Coverage Control and Experimental Setup

FL07-05-2

小林尚斗

Outline

- Distributed Control of Multi-agent System
- Coverage Control
  - Problem
  - Voronoi partitions
  - Continuous-time Lloyd Algorithm
  - Continuous-time Gradient Flow
- Experimental Setup
- Future Works

Distributed Control of Multi-agent System

Centralized Control

- one main computer control all agents

⇒
- easy algorithms
- large communication cost
- in big system, calculation by one computer is hard
- system doesn't work when the main computer goes wrong

Distributed Control

- each agent communicate only with its neighbors
- each agent move autonomously

⇒
- small amount of calculation for each agent
- system works even if some agents go wrong

Coverage Control

Distributed Control

- Consensus Problem
- Flocking Problem
  - Leader Following
- Formation Problem
- Coverage Problem

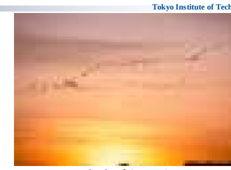


Fig. Flock of Snow Geese

Coverage Problem

: an optimal sensor placement problem

(← locational optimization problem)

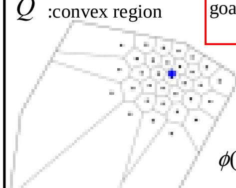
Fig. Territories of Tiapia mossambica

J.Cortes, S. Martinez, T. Karatas and F. Bullo "Coverage control for mobile sensing networks," IEEE Transactions on Robotics and Automation, 2004

Problem

Q :convex region

goal: plan robots(sensors)' motion in order to maximize the detection probability



$P=(p_1,\dots,p_n)$:location of n sensors

$W=\{W_1,\dots,W_n\}$:dominance region

i th sensor is responsible for measurements over its "dominance region": W_i

$\phi(q)$:density function

probability that some event take place

$f(\|q-p_i\|)$:how poor p_i sense q

(non-decreasing differentiable function)

$\|q-p_i\|=\text{big}\rightarrow$ $f=\text{big}\rightarrow$ poor sensing

$$H(\underline{P},\underline{W})=\sum_{i=1}^{n}\int_{W_i} f(\|q-p_i\|)\phi(q)dq$$:objective function

minimize the objective function with respect to P and W

Voronoi Partitions(1)

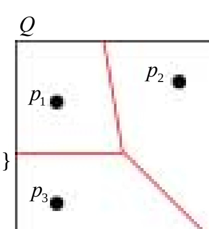
$$H(\underline{P},\underline{W})=\sum_{i=1}^{n}\int_{W_i} f(\|q-p_i\|)\phi(q)dq$$

fixed (P) consider the optimal partition W

⇓

$V(P)=\{V_i,\dots,V_n\}$:Voronoi partition

$$V_i=\{q\in Q \mid \|q-p_i\|\le\|q-p_j\|,\ \forall j\ne i\}$$



→ • minimize $f(\|q-p_i\|)$

(proof is on next page)

• $$\frac{\partial H_V}{\partial p_i}(P)=\frac{\partial H}{\partial p_i}(P,V(P))=\int_{V_i}\frac{\partial}{\partial p_i}f(\|q-p_i\|)\phi(q)dq$$

depends only on its own position and that of Voronoi neighbors

→ Distributed

Voronoi Partitions(2)

proof :

$H(P,V) \le H(P,W)$:means that Voronoi partition is optimal partition

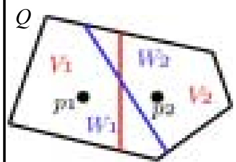
$$\sum_{i=1}^{n}\int_{V_i} f(\|q-p_i\|)\phi(q)dq \le \sum_{i=1}^{n}\int_{W_i} f(\|q-p_i\|)\phi(q)dq$$

$$\int_{V_1} f(\|q-p_1\|)\phi dq + \int_{V_2} f(\|q-p_2\|)\phi dq \le \int_{W_1} f(\|q-p_1\|)\phi dq + \int_{W_2} f(\|q-p_2\|)\phi dq$$

