Control of Swarm of Mobile Robots in Unknown Environment

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Overview

Consensus problem

- A multi robot system (MRS) consists of N mobile robots and let $\mathbf{x} = [\mathbf{x}_1^T\ \mathbf{x}_2^T \cdots \mathbf{x}_N^T]^T$, where $\mathbf{x}_i \in \mathbb{R}^2$ denotes the position coordinates of i^{th} robot.
- A task can be modelled as driving the MRS from an initial state $\mathbf{x}_0$ to a final state $\mathbf{x}_f$
- Let initial state be $\mathbf{x}_0$ and final state be $\mathbf{x}_f = [\mathbf{c}^T\ \mathbf{c}^T \cdots \mathbf{c}^T]^T$, where $\mathbf{c} \in \mathbb{R}^2$

$$\mathbf{u}_i = \dot{\mathbf{x}}_i = k_p(\mathbf{c} - \mathbf{x}_i),$$

$$\dot{\mathbf{x}} = k_p\left(\mathbf{A}\mathbf{x} + \mathbf{b}\right)$$

$$\mathbf{A} = \begin{bmatrix} -1 & 0 & 0 & \cdots & 0 \\ 0 & -1 & 0 & \cdots & 0 \\ \vdots & & & & \\ 0 & \cdots & 0 & -1 & 0 \\ 0 & 0 & 0 & \cdots & -1 \end{bmatrix} \text{ and } \mathbf{b} = \begin{bmatrix} \mathbf{c} \\ \mathbf{c} \\ \vdots \\ \mathbf{c} \end{bmatrix}, \qquad (1)$$

where $\mathbf{A} \in \mathbb{R}^{2N \times 2N}$ and $\mathbf{b} \in \mathbb{R}^{2N}$

Objective

1. To drive the state of MRS from $\mathbf{x}_0$ to $\mathbf{x}_f$
2. Avoid intermittent obstacles.
3. Avoid collisions with neighboring robots.

