Deflection and inclination measuring system for floating dock based on wireless networks

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A B S T R A C T

When going in or out of a dock, the self weight of the ship may cause the deflection of the pontoon deck and/or inclination of a floating dock. This paper investigates the measurements of the deflection and inclination of a floating dock within a wireless network. A deflection measurement model is constructed on the basis of the multi-points liquid levels in the connected pipes. The water levels at different points are measured by the pressure transmitters connected to the connection pipes along the longitudinal direction of the floating dock. The inclination is measured by 4 pneumercators installed on 4 corners of the floating dock. The measured data are transmitted to a server with a wireless sensor network. With the proposed model, the deflection and inclination calculation methods are analyzed and presented. The experimental results show that the accuracy of the deflection (hog or sag) can reach 95% and the error for the inclination measurement (heel or trim angle) is less than 8%. It is verified that the measuring system in the wireless sensor network supports the proposed deflection model and data collision avoiding algorithm. The measuring system could provide the required information during the operation of the floating dock.

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1. Introduction

A floating dock is a ship-repairing platform (Shan et al., 2009), on which the damaged ship and its steel structure below the waterline can be conveniently repaired. Therefore it is widely used in the port or shore areas.

The architecture of a floating dock is illustrated in Fig. 1, which consists of a pontoon deck, two wing walls on both sides of the pontoon deck, and multi ballast tanks under the pontoon deck. The pontoon deck supports the self weight of the ship. The two wing walls accommodate comprehensive facilities such as operation channels, central controlling room, workers' rest rooms, electrical devices etc. The ballast tank is a water container responsible for controlling the rising or sinking of the floating dock. When the ballast tanks are filled with water, the dock will sink, and vice versa. Fig. 2 shows a practical industry floating dock.

The floating dock faces safety issues when the ship goes in or out of the dock. Normally, the self-weight of the ship is transferred through docking blocks to the pontoon deck, resulting in the deflection and inclination of the dock. The deflection and inclination can be adjusted by controlling the water in the blast tanks. The deflection over the length of the floating dock and the inclination angles (both trim and heel) should be limited within a valid range to ensure the safety operation of a floating dock. In this way, the bending stress (Det Norske Veritas (DNV), 2012) associated with the deflection of the floating dock can be limited. Therefore, the deflection and inclination of the floating dock must be measured and displayed according to Chinese “Rules for Classification of Floating Docks (2009)” (China Classification Society (CCS), 2009).

The deflection and inclination (draft) monitoring of a floating dock has been studied by some researchers. A kind of arithmetic for the adjustment of the floating dock was presented in Xie et al. (2006) and Han et al. (2009). Accordingly, a real-time control and simulation system was developed based on the platform of LabVIEW by Smith et al. (2009); Zeyi et al. (2011) investigated the management system of the floating dock. The design scheme and the practical operation effect of an assembly-type floating dock were systematically presented by Zhi (2010); Chen and Wu (2007) presented another deflection monitoring system, and an intellectual control scheme of ship immersion. These achievements have greatly improved the safe operation of the floating dock. However, some issues still remain unsolved in this area, e.g. the calculation models are not accurate enough or it could not satisfy the stringent requirements in the industry environment when the wired data transmission is used. The deflection model is not constructed on the basis of connection pipes.
More seriously, the measuring results are generally transmitted to a central room by a manually reading or a wired system.

Wireless Sensor Networks (WSN) (Kovács et al., 2010) is being increasingly used in many fields, such as industrial monitoring, structural health monitoring (Quek et al., 2009, 2011), agriculture storage, environment and education (Dikovic et al., 2011). The wireless sensors are integrated into damage detection systems by Quek et al. (2009). An algorithm to patch the lost data is proposed. The design and evaluation of a wireless sensor network system for structural data acquisition is presented by Xu et al. (2004). A suite of algorithms for self-organization of wireless sensor networks in which there is a large number of mainly static nodes with highly constrained energy resources is presented by Sohrabi et al. (2000). The design of the sensor nodes is important, since they are basic units of these networks. The design of a WSN depends significantly on the application, and it must consider factors such as the environment, the application’s design objectives, cost, hardware, and system constraints (Yick et al., 2008). In this paper, the deflection and inclination measurement model of a floating dock is proposed by implementation of WSN, with which deflection and inclination related parameters can be easily measured and transmitted. This model is constructed on the basis of the liquid level in connection pipes. All sensors in the same line can test their own liquid levels which are connected by pipes. When the line deflected, the maximum deflection can be calculated by the liquid levels measured at each sensor point. Traditionally the deflection and inclination are measured with a wired system or by manually reading. All data packages of sensor are planned to access to the receiver with a BEB algorithm, data collisions are lowered. Furthermore, the Silicon Laboratories Si4432 ISM Band transceiver (Silicon Laboratories, 2010) is introduced in the measuring system, so that the cost of the WSN can be greatly reduced and the existing protection and monitoring systems can be extended.