($Xw(q)=1$ if $q \in W$, $Xw(q)=0$ if not)

$$\int_{Q}\{f(\|q-p_1\|)\phi Xv_1 + f(\|q-p_2\|)\phi Xv_2\}dq \le \int_{Q}\{f(\|q-p_1\|)\phi Xw_1 + f(\|q-p_2\|)\phi Xw_2\}dq$$

$$f(\|q-p_1\|)\phi Xv_1 + f(\|q-p_2\|)\phi Xv_2 \le f(\|q-p_2\|)\phi Xw_1 + f(\|q-p_2\|)\phi Xw_2$$



Let $q \in V_1$, if $q \in W_1$

$$f(\|q-p_1\|)\phi Xv_1 = f(\|q-p_1\|)\phi Xw_1$$

if $q \in W_2$

$$f(\|q-p_1\|)\phi Xv_1 < f(\|q-p_2\|)\phi Xw_2$$

Likewise if $q \in V_2$

Centroidal Voronoi Partitions

Mass, Centroid and Polar Moment are defined as

$$M_V = \int_V \rho(q)dq \ , \ C_V = \frac{1}{M_V}\int_V q\rho(q)dq \ , \ J_{V,p} = \int_V \|q-p\|^2 \rho(q)dq$$

by parallel axis theorem

$$J_{V,p} = J_{V,C_V} + M_V\|p-C_V\|^2$$

$$H_V(P) = \sum_{i=1}^{n}\int_{V_i} f(\|q-p_i\|)\,\phi(q)dq$$

$$= \sum_{i=1}^{n}\int_{V_i} \|q-p_i\|^2 \rho(q)dq$$

$$= \sum_{i=1}^{n} J_{V_i,C_{V_i}} + \sum_{i=1}^{n} M_{V_i}\|p_i - C_{V_i}\|^2$$

suppose that
$f(\|q-p_i\|) = \|q-p_i\|^2$
$\phi(q) = \rho(q)$

$$\frac{\partial H_V}{\partial p_i}(P) = 2M_{V_i}(p_i - C_{V_i})$$

(*) $H(P,V) \overset{def}{=} H_V(P)$

crirical partitions and points for H: centroidal Voronoi partitions

Continuous-time Lloyd Algorithm(1)

goal : algorithm to compute the location of sensors that minimize H

kinematics of robots(sensors)

$$\dot{p}_i = u_i$$

$$H_V(P) = \sum_{i=1}^{n} J_{V_i,C_{V_i}} + \sum_{i=1}^{n} M_{V_i}\|p_i - C_{V_i}\|^2$$

$$\frac{\partial H_V}{\partial p_i}(P) = 2M_{V_i}(p_i - C_{V_i}) \quad \Rightarrow \quad u_i = -k_{prop}(p_i - C_{V_i}) \quad \text{(A)}$$

gradient descent flows

Proposition : For the closed-loop system induced by equation (A), the sensors location converges asymptotically to the set of critical points of H_V, i.e. , the set of centroidal Voronoi configurations on Q.

Continuous-time Lloyd Algorithm(2)

proof :

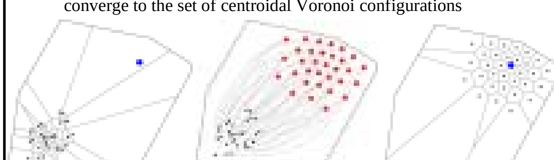
take H_V as candidate of lyapunov function

$$\frac{dH_V}{dt}(P(t)) = \sum_{i=1}^{n}\frac{\partial H_V}{\partial p_i}\dot{p}_i$$

$$= -2k_{prop}\sum_{i=1}^{n} M_{V_i}\|p_i - C_{V_i}\|^2 \le 0$$

by LaSalle's principle

converge to the set of centroidal Voronoi configurations



Continuous-time Gradient Flow

$$\frac{\partial H_V}{\partial p_i}(P) = \int_{V_i}\frac{\partial}{\partial p_i} f(\|q-p_i\|)\phi(q)dq$$

distributed

gradient flows are still implementable for arbitrary f

$$\dot{p}_i = u_i \ , \quad u_i = -\frac{\partial H_V}{\partial p_i}$$

converge to a critical point of H_V
(but not centroidal Voronoi congiguration)

