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Attitude and position measurement of bit for underwater horizontal directional drilling system

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ABSTRACT

In order to solve the problem of attitude and position measurement of bit, a new navigation algorithm was developed based on nonholonomic constraints and steady-state component constraints. The state error propagation model based on random walk of sensors was deduced. Underwater horizontal directional drilling system has two states: drilling and static. In the drilling state, the velocity of bit in the plane perpendicular to the forward direction is almost zero (nonholonomic constraints), and the steady-state component of acceleration and angular velocity of bit does not exist (steady-state component constraints). In the static state, velocity, acceleration, angular velocity, and the steady-state component of acceleration and angular velocity are equal to zero. So, the information of nonholonomic constraints and steady-state component constraints can be integrated with navigation algorithm by indirect Kalman filter based on state error propagation model. IMU7200 mounted in the bit can provides measurement of acceleration and angular velocity of bit. The encoder mounted in the injection head (encoder 1) can provide measurement of velocity of bit. The encoder mounted in the coil winch (encoder 2) can be used to discover slippage between coiled tubing and the shaft of injection head. The experimental results show that the navigation algorithm proposed in this paper can realize accurate measurement of attitude and position of bit.

1. Introduction

Since HDD (horizontal directional drilling) has characteristics of trenchless, minimizes surface and environmental disruption, shorter construction period, higher construction quality, accurate guide, high efficiency, and fewer external constrains, it has been used in construction of ASR (aquifer storage recovery) wells (David et al., 2004), reaming program in rock strata (Lan et al., 2011), Jiangyin Yangtze River crossing project (Wu et al., 2014), pipe installations, and so on. There are also some factors which can affect productivity of HDD operations (Zayed and Mahmoud, 2013). Such as, drill pipe thread gluing (Zhu et al., 2013), lateral vibration of the reamer (Zhu et al., 2014), hydraulic fracturing (Ariaratnam et al., 2007; Wang and Sterling, 2007), surface heave (Lueke and Ariaratnam, 2006), steering (Royal et al., 2010), stress-strain of pipe (Polak and Lasheen, 2002; Polak et al., 2004; Cholewa et al., 2010), pulling loads of pipe (Cheng and Polak, 2007; Ariaratnam et al., 2010), pipe length (Chehab and Moore, 2010), and arching factor of pipe (Akbarzadeh and Bayat, 2014). Pipe diameter, steering problems, soil type, operator and crew skills are the most significant factors while pipe type, pipe length, depth and weather conditions are the least impacting factors (Zayed and Mahmoud, 2013). The decision support system consisted of decision making criteria and rules is necessary, which can be used to select appropriate equipment for HDD projects (Baik et al., 2003). For wider acceptance of HDD by engineering community, the criteria of quantitative risk assessment, quality assurance, operating standards, and quality control has been formulated (Allouche, 2002; Gierczak, 2014a, 2014b). These achievement will promote the further development of HDD.

UHDD (see Fig. 1) combining related techniques of HDD and underwater vehicle is designed by Shanghai Jiaotong University. There are similar working principle between HDD and UHDD. There are also some differences between HDD and UHDD due to the different working environment. UHDD takes into account the sealing and pressure at the beginning of design. The drill pipe of HDD is the sectional type. However, the coiled tubing of UHDD is continuous type. We have also made improvement in other areas. Such as, hydraulic system, electronic controlling system, attitude and position measurement of the bit, water leakage detection, insulation monitoring, and so on. UHDD is mainly used to salvage the sinking boat and reuse the vessels. In the process of salvage the

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Fig. 1. The experiment of UHDD.

sinking boat, UHDD will be sunk into the water until it is completely located on the bottom. In order to maintain the stability of UHDD, the screw anchor will be embedded in the soil. We can choose the soil on one side of the sinking boat as the drilling point and realize directional drilling under the sinking boat through control console, navigation interface and monitoring interface. When the bit drill through the soil on the other side of sinking boat, we can see the bubbles in the water which generated by the gas flowing through the bit. The diver can find the bit according the bubbles and tie the cable in the ring located on the bit. The cable can pass through the soil under the sinking boat by pullback of UHDD. The key problem of UHDD is attitude and position measurement of bit which can be used to control the drilling depth and lateral deviation of bit. The attitude and position measurement method used in HDD (Xu et al., 2005a, 2005b; Liu and Wang, 2011; Liu et al., 2012; Wu et al., 2002; Jaganathan et al., 2011) do not apply to UHDD due to its working environment. So, we need to design a navigation system satisfied working environment and characteristics of UHDD.