2. System architecture

2.1. System topology

The topology of the proposed deflection and inclination measuring system is presented in Fig. 3. Each RF (Radio Frequency) Module node is connected to a sensor, which is a transmitter used for detecting the water level in the connection pipes. RF module sends the detected data to the receiver via wireless network. The receiver is responsible for collecting the results of all RF modules and transporting the data to the monitoring server through RS485 communication link.

2.2. Structure of the measurement instrumentation

According to Chinese “Rules for Classification of Floating Docks (2009)”, independent systems for measuring the deflection of the dock over its length shall be installed if the full length exceeds 90 m. The deflection should be readable from the control room of the dock. In order to measure the deflection of the floating dock, the connection pipes principle (Yang and Notodirdjo, 2011) is applied. Connection pipes are used in many fields for detecting the parameters like level, pressure, deformation etc. Liquid level transmitters are set up according to the locations of the connection pipes, so that the liquid level at various testing points can be detected and thus the deflection can be calculated. The connection pipe and the liquid level transmitters are illustrated in Fig. 4.

A deflection and inclination measurement scheme is illustrated in Fig. 5. The deflection can be measured by the sensors connecting to the pipes which are installed on each of the two wing walls. In addition, four pneumercators are installed at the four corners of the floating dock for inclination (draft) measurement.

3. Wireless networks solution

3.1. Introduction of the RF transceiver

The Si4432 (Chen et al., 2011) is a highly integrated, single chip wireless ISM (Industrial Scientific Medical) band transceiver. The low receiving sensitivity (−121 dBm) coupled with +20 dBm output power ensures the extended range and the improved link performance. Built-in antenna diversity and its support for frequency hopping can further extend range and enhance the performance. The Si4432 offers advanced radio features including
continuous frequency coverage from 240–960 MHz in 156 Hz or 312 Hz steps allowing precise tuning control. Its direct digital transmit modulation and automatic PA (Power Amplifier) power ramping promise the precise transmit modulation and reduced spectral spreading. Therefore, the compliance with global regulations including FCC (Federal Communications Commission), ETSI (European Telecommunications Standards Institute), ARIB (Association of Radio Industries and Businesses), and 802.15.4 d regulations can be ensured.

3.2. RF module design

The RF Module is the sensor node in WSN devised with si4432 transceiver. The si4432 is designed to work with a microcontroller, crystal, and a few passives to create a low cost system. Voltage regulator is integrated on-chip which allows a wide range of operating supply voltage conditions from +1.8 to +3.6 V. A standard 4-pin SPI bus is used to communicate with the microcontroller. Three configurable general purpose I/Os (Input/Output) are available to satisfy the needs of the system.

The RF Module is responsible for acquiring output signal from the sensors and transmitting the data to the receiver. A STM8 series microcontroller is chosen as the MCU (Micro Control Unit) of the module, and output signal of 4–20 mA current is connected to AD (Analog to Digital) transfer module. When MCU gets the AD result, it sends the data of water level to RF transceiver. The internal architecture is shown in Fig. 6.

3.3. Receiver module design

The receiver is the key device of wireless network for communication with RF modules. Si4432 transceiver module is integrated in the receiver for radio frequency communication. STM32103 chip is the MCU of receiver. The receiver module gets all the data from RF modules and transmits them to the server via RS485 communication interface. The server is located in the control room of the floating dock. With the collected data from all of the sensor nodes, the monitoring system on the server can work out the maximum deflection and inclination. The result is then transmitted to the receiver for possible display and alarm. The internal hardware block diagram of the receiver is shown in Fig. 7.

4. Parameters measurement methodology

According to the measurement scheme described in Section 2.2, the deflection and inclination of the floating dock can be easily measured.

4.1. Deflection measurement model

The sensor used for detecting the deflection is Rosemount 1151 pressure transmitter (Rosemount 1151 pressure transmitter reference manual, 2008) which offers a variety of configurations for differential, gage, absolute and liquid-level measurements including integrated solutions for pressure, level, and flow.

