바퀴형 이동로봇에 대한 고장검출 알고리즘 개발
Fault Detection in Wheeled Mobile Robots

*황녹백 [1], #강희준 [2], 서영수 [2], 노영식 [2]
*Ngoc Bach. Hoang[1], #Hee-Jun. Kang[2] (hjkang@ulsan.ac.kr), Young-Soo Suh[2], Young-Shick Ro[2]
[1] 울산대학교 전기공학부대학원, [2] 울산대학교 전기공학부

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1. Introduction

In recent years, wheeled mobile robots are widely used in industries such as manufacturing, medical, healthcare industries. Because most of them are designed to act autonomously, any fault can cause serious damages not only for robot system but also for working environments. Especially, when mobile robots become common household items, human being can be injured because of robot faults. Hence, to increase the safety and reliability of mobile robots, fault detection is needed to be considered.

2. Modeling of Mobile robot

The following notation is used in this paper: I_c: Moment of inertia of the mobile platform about P_c; I_m: Moment of inertia of wheel about its diameter; I_w: Moment of inertia of wheel about its rotation axle; m_c: Mass of the mobile platform without wheels; m_w: Mass of each wheel; O-xy: The world coordinates system; P-XY: The coordinate system fixed to mobile platform; P_c: Center of mass of WMR without wheels; d : Distance from P to P_c; b: Distance from each wheel to P; r_R: Radius of right wheel; r_L : Radius of left wheel;

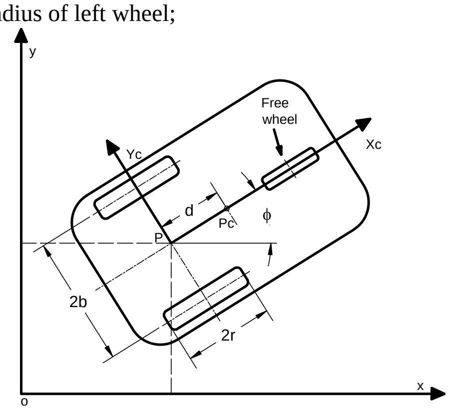

Fig. 1. Mobile Robot

The configuration of the WMR can be described by five generalized coordinates:

$q_0 = [x, y, \phi, \theta_r, \theta_l]^T$ where $X = [x, y, \phi]^T$ are the Cartesian coordinate of P and the robot's orientation with reference to O-xy frame. $q = [\theta_r, \theta_l]^T$ are the angular displacements of right and left wheels.

The motion model including kinematics and dynamics of mobile robot [5]:

$$\dot{q}_0 = S(q_0)\dot{q}$$

$$M_0(q_0)\ddot{q}_0 + V_0(q_0, \dot{q}_0)\dot{q}_0 + F_0(\dot{q}_0) + \tau_0^d = B\tau - A^T(q_0)\lambda$$

where $\dot{q} = [\dot{q}_1, \dot{q}_2]^T = [\dot{\theta}_1, \dot{\theta}_2]^T$ are the angular velocities of two wheels. $M_0(q_0)$ is the symmetric positive definite inertia matrix, $V_0(q_0, \dot{q}_0)$ is the centripetal and Coriolis matrix, $F_0(\dot{q}_0)$ is the vector of friction force, τ_0^d is a unknown disturbances including uncertainty in dynamics, B is the input transformation matrix, τ is the torque input vector, and $A^T(q_0)$ is the vector of constraint forces.

$$S(q_0) = \begin{bmatrix} \frac{r_R}{2}\cos\phi & \frac{r_L}{2}\cos\phi \\ \frac{r_R}{2}\sin\phi & \frac{r_L}{2}\sin\phi \\ \frac{r_R}{2b} & -\frac{r_R}{2b} \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$$

By eliminating the constraint matrix, we get the resulting dynamic model:

$$M(q)\ddot{q} + V(\dot{q})\dot{q} + F(\dot{q}) + \tau_d = \tau$$

where

$$M = \begin{bmatrix} I_w + (mb^2 + I)\frac{r_R^2}{4b^2} & (mb^2 - I)\frac{r_R r_L}{4b^2} \\ (mb^2 - I)\frac{r_R r_L}{4b^2} & I_w + (mb^2 + I)\frac{r_R^2}{4b^2} \end{bmatrix}$$