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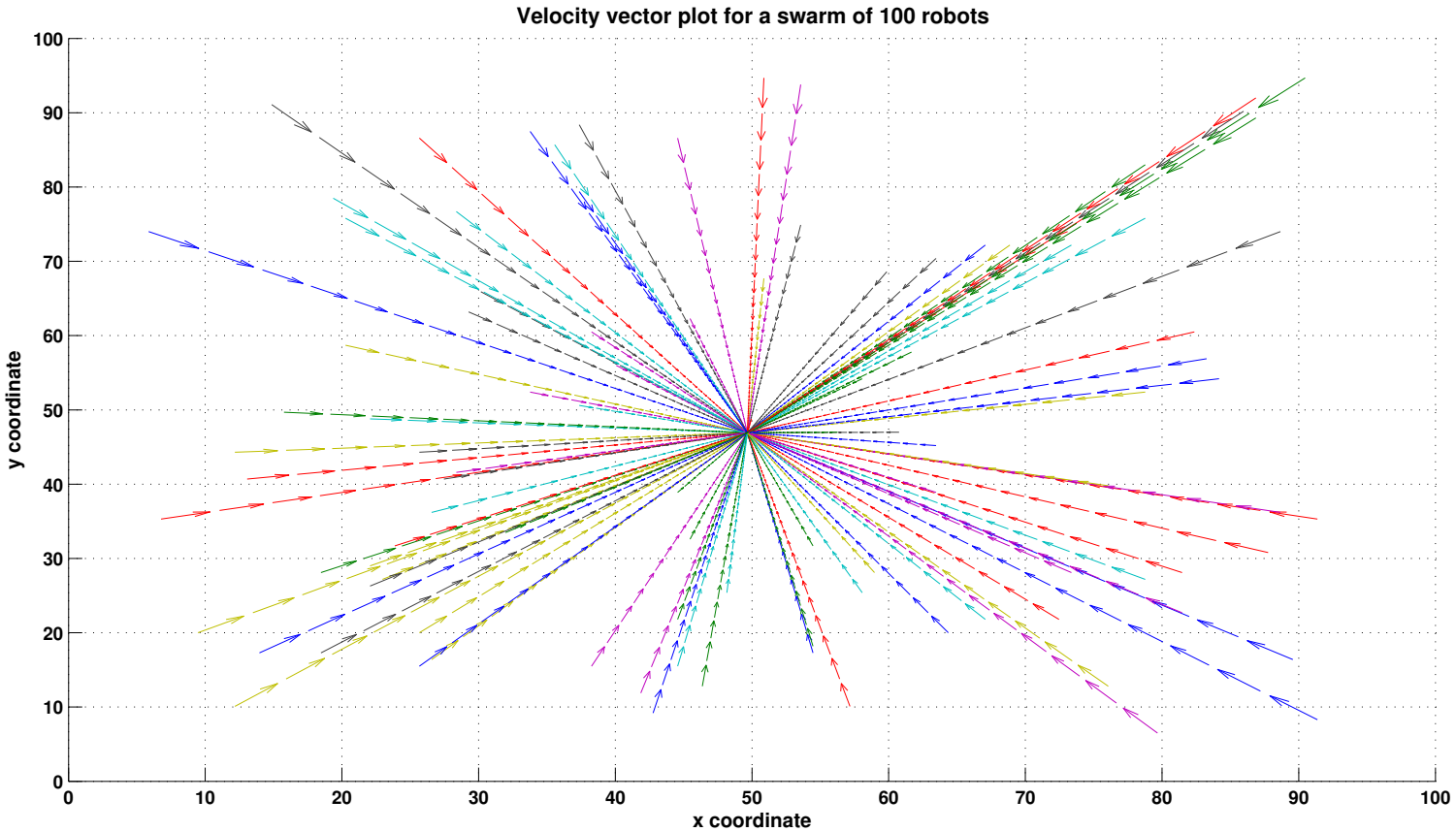
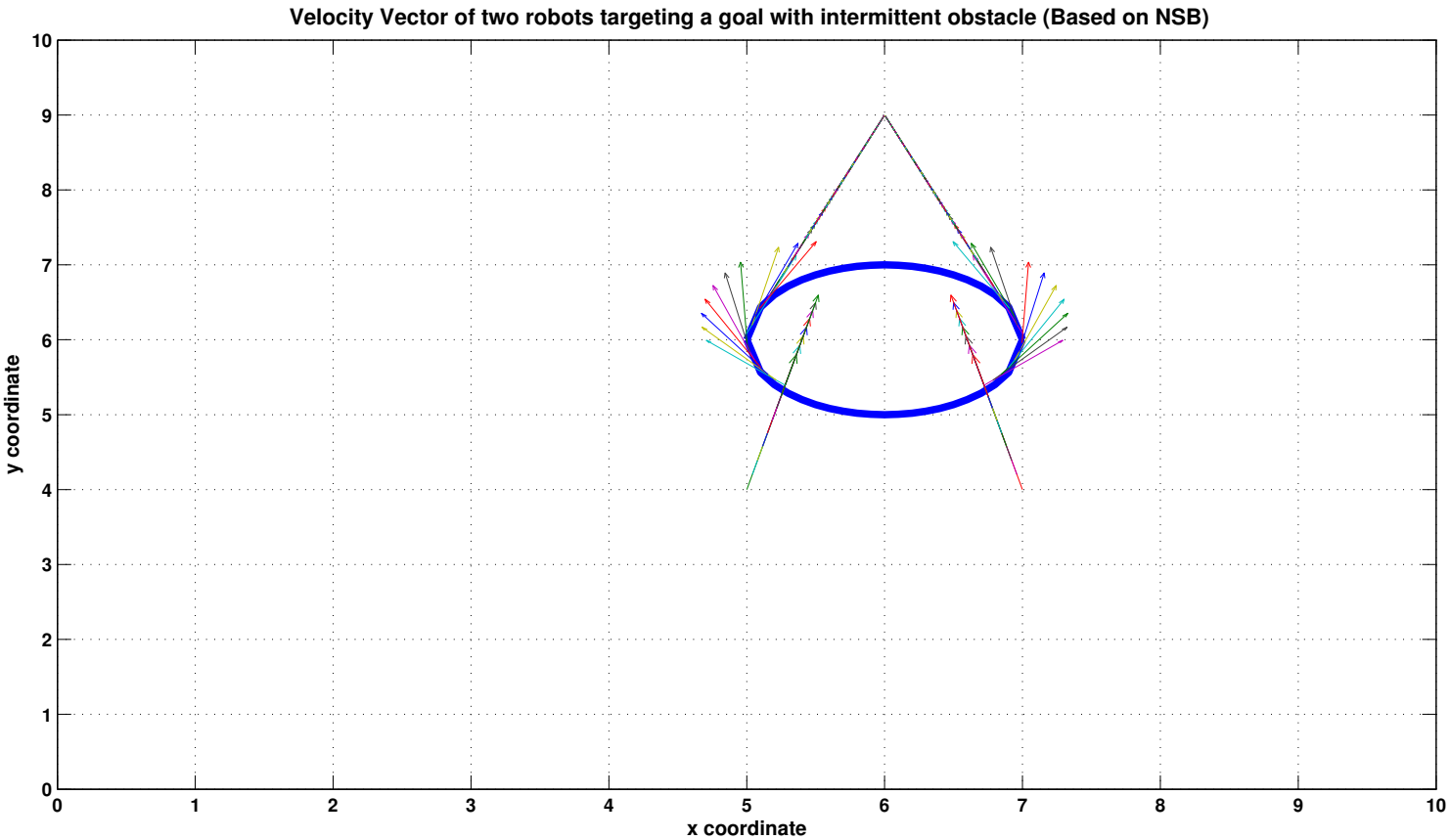
- Generating appropriate control signals to satisfy all the aforementioned objectives simultaneously
- Handling conflicting tasks
- NSB at rescue.....

