APPLYING RADIO DIRECTION FINDING SYSTEM FOR IMPROVEMENT OF HORIZONTAL DIRECTIONAL DRILLING METHOD

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Abstract: This study improves the horizontal directional drilling method (HDD) by using an autonomous land vehicle (ALV) with a radio directional finding (RDF) system. The ALV with an RDF system carrying a digital positioning device can locate a moving or static underground drill bit and track it. Not limited to a pre-determined track or path, the ALV system utilizes its on board RDF system instantaneously to seek and to track a moving or static drill bit. Compared to conventional systems, the system reduces the number of operators, minimizes costs, prevents accidents, and enhances the degree of automation.

Keywords: ALV, HDD, Trenchless, Construction Automation.

1. INTRODUCTION

Recently, HDD has become increasingly popular for laying pipes, including gas pipes, water supply pipes, underground water pipes, communication pipes, optical fiber pipes, cable TV, and rainwater and sewage channels. HDD is unique in trenchless technology in which it is designed for small pipes. This study concentrates on some proposals for improving the HDD equipment.

Usually, HDD requires a work team of four people on average. This work force is much less than that for traditional open-cut methods. Meanwhile, the work team can be arguably reduced to just two people with the latest HDD machines, namely the operators for the digital positioning device and the horizontal directional drilling equipment [2]. Because of savings in labor costs, the reduced manpower for the HDD is very positive. The operation procedures are that the operator of the digital positioning device holds the device to receive the data, including the position, depth and direction of the drill bit, transmitted from the transmitter installed on the drill bit. The received data can be simultaneously transferred and shown on a monitor installed on the horizontal directional drilling equipment. Thus, the operator of the horizontal directional drilling equipment can operate the equipment according to the received data. Figure. 1 illustrates the HDD direction control technique.

The individual who is responsible for using the digital positioning device, under certain circumstance, may need to operate the device from the middle of a road. Or, the operator for the digital positioning device needs to constantly hold the device to receive the transmitted data from the transmitter installed on the drill bit. In such cases, an ALV with an RDF system to carry the digital positioning device seems attractive. Such development can reduce the number of operators, minimize costs, prevent accidents, and enhance construction automation.

The major parts of an ALV are its guiding system and motion controller, which allow the ALV to determine its future path and direction, and then move from its current location to the desired one. The conventional guiding methods consist of track and trackless types. The track type has a pre-determined path with colored tapes on the floor as a reference to guide an ALV to its destination [3]. Although such marking based navigation systems can simplify tracking; their applications are limited. The trackless type involves several sources of ultrasonic [4], sonar [5,6], or laser [7,8] in the working environment, and the position is then estimated based on the time difference of the signal received by the ALV. The current position of the ALV can be further estimated from its feedback based on special characteristics of the working environment that are already known [9]. Generally, the sensor system of ALVs can be classified into laser, ultrasonic, sonar, image systems, and CCD cameras.

To make a low budget development possible, this study uses a transmitter to simulate the transmitter installed on the drill bit. An autonomous land vehicle (ALV) with a radio direction finding (RDF) system carrying the digital positioning device simulates the operator holding the digital positioning device during the construction. The system is implemented to track a moving and a static target, as given as follows.

2. SYSTEM ARCHITECTURE

Many successful ALV systems have been established for various purposes. This section describes the architecture of the ALV in this study. Figure 2 displays the system architecture of the ALV. This ALV is driven by the front wheels, which are supported by two step motors through two gears. The ALV has no transition mechanism (deflection) and is steered by the speed difference between the front wheels. The rear wheels are universal wheels that rotate freely. The Yagi antenna is used to find the bearing of the transmitter. The antenna is driven to rotate by the step motor, and receives the radio frequency (RF) signal from the transmitter. The receiver converts the radio frequency signal to an audio frequency (AF) signal/intensity, and the intensity signal is fed into the computer. The two step motors are controlled by control signals sent from the controller based on the measured signals. Figure 3 illustrates the ALV with the RDF systems.

