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Development and Implementation of Remote Control System for An Unmanned Heavy Tracked Vehicle

Guangming Xiong, Huiyan Chen, Jianwei Gong, Shaobin Wu

Abstract - A remote control system for a unmanned heavy tracked vehicle was developed. Autonomous driving system is accomplished by rebuilding of the original turning accessories. A friendly human-machine interactive interface was designed to control the vehicle easily. In order to follow desired path, a control strategy was proposed, in which the local autonomous and remote control modes are combined together. A teaching playback method based on preview heading involving with the location modification made by remote operator was presented to reduce the path deviation. Experiments show that this system is able to perform the outdoor task with the proposed control strategy.

I. Introduction

Recently, the intelligent unmanned land vehicles are playing more and more important roles in some fields, such as reconnaissance, rescue, military and space exploration. However, it would be very difficult for unmanned land vehicles to perform tasks autonomously under complex or hazardous conditions. Therefore, a human operator at the remote site is needed to contribute his intelligence for the system. Many control systems for unmanned land vehicles make use of human qualities, such as flexible judgments and decision ability. The tele-operation of these systems significantly enhances their ability and improves their performance [1-2].

Previous studies on human–machine systems have focused on cooperation between the human operator and the wheeled vehicle, but not the tracked vehicle, especially heavy tracked vehicle [3]. In this paper, our target is to implement a system with which a single operator controls a 13.6t unmanned heavy tracked vehicle. The local autonomous control is introduced to share the motion control between the operator and the unmanned heavy tracked vehicle. It can alleviate the tension in the tele-operation for the operator and improve its efficiency.

The configuration sketch of the system is shown in Fig.1. It consists of a tracked vehicle, a remote command vehicle and a microwave communications system. The command vehicle includes a car, system control computer, remote driving apparatus and image display. The tracked vehicle system includes the tracked vehicle, control computer and sensors, such as electronic magnetic compass and GPS receiver. The microwave communication system includes two transmitters and recievers installed in the command vehicle and the tracked vehicle respectively. The microwave communication system provides two one-way image channels, two duplex voice channels and one duplex data channel.

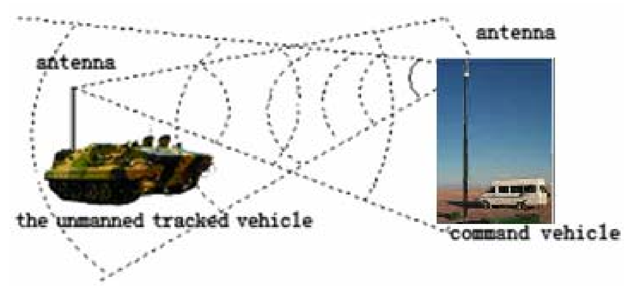

Fig.1 The configuration sketch of the whole system

The tracked vehicle can run under the control of remote instructions from the command vehicle and also autonomously. Using the microwave communication equipment, the remote control driving system on the command vehicle can send the remote control driving instructions to the unmanned tracked vehicle and obtain the information about the tracked vehicle and the road status.

II. Human-Machine Interactive System

The human-machine interactive system for the remote tracked vehicle is shown in Fig.2 and it is located on the command vehicle. The control computer is linked to the remote driving apparatus and microwave communicator through RS-232 serial ports. It receives some driving instructions, such as the start, acceleration, deceleration, turning, flameout and break, from the remote driving apparatus, and sends the commands to the tracked vehicle through the microwave communicator to control the vehicle's movement.

To improve human-machine interactive efficiency, a friendly user interface, as shown in Fig.3, is designed. All status information of the tracked vehicle can be displayed in the interface. They include the operation status of the shift subsystem, turning subsystem, GPS receiver, electronic compass, microwave communicator and remote driving apparatus. The movement trajectory of the tracked vehicle obtained by dead-reckoning is displayed on the top right. The velocity of the tracked vehicle, rotation speed of the engine,

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Guangming Xiong is with Intelligent Vehicle Research Center, Beijing Institute of Technology,Beijing, China (e-mail: xiongguangming @bit.edu.cn)

Huiyan Chen is with Intelligent Vehicle Research Center, Beijing Institute of Technology,Beijing, China

Jianwei Gong is with Intelligent Vehicle Research Center, Beijing Institute of Technology,Beijing, China

