FAULT DIAGNOSIS AND FAULT-TOLERANT CONTROL OF A JOYSTICK CONTROLLED WHEELCHAIR

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Abstract: This paper presents a method of fault diagnosis and fault-tolerant control for a joystick controlled wheelchair. The hard faults of sensors and actuators in two drive/steering units of the wheelchair are handled. A fault diagnosis of the sensors and actuators is achieved based on the interacting multiple-model (IMM) estimator. To make better fault decision, mode probability averaging and heuristic decision-making rule are incorporated into the IMM based algorithm. A fault-tolerant control system, which allows a safe motion of the non-holonomic wheelchair even though the drive and steering units have partially failed, is designed based on the Ackerman geometry. Experimental results validate the proposed method.

Keywords: Mobile robots, Vehicles, Sensor failures, Actuators, Fault diagnosis, Fault-tolerant systems, Kalman filters, Estimators, Models

1. INTRODUCTION

In mobile robotics and vehicle automation the demand of fault diagnosis of sensors, actuators, or system components is significantly growing for assuring system reliability and safety. Techniques of the fault diagnosis are broadly classified into the two approaches (Chen, *et al*., 1999): model based approach (e.g., Kalman filter and observer based approach) and model-free based approach (e.g., soft computing based approach). Now we focus on the model-based approach to the fault diagnosis.

Roumeliotis *et al*. (1998a,b) presented a multiple-model adaptive estimation (MMAE) based fault diagnosis of internal sensors of mobile robot. The MMAE algorithm is one of non-interacting multiple-model algorithms. It does not thereby fit well under situations where the system failures do occur suddenly. To make the MMAE algorithm fit better into such situations, various ad hoc techniques have been investigated. To cope with the weakness of the MMAE method we applied the interacting multiple-model (IMM) estimator for fault diagnosis of internal sensors (Hashimoto, *et al*., 2001, 2003).

Soika (1997) addressed a fault diagnosis of external sensors as well as internal sensors of mobile robot. In the model-based algorithm of the fault diagnosis the state equations are based on simple kinematical models. These would be sufficient for the fault diagnosis of mobile robot navigating at low speed. A dynamical model is implemented to provide the correct fault diagnosis for mobile robot moving at high speed (Dixon, *et al*., 2001). A fault-tolerant control is closely related with the fault diagnosis, and fault-tolerant control methods and techniques have been proposed in robotics society (Prasad, *et al*., 1990, Tinos, *et al*., 2002, Zhang, *et al*., 2003).

In this paper we present an IMM based fault diagnosis for a non-holonimic wheelchair controlled with a joystick, where the faults of both internal sensors and actuators are handled. This is extension of our IMM based sensor fault diagnosis (Hashimoto, *et al*., 2001, 2003). Moreover we design a fault-tolerant controller that allows controlling the wheelchair with the joystick even though the sensors and actuators have partially failed. This paper is organized as follows: in Section 2 our experimental wheelchair is overviewed. In Sections 3 and 4 fault diagnosis and fault-tolerant control systems, respectively, are designed. In Section 5 experiments are conducted to validate the proposed systems, followed by conclusions.

2. EXPERIMENTAL WHEELCHAIR

Figure 1 shows a wheelchair controlled with a joystick used in our research. It has two active wheels in its front and at rear, each of which consists of a steering unit and a drive unit. As illustrated in this figure, a potentiometer is attached at the steering unit to sense the steering angle, and an encoder is attached at the drive unit to measure the wheel velocity. Four passive casters are set at the four corners of the wheelchair in order to sustain the weight of the wheelchair and the human operator.

Figure 2 shows notions related to the motion of the wheelchair, and Figure 3 shows the architecture of the motion control system, which consists of a chassis-level controller, drive-unit controllers and steering-unit controllers. The human operator commands the desired linear and turning velocities, V^* and $\dot{\theta}^*$, of the wheelchair to the chassis-level controller with the joystick. The chassis-level controller generates the target velocities, v_f^* and v_r^*, and the target steering angles, γ_f^* and γ_r^*, by the inverse kinematics based on the Ackerman geometry of the wheelchair. The drive- and steering-unit controllers control their own units to ensure the desired motion of the wheelchair. Determining the target commands (velocities and steering angles) is detailed in Section 4.

We use the steering and drive units, commercially available. Figure 4 shows the configuration of their units; the PD and P controllers in the drive and steering units, respectively, deteriorated the control performance. To improve the control performance we embed PI controller into the original drive- and steering-unit controllers.

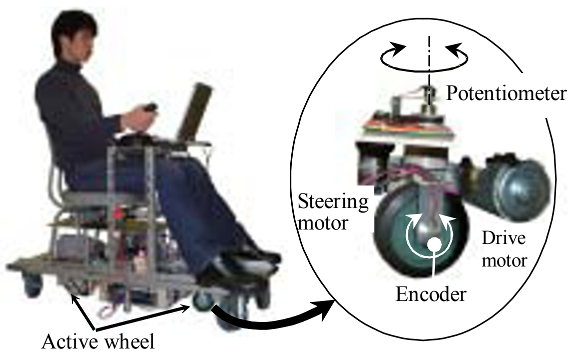

Fig. 1. Experimental wheelchair

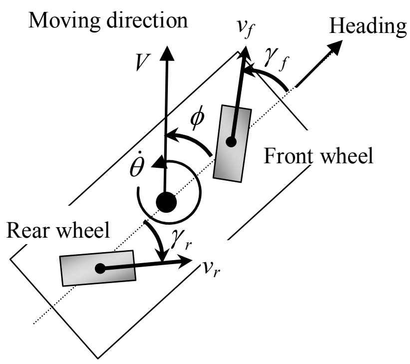

Fig. 2. Notation related to the wheelchair

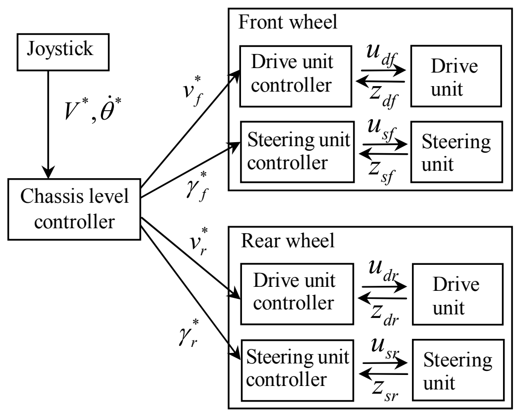

Fig. 3. Architecture of motion control

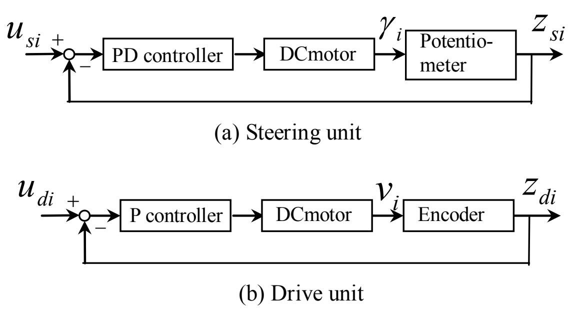

Fig. 4. Configuration of steering and drive units; the subscript *i* means *f* and *r*.