Considering the cost and complexity, five testing points on each wing walls are designed in this paper. The deflection measurement model on the wing wall is presented in Fig. 8.

Theoretically, the water level of the connection pipes at all points is the same and is referred to as the initial value. The water level sensors are equally distributed along the pontoon deck as shown in Fig. 8. At the beginning, each point has the same water level, \( l_{\text{init}} \), which is

\[
l_{\text{init}} = l_1 = l_2 = ... = l_{n}(n = 5)\]  

(1)
In which, \( n \) is the total number of sensors. In this case, it is 5. And the deflection \( \Delta h_i \) of each point is ideally equal to zero
\[
\Delta h_i = l_i - l_{\text{init}} = 0, \quad i = 1 \sim n \tag{2}
\]

4.1.1. Hog type deflection measurement
Firstly, it is assumed that the deck has an upward deflection-hog as shown in Fig. 9. This hog type deflection can be generated when the middle ballast tanks are filled with less water. The measurement of such deflection is then discussed under two conditions: when there is no dock inclination and when there is a dock inclination.

**Deflection measurement when there is no inclination.** Under this condition, the deflection pattern of the pontoon deck is presented in Fig. 10, in which \( l_i \) is the initial liquid level of the \( i \)th testing point on the pontoon deck; \( l'_i \) is the new liquid level value due to the pontoon deck deflection. \( x_i \) (\( i = 1 \sim 5 \)) represents the length of each point.

Therefore, the deflection \( \Delta h_i \) (\( i = 1 \sim 5 \)) at each point can be computed by the following equation
\[
\Delta h_i = l_i - l'_i \tag{3}
\]

Note that there is no deflection for the two end points \( x_1 \) and \( x_5 \) on the line, we have
\[
\Delta h_1 = \Delta h_5 = l_1 - l'_1 = l_5 - l'_5 = 0 \tag{4}
\]

When the deflection of each sensor point is calculated by Eq. (4), the deflection at any point on the line can be obtained with a LAGRANGE interpolation algorithm. LAGRANGE interpolation is a well known, classic technique for interpolation, using an approximating or interpolating function to fit \( N+1 \) known discrete points with an \( N \)th degree polynomial. Thus, the deflection at any point along the full length of pontoon deck can be computed as
\[
\Delta h(x) = \sum_{k=0}^{n} \Delta h_k l_k(x) \tag{5}
\]
where
\[
l_k(x) = \prod_{j=0, j \neq k}^{n} \frac{x - x_j}{x_k - x_j} \tag{6}
\]

\[\text{Fig. 8. Deflection model.}\]

\[\text{Connection pipe} \quad \text{Deck of} \quad \text{Floating Dock} \]

\[\quad \text{Sensor} \]

\[\quad \text{Fig. 9. Deflection model—hog.}\]

\[\Delta h_1 \quad \Delta h_2 \quad \Delta h_3 \quad \Delta h_4 \quad \Delta h_5\]

\[\quad x_1 \quad x_2 \quad x_3 \quad x_4 \quad x_5\]

\[\text{Fig. 10. Deflection model—hog—no inclination.}\]

\[\text{Fig. 11. (a) Deflection model—hog—inclination (b) connection pipes show of (a).}\]

**Deflection measurement when there is an inclination.** Under this condition, the deflection is coupled with inclination measurement as shown in Fig. 11.

In Fig. 11(b), point P is one of the points equipped with sensors on the deck. Point O and W are two end points on the pontoon deck. Before the deflection, point P is overlapping with point B, line OBW is a ramp line. The inclination angle of \( \alpha \) between line OBW and the horizontal line (X axis) can be measured by four sensors as will be discussed in Section 4.2. When deflection is generated, OBW becomes an arc OPW. The projection of point P on the X axis is C. The cross point of line PC and line OBW is A. The projection of point P on line OAW is B. As the angle \( \alpha \) is very small, OC can be regarded as approximately equal to OB. The straight line MDN refers to the water level in the connection pipes. According to the Torricelli’s Experiment, regardless of the inclination of the connection pipes, the water level height DC is a constant. We have
\[
DC = l_{\text{init}} \quad (l_{\text{init}} \text{ is the initial liquid level of each point when pontoon deck have no deflection.)}
\]
\[
OC = x_i \quad (i = 1, 2, \ldots, 5) \quad x_i \text{ is the length of } i \text{th point. In this case, } i = 3.
\]
\[
DP = l'_i \quad (l'_i \text{ is the new liquid level of each point when pontoon deck is deflected. In this case, } i = 2.)
\]
\[
AC = \Delta l_i = x_i \tan(\alpha) \quad \Delta l_i \text{ is the liquid level difference of each point when deck is deflected with inclination.}
\]