$$V(\dot{q}) = \begin{bmatrix} \frac{m_c d r_R r_L}{4b^2}(r_R \dot{q}_1 \dot{q}_2 - r_L \dot{q}_2^2) \\ \frac{m_c d r_R r_L}{4b^2}(r_L \dot{q}_1 \dot{q}_2 - r_R \dot{q}_1^2) \end{bmatrix}$$

$$F(\dot{q}) = S^T(q_0)F_0(\dot{q}_0), I = (I_c + m_c d^2) + 2(I_w + m_w b^2)$$

$$m = m_c + 2m_w$$

3. Fault detection scheme

In the presence of fault, the WMR dynamic model can be represented as:

$$\ddot{q} = M(q)^{-1}(\tau - V(\dot{q})\dot{q} - F(\dot{q}) - \tau_d) + \beta(t-T)\psi(q,\dot{q},\tau)$$

The fault function is represented by the term $\beta(t-T)\psi(q,\dot{q},\tau)$, where $\psi(q,\dot{q},\tau)$ is a vector which represents the fault in WMR, $\beta(t-T)$ represents the time profile of the fault, and T is the time of occurrence of the fault.

The modeling uncertainty is bounded: $M(q)^{-1}(F(\dot{q}) + \tau_d) \le \eta$ where η a known constant.

Let $x = \dot{q}(t)^T$. The dynamic model can be rewritten as

$$\dot{x} = M(q)^{-1}(\tau - V(\dot{q})\dot{q} - F(\dot{q}) - \tau_d) + \beta(t-T)\psi(q,\dot{q},\tau)$$

The estimated model is considered:

$$\dot{\hat{x}} = M(q)^{-1}(\tau - V(\dot{q})\dot{q}) + A(\hat{x} - x)$$

The error dynamic equation:

$$\dot{e} = A(\hat{x} - x) - M(q)^{-1}(F(\dot{q}) - \tau_d) + \beta(t-T)\psi(q,\dot{q},\tau)$$

where $e = \hat{x} - x$ is the error dynamics.

Since, the fault output is zero when $t < T$, thus we intend to derive an upper bound for $\|e\|$ during the time interval (0, T). We have the residual e given by

$$e = \exp(At)e(0) + \int_0^t \exp(A(t-\tau))M(q)^{-1}(F(\dot{q}) - \tau_d)d\tau$$

Therefore, the threshold bound can be chosen as

$$\|e\| \le \exp(At)|e(T_d)| + \int_0^t \exp(A(t-\tau))\|M(q)^{-1}\|\eta d\tau$$

Fault detection scheme: The decision on the occurrence of fault is made when at least one of the residual e exceeds its corresponding threshold bound e_M.

4. Simulation results

The WMR parameters are used for our simulation: I_c = 0.85(Kgm^2); I_m = 0.0061(Kgm^2); I_w = 0.012(Kgm^2); m_c = 29(Kg); m_w = 3.54(Kg); d = 0.053(m); b = 0.149(m); r_R = 0.08(m); r_L =0.08(m).

The exact values of $F(\dot{q})$ are unknown. However, they are assumed to be bounded by:

$$|F(\dot{q}) + \tau_d| \le 0.05$$

We consider a fault which occurs at T = 10s and results 2kg loss in mass of platform. Fig.2. shows the fault is successfully detected at T_d = 10. 1s.

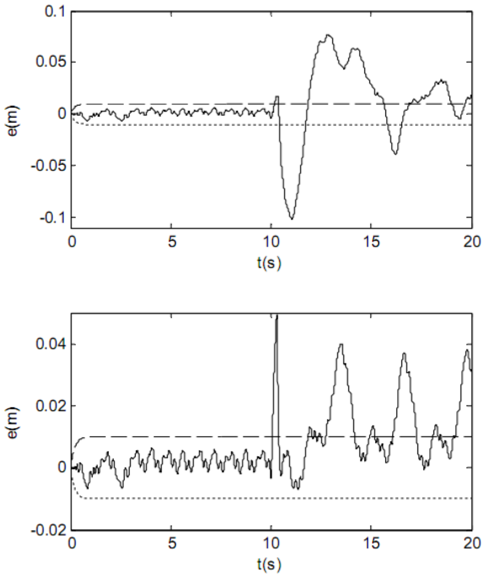

Fig. 2. Fault detection(Threshold-dotted line and dashed line, residual-solid line)

Conclusion

This paper presents a fault detection scheme for wheeled mobile robot. A nonlinear observer is de signed based on the mobile robot dynamic model. The fault is detected when at least one of the r esiduals exceeds its corresponding threshold.

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