Human-Robot team Attitude Synchronization

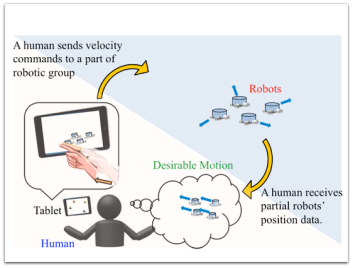
Junya Yamauchi
Fujita Laboratory

2nd December, 2013

Human-Robot team Control

Computer, Robot
Data processing
Flexibility

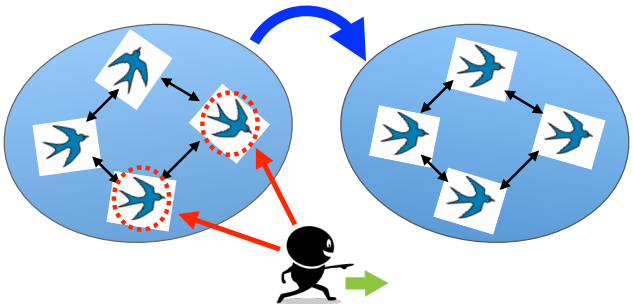
Human
Flexibility
Data processing



Human-Robot team

Human-Robot team Attitude Synchronization

Attitude synchronization



Attitude Synchronization

ith rigid-body motion

$$\dot{g}_i = g_i \hat{V}_i^b \qquad i = \{1, \cdots, n\}$$

$$g_i = (p_i,\ e^{\hat{\xi}\theta_i}) \in SE(3)$$

$$V_i^b = [v_i^T \omega_i^T]^T$$

Orientation

$$\dot{e}^{\hat{\xi}\theta_i} = e^{\hat{\xi}\theta_i}\hat{\omega}_i$$

ω_i : angular velocity

Goal

$$\lim_{t\to\infty}\{e^{-\hat{\xi}\theta_i}e^{\hat{\xi}\theta_r}\} = 0 \quad \forall i$$

$e^{\hat{\xi}\theta_r}$: desired orientation in human brain

Control Input

$$\omega_i = k_i \left\{ \sum_{j\in N_i} \mathrm{sk}(e^{\hat{\xi}\theta_{ij}})^\vee + c_i\omega_o \right\}$$

k_i : feedback gain

$$e^{\hat{\xi}\theta_{ij}} = e^{-\hat{\xi}\theta_i}e^{\hat{\xi}\theta_j}$$

$$c_i = \begin{cases} 1 & \text{Operational} \\ 0 & \text{Not operational} \end{cases}$$

Control input for

cooperation in robotic network Human cannot operate all objects	synchronization with orientation in human brain ω_o Command from human

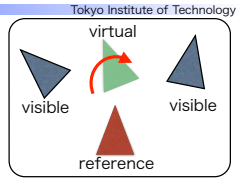
Input to Human

1. average of orientation error

$$\tau = -\frac{1}{m}\sum_{i\in I}\mathrm{sk}(e^{\hat{\xi}\theta_{ri}})^\vee$$

2. worst error

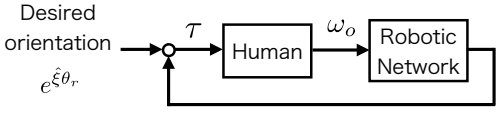
$$\tau = -\mathrm{sk}(e^{\hat{\xi}\theta_{rk}})^\vee$$



m : the number of operational body

$$I = \{i \mid c_i = 1, i = 1, \cdots, n\}$$

$$k = \arg\max_{i\in I} \|\mathrm{sk}(e^{\hat{\xi}\theta_{ri}})^\vee\|$$



Assumption : Human Passivity

Storage function

$$U = \frac{1}{m}\sum_{i=1}^{n}\phi(e^{\hat{\xi}\theta_{ir}}) \qquad \phi(e^{\hat{\xi}\theta_{ir}}) = \frac{1}{2}\mathrm{tr}(I - e^{\hat{\xi}\theta_{ir}})$$

time derivative

$$\dot{U} = \frac{1}{m}\sum_{i=1}^{n}\dot{\phi}(e^{\hat{\xi}\theta_{ir}}) = \frac{1}{m}\sum_{i=1}^{n}(\mathrm{sk}(e^{\hat{\xi}\theta_{ir}})^{\vee})^{T}\omega_{ir}$$

$\dot{U} + \dot{S} \leq 0$?

Human passivity ···assumption

$$\dot{S} \leq \tau^{T}\omega_{o}$$

Human Passivity

$$\dot{U} = \frac{1}{m}\sum_{i=1}^{n}\dot{\phi}(e^{\hat{\xi}\theta_{i}}) = \frac{1}{m}\sum_{i=1}^{n}(\mathrm{sk}(e^{\hat{\xi}\theta_{ir}})^{\vee})^{T}\omega_{i} \qquad \omega_{i} = k_{i}\left\{\sum_{j\in N_{i}}\mathrm{sk}(e^{\hat{\xi}\theta_{ij}})^{\vee} + c_{i}\omega_{o}\right\}$$

$$\dot{U} = \frac{1}{m}\sum_{i=1}^{n}\sum_{j\in N_{i}}k_{i}(\mathrm{sk}(e^{\hat{\xi}\theta_{i}})^{\vee})^{T}\mathrm{sk}(e^{\hat{\xi}\theta_{ij}})^{\vee} + \frac{1}{m}\sum_{i=1}^{n}c_{i}k_{i}(\mathrm{sk}(e^{\hat{\xi}\theta_{i}})^{\vee})^{T}\omega_{o}$$

$$= U_{A} + U_{o} \leq U_{o} \longleftarrow U_{A} \leq 0$$

$\dot{S} \leq \tau^{T}\omega_{o}$ Human passivity

average

$$\tau = -\frac{1}{m}\sum_{i\in I}\mathrm{sk}(e^{\hat{\xi}\theta_{i}})^{\vee}$$

New storage function

$$U_{all} = U + S$$

$$\dot{U}_{all} = \dot{U} + \dot{S} \leq 0$$

Interfaces for Human-Robot on 3-D

3D Mouse

- Intuitive operation
- Accuracy

Kinect

- Motion sensor
- Speech recognition

Entertainment!!

Future work

- Verification
- Application to SE(3)
- Representation as a stochastic process

- Simulation and experiment