Accordingly, the PA is given that
\[
PA = DC - DP - AC = l_{\text{init}} - l'_i - x_i \tan(\alpha) \tag{7}
\]

From Fig. 11(b), the deflection at point P is PB (it is \( \Delta h_i \), \( i = 2 \)), we have
\[
\Delta h_i = PB = PA \cos(\alpha) = (l_{\text{init}} - l'_i - x_i \tan(\alpha)) \cos(\alpha) \tag{8}
\]

Specifically, as point O and point W are end points, there are no deflections on these two points. Generally, if there is no inclination, angle \( \alpha = 0 \), the deflection \( \Delta h_i \) at each point is given as the
The following equation

\[ \Delta h_i = PB = PA \cos(\alpha) = (l_{in} - l_i - x_i \tan(\alpha)) \cos(\alpha) = l_{in} - l_i \]  (9)

This equals to the values under the condition of “There is no inclination”.

It should be noted that, the above derivations are based on the assumption that the inclination angle \( \alpha \) is less than 90°, that is point “W” is higher than point “O”. Similar results can also be derived when the inclination angle \( \alpha \) is greater than 90°, that is point “W” is lower than point “O”. The general equation when the deflection pattern is a hog is

\[ \Delta h_i = \begin{cases} (l_{in} - l_i - x_i \tan(\alpha)) \cos(\alpha), & \alpha < \frac{\pi}{2} \\ (l_{in} - l_i - x_i \tan(\pi - \alpha)) \cos(\pi - \alpha), & \alpha > \frac{\pi}{2} \end{cases} \]  (10)

Similarly, on the basis of LAGRANGE interpolation, the deflection at any point along the full length of pontoon deck can be interpolated as

\[ \Delta h_{ik}(x) = \sum_{k=0}^{n} \Delta h_i k(x) \]  (11)

4.1.2. Sag-type deflection measurement

The floating dock may also experience sag-type deflection when loaded with a ship as briefly shown in Fig. 12.

Similar to hog-type deflection measurement when the inclination angle \( \alpha \) is considered, the deflection at each sensor point is given by

\[ \Delta h_i = PB = PA \cos(\alpha) = (x_i \tan(\alpha) - (l_{in} - l_i)) \cos(\alpha) = -(l_{in} - l_i - x_i \tan(\alpha)) \cos(\alpha) \]  (12)

Comparing Eqs. (8) and (12), the deflection of the dock deck, regardless of hog or sag type deflection, can be given by a general equation as follows

\[ \Delta h_i = \begin{cases} (l_{in} - l_i - x_i \tan(\alpha)) \cos(\alpha), & \alpha < \frac{\pi}{2} \\ (l_{in} - l_i - x_i \tan(\pi - \alpha)) \cos(\pi - \alpha), & \alpha > \frac{\pi}{2} \end{cases} \]  (13)

When \( \Delta h_i > 0 \), it is a hog (Fig. 11), \( \Delta h_i < 0 \), it is a sag (Fig. 12).

4.2. Inclination measurement model

Four transducers are arranged on the four bottom corners of pontoon deck as shown in Fig. 13. Transducers No. 1 and No. 2 are distributed on the port of the dock, and lie on the forward and aft respectively. Similarly, transducers No. 3 and No. 4 are installed on the starboard of the dock, and lie on the forward and aft respectively. These transducers are pressure-based and waterproof measuring devices which are named pneumercators. They are easy to install and suitable for applications in slurries and dirty liquids. Therefore these transducers are reliable for inclination (draft) measurement of the floating dock.