The radio direction finding system is depicted in Figure 4, which exhibits the whole architecture including the step motors, motor drivers, a Yagi antenna, a receiver, and a CPU. The Yagi antenna is mounted on a gear linked with a step motor. The RDF system rotates the Yagi antenna via the step motor, which is controlled by the computer and the RF signal applied to the receiver. The RF signal is converted to the intensity signal via the receiver. While the antenna is rotating, the computer counts the intensity signals and then judges the bearing of the source. The RDF process aims to locate the bearing of the transmitter. The receiving power of the antenna is the greatest when the antenna is directed at the transmitter. It should be noted that the direction with the maximum intensity in the polar diagram is the bearing of the transmitter. The processes are described as follows:

（1）Rotate the Yagi antenna and record the intensity and

（2）Identify the direction with the maximum intensity.

3. CONTROLLER DESIGN FOR THE ALV SYSTEM

In our experiments, the ALV is controlled to track the target. First, the vehicle coordinates, as shown in Fig. 13, should be defined. The origin of the coordinates is placed at the center of the RDF system, which is on the left-hand side of the ALV. The degree is increased in a clockwise direction. During the experiment, the bearing of the target (y^o) is determined first, then the degrees of error defined as $90^0 - y^0$ are used to adjust the ALV to point to the target. For example, if the error is bigger than zero, and the target lies to the left of the car, then the speed of the right wheel should be increased to turn the ALV left until it points to the target. The differential speed (dv) is defined as the speed of the right wheel minus the speed of the left wheel. In the proposed system, the PID controller and the fuzzy controller are used to control the differential speed of the front wheels of the ALV.

4. EXPERIMENT RESULTS AND DISCUSSION

The operating procedures of the HDD are that the operator in charge of the digital positioning device holds the device to receive the data, including position, depth and direction, transmitted from the transmitter installed on the drill bit. The received data can be simultaneously shown on a monitor installed on the horizontal directional drilling equipment. Then, the operator in charge of the horizontal directional drilling equipment can operate it according to the received data.

If an ALV with an RDF system is employed to carry the digital positioning device, while the ALV instantaneously seeks and tracks the underground drill bit, the operator in charge of the digital positioning device can be replaced by the ALV. This situation would reduce the number of operators, minimize costs, prevent accidents, and enhance the degree of automation of construction.

Due to budget and site limitations, this study simulates the transmitter on the drill bit with a separate transmitter. Besides, an ALV with an RDF system carrying the digital positioning device simulates the operator holding the digital positioning device during construction. To prove that the ALV can locate and track a moving or static target, the transmitter and the ALV are not collinear, forcing the ALV to adjust direction continuously to trace the transmitter. The experiment below is performed on a two-dimensional plane. The ALV with an RDF system tracks the transmitter simulated as the drill bit both in still and in motion.

The PID controller and fuzzy logic controller of the ALV were developed based on the methods described previously. Because the ALV is not equipped with an encoder, a pen is mounted under the chassis of ALV roughly mid-way between the front wheels to record the trajectory of the ALV.

4.1Tracking a static target

In experiment #1, the transmitter is placed 120 cm north and 240 cm west of the ALV. Both the PID controller and FLC can modify the direction of the ALV to track the transmitter for a short distance. To measure the distance, which the ALV moves before the direction of the ALV modified to point to the transmitter, an XY plane is coordinated by choosing perpendicular lines X (X-axis) and Y (Y-axis). The ALV is initially placed at the origin of XY plane, as shown in Fig. 19. Meanwhile, the transmitter is on the X axis near the point (-270,0) on the XY plane. During the navigation, the RDF system should obtain the polar diagram to get the direction, which is the bearing of the maximum intensity toward the target. Because the RDF system belongs to the off-line navigation system, the ALV should stand to obtain the correct polar diagram. After finding the direction of the transmitter, the controller controls the ALV in a short time, such as 2 seconds. Then the RDF system once again finds the direction of the transmitter. The above processes continue until the ALV points to the transmitter.

