Motorcycle Dynamics and Control of the MOTOROiD That Stands Upright Even When Stopped

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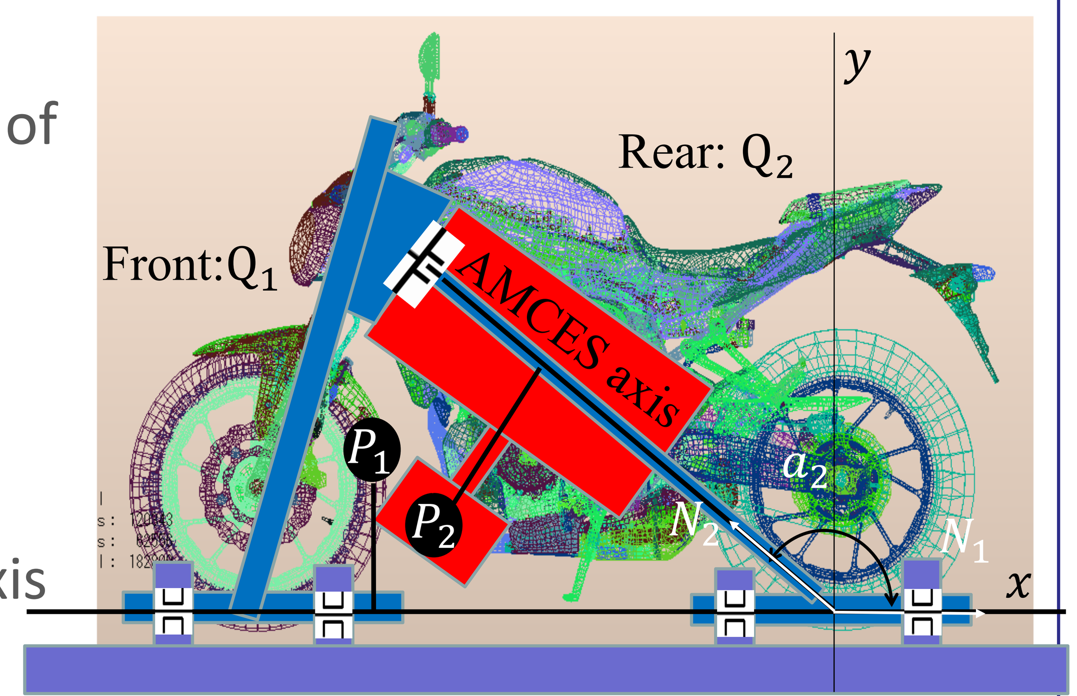
Introduction

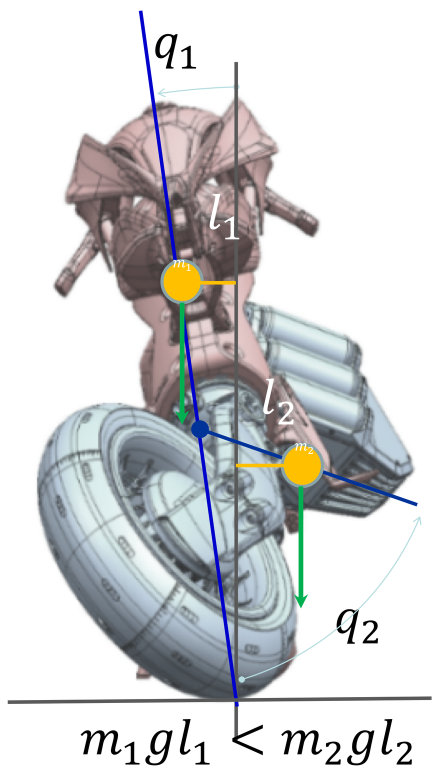
In this report, we developed motorcycle "MOTOROiD" that can sense its own state, stand up off its kickstand and remain upright unassisted by applying the invert pendulum principle.

Simplification of motorcycle

The MOTOROiD body has a rotating axis that is capable of shifting the position of the center of gravity of the motorcycle as a whole. The mechanism is called the Active Mass Center Control System (AMCES), and the axis is referred to as the AMCES axis.



