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Evaluation of ultrasonic berth sensors in the port environment: case study Port of Cristo

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***Abstract*— Berth occupancy sensors are used to monitor and determine the presence of vessels at a berth on a daily basis to improve port management and make a port more efficient and competitive. This paper presents an evaluation of wireless ultrasonic berth occupancy sensors by analyzing the accurate and inaccurate detection of berth occupancy and the efficiency of the sensors under different berth status conditions, highlighting the main causes of false detections. Results revealed that sensors' accuracy for berth status detection range from 35% to 92%. The most common causes of inaccurate berth occupancy detection are sea currents, inadequate sensor positioning, damage to the sensor, exceeding boat-to-sensor distance, ropes from adjoining berths, and surrounding vegetation.**

Keywords—berth occupation, sensors, Internet of Things (IoT), smart ports, evaluation

I. INTRODUCTION

Nowadays, Internet of Things (IoT) technologies are being integrated into key aspects of port management such as optimizing logistics and monitoring the environmental impact of port operations [1]. Similarly, IoT can help ports to overcome the challenges they face by increasing efficiency and creating greater awareness of their activities. Indeed, port activities encompass a variety of use cases that can benefit from IoT adoption [2]. These include asset tracking, continuous measurement of environmental conditions and energy consumption, and finally remote operational support [3]. Information sharing enables optimization, management, and automation of port processes and improves port efficiency and competitiveness [4]–[6]. For example, the integration of Artificial Intelligence (AI) into the port system enables the calculation and prediction of an accurate estimated time of arrival (ETA) of ships at the port as a key factor to optimize the time, resources, and costs of port operations [7], [8]. The IoT can be used in ferry ports to set up berths, reduce service processing time, and organize the loading and unloading of vehicles and the embarkation and disembarkation of passengers [9]. IoT can also be used to automate tethering procedures by searching for available locations via port-mounted sensors and scheduled ship notifications [10]. Furthermore, to achieve safer autonomous navigation and automatic berthing, an imaging system that integrates various information (e.g., a 3D model with a stereo camera) is becoming essential [11].

By combining IoT and AI, the real-time vessel activity monitoring system enables a port to manage and optimize maritime activities related to vessel traffic and displays information about vessels in the vicinity of the port [12]. The port sector can benefit from the IoT by using sensor devices to automate maritime activities. In this case, the IoT-based system is used to automate the berthing process for vessels, i.e., using sensors installed in the port to automatically search for available berths and transmit the data to vessels that want to berth. In addition, a novel artificial intelligence-based monitoring system has been developed to provide real-time image information of the vessel approaching the berth to ensure the safe berthing of the vessel [13]. A berthing assistance system using laser sensors is also widely used for berthing vessels to ensure safety [14]. Recently, a berthing assistance system has been proposed that determines the exact berth location by measuring distance and approach speed [15]. In addition, a berth monitoring system has been developed for marinas to detect berth occupancy using wireless ultrasonic sensor nodes installed at each berth [16].

Most studies so far have only given recommendations on how to make the port smarter, but no implementation with test results. They only provide recommendations or analysis on the impact of using IoT in ports both for logistics and transportation services that connect a port to other ports and for supporting fast and efficient service processes, such as the supply chain process. Despite the implementation of various smart applications, there is relatively little work to test IoT platforms for smart applications on vessels and yachts in smaller nautical ports. Therefore, the significance and novelty of this study is the application of smart technologies for monitoring and controlling berth occupancy in the Port of Cristo to make services more efficient. The contribution of this study also lies in the identification of deficiencies and effectiveness in the operation of the tested technology during the test period.

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The paper is organized as follows: Chapter II describes the methodology used to detect berth occupancy, while Chapter III presents the study performed and the results obtained. Finally, in Chapter IV the results are discussed, and concluding remarks are given.

II. Berth Sensors Layout

The ultrasonic berth sensors are used as occupancy detectors for the detection of the presence of a vessel at the berth, i.e., to monitor the berth. They direct the signal according to the angle of the situation and analyze its rebound.