Formulations Presented So Far

- Swarm robotics
- Decentralized and centralized architecture
- Indeterminate systems
- Notion of Null Space behavioral control

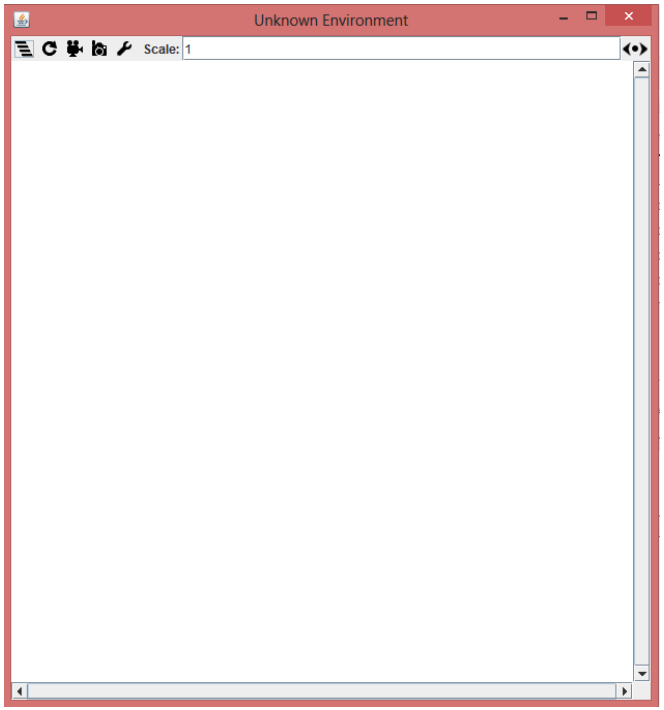

Velocity vector plot for a swarm of 100 robots
y coordinate
x coordinate
0
10
20
30
40
50
60
70
80
90
100



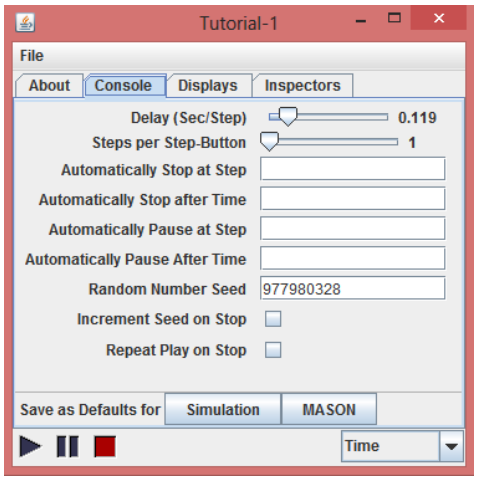
Show simulation video 1.