The front body (blue: Q_1) and the rear body(red: Q_2) are rotated using the actuators (white) at the ends of the AMCES axis. This structure acts as an inverted double pendulum, with the portion linking Q_1 and Q_2 dubbed Acrobot due to the placement of the actuators. The Q_1 roll angle is defined as q_1, and the Q_2 rotation angle as q_2.



Equation of motion

A Lagrangian function was used to define a state equation from the vehicle specifications and calculate the Q_1 and Q_2 center of gravity position and mass, as well as the actuator torque and rotation speed, that would enable standing up off the kickstand.

$$\begin{cases} \dfrac{d}{dt}\left(\dfrac{\partial L}{\partial \dot q_1}\right) - \dfrac{\partial L}{\partial q_1} + \dfrac{\partial D}{\partial \dot q_1} = 0 \\ \dfrac{d}{dt}\left(\dfrac{\partial L}{\partial \dot q_2}\right) - \dfrac{\partial L}{\partial q_2} + \dfrac{\partial D}{\partial \dot q_2} = u \end{cases}$$

T_i : Kinetic energy of Q_i

U_i : Potential energy of Q_i

D_i : Dissipated energy of Q_i

$L = \Sigma T_i - \Sigma U_i$

$D = \Sigma D_i$

u : Torque

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{Bmatrix} \ddot q_1 \\ \ddot q_2 \end{Bmatrix} = \begin{bmatrix} b_{11} & -c_1 & b_{13} & 0 & 0 \\ b_{21} & 0 & b_{23} & -c_2 & 1 \end{bmatrix} \begin{Bmatrix} q_1 \\ \dot q_1 \\ q_2 \\ \dot q_2 \\ u \end{Bmatrix}$$

$$a_{11} = i_{1xx} + i_{2xx} + m_1 p_{1y}{}^2 + m_2 p_{2y}{}^2$$
$$a_{12} = i_{2xx}\alpha - i_{2xy}\beta + m_2 p_{2y}(p_{2y}\alpha - p_{2x}\beta)$$
$$a_{21} = a_{12}$$
$$a_{22} = i_{2xx}\alpha^2 - 2 i_{2xy}\alpha\beta + i_{2xx}\alpha^2 + m_2(p_{2y}\alpha - p_{2x}\beta)^2$$
$$b_{11} = m_1 g p_{1y} + m_2 g p_{2y}$$
$$b_{13} = m_2 g(p_{2y}\alpha - p_{2x}\beta)$$
$$b_{21} = b_{13}$$
$$b_{23} = m_2 g(p_{2y}\alpha - p_{2x}\beta)\alpha$$
$$\alpha = \cos(a_2),\ \ \beta = \sin(a_2)$$

Experimental identification and control

① Manufacture experimental motorcycle

② PD control(K) for motorcycle stabilization

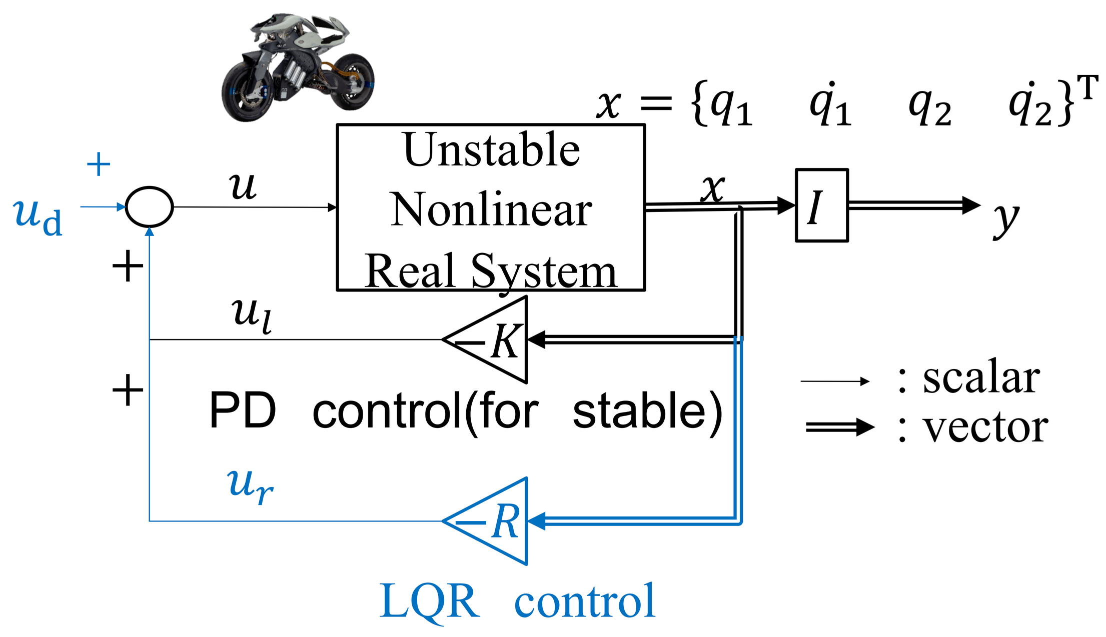
③ Measure state quantity(x) and torque(u_d) by applying torque disturbance