Formation Control with Objective Function

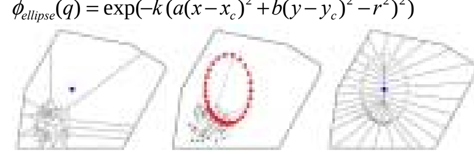
$$H(P,W) = \sum_{i=1}^{n}\int_{W_i} f(\|q-p_i\|)\phi(q)dq$$

design density function

minimize $H(P,W)$

formation control

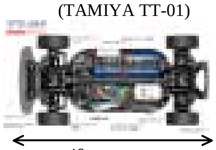
$$\phi_{ellipse}(q) \overset{def}{=} \exp(-k(a(x-x_c)^2 + b(y-y_c)^2 - r^2)^2)$$



Experimental Setup(1)

for
- Flocking, Leader Following
- Coverage Problem

3 car radicons
(TAMIYA TT-01)



3 mini car radicons
(KYOSHO mini z)

•too big for the experimental room
•weak against noises

- small
- slippy → carpet
- small capacity of battery → regulator

*www.tamiya.com
*www.kyosho.com

Experimental Setup(2)

Camera — color movie → PC

RC Cars

control signals
•stearing
•throttle

PC:
PicPort (image capture board)
↓ image
HALCON (image processing program)
↓ orientation, position, etc
Simulink (control model)
↓ implement
dSPACE (AD-DA, computing board)

voltage inputs

Remote Controlers(Propo)

Fig. experimental environment

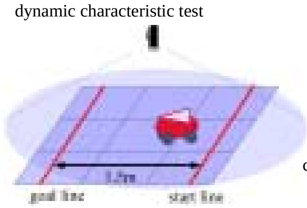
Experimental Setup(3)

before
monocrome movie
hard-coded velocity control

now
color movie (Camera)
velocity PID control (Simulink)
dynamic characteristic test(RC Cars)

Precise Experiment

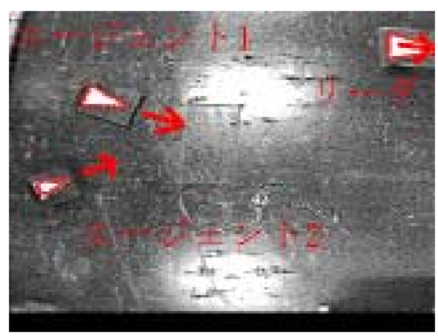
dynamic characteristic test



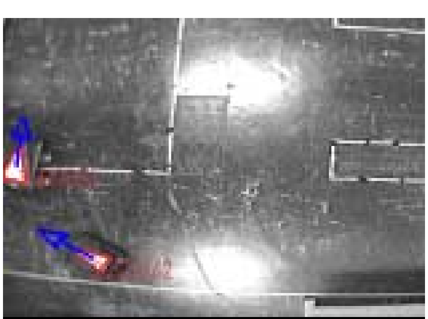
$$v(\mathrm{m/s}) = \frac{1.5(\mathrm{m})}{\mathrm{runningtime(s)}}$$

check the velocity for every voltage input from PC to Propo

Leader Following Experiment(1)



Leader Following Experiment(2)



Future Works

•Experiment
- •dynamic characteristic test
- •modify the program for leader following experiment (miniz, pid, color, etc)
- •make(modify) some programs with multi-vehicle for lab-introduction tour
- •coverage control experiment

•write paper about leader following for Movic
•Read more papers about coverage control