi: 10.1109/ACCESS.2020.2990961.
[20] N. Zrnić, Z. Petković, and S. Bošnjak., "Automation of ship-to-shore container cranes: A review of state-of-the-art," *FME Transactions*, vol. 33, no. 3, pp. 111–121, 2005.
[21] A. K. Bhimani and M. Sisson, "Increasing quayside productivity," *2002 Pan Pacific Conference*, 2002.
[22] P. Sun, "5GtoB enables enterprise production," in *Unleashing the Power of 5GtoB in Industries*, Singapore: Springer Singapore, 2021, pp. 41–58.
[23] Huawei, "5G smart port white paper." Huawei Technologies Co., Ltd, 2019.
[24] P. Blaiklock, *Automated stacking cranes in port terminals*. Port Technology, 2017.
[25] P. S. Pratama, T. H. Nguyen, H. K. Kim, D. H. Kim, and S. B. Kim, "Positioning and obstacle avoidance of automatic guided vehicle in partially known environment," *International Journal of Control, Automation and Systems*, vol. 14, no. 6, pp. 1572–1581, Dec. 2016, doi: 10.1007/s12555-014-0553-y.
[26] J. Zhang, P. A. Ioannou, and A. Chassiakos, "Automated container transport system between inland port and terminals," *ACM Transactions on Modeling and Computer Simulation*, vol. 16, no. 2, pp. 95–118, Apr. 2006, doi: 10.1145/1138464.1138465.
[27] X. Li and Q. Xu, "A reliable fusion positioning strategy for land vehicles in GPS-denied environments based on low-cost sensors," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 4, pp. 3205–3215, Apr. 2017, doi: 10.1109/TIE.2016.2637306.
[28] A. Carullo and M. Parvis, "An ultrasonic sensor for distance measurement in automotive applications," *IEEE Sensors Journal*, vol. 1, no. 2, p. 143, 2001, doi: 10.1109/JSEN.2001.936931.
[29] P. T. Doan, T. T. Nguyen, V. T. Dinh, H. K. Kim, and S. B. Kim, "Path tracking control of automatic guided vehicle using camera sensor," in *Proceedings of the 1st International Symposium on Automotive and Convergence Engineering*, 2011, pp. 20–26.
[30] P. S. Pratama, B. T. Luan, T. P. Tran, H. K. Kim, and S. B. Kim, "Trajectory tracking algorithm for automatic guided vehicle based on adaptive backstepping control method," in *AETA 2013: Recent Advances in Electrical Engineering and Related Sciences*, Springer Berlin Heidelberg, 2014, pp. 535–544.
[31] C. Chao, W. Bing, and Y. Qingtai, "Application of automated guided vehicle (AGV) based on inductive guidance for newsprint rolls transportation system [J]," *Journal of Donghua University*, vol. 21, no. 2, pp. 88–92, 2004.
[32] Y.-S. Chen and L. Yao, "Robust type-2 fuzzy control of an automatic guided vehicle for wall-following," in *2009 International Conference of Soft Computing and Pattern Recognition*, 2009, pp. 172–177, doi: 10.1109/SoCPaR.2009.44.
[33] S.-Y. Lee and H.-W. Yang, "Navigation of automated guided vehicles using magnet spot guidance method," *Robotics and Computer-Integrated Manufacturing*, vol. 28, no. 3, pp. 425–436, Jun. 2012, doi: 10.1016/j.rcim.2011.11.005.
[34] C. I. Liu, H. Jula, K. Vukadinovic, and P. A. Ioannou, "Comparing different technologies for containers movement in marine container terminals," in *ITSC2000. 2000 IEEE Intelligent Transportation Systems. Proceedings (Cat. No.00TH8493)*, 2000, pp. 488–493, doi: 10.1109/ITSC.2000.881118.
[35] F.-X. Delenclos, A. Rasmussen, and J. Riedl, *To get smart, ports go digital*. BCG, 2018.
[36] L. Heilig and S. Voß, "Information systems in seaports: a categorization and overview," *Information Technology and Management*, vol. 18, no. 3, pp. 179–201, Sep. 2017, doi: 10.1007/s10799-016-0269-1.
[37] J. Zhang and C. Zhang, "Smart container security: the E-seal with RFID technology," *Modern Applied Science*, vol. 1, no. 3, Aug. 2007, doi: 10.5539/mas.v1n3p16.
[38] R. F. Brackmann, J. R. Brackmann, D. J. Kossnar, D. Ash, and J. M. Dulin, "Smart pallet-box cargo container," Google Patents, 2010.