④ Identify state equations using MATLAB arx

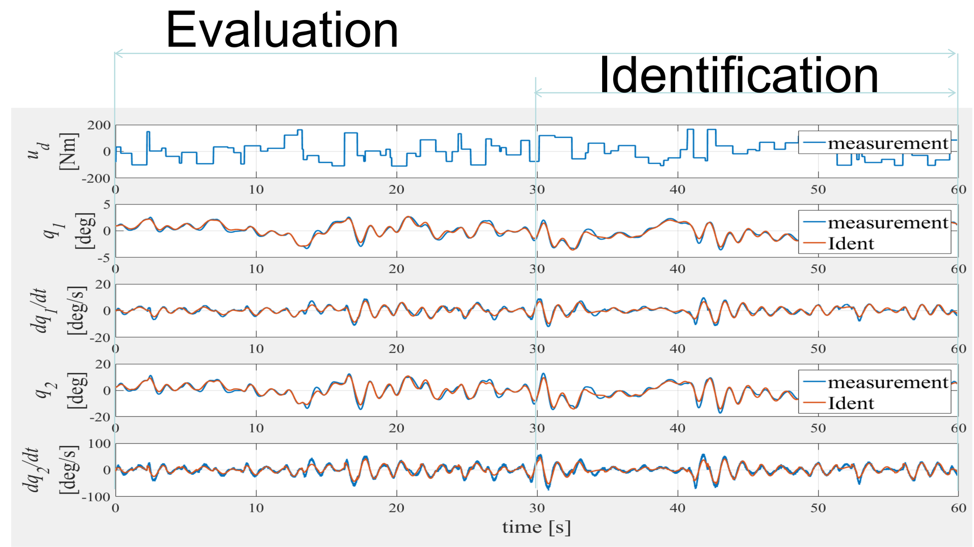
⑤ linear secondary regulator(lqr) design was applied weight only to q_1 and its speed $\dot q_1$