Two inclination angles are to be measured: trim angle in the length direction of the dock and heel angle in the transverse direction. Given that the length of the dock is \( L_D \), the width of dock is \( W_D \). The trim angle in Fig. 14 can be obtained by measuring the liquid levels at the forward and the aft. Assuming that the readings of the transducers are \( d_i(i = 1 \sim 4) \). When there is no inclination, the draft readings on the four corners are equal to the initial value. If the floating dock inclines, we have

Trim angle in the portside

\[ \tan(\beta) = \frac{d_1 - d_2}{L_D} \]  (14)

Because the trim angle is very small and the value of \( d_1 - d_2 \) is very small compared to the \( L_D \). Therefore, \( \sin(\beta) \) is approximately equal to the \( \tan(\beta) \). And trim angle in the starboard

\[ \tan(\beta) = \frac{d_3 - d_4}{L_D} \]  (15)

For fairness, considering the inclination in the port and starboard of the floating dock, the average difference should be used for relative trim angle computation, as given by the following equation

\[ \tan(\beta) = \frac{(d_1 - d_2) + (d_3 - d_4))/2}{L_D} \]  (16)

Thus, the relative trim angle is given by

\[ \beta = \arctan\left(\frac{(d_1 - d_2) + (d_3 - d_4))/2}{L_D}\right) \]  (17)

The relative heel inclination angle model is presented in Fig. 15. The heel angle \( \gamma \) is calculated by the measuring results of liquid levels at the port and the starboard. According to the discussion above, we have

Heel angle at the forward

\[ \tan(\gamma) = \frac{d_1 - d_3}{W_D} \]  (18)
5. System verification experiments

The proposed floating dock deflection and inclination measuring scheme is validate by the experiments. The experiments were successful conducted on two floating docks, “Flying Dragon Mountain” and “Yuexiu Mountain” (shown in Fig. 16) in Guangzhou, China. The experimental data on the “Flying Dragon Mountain” are chosen for analysis in this paper. The parameters of “Flying Dragon Mountain" needed for the measurement are listed as follows

- Total length of the pontoon dock \(L_D = 184.32 \text{ m}\);
- Total width of the wing wall \(W_0 = 47.00 \text{ m}\);
- Lifting capacity = 16,000 t;
- Maximum permissible deflection \(D_{\text{max}} = L_D \times 0.5\% = 92 \text{ mm}\);
- Maximum permissible trim \(\beta_{\text{max}} = 1.00^\circ\) (Zhao, 2007);
- Maximum permissible heel \(\gamma_{\text{max}} = 2.00^\circ\) (Sun, 1995);
- The detailed position of each sensor is introduced in Fig. 17. It is noted that the unit in this figure is meter \(\text{(m)}\). The five sensors are placed on the bottom of pontoon with the same interval which is 40 m in the figure. The sensors are installed just closed to the two wing walls. All of the RF modules are installed on the top of the two wing walls, which can avoid modules being immersed into sea water when the floating dock is sinking. The sensor and the RF module are connected with a pair of copper cables which can transferred the output signal of sensor to the RF module. The output signal of sensor is a DC (Direct-current) current of 4–20 mA.

The developed monitoring system software is shown in Fig. 18, in which the deflections of the port and starboard, and the inclination angles (trim and heel) can be displayed. If the deflection and inclination exceed the maximum permissible values, alarm sounds and warning light is illuminated. The operator can get enough information from the software and adjust the deflection and inclination of the floating dock by pumping compensating water in the corresponding blast tanks.

5.1. Deflection measuring experiment

The calculated deflection results were compared with the results from finite element analysis (Xu and Shen, 2011; Duan et al., 2007). The finite element analysis is a reliable and efficient method for structure calculation, validation and verification. Therefore the calculation results are used for the calibration of the deflection. The relative error ration in Table 1 is the calculation results divided by difference of calculation result and the measured result. The experiments were carried out under different ship loading conditions: Light Loaded floating dock and Heavy loaded floating dock. The measured results and calibrated results are listed in Table 1.

According to Table 1, the maximum measured deflection does not exceed the maximum permissible deflection. The maximum measuring error of the deflection in this system is about 5.0%, which indicates that the experimental results satisfy the design specification.

The measuring results at the three different points when ship 1 was lifted in the floating dock are shown in Table 2. The “max proportion of \(L_D\)” means the proportion of maximum measured deflection to the full length of pontoon dock. In this study, \(L_D\) is given at the beginning of this section, it is 184.32 m.

From Table 2, the maximum deflections \(\Delta h\) measured at different sampling time always occur at point 3, which means that the pontoon deck has a sag deflection and the maximum deflection occurred in the middle of the pontoon deck. The deflection increases with time, indicating that the pontoon deck is gradually loaded more during the lifting process. In this case, the maximum deflection does not exceed 0.5% of \(L_D\).