[39] S. Jakovlev, A. Senulis, M. Kurmis, Z. Lukosius, and D. Drungilas, "Intelligent containers network concept," in *Proceedings of the 4th International Conference on Vehicle Technology and Intelligent Transport Systems*, 2018, pp. 568–574, doi: 10.5220/0006801305680574.
[40] P. Ruckebusch, J. Hoebeke, E. De Poorter, and I. Moerman, "Smart container monitoring using custom-made WSN technology: from business case to prototype," *EURASIP Journal on Wireless Communications and Networking*, no. 1, Dec. 2018, doi: 10.1186/s13638-018-1024-6.
[41] Ç. Iris and J. S. L. Lam, "A review of energy efficiency in ports: Operational strategies, technologies and energy management systems," *Renewable and Sustainable Energy Reviews*, vol. 112, pp. 170–182, Sep. 2019, doi: 10.1016/j.rser.2019.04.069.
[42] J.-K. Woo, D. S. H. Moon, and J. S. L. Lam, "The impact of environmental policy on ports and the associated economic opportunities," *Transportation Research Part A: Policy and Practice*, vol. 110, pp. 234–242, Apr. 2018, doi: 10.1016/j.tra.2017.09.001.
[43] G. Wilmsmeier and T. Spengler, "Energy consumption and container terminal efficiency," *Bulletin FAL*, pp. 1–10, 2016.
[44] T. Zis, R. J. North, P. Angeloudis, W. Y. Ochieng, and M. G. Harrison Bell, "Evaluation of cold ironing and speed reduction policies to reduce ship emissions near and at ports," *Maritime Economics and Logistics*, vol. 16, no. 4, pp. 371–398, Dec. 2014, doi: 10.1057/mel.2014.6.

[45] E. A. Sciberras, B. Zahawi, and D. J. Atkinson, "Electrical characteristics of cold ironing energy supply for berthed ships," *Transportation Research Part D: Transport and Environment*, vol. 39, pp. 31–43, Aug. 2015, doi: 10.1016/j.trd.2015.05.007.
[46] T. Coppola, M. Fantauzzi, S. Miranda, and F. Quaranta, "Cost/benefit analysis of alternative systems for feeding electric energy to ships in port from ashore," in *2016 AEIT International Annual Conference (AEIT)*, 2016, pp. 1–7, doi: 10.23919/AEIT.2016.7892782.
[47] W. J. Hall, "Assessment of CO2 and priority pollutant reduction by installation of shoreside power," *Resources, Conservation and Recycling*, vol. 54, no. 7, pp. 462–467, May 2010, doi: 10.1016/j.resconrec.2009.10.002.
[48] T. K. Tran, "Study of electrical usage and demand at the container terminal," Thesis, Deakin University, 2012.
[49] G. Parise and A. Honorati, "Port cranes with energy balanced drive," in *2014 AEIT Annual Conference-From Research to Industry: The Need for a More Effective Technology Transfer (AEIT)*, Sep. 2014, pp. 1–5, doi: 10.1109/AEIT.2014.7002047.
[50] D. Colarossi and P. Principi, "Technical analysis and economic evaluation of a complex shore-to-ship power supply system," *Applied Thermal Engineering*, vol. 181, Nov. 2020, doi: 10.1016/j.applthermaleng.2020.115988.
[51] J. C. Rijsenbrij and A. Wieschemann, "Sustainable container terminals: a design approach," in *Operations Research/Computer Science Interfaces Series*, Springer New York, 2011, pp. 61–82.
[52] M. Acciaro *et al.*, "Environmental sustainability in seaports: a framework for successful innovation," *Maritime Policy and Management*, vol. 41, no. 5, pp. 480–500, Jul. 2014, doi: 10.1080/03088839.2014.932926.
[53] I. N. K. Wardana, N. N. K. Krisnawijaya, and I. W. A. Suranata, "Sub-1 GHz wireless nodes performance evaluation for intelligent greenhouse system," *Telecommunication Computing Electronics and Control (TELKOMNIKA)*, vol. 16, no. 6, Dec. 2018, doi: 10.12928/telkomnika.v16i6.11556.
[54] JP, "Jurong port," https://www.jp.com.sg/about-us/awards-and-milestones/ (accessed Sep. 26, 2017).
[55] S. Song and K. L. Poh, "Solar PV leasing in Singapore: enhancing return on investments with options," *IOP Conference Series: Earth and Environmental Science*, vol. 67, May 2017, doi: 10.1088/1755-1315/67/1/012020.