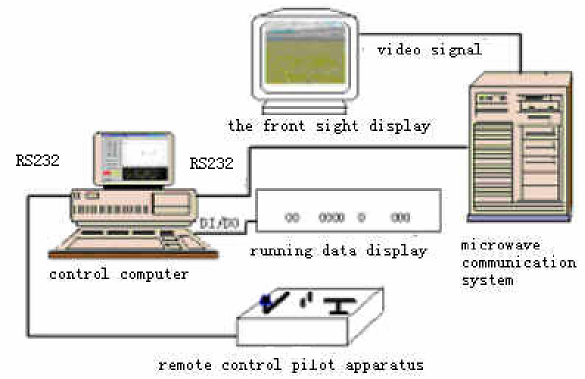


Fig.2 Human-machine interaction

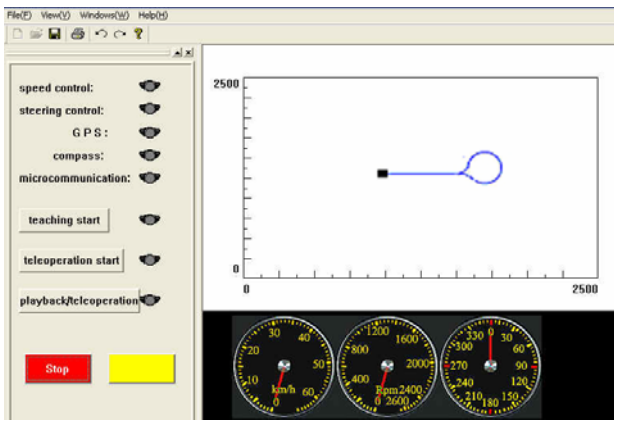


Fig.3 User Interface

heading angle and travel distance are displayed on the bottom.

The control computer can also send the data to LED display through DI/DO to help remote operator manipulate better. If an alarm signal exists, the remote operator can handle the fault in time. At the same time, the control computer records the operation data, and can print the velocity curve and the operation report after the test.

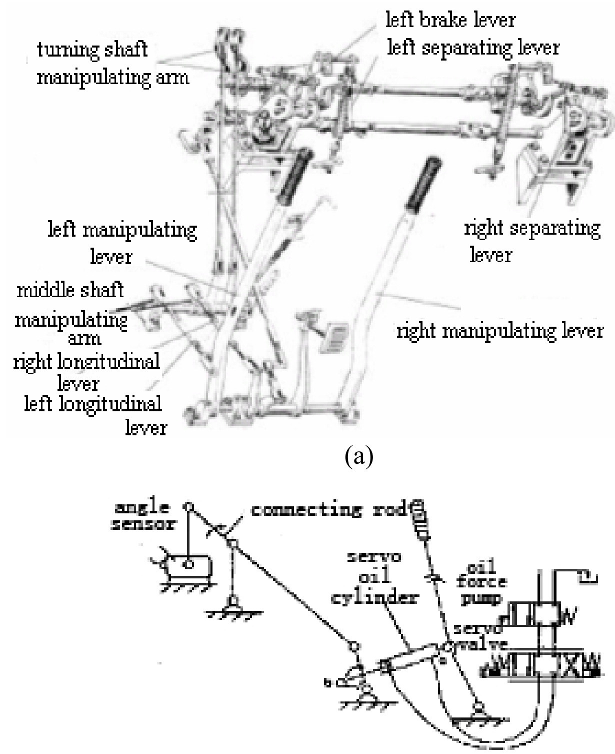
III. UNMANNED TRACKED VEHICLE SYSTEM

The unmanned tracked vehicle is a heavy vehicle weighted 13.6t. Two electronic units can control the vehicle to perform the engine ignition, start, shifting, turning, stop and going dead. The autonomous driving facility does not influence its original manual driving function, and the two driving system could be changed over each other. The turning system utilizes hydraulic servo cylinder to operate the left and right clutch. The velocity control system adjusts the vehicle's throttle.

The original structure of the turning clutch in the tracked vehicle is shown in Fig. 4 (a). Two kinds of turning, braking and separating, may be carried out through a manipulating lever. The lever should be operated properly in order to fulfill the desired turning. For autonomous driving, the two vertical levers shown in Fig. 4 (a) were replaced with two servo cylinders respectively, which were controlled by electro-magnetic servo valve [4]. These modifications are shown in Fig. 4(b).