MASON

MASON is a discrete-event multiagent simulation **Library** in Java **Environment**



Controller



Some of inbuild functions used

Steppable(class)
Simstate(class)
doLoop(Name.class,args)
Jframe,controller

Task function associated with Flocking

$$\sigma_{2i} = ||\mathbf{x}_i - \mathbf{x}_j||$$

$$\mathbf{J}_{2_i} = \left[\frac{\mathbf{x}_i - \mathbf{x}_j}{||\mathbf{x}_i - \mathbf{x}_j||}\right]^T = \hat{\mathbf{r}}_{2_i}^T$$

$$\mathbf{J}_{2_i}^+ = \hat{\mathbf{r}}_{2_i} \cdot \hat{\mathbf{r}}_{2_i}^T$$

$$\sigma_{2_{d_i}} = d$$

$$\mathbf{u}_{RA_i} = \mathbf{v}_{2_i} = J_{2_i}^+ \Lambda_f (d - ||\mathbf{x}_i - \mathbf{x}_j||)$$

$$\mathcal{N}_{2_i} = \mathcal{N}(\mathbf{J}_{2_i}) = \mathbf{I} - \hat{\mathbf{r}}_{1_i} \cdot \hat{\mathbf{r}}_{1_i}^T$$

Task function associated with Go To Goal and Obstacle Avoidance

Obstacle Avoidance

$$\sigma_{1_i} = ||\mathbf{x}_i - \mathbf{x}_{ob}||$$

$$\mathbf{J}_{1_i} = \left[\frac{\mathbf{x}_i - \mathbf{x}_{ob}}{||\mathbf{x}_i - \mathbf{x}_{ob}||}\right]^T = \hat{\mathbf{r}}_{1_i}^T$$

$$\mathbf{J}_{1_i}^+ = \hat{\mathbf{r}}_{1_i} \cdot \hat{\mathbf{r}}_{1_i}^T$$

$$\sigma_{2_{d_i}} = d$$

$$\mathbf{v}_{1_i} = \mathbf{u}_{OA_i} = J_{1_i}^+ \Lambda_{ob}(d - ||\mathbf{x}_i - \mathbf{x}_{ob}||)$$

$$\mathcal{N}_{1_i} = \mathcal{N}(\mathbf{J}_{1_i}) = \mathbf{I} - \hat{\mathbf{r}}_{1_i} \cdot \hat{\mathbf{r}}_{1_i}^T$$