[56] M. Acciaro, H. Ghiara, and M. I. Cusano, "Energy management in seaports: A new role for port authorities," *Energy Policy*, vol. 71, pp. 4–12, Aug. 2014, doi: 10.1016/j.enpol.2014.04.013.
[57] Y. Du, Q. Chen, J. S. L. Lam, Y. Xu, and J. X. Cao, "Modeling the impacts of tides and the virtual arrival policy in berth allocation," *Transportation Science*, vol. 49, no. 4, pp. 939–956, Nov. 2015, doi: 10.1287/trsc.2014.0568.
[58] A. S. Abdalkafor and S. A. Aliesawi, "Applying of (SOM, HAC, and RBF) algorithms for data aggregation in wireless sensors networks," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 11, no. 1, pp. 354–363, Feb. 2022, doi: 10.11591/eei.v11i1.3462.
[59] F. Muzafarov and A. Eshmuradov, "Wireless sensor network based monitoring system for precision agriculture in Uzbekistan," *Telecommunication Computing Electronics and Control (TELKOMNIKA)*, vol. 17, no. 3, Jun. 2019, doi: 10.12928/telkomnika.v17i3.11513.
[60] D. D. Khudhur and M. S. Croock, "Physical cyber-security algorithm for wireless sensor networks," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 19, no. 4, pp. 1177–1184, Aug. 2021, doi: 10.12928/telkomnika.v19i4.18464.
[61] R. S. Cotrim, J. M. L. P. Caldeira, V. N. G. J. Soares, and Y. Azzoug, "Power saving MAC protocols in wireless sensor networks: a survey," *Telecommunication Computing Electronics and Control (TELKOMNIKA)*, vol. 19, no. 6, Dec. 2021, doi: 10.12928/telkomnika.v19i6.19148.
[62] A. Y. Ardiansyah and R. Sarno, "Performance analysis of wireless sensor network with load balancing for data transmission using xbee zb module," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 18, no. 1, pp. 88–100, Apr. 2020, doi: 10.11591/ijeecs.v18.i1.pp88-100.
[63] S. R. J. Ramson and D. J. Moni, "Applications of wireless sensor networks-A survey," in *2017 International Conference on Innovations in Electrical, Electronics, Instrumentation and Media Technology (ICEEIMT)*, Feb. 2017, pp. 325–329, doi: 10.1109/ICIEEIMT.2017.8116858.
[64] D. Merkle, "Part one: introduction," *TranscUlturAl: A Journal of Translation and Cultural Studies*, vol. 10, no. 1, pp. 9–10, Sep. 2018, doi: 10.21992/tc29389.
[65] E. W. T. Ngai *et al.*, "Design and development of an intelligent context-aware decision support system for real-time monitoring of container terminal operations," *International Journal of Production Research*, vol. 49, no. 12, pp. 3501–3526, Jun. 2011, doi: 10.1080/00207541003801291.
[66] S. C. Ergen, "ZigBee/IEEE 802.15. 4 Summary," *UC Berkeley, September*, vol. 10, no. 17, 2004.
[67] A. Muharam, A. Wahab, and M. Alaydrus, "Improved fingerprinting performance in indoor positioning by reducing duration of the training phase process," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 24, no. 1, pp. 236–244, Oct. 2021, doi: 10.11591/ijeecs.v24.i1.pp236-244.
[68] R. Sudarmani, K. Venusamy, S. Sivaraman, P. Jayaraman, K. Suriyan, and M. Alagarsamy, "Machine to machine communication enabled internet of things: a review," *International Journal of Reconfigurable and Embedded Systems (IJRES)*, vol. 11, no. 2, pp. 126–134, Jul. 2022, doi: 10.11591/ijres.v11.i2.pp126-134.
[69] S. Schaefer, "Secure trade lane," *Companion to the 21st ACM SIGPLAN conference on Object-oriented programming systems, languages, and applications-OOPSLA '06*, 2006, doi: 10.1145/1176617.1176732.
[70] N. Bahnes, B. Kechar, and H. Haffaf, "Cooperation between intelligent autonomous vehicles to enhance container terminal operations," *Journal of Innovation in Digital Ecosystems*, vol. 3, no. 1, pp. 22–29, Jun. 2016, doi: 10.1016/j.jides.2016.05.002.
[71] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions," *Future Generation Computer Systems*, vol. 29, no. 7, pp. 1645–1660, Sep. 2013, doi: 10.1016/j.future.2013.01.010.
[72] M. S. M, S. Das, S. Heble, U. Raj, and R. Karthik, "Internet of things based wireless plant sensor for smart farming," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 10, no. 2, pp. 456–468, May 2018, doi: 10.11591/ijeecs.v10.i2.pp456-468.