By the stretching out and drawing back of piston stick, on condition that the manual manipulate stick was locked, turning could be performed through detaching the clutch. By cutting off the inlet and outlet oil route of the servo pump, manual operation mode could substitute remote driving mode.

The schematic structure of the running control system in the tracked vehicle is shown in Fig. 5.



(a)

(b)

Fig.4 Structure of the turning clutch

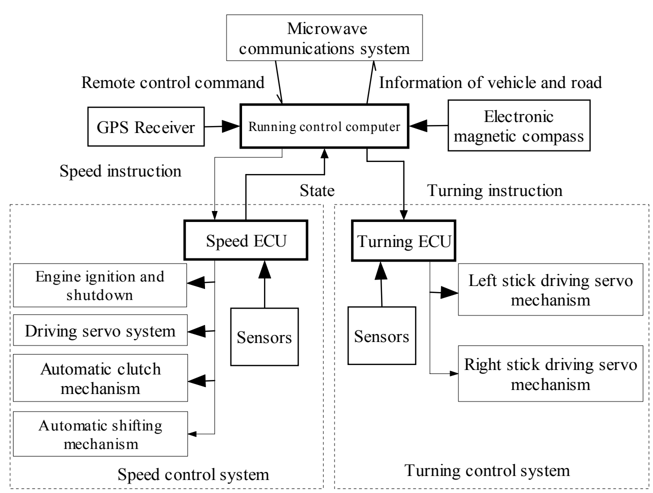


Fig.5 Control system of tracked vehicle

IV. An Improved Method of Path Following for Unmanned Tracked Vehicle

The unmanned tracked vehicle is a complex nonlinear platform with multiple variables and strong coupling. According to the characteristics of tracked vehicle and some experiment results, autonomous and remote control modes are both introduced in the practices to perform some tasks, and remote control manner is primarily considered. Also we have ever proposed the teaching playback method to perform path following [5]. First, the teaching was carried out by driving the tracked vehicle along the designated path. At the same time, the data of the potion, velocity and heading angle from the electronic compass and the GPS sensors are recorded by the running control computer. Subsequently, the computer directed the tracked vehicle to move automatically according to the teaching files. If a deviation is observed, the remote control operator would send out a command for modification. The running control computer may perform this command prior to the others. In this way, not only the track of the vehicle could be ensured, but also the action of the operator would be minimized. Moreover, remote control can still work even if errors happen to the autonomous system. However, in this way, the choice of the teaching interval and parameters of the controller was not easy, and the real experiments also confirmed there is the relatively high level of deviation for heading and path. In this section, a preview heading based teaching playback method is proposed, combined with the location modification made by remote operator.

The modified method is not complex, whose teaching process was identical with the former approach. The only difference between them is that the preview heading method read the heading data twice in the teaching beginning. In other word, both the heading data of the starting point and the next point are recorded.

Nevertheless, the shortcoming belonging to the former approach still appears in the improved method, thus, position-revising algorithmic method is introduced to avoid large path deviation.

Fig. 6 illustrates the position relation of the tracked vehicle in the path following using teaching playback method based on preview heading. *G* stands for the playback position of the tracked vehicle, while θ is the current heading angle of the movement. $H(i)$ and $H(i+1)$ is the *i*-th and (*i*+1)-th location in the heading teaching recorded file, where, $\theta(i)$ and $\theta(i+1)$ respectively represents the direction at the point $H(i)$ and $H(i+1)$. If the vehicle exceeds the point $H(i)$ according to the odometer calculation, the recorded parameter $\theta(i+1)$ at the point $H(i+1)$ would become next expected heading. Therefore, the heading deviation is

$$\varphi_H = \theta(i+1) - \theta \tag{1}$$

If only φ_H is inputted as the error of the controller, the position deviation could not be modified. Therefore, it is necessary to input the difference between the current position and teaching position. The modified heading deviation including position information in the point $H(i+1)$ could be gained in term of path following method based on heading [6].

$$\varphi_{GH} = \theta_{GH} - \theta \tag{2}$$

where, θ_{GH} is the angle between $H(i)$ $H(i+1)$ and the north orientation, it could be deduced by

$$\theta_{GH} = ARCTAN\,[(x(i+1) - x_g)/(y(i+1) - y_g)] \tag{3}$$

where, $ARCTAN\ (\ )$ is defined as below

$$ARCTAN\ (x/y) = \begin{cases} \arctan(x/y), (y \neq 0) \\ 0, \quad (y = 0, x = 0) \\ \pi/2, \quad (y = 0, x > 0) \\ -\pi/2, \quad (y = 0, x < 0) \end{cases}$$