During the experiment, the bearing of the target (y^o) should be determined first, then the degrees of error, defined as $90^0 - y^0$, is used to point to the ALV at the target. A controller is designed to reduce the degrees of error. Because the precise dynamic model of the ALV is unknown, the gain K_p of the P controller must be tuned by experience. Initially, let K_p be zero, and increase the value of K_p from zero until the controller modifying the direction is reasonably efficient. Figure 5 shows the trajectories of the ALV with the FLC and the PID controllers respectively, and the gain of the P controller is 10.

To track the transmitter (target), the immediacy and stability of the controller are important. Both the PID controller and the FLC can modify the direction of the ALV to the bearing of the transmitter. After comparing the trajectories shown in Fig. 20, clearly both PID controller and FLC modify the direction of the ALV to point to the transmitter within a short distance. Point A is the position where the direction of the ALV with the FLC has already pointed to the transmitter after moving to the X-projection near 55 cm. Meanwhile, point B is the position where the direction of the ALV with the PID controller has also already pointed to the transmitter after moving to the X-projection near 98 cm. Initially, the PID controller can modify the direction of the ALV more quickly than that of the ALV with the FLC. However, the distance and time required for the FLC to modify the direction of the ALV to point to the transmitter are less than those of the PID controller. The trajectory bears to the point (-270,12) and not to the point (-270,0) because the pen was placed about 12 cm away from the center of the RDF system.

4.2 Tracking a moving target

Experiment #2 was performed to test the performance of the ALV in tracking a moving target via the FLC. Initially, the transmitter is placed at the point (0,240) of the XY plane and the ALV is placed at the origin of the XY plane, as shown in Fig. 21. Then, the transmitter is moved to the point 30 cm on the right of its previous position, and the direction of the ALV is modified two times to track the transmitter. The above steps are repeated six times.

During the experiment, the positions of the ALV and the transmitter are recorded. Figure 6 shows the trajectory of the ALV, which tracks the moving target. For example, let the ALV placed at A（0,0） and transmitter placed at (0,240) in the XY plane. Initially, the ALV is at A(0,0) and the target is moved from （0,240） to point A'B'(30,240). As mentioned above, the bearing of the target (y^o) should be determined first, then the degrees of error defined as $90^0 - y^0$ is used to adjust the ALV to point to the target. The degrees of error for the ALV at point A to point to the target at point A'B' is 9.9°. When the ALV moves to point B, the degrees of error of the ALV to point to the target at point A'B' is 0.9°. The ALV evidently can track the target approximately. The ALV moves to point C, and the target is moved from point A'B' to point C'D' located at （60,240）. The steps described above are repeated. The degrees of error of the ALV at points C and D to point to the target at point C'D' are 5.4°and -0.9° respectively. Thus, the ALV can track the target approximately. The corrections of the direction of the ALV detected via the RDF system can also be plotted. The length of the arrows denotes the corrections. The steps described above are executed six times, and this reveals that the ALV with the FLC performs better at tracking a moving target. If the steps described above are continuously repeated, the direction of the ALV will be modified to point exactly to the target via the FLC, and the ALV will finally move straight and track the target at (180,240).

5. CONCLUSION

This work has successfully developed an ALV with an RDF system that is capable of locating a moving or static target and then tracking it. The ALV with the RDF system has low manufacturing costs with high performance. This study includes setting-up such an RDF system to determine subsequent path and direction of the ALV. To overcome the difficulty in obtaining the precise dynamic model of the ALV with the RDF system, a “fuzzy logic controller” is designed to control the system and gives it a target-tracking capability. The results of relevant experiments have verified that the ALV with an RDF system can precisely track a static or moving target.