[73] I. Salehin *et al.*, "IFSG: Intelligence agriculture crop-pest detection system using IoT automation system," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 24, no. 2, pp. 1091–1099, Nov. 2021, doi: 10.11591/ijeecs.v24.i2.pp1091-1099.
[74] J. Mona, "Data communication in internet of things: vision, challenges and future direction," *Telecommunication Computing Electronics and Control (TELKOMNIKA)*, vol. 16, no. 5, Oct. 2018, doi: 10.12928/telkomnika.v16i5.9402.
[75] R. H. Putra, F. T. Kusuma, T. N. Damayanti, and D. N. Ramadan, "IoT: smart garbage monitoring using android and real time database," *Telecommunication Computing Electronics and Control (TELKOMNIKA)*, vol. 17, no. 3, Jun. 2019, doi: 10.12928/telkomnika.v17i3.10121.
[76] F. Kamaruddin, N. N. Nik Abd Malik, N. A. Murad, N. M. A. Latiff, S. K. S. Yusof, and S. A. Hamzah, "IoT-based intelligent irrigation management and monitoring system using Arduino," *Telecommunication Computing Electronics and Control*

*(TELKOMNIKA)*, vol. 17, no. 5, Oct. 2019, doi: 10.12928/telkomnika.v17i5.12818.
[77] M. Eriyadi, A. G. Abdullah, H. Hasbullah, and S. B. Mulia, "Internet of things and fuzzy logic for smart street lighting prototypes," *IAES International Journal of Artificial Intelligence (IJ-AI)*, vol. 10, no. 3, pp. 528–535, Sep. 2021, doi: 10.11591/ijai.v10.i3.pp528-535.
[78] H. Ouldzira, A. Mouhsen, H. Lagraini, M. Chhiba, A. Tabyaoui, and S. Amrane, "Remote monitoring of an object using a wireless sensor network based on NODEMCU ESP8266," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 16, no. 3, pp. 1154–1162, Dec. 2019, doi: 10.11591/ijeecs.v16.i3.pp1154-1162.
[79] J. K. Panigrahi, C. P. Padhy, D. Sen, J. Swain, and O. Larsen, "Optimal ship tracking on a navigation route between two ports: a hydrodynamics approach," *Journal of Marine Science and Technology*, vol. 17, no. 1, pp. 59–67, Mar. 2012, doi: 10.1007/s00773-011-0116-3.
[80] C.-M. Yeoh *et al.*, "Ubiquitous containerized cargo monitoring system development based on wireless sensor network technology," *International Journal of Computers Communications and Control*, vol. 6, no. 4, Dec. 2011, doi: 10.15837/ijccc.2011.4.2109.
[81] A. Belfkih, C. Duvallet, and B. Sadeg, "The internet of things for smart ports: application to the port of Le Havre," *Proceedings of IPaSPort*, 2017.
[82] R. Jamshidi and M. M. S. Esfahani, "A novel hybrid method for supply chain optimization with capacity constraint and shipping option," *The International Journal of Advanced Manufacturing Technology*, vol. 67, no. 5–8, pp. 1563–1575, Jul. 2013, doi: 10.1007/s00170-012-4590-5.
[83] H.-C. Burmeister, W. Bruhn, Ø. J. Rødseth, and T. Porathe, "Autonomous unmanned merchant vessel and its contribution towards the e-navigation implementation: The MUNIN perspective," *International Journal of e-Navigation and Maritime Economy*, vol. 1, pp. 1–13, Dec. 2014, doi: 10.1016/j.enavi.2014.12.002.

## BIOGRAPHIES OF AUTHORS

**Hayder Ali Al-Fatlawi** he was born in Babylon-Iraq. He received a B.Sc. degree in electrical engineering from the University of Babylon in 1998 and an M.Sc. degree in electrical engineering from the University of Babylon in 2015, He is currently working on his Ph.D. degree at the same department in the University of Babylon. His research interests include optical communication, cloud computing, and IoT. He can be contacted at email: hayderalialiali@gmail.com.

**Hassan Jassim Motlak** received B.Sc. in electrical engineering and M.Sc. in Electrical Engineering from University of Babylon, Babylon, Iraq and Ph.D. from Jamia Millia Islamia, Delhi, India. He has been with Department of Electrical Engineering, Engineering College, University of Babylon, Iraq. His scientific degree is Professor and research interests include communication electronics, analog and digital signal processing, and analog integrated circuit design. He can be contacted at email: hssn_jasim@yahoo.com.