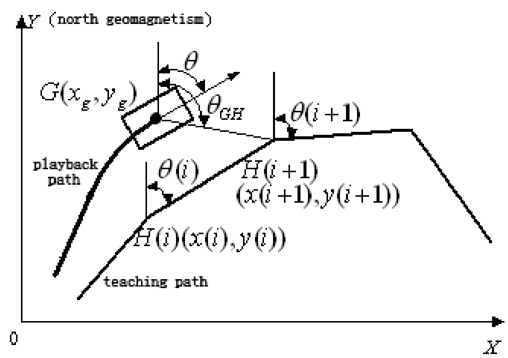


Fig.6 Position relation of the tracked vehicle

Let the distance interval between the points of teaching path is Δs , and the following can be gained.

$$x(i+1) = \Delta s \sum_{j=1}^{i+1} \sin\theta(j-1) \tag{4}$$

$$y(i+1) = \Delta s \sum_{j=1}^{i+1} \cos\theta(j-1) \tag{5}$$

Using modified algorithmic method, the input error is as below

$$\varphi = \varphi_H + k_{GH}\varphi_{GH} \tag{6}$$

where, k_{GH} is position modification coefficient, and $0 < k_{GH} < 1$. Considering the results of the experiments, k_{GH} is approximately between 0.2~0.4. Thus, the expected heading is mainly described by the teaching record file through the teaching playback control algorithmic method. Fig.7 demonstrated the above approach.

With considering of actual situation, φ_{GH} should also be limited:

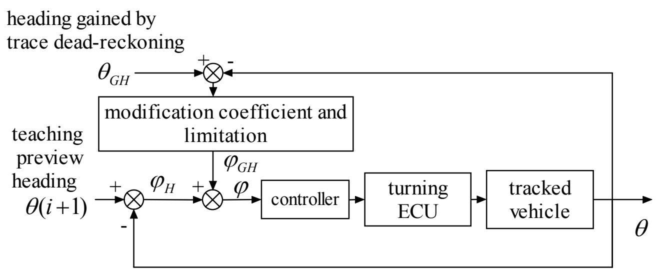


Fig.7 Modified algorithm

$$\varphi_{GH} \in [-\varphi_{GH\max}, -\varphi_{GH\min}] \cup [\varphi_{GH\min}, \varphi_{GH\max}] \quad)$$

$$(\varphi_{GH\min} > 0,\ \varphi_{GH\max} > 0)$$

If $-\varphi_{GH\min} < \varphi_{GH} < \varphi_{GH\min}$, let $\varphi_{GH} = 0$

If $\varphi_{GH} < -\varphi_{GH\max}$, let $\varphi_{GH} = -\varphi_{GH\max}$

If $\varphi_{GH} > \varphi_{GH\max}$, let $\varphi_{GH} = \varphi_{GH\max}$.

Owing to the limitation above, the steady movement of the tracked vehicle could be maintained and the position deviation could be reduced.

V. EXPERIMENTS

The experiment path consisting of arcs and lines is shown in Fig.8. The remote operator only controls the speed of the tracked vehicle, while the self-autonomous control system is responsible for turning control of the vehicle. According to the experiences from many experiments, some parameters are as below

$$\Delta s = 10\text{m},\ \varphi_{GH\min} = 5^\circ,\ \varphi_{GH\max} = 30^\circ$$

The heading following curve according to the former method is shown in Fig.9(a) and the movement trace in Fig.9(b), and then, the corresponding curves using the presented method are illustrated in Fig.10.