5.2. Inclination measuring experiment

With the model described in Section 4.2 the inclination (trim and heel) angles can be calculated. The conventional method of inclination measurement is manual observation of the ruler calibrations. This method is accurate but time consuming and less efficient. In this paper, the manual observation method is used for comparison purpose. There are 4 m calibrations equipped at the four corners of the two wing walls. When the floating dock rises or drops, workers at the four corners would read the real time meters and report the results to the central room. In this way, the
The inclination angle can be calculated. The computer measured results are then compared with the manual observations. The inclination experiment results are listed in Table 3.

According to Table 3, the maximum measured trim or heel angles are less than the maximum permissible inclination angle. The maximum error of measured inclination angle in this system is about 7%. Therefore, the measurement result is accurate enough for the floating dock application.

The measured trim and heel angles are compared with the manual observations in Figs. 19 and 20, respectively. The solid line represents the manual observation result and the dashed line represents the measured one. The sampling time interval is 10 s. According to the figure, the measurement curves generally compares well with the manually observed results.

In these two subsections, deflection and inclination experiments are implemented by the deflection and inclination model with the monitoring system. The proposed monitoring system collects the data from sensors to calculate the required parameters. The calculation methods come from the proposed liquid level measuring algorithm. With the equipped connection pipes, the deflection and inclination angle are measured in the proposed monitoring system.
Table 4
Data transmission experiment.

<table>
<thead>
<tr>
<th>n</th>
<th>Distance (m)</th>
<th>Data loss rate (%)</th>
<th>Data rate (bps)</th>
<th>Data package length (bits)</th>
<th>Error data rate (%)</th>
<th>Collection time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10–125</td>
<td>0.7</td>
<td>1200</td>
<td>64</td>
<td>0</td>
<td>0.96</td>
</tr>
<tr>
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<td>1.2</td>
<td>2400</td>
<td>64</td>
<td>0</td>
<td>0.88</td>
</tr>
<tr>
<td>3</td>
<td>10–125</td>
<td>1.8</td>
<td>4800</td>
<td>64</td>
<td>0</td>
<td>0.85</td>
</tr>
</tbody>
</table>

5.3. Wireless transmission experiment

Silicon Laboratories Si4432 ISM Band transceiver is designed to work on 433.9 MHz frequency band. Since it is a very slow adjusting process of the floating dock, the data transmission rate of 1200 bps (bits per second) is adequate for the system application. The data package is totally 8 bytes length. As mentioned above, there are 10 sensor nodes in the WSN. To avoid and reduce data collision in the network link, a Binary Exponential Back off (BEB) algorithm (Yang et al., 2012) is introduced in the wireless network. Theoretically the receiver collects all the data packages from the 10 sensor nodes within 0.53 s with a 1200 bps baud rate. Considering the package loss caused by link collision, 1.07 s is the maximum upper time limit. The sampling period is 2 s. Table 4 presents the experimental results. In this table, the data loss rate is the ratio of actually received bytes by receiver to the totally transmitted bytes by each RF modules connected to the sensor nodes. The error data rate is the ratio of received correct bytes by receiver to the original bytes transmitted by each RF modules.

According to Table 4, the maximum data loss rate is less than 0.7% with the 1200 bps data rate which consumes an average collection time of 0.96 s. When the data rate grows, the data loss rate increases. When the data rate is less than 4800 bps, the data loss rate and error data rate are still accurate enough for the slow adjustment process of floating dock. The error data rate is 0% shows that the WSN is reliable and there is no error bytes received. But a very small amount of data will be lost when the data rate increasing. Experimental results validate the reliability of the proposed wireless sensors network.

6. Conclusions

A deflection and inclination measurement system in a WSN of the floating dock is proposed in this paper. The deflection measuring model of a floating dock is presented. This model is constructed based on the liquid level in the connection pipes. The data transmitted within a WSN are planned to access to the receiver with a BEB algorithm, data collisions are avoided. The experimental results indicate that the measurement accuracies of deflection and inclination measurement models are about 95% and 93%, respectively. The wireless data transmitting is reliable with a lower data loss ratio of 0.7%. The traditional parameters monitoring system of floating dock is implemented by a wired one. As the poor work environment in the floating dock, a wireless sensor networks system can eliminate the inconvenience and lower the cost of a wired measuring system. Therefore, it is cost effective and more convenient than a wired system.

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References