Go To Goal

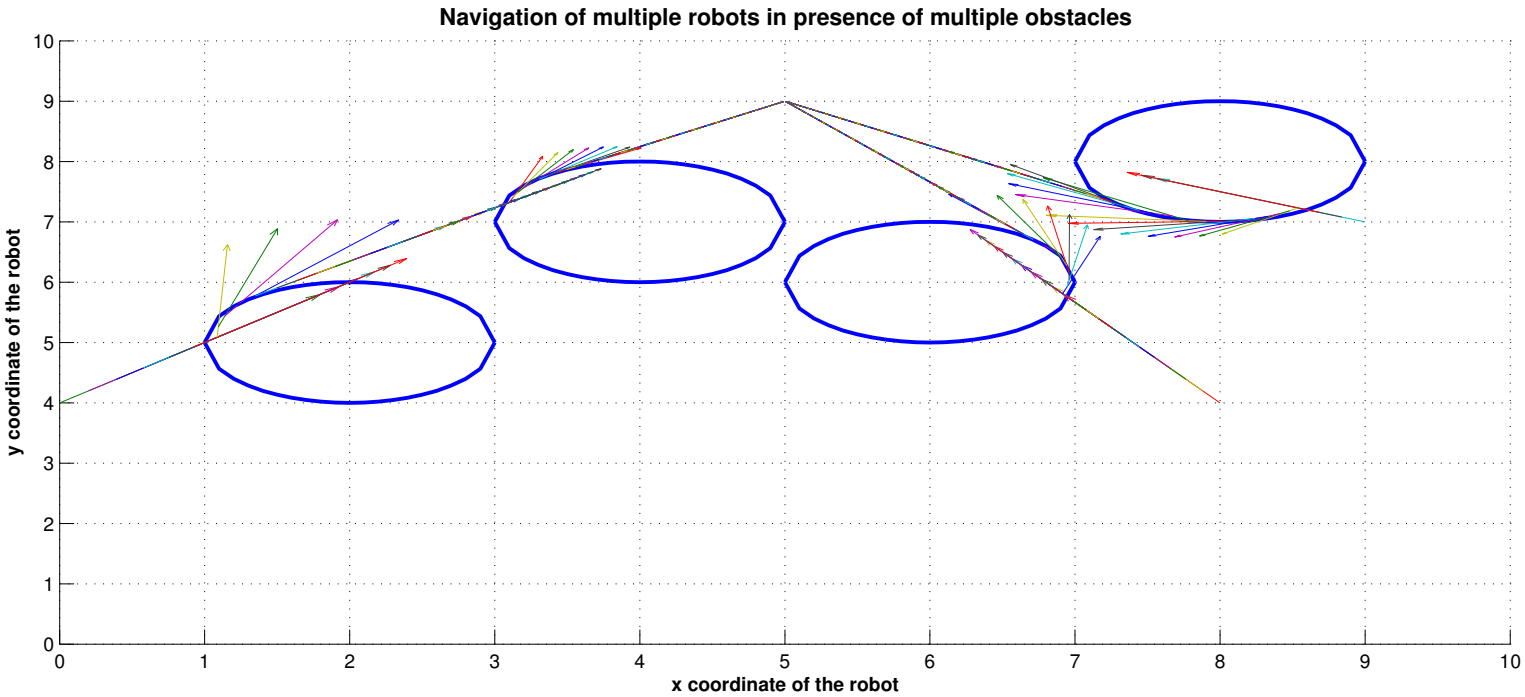
$$\sigma_{3_i} = \mathbf{x}_i$$

$$\sigma_{2_{d_i}} = \mathbf{x}_g$$

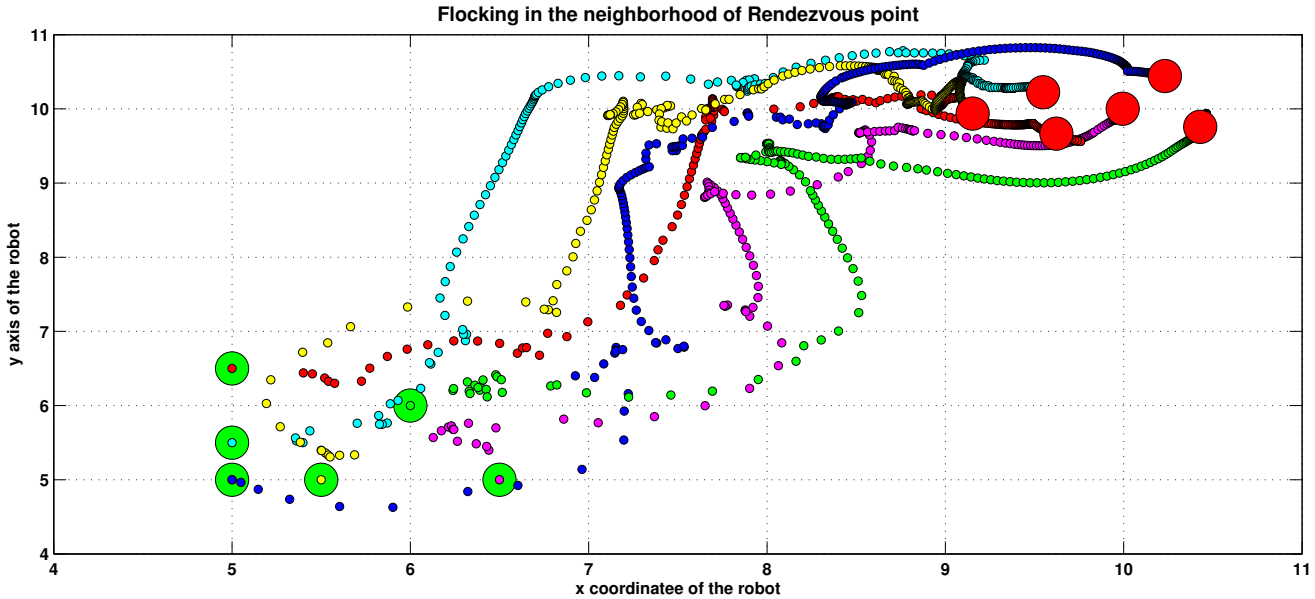
$$J_{3_i} = \mathbf{I} = J_{3_i}^+$$

$$\mathbf{v}_{3_i} = \mathbf{u}_{GTG_i} = \mathbf{\Lambda}_{GTG}(\mathbf{x}_g - \mathbf{x}_i)$$

Parameters	**Value**
Simulation Platform	MATLAB 2012a
No. of Robots (N)	3
Position of Robot 1 ($\mathbf{x}_1$)	$[0\ 4]^T$
Position of Robot 2 ($\mathbf{x}_2$)	$[8\ 4]^T$
Position of Robot 3 ($\mathbf{x}_3$)	$[9\ 7]^T$
Position of Obstacle 1	$[2\ 5]^T$
Position of Obstacle 2	$[4\ 7]^T$
Position of Obstacle 3	$[6\ 6]^T$
Position of Obstacle 4	$[8\ 8]^T$
Rendezvous point	$[5\ 9]^T$
Go to Goal Proportional gain	0.4
Safe distance	1
Obstacle Avoidance Proportional gain	**I**


Navigation of multiple robots in presence of multiple obstacles
y coordinate of the robot
x coordinate of the robot
0
1
2
3
4
5
6
7
8
9
10

Parameters	**Value**
Simulation Platform	MATLAB 2012a
No. of Robots (N)	3
Position of Robot 1 ($\mathbf{x}_1$)	$[5.5\ 5]^T$
Position of Robot 2 ($\mathbf{x}_2$)	$[6.5\ 5]^T$
Position of Robot 3 ($\mathbf{x}_3$)	$[5\ 5.5]^T$
