3.6 'Sensor-less Collision Detection and Isolation' (MC-P-01)

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Abstract

Safety is becoming an important issue as the next generation of robots will be working closely with the humans possibly without any physical safety cages. To increase the safety, the robot must be able to detect and react to collisions possibly using only the robot's internal sensors (e.g. joint position and joint velocity). This poster presents the theory of sensor-less collision detection and isolation using residual energy and residual momentum approaches from the literature and its implementation on the COMPI robot platform. The implementation does not require any torque sensing or external sensors and hence, it is sensor-less. Additionally, a roadmap to safer physical human robot interaction is presented in the form a collision event pipeline which uses these two approaches to identify, classify and react towards different collisions. In the future work, the collision event pipeline will be implemented and extended.

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Sensorless Collision Detection & Isolation

Towards safer physical Human Robot Interaction (pHRI) - Shivesh Kumar

Motivation

Industrial robotics research is gradually shifting its focus from robots that can *replace* humans to robots that can *work with* humans because this can augment the abilities of human workers and increase overall productivity. Thus, safety becomes a key issue in next generation of robots.

To increase the safety, the robot must be able to detect and react to collisions possibly using only the robot’s internal sensors (e.g. joint position and joint velocity).

Theory of Sensorless Collision Detection and Isolation (CDI)

If $\boldsymbol{F}_c$ is the external force acting during a collision at point ($\boldsymbol{q}_c$), the dynamics of the overall system becomes:

$$\boldsymbol{M}(\boldsymbol{q})\ddot{\boldsymbol{q}} + \boldsymbol{C}(\boldsymbol{q},\dot{\boldsymbol{q}})\dot{\boldsymbol{q}} + \boldsymbol{G}(\boldsymbol{q}) + \boldsymbol{\tau}_f = \boldsymbol{\tau}_m + \boldsymbol{\tau}_c = \boldsymbol{\tau}_m + \boldsymbol{J}^T(\boldsymbol{q}_c)\boldsymbol{F}_c$$

Sensor-less Collision Detection deals with detection of collision with the robot without the use of any external sensors. The collisions can be detected by observing a disturbance in total energy of the robot $E(t)$.[De Luca et al, 2006]

$$\sigma(t) = K_\sigma\left[E(t) - \int_0^t \left(\dot{\boldsymbol{q}}^T(\boldsymbol{\tau}_m - \boldsymbol{\tau}_f) + \sigma(t)\right)dt - E(0)\right]$$

Commanded Total Power

This leads to a first order stable linear filter driven by work performed by the joint torques due to collision:

$$\dot{\sigma} = -K_\sigma \sigma + K_\sigma \dot{\boldsymbol{q}}^T \boldsymbol{\tau}_c$$

Collision Isolation deals with identification of contact link where the collision occurs. Collision can be isolated using momentum $\boldsymbol{p}(t)$ based residual disturbance observer.[De Luca et al, 2006]

$$\boldsymbol{r}(t) = \boldsymbol{K}_r\left[\boldsymbol{p}(t) - \int_0^t \left((\boldsymbol{\tau}_m - \boldsymbol{\tau}_f) + \boldsymbol{C}^T(\boldsymbol{q},\dot{\boldsymbol{q}})\dot{\boldsymbol{q}} - \boldsymbol{G}(\boldsymbol{q}) + \boldsymbol{r}\right)dt - \boldsymbol{p}(0)\right]$$

Commanded Torque

This also leads to a first order linear filter driven by external torques:

$$\dot{r} = -K_r r + K_r \boldsymbol{\tau}_c$$

When there is a collision with i^{th} link, r will take the form:

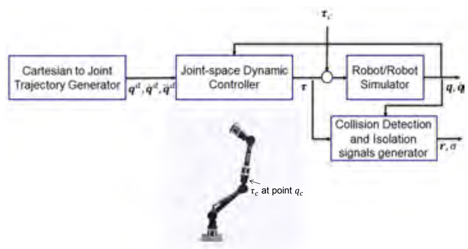
$$\boldsymbol{r} = [r_1 \quad r_2 \quad \cdots \quad r_i \quad 0 \quad 0]$$

Remarks:

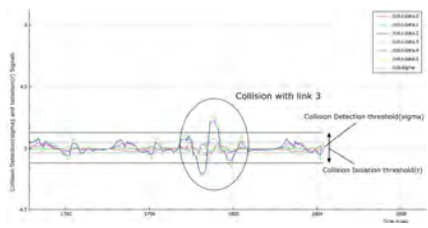
- $\boldsymbol{r}(t)$ and $\sigma(t)$ are ideally zero during the free motion of the robot and become non-zero as soon as there is a collision. In reality, a collision is detected and isolated using threshold values which depends on the noise characteristics of the system.
- $\sigma(t)$ is insensitive to collisions when robot is at rest ($\dot{\boldsymbol{q}} = \boldsymbol{0}$) or when Cartesian velocity at the contact point is perpendicular to the collision force ($\boldsymbol{V}_c \perp \boldsymbol{F}_c$).
- Theoretically, for infinite observer gains($\boldsymbol{K}_r \longrightarrow \infty$), $r_i \cong \tau_{c,i}$. Practically, observer gains must be chosen as high as possible keeping in mind the noise characteristics of the system.

Results and Discussions

- Development of RoCK software library named CDI
- Inputs for CDI library: Dynamic model, Robot joint position ($\boldsymbol{q}$) and velocity ($\dot{\boldsymbol{q}}$), Commanded Torque.
- Output: Collision Detection(σ) and Isolation ($\boldsymbol{r}$) signals
- No torque sensing at joints or external sensors are needed to detect collisions – Sensorless.



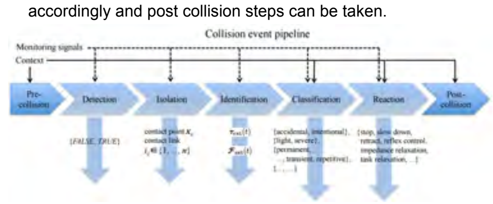
Implementation of CDI library and tests on COMPI robot



Collision Detection and Isolation signals – collision with link 3

Future work

- Residual momentum signal can be used to calculate external torque/forces and hence perform collision identification.
- Intention of the collisions can be classified based on the magnitude and frequency response of external torque.
- Several reactive strategies for the robot can be defined accordingly and post collision steps can be taken.



Collision Event Pipeline (Prof. De Luca, ICRA Keynote 2015)

References

A. D. Luca, A. Albu-Schaffer, S. Haddadin and G. Hirzinger, "Collision Detection and Safe Reaction with the DLR-III Lightweight Manipulator Arm," *Intelligent Robots and Systems, 2006 IEEE/RSJ International Conference on*, Beijing, 2006, pp. 1623-1630

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