The tested sensors met the following requirements:

- operate without a wired power supply,
- communicate wirelessly,
- can be installed on any surface: concrete docks, floating docks, stone docks, as they are exposed to strong impacts, sea-water splashes, rain, etc.,
- detect the vessels regardless of their shape and size, and track the movement of the vessels when docking,
- send their status regularly every 15 minutes or when a change of status (free /occupied) is detected,
- an information system collects the data sent by the sensors.

Communication with the sensors is established through the long-range (LoRa) communication network of the Government of the Balearic Islands. The LoRa network is the first public IoT network in the Balearic Islands. LoRa communication network of the Government of the Balearic Islands is managed by the public company IBETEC and named IoTIB.

The computerized system for monitoring and collecting information generated by the sensors consisted of three main modules:

1. Representational State Transfer Application Programming Interface (REST API) for collecting data from the sensors and retrieving the information in an unsupervised manner, using secure methods.
2. The collection of information from the sensors is done by communicating with the IoTIB platform managed by the IBETEC unit to provide information from the sensors communicating through their LoRa IoTIB communication network.
3. A dashboard for displaying the state of the berths in real time, their management, the associated sensors, querying the occupancy history, and exporting the generated data, among other functions. It allows changes in the location of the sensors as they are dynamically assigned to the berths and even to the port.

The LoRa IoTIB communication network used to communicate the sensors of the Port of Cristo collects their (raw) information and makes them available through the corresponding REST API (Fig. 1). Consequently IBETEC also provides the IoTIB network platform to manage device registrations and view their communication parameters. Furthermore, the corresponding REST API was developed to query/communicate all generated information.

III. Test and Results

The test was carried out in the Port of Cristo on Mallorca island in Spain as part of the PSAMIDES project (Ports small and medium alliance for sustainable development, Interreg MED Programme, co-funded by the European Regional Development Fund).

Port of Cristo (Mallorca Island – Spain) is a public port with a capacity of 276 berths. For this test, 10 wireless ultrasonic berth sensors were installed to control 10 consecutive berths in the area of Port of Cristo (Fig. 2).

The objectives of this test were to determine if these sensors are capable of providing the desired information about berth occupancy remotely and to determine the data reliability of such a system in daily use.

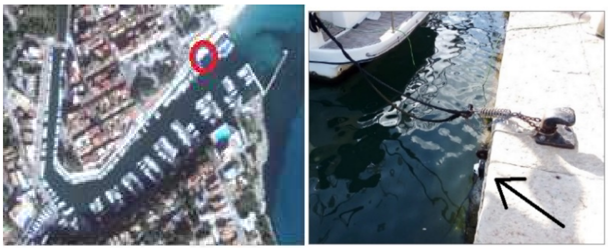
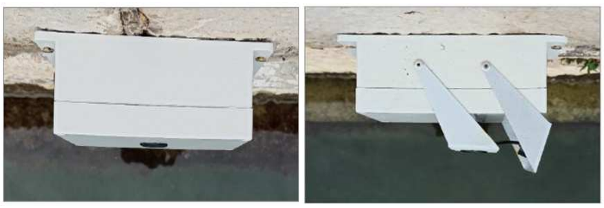


Fig. 2. The location of the installed berth occupation sensors in Port of Cristo

Two different types of sensors had been installed in Port of Cristo as follows: devices with a single sensor and frontal reading (Fig. 3a) and devices with two sensors with lateral reading, but with the possibility of adjusting the reading angle. This allowed the testing of the behavior of the sensors under different orientation angles and obtaining the optimum angle of adjustment (Fig. 3b)



a) b)

