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Mechanical analysis of mass drifts due to accelerations and decelerations of mobile platforms

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Abstract - In the mobile platforms such as legged platforms and wheeled platforms, there is a mass drift due to the acceleration and deceleration. This mass drift induces a rotating pitch angle based on an axis of mass center. In the mobile platforms, if the front or rear driving axis such as wheels and legs axis does not contact with the terrain, then the driving power does not contribute to get the traction forces with the low efficiency. Further, if the mass drifts and induced pitch angles are bigger than a certain threshold value, then there is the pitch-over phenomenon with the mechanical damages to mobile platforms. In order to reduce the mass drifts of mobile platform, in this paper, we describe mechanical analysis of mass drifts due to the acceleration and deceleration of mobile platforms. Firstly, we describe the analysis of mass drift amounts due to acceleration and deceleration. Then, we propose the design guides of mobile platform for reducing the mass drift amounts.

Keywords - Mobile Platform, Mass Drift, Pitch Angle, Pitch-over

1. Introduction

In the mobile system such as vehicles and mobile robots [1-9], there is a mass drift due to acceleration and deceleration. This mass drift induces a rotating pitch angle based on an axis of mass center. If there is pitch angles based on an axis of mass center, then the front wheel or leg axis on the acceleration and the rear wheel or leg axis on the deceleration can't contact with the terrain except the tracked platforms [10]. This states induces the loss of traction forces. Further, this pitch angle is bigger than a certain threshold value, then the mobile system has a pitch-over phenomenon with the physical damages of mobile platforms.

In general wheel base platforms like vehicles, the geometric ratio H/L between heights H from terrain to mass center and lengths L from front axis to rear axis is designed to get small values. Then there is a few mass drift. Further the vehicle has the additional suspension systems. Therefore the vehicles has a few pitch angle on the even high acceleration driving and high deceleration braking conditions.

However most mobile platforms except vehicles, it is difficult to dispose the suspension system. Therefore it is important for most mobile platforms to consider mass drifts amounts and the induced pitch amounts from design steps.

In this paper, we describe the analytical approach of mass drift amounts and the mechanism for reducing pitch angles due to acceleration and deceleration of mobile platforms without suspension systems.

2. Analysis of mass drift amounts

Figure 1 shows the schematic diagram of the simplified wheeled mobile platform (left) and legged mobile platform (right). The length H means the distance between the mass center of platform and the terrain. The length L means the distance between the front wheel or leg axis and the rear wheel or leg axis. Figure 2 shows the free body diagram of the simplified wheeled mobile platform. Here, A and B mean the contact point with terrains. Through the static analysis with the force equilibrium condition and the moment equilibrium condition based on point A, the equation 1 is induced.

Here, we assume that the mass center is disposed right in the middle between the point A and the point B. Through the equilibrium condition of force and the equilibrium condition of moment on point A, the equation 1 is induced.

$$R_{A\_S} = R_{B\_S} = \frac{mg}{2} \quad (1)$$

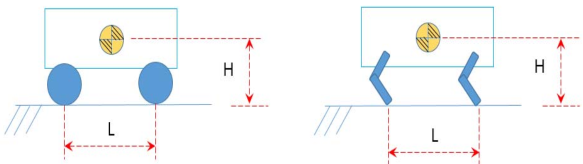

Fig. 1 Schematic diagram of the simplified wheeled mobile platform (left) and legged mobile platform (right).

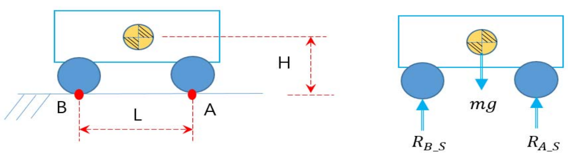

Fig. 2 Free body diagram of the simplified wheeled mobile platform on static conditions.

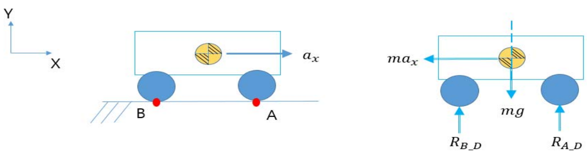

Fig. 3 Free body diagram of the simplified wheeled mobile platform on acceleration conditions.

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Here, R_{A_S} means the static reaction force on point A.

Figure 3 shows the free-body diagram of mobile platform when the kinematic acceleration exists along x direction. Here, ma_x means reaction force, so to speak inertial forces according to the existence of acceleration a_x.

On this quasi-static condition, through the equilibrium condition of moment on point A and B, the equation 2 and equation 3 are induced.

$$R_{B\_D} = \frac{mg}{2} + ma_x \times \frac{H}{L} \tag{2}$$

$$R_{A\_D} = \frac{mg}{2} - ma_x \times \frac{H}{L} \tag{3}$$

R_{A_D} means the dynamic reaction force on point A when the kinematic acceleration exists along x direction.

Figure 4 shows the imaginary free body diagram for the extraction of mass drift amounts. Through the equilibrium condition of moment based on point A and the equation 2, the equation 4 is induced.

$$\Delta x = \frac{R_{B\_D} \times L}{mg} - \frac{L}{2} = \frac{a_x}{g} H \tag{4}$$

As a result, the mass drift amount Δx is proportional to acceleration a_x and the height H of distance from the terrain to mass center. So to speak, if the mobile platform has the kinematic acceleration or deceleration, then the mass drift Δx exists.