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Figure 1 The HDD directional control technique

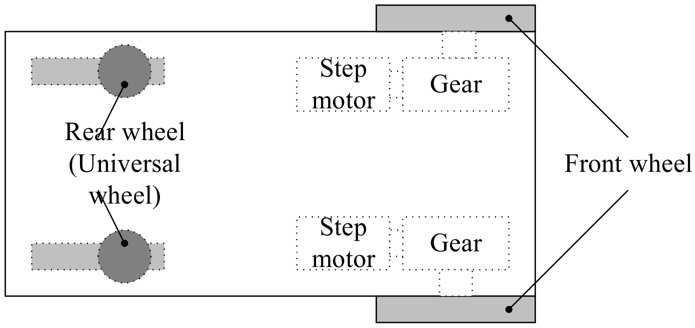

Figure 2 The allocation of driving devices of the ALV

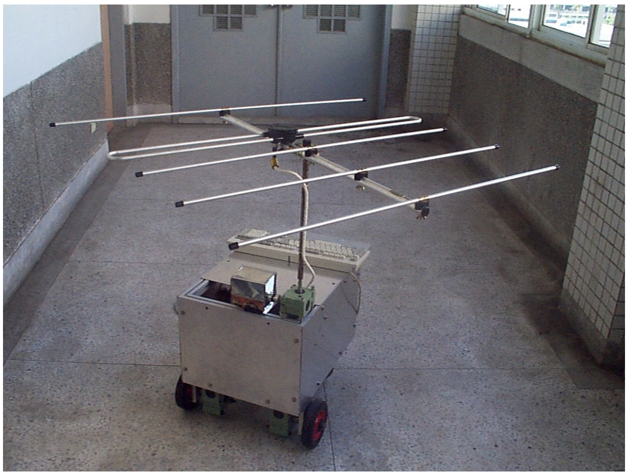

Figure 3 The Prototype ALV with the RDF system