Fig. 3. Types of sensors for berth occupation detection

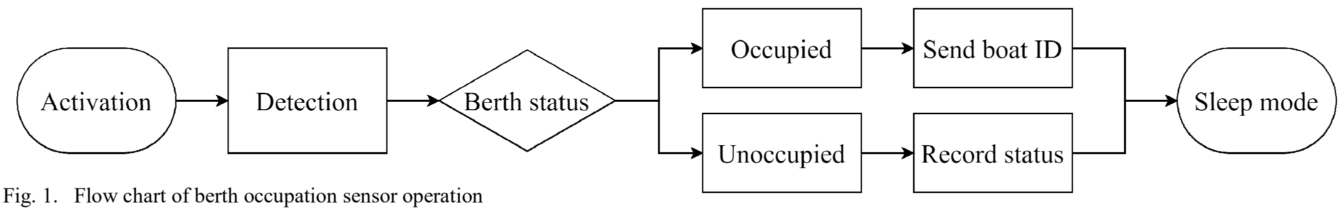


Fig. 1. Flow chart of berth occupation sensor operation

The testing process was conducted from January 2020 to July 2021. During the test, the positions of the installed devices were changed. Some berths had both types of devices installed, while others had only one type of device installed. During the seven-month test period, different device positions were tested at 10 observed berths to find the best combination of sensor positioning, minimizing erroneous sensor readings, and maximizing the protection of the sensors from external influences such as tides, etc. It was found that the sensor could most accurately detect berth occupancy when positioned in the center of each berth. All sensors were placed so that they read head-on (frontal reading). The layout of the installed devices is shown in Fig. 4.

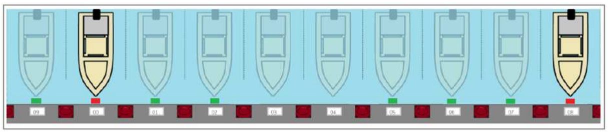


Fig. 4. The layout of installed berth occupation sensors

Of the total of ten berths observed, three berths were continuously occupied (09, 00, and 08), while the remaining seven were occasionally occupied. The reason for the lower average rate of sensor readings accuracy at berth 09 was the sailboat, which was constantly moored at the bow and made sensor readings difficult due to the presence of sea currents. The results for the test period are shown separately for each berth in Table I.

TABLE I. RESULTS FOR TESTING PERIOD JANUARY-JULY 2021

Berth ID	**Berth status**	**Average accurate alarm rate**	**Average false alarm rate**	**Cause of false alarm**
09	Non-stop occupied	56.01%	43.99%	The presence of sea currents; Negative effects of lateral sensor readings
00	Occasionally occupied	92.18%	7.82%	The sensor was temporarily damaged by the impact of the vessel during the storm and disabled due to damage to the electronic circuit boards from water intrusion.
01	Occasionally occupied	82.78%	17.22%	The presence of sea currents; The sensor was temporarily damaged by the impact of the vessel during the storm.
02	Non-stop occupied	34.85%	65.15%	The distance between the vessel and the sensor was at the edge of the sensor's maximum detection range (250 cm); Significant vessel movement due to the use of ropes from adjoining berths.
03	Occasionally occupied	81.46%	18.54%	Crossed ropes from adjoining berth 02 obstructed the sensor's view; Surrounding vegetation obstructed the sensor's reading.
04	Occasionally occupied	84.81%	15.19%	The sensor was not functioning properly because the mooring distance of the vessel had changed in relation to the range of the sensor.
05	Occasionally occupied	85.80%	14.20%	The sensor was temporarily out of service due to a collision with a vessel.
06	Occasionally occupied	87.02%	12.98%	The sensor detected a vessel moored at the intermediate bollard between berths 06 and 07 due to sea currents.
07	Occasionally occupied	89.61%	10.39%	The sensor detected ropes tied to the bollards of the adjacent berths; The vessel moored at berth 08 was constantly drifting towards berth 07 due to sea currents.
08	Non-stop occupied	86.83%	13.17%	The vessel moored at berth 08 was constantly drifting towards berth 07 due to sea currents.

The highest average rate of correct alarms (92.18%) and at the same time the lowest average rate of false alarms (7.82%) were recorded at berth 00. At this berth, the main cause of incorrect occupancy detection was sensor failure (damage to electronic circuit boards caused by water intrusion) due to vessel impact in a storm. In contrast, the lowest average accurate alarm rate (34.85%) and the highest average false alarm rate (65.15%) were observed for the sensor at berth 02.