Position of Robot 4 ($\mathbf{x}_4$)	$[5\ 6.5]^T$
Position of Robot 5 ($\mathbf{x}_5$)	$[6\ 6]^T$
Position of Robot 6 ($\mathbf{x}_6$)	$[5\ 5]^T$
Rendezvous point	$[10\ 10]^T$
Go to Goal Proportional gain	0.8
Safe distance	1
Obstacle Avoidance Proportional gain	$1.2\mathbf{I}$



Modes of operation

1. No Robot sensed in the vicinity: $\mathbf{v}_{d_i} = \mathbf{u}_{GTG_i}$
2. One neighboring robot sensed: $\mathbf{v}_{d_i} = \mathbf{u}_{RA_i} + \mathcal{N}_{2_i} \cdot \mathbf{u}_{GTG_i}$
3. More than one neighboring robot sensed:
   $\mathbf{v}_{d_i} = \mathbf{u}_{RA'_i} + \mathcal{N}'_{2_i} \cdot \left(\mathbf{u}_{RA''_2} + \mathcal{N}''_{2_i} \cdot \mathbf{u}_{GTG_i} \right)$

Mode of Operation

1. **No obstacle or other robot sensed** : $\mathbf{v}_{d_i} = \mathbf{u}_{GTG_i}$
2. **Only obstacle sensed** : $\mathbf{v}_{d_i} = \mathbf{u}_{OA_i} + \mathcal{N}_{1_i} \cdot \mathbf{u}_{GTG_i}$
3. **Only other robot sensed**: $\mathbf{v}_{d_i} = \mathbf{u}_{RA_i} + \mathcal{N}_{2_i} \cdot \mathbf{u}_{GTG_i}$
4. **Both obstacle and other robot sensed**: $\mathbf{v}_{d_i} = \mathbf{u}_{