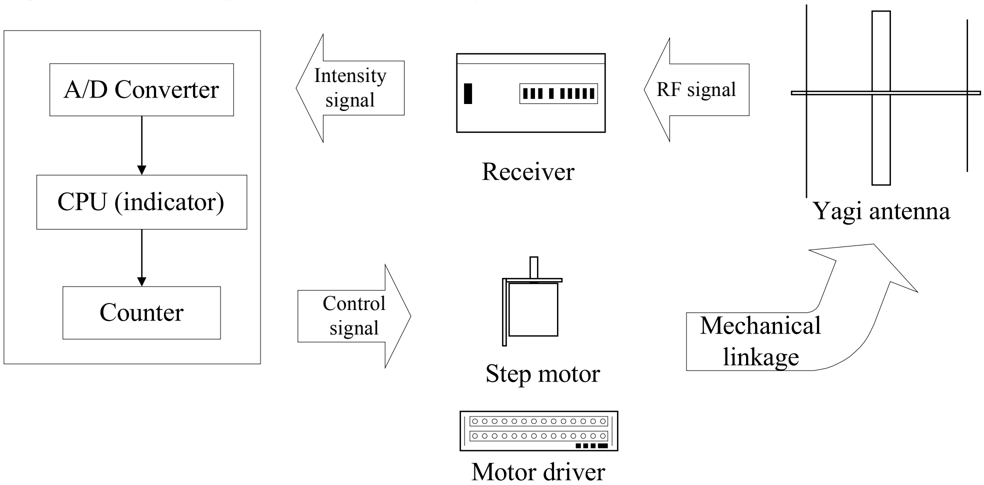

Figure 4 The architecture of the RDF system

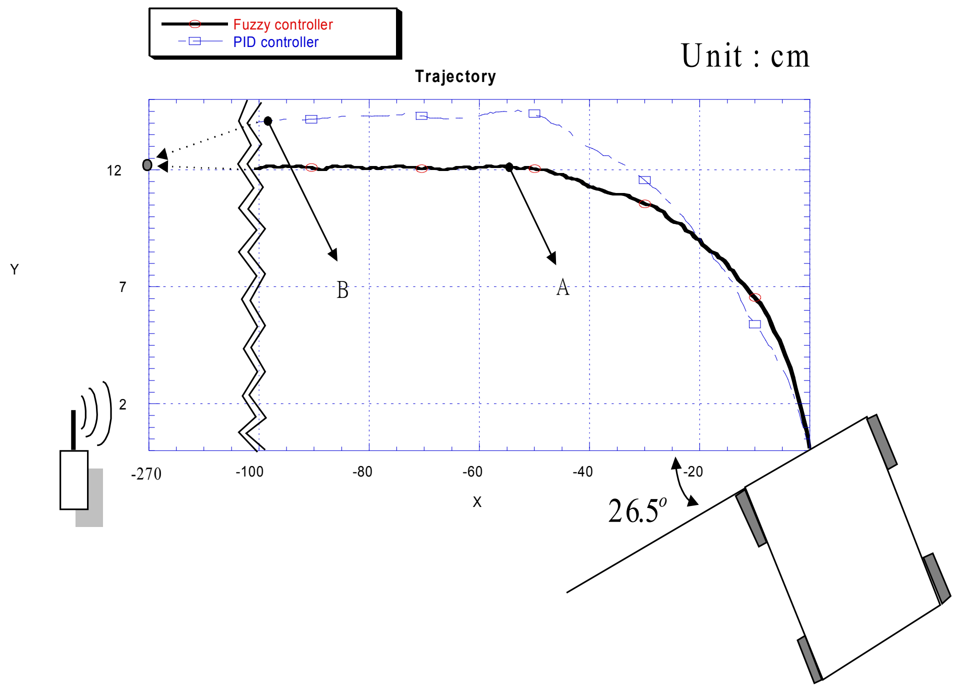

Figure 5 The trajectories of the ALV with the FLC and the PID controller

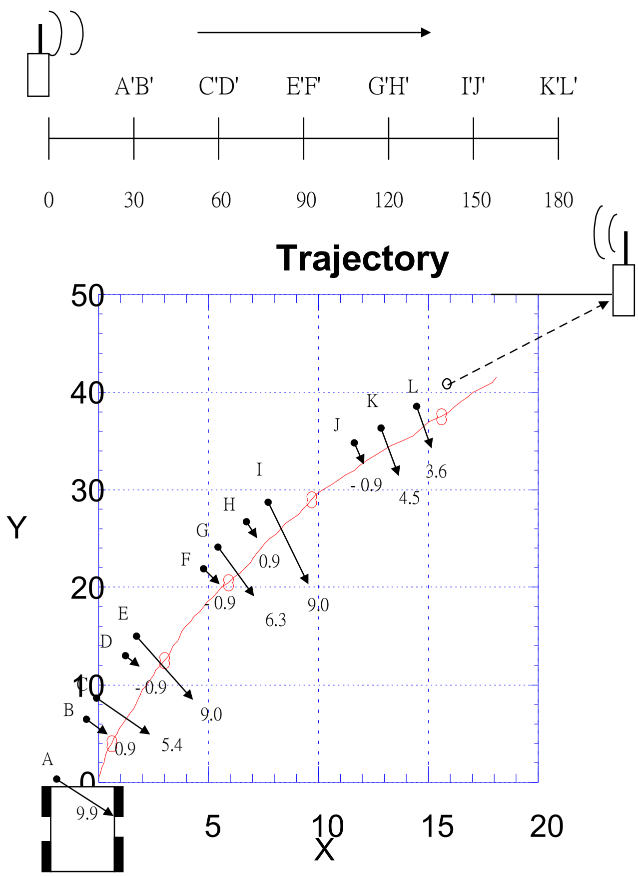

Figure 6 The trajectory of the ALV tracking a moving target