Overall, the most common cause of inaccurate berth occupancy detection was the influence of sea currents, followed by inadequate sensor positioning, damage to the sensor due to a storm, exceeding vessel-to-sensor distance, ropes from neighboring berths, and vegetation in the vicinity interfering with sensor readings.

In general, non-stop occupied berths have a lower average accurate alarm rate than occasionally occupied berths. All occasionally occupied berths have a high average accurate alarm rate of over 80%. If only the occasionally occupied berths are observed and their corresponding accurate alarm rates are considered, an overall average accurate alarm rate for occasionally occupied berths of 86.24% is obtained. Considering only the false alarm rates at occasionally occupied berths, the total average false alarm rate is 13.76%. On the other hand, taking into account only the accurate alarm rates for non-stop occupied berths, the overall average accurate alarm rate is 59.23%, while the overall average false alarm rate for non-stop occupied berths is 40.77%.

The overall average accurate alarm rate at all 10 moorings during the entire test period is 78.13%, while the overall average false alarm rate is 21.87%. Therefore, it can be concluded that this technology has justified the basic objectives of the test and that the sensors generally have high accuracy in detecting berth occupation. Considering the high accuracy rates, it can be concluded that the data collected during the tests are reliable.

From the behavior and data obtained in this study, the following can be inferred:

- The location of the devices is a crucial aspect of the proper functioning of the system. The best location to place the sensors is on the height of dock pedestals at approximately 70 cm above the sea surface. In this way, the effects of the variations in sea level, the currents that move the vessels, and the vibrations caused by them would be minimized.
- The frontal reading gives better results, but the sensors must be protected to avoid vessel collisions.
- Low berth occupancy combined with the effect of ocean currents results in significant vessel displacement that prevents the correct reading of the sensors.
- The design of catamaran-type vessels influences the deterioration of the detections: they do not have a good reflective surface for the sensor signals and constantly generate false alarms.
- Human vandalism should be considered an existing and significant risk for the sensors at the berths.
- The importance of port personnel behavior and the information they can provide to the vessels mooring in the port for the proper use and operation of the tracking system (mooring at the optimal distance, avoiding disturbing objects such as ropes, signs, or surrounding vegetation, and information about the tracking system to avoid collisions).

IV. DISCUSSION AND CONCLUSION

The berth occupation sensors are used to detect a vessel's presence on a berth and thus to plan the berth occupancy remotely. Therefore, it improves and speeds up the tasks of reception staff and eases (or eliminates) the tasks of operative employers who have to manually check the vessels' presence (inventory) and record and report the berth availability regularly. In addition, automatic detection of berth occupancy can significantly improve a booking management system if the berth sensor data are connected with the booking system providing real-time data 24 hours a day. In this way, clients can see in advance if there are free berths in the marina/port and thus optimize their trip plan. Furthermore, the introduction of berth sensors connected with the information system is a relatively low investment, and also, the sensors have very low electric power consumption.

Also, there are some disadvantages to using the berth occupation sensors. The sensors are very sensitive to external influences like fluctuations in sea level or the currents that move the vessels, causing the detection of false negatives and thus reducing the quality of the sensor's reading. Furthermore, the sensors must be protected to avoid vessel collisions because, without protection, there is a high possibility of sensor damage, which was confirmed during testing. The tested sensors have a reading range of approximately 2.5 meters. The reliability of the detection system is significantly reduced for vessel separation distances greater than 2.5 meters.

Therefore, it must be ensured that the vessels do not berth at distances greater than 2.5 meters and are well anchored in their berth. There was also a problem while detecting a berth occupation when a catamaran-type vessel is moored. The design of catamaran-type vessels does not offer an excellent reflective surface for the sensor signals, and they constantly generate false negatives.

When solving the problems mentioned above (e.g. by making particular adaptations to existing sensors), berth occupation sensors have a great prospect of using within the ports/marinas of the future.

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