⑥ Confirm performance with simulation and apply to motorcycle

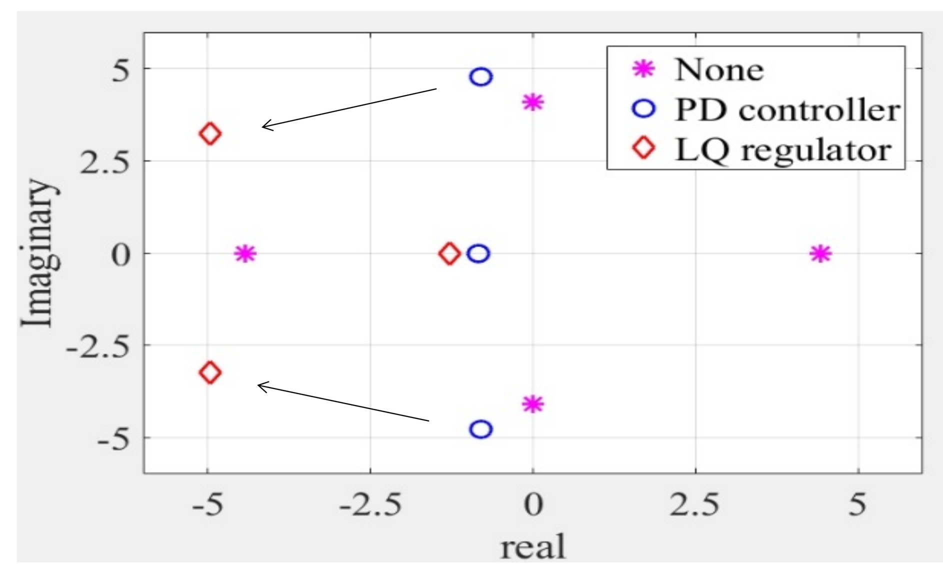
MOTOROiD block diagram



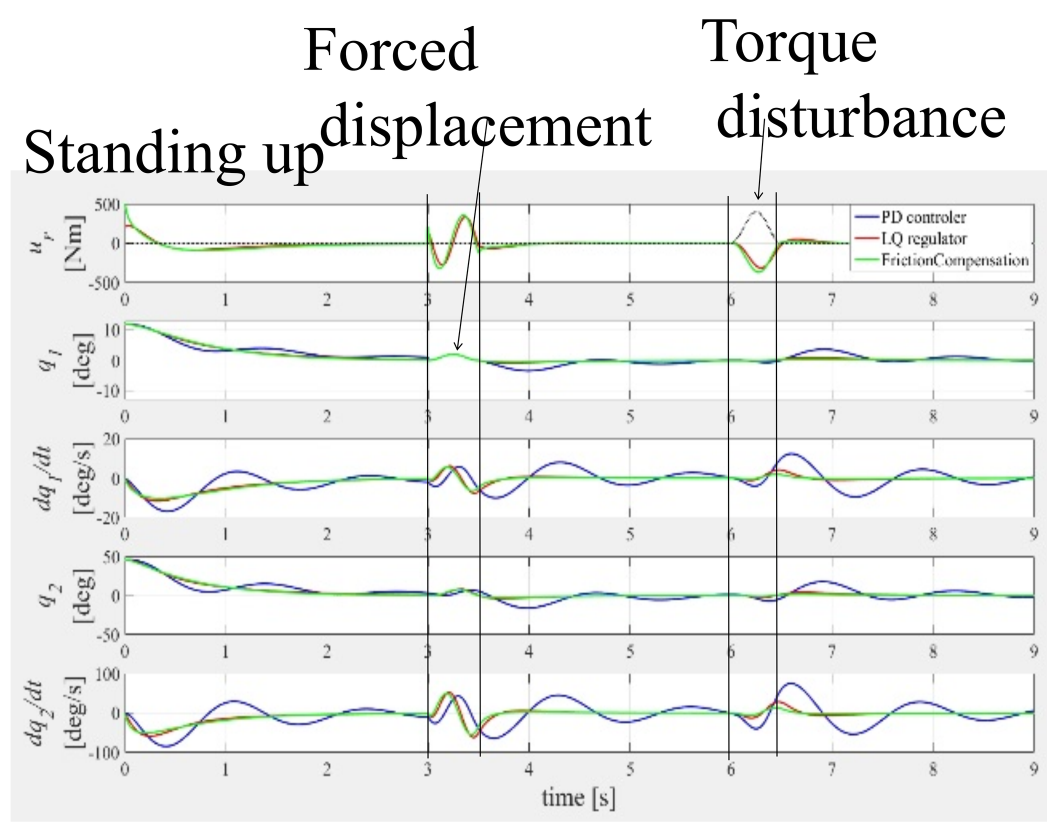
Experimental identification



Eigenvalue



3patterns simulation



Summary

- ✓ **The MOTOROiD body has a rotating axis that is capable of shifting the position of the center of gravity of the motorcycle.**
- ✓ **Experimental identification of motorcycle with stabilized feedback and refined state equation.**
- ✓ **To enhance vehicle stability, a linear secondary regulator(lqr) design was applied weight only to q_1 and its speed ($\dot q_1$).**

Bicycle and Motorcycle Dynamics 2019
Symposium on the Dynamics and Control of Single Track Vehicles,
9 – 11 September 2019, University of Padova, Italy