In this paper, we proposed a navigation algorithm based on nonholonomic constraints and steady-state component constraints. IMU7200 provides acceleration and angular velocity information of bit. Encoders mounted in injection head and coil winch can provide drilling velocity of bit and solve the slippage between coiled tubing and the shaft of injection head. The experimental results show that the accuracy of navigation algorithm satisfy the engineering requirements.

2. Underwater horizontal directional drilling system

System composition of UHDD can be seen in Fig. 2. Control console can control drilling process according to working state of UHDD and attitude and position of bit. High voltage control cabinet supply power for UHDD. Umbilical cord cable winch driven by hydraulic system can control the length of the umbilical cord cable according to working requirements. The main parameters of UHDD can be seen in Tables 1 and 2.

Fig. 3 shows the function modules of UHDD ontology. Coil winch is synchronized with injection head. Screw can be used to maintain the stability of UHDD ontology and resist tilt and translation caused by drilling, pullback, and current. The navigation

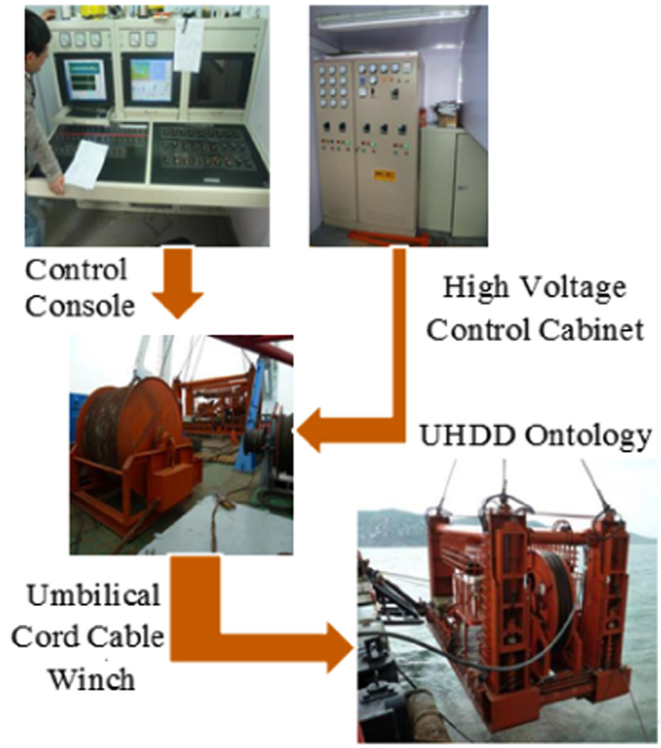

Fig. 2. Underwater horizontal directional drilling system.

Table 1
Basic parameters.

Length (m)	Width (m)	Height (m)	Mass (t)	Power (kW)
9.1	4.1	4.51	40	107

Table 2
Performance indicators.

Working depth (m)	Drilling distance (m)	Drilling force (t)	Pullback force (t)
200	100	3	6

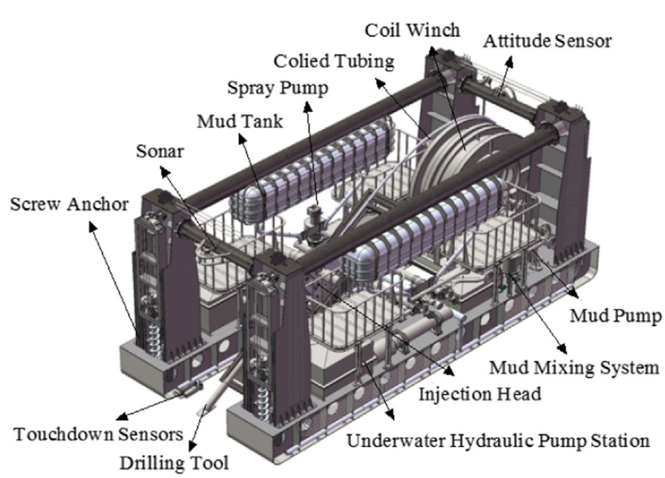

Fig. 3. Function module of UHDD ontology.

system, consisting of IMU7200 and two encoders, can provides attitude and position of bit. IIMU7200 mounted in bit can provide acceleration and angular velocity. Two encoders mounted in