Further, if the mass drift Δx is bigger than the 2/L, then the mobile platform has the pitch-over phenomenon. So to speak, shown in figure 4, the physical limit is red dot line for the prevention of pitch-over. The equation 5 shows the allowable acceleration with the determined H/L as a requirement.

$$a_x < \frac{g}{2} \times \frac{L}{H} = (a_x)_{Allowable\_LIMIT} \tag{5}$$

As a result, if it is necessary for the mobile platform to have more acceleration a_x, then it is proper that the horizontal length L of distances between the front wheel and the rear wheel is bigger, and the vertical length H of distances between the mass center and the terrain is smaller.

On the other hands, if the acceleration a_x is determined as a requirement, then the design factor of H/L had to be considered like the equation 6.

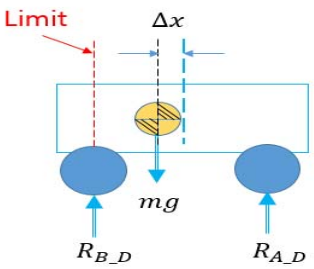

Fig. 4 Imaginary free body diagram for the extraction of mass drift amounts.

$$\frac{H}{L} < \frac{g}{2a_x} = (\frac{H}{L})_{Allowable\_LIMIT} \tag{6}$$

In the common vehicles, it is designed that the vehicle does not have the pitch-over phenomenon. So to speak, based on the given acceleration ability of the engines, the vehicle is designed to have the proper ratio of H/L. Further the vehicles have the suspension system composed of springs and dampers. However, it is difficult for the common robots to have suspension system due to constraints of space.

3. Methods for reducing mass drifts

As afore-mentioned, in order to prevent the pitch-over and to reduce loss of tractions, it is important to design H/L ratio. At a given H/L ratio, we can get the limitation of acceleration and deceleration shown in equation 5. Otherwise, at a given acceleration and deceleration ability, we can get design guides of H/L shown in equation 6.

There are other approaches for reducing the mass drift amounts those are the design of pitch inertia and the additional mechanism for reducing the mass drift amounts.

The relation of the pitch inertia J_{pitch}, rotational acceleration of pitch angles, torques along pitch axis T_{pitch} and mass drift amounts Δx due to acceleration and deceleration is shown in the equation 7.

$$J_{pitch}\ddot{\theta}_{pitch} = T_{pitch} = mg\Delta x \tag{7}$$

The equation 8 shows the pitch inertia J_{pitch}.

$$J_{pitch} = \int^{2} dm \tag{8}$$

This pitch inertia means the mass distribution based on mass center along pitch directions. If the pitch inertia is bigger, then the pitch angle is lower at same mass drifts. Therefore, it is necessary for the pitch inertias to get bigger amounts in order to get smaller pitch angles, on design steps. So to speak, it is proper for most masses to dispose far away from the position of mass center. Figure 5 shows the proper platform body to get larger pitch inertias.

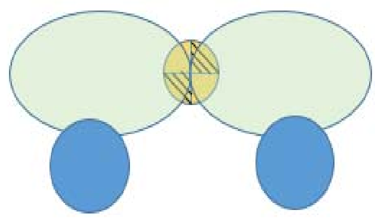

Fig. 5 Proper body shapes for reducing the pitch angles.

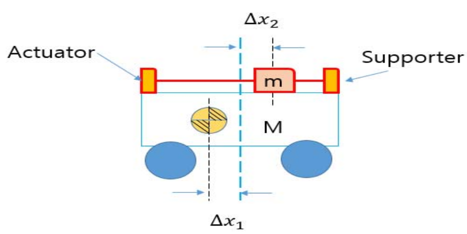

Fig. 6 Pitch balancing devices (bold red lines).

This shape is possible for not vehicle that the humans are getting in the front and rear seats, but the unmanned mobile platforms. But this shape can have bigger the air drags on the high speed driving conditions.

Therefore, if the mobile platform needs high speed driving with conventional body shapes, it is proper to add the additional pitch balancing devices. Figure 6 shows the concept of this devices.

The compensational mass m is disposed above the conventional body with the left actuator and right supporter. Equation 9 shows the command position of the compensational mass for reducing induced pitch angles due to accelerations and decelerations.

$$\Delta x_2 = \frac{M}{m}\Delta x_1 = \frac{M}{m} \times \frac{a_x H}{g} \tag{9}$$

4. Conclusion

In this paper, we describe the analytical approach of mass drift amounts. Equation 4 shows this mass drift amount on accelerations or decelerations. Further, we describe the design guides of H/L ratio at the predefined acceleration ability shown in equation 6. Then, we describe the allowable acceleration without pitch-over phenomenon at the predefined of H/L ratio shown in equation 5. Finally, we describe the proper body shape and the concept of pitch balancing devices with the extraction of command position signals for reducing pitch angles shown in equation 9. As a further works, we plan to investigate the additional roll motion due to the lateral accelerations and decelerations with 3D model.

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