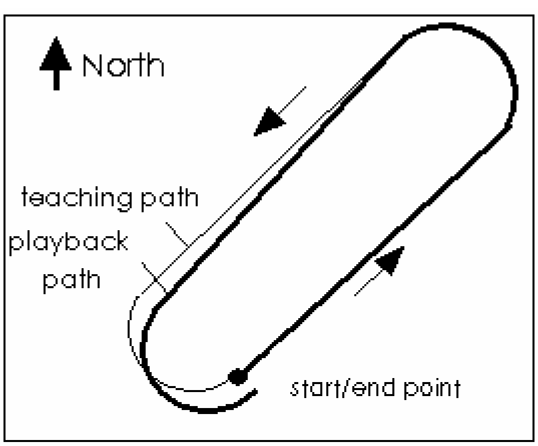
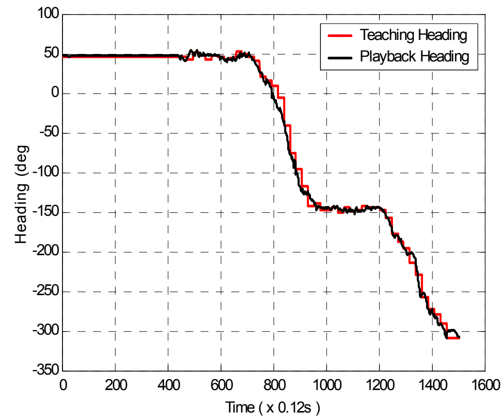
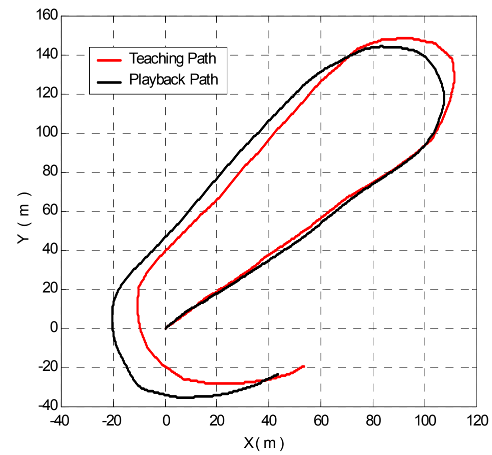


Fig.8 Experiment path



(a)



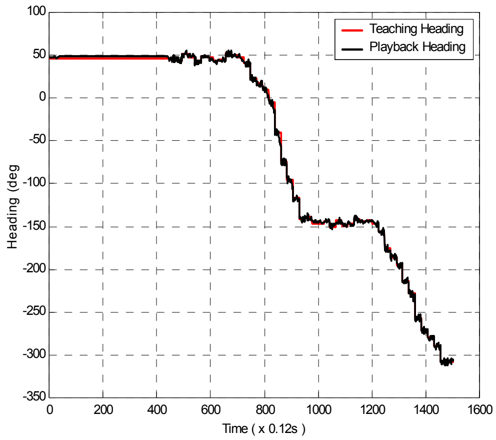
(b)

Fig.9 Curves obtained by original method

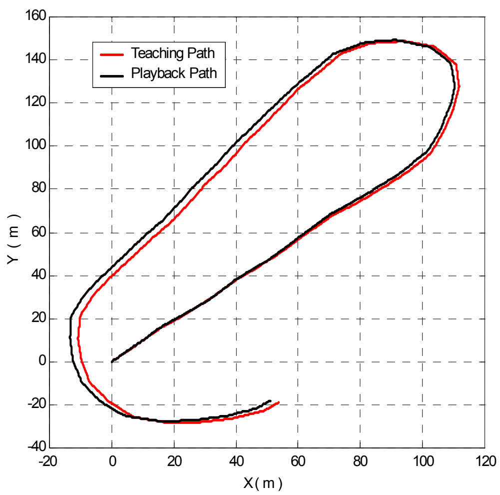
Because the proposed method uses preview heading and position modification and combines with the operator's intelligence, the performance of heading and path following is enhance observably. In the experiment, the manipulation is simple, the task is accomplished easily. However, it is rather difficult to perform the same task using the pure remote control method, several times of shutdown appearing.

VI. CONCLUSIONS

In this paper, we constructed a remote control system for a heavy unmanned tracked vehicle, including the control system in the command vehicle, running control system in the tracked vehicle and associated software. Autonomous driving was accomplished by rebuilding of the turning accessories of the tracked vehicle. Using the proposed method, the system only needs a few sensors such as GPS, compass and odometer. Experiment results indicated that this system is competent to perform the outdoor task owing to using proposed structure and control strategy. Especially, with the introduction of teaching playback capability, the system not only alleviates the tension in the tele-operation for the operator, but also exerts its particular function in some situations such as when the front sight is limited.



(a)



(b)

Fig.10 Curves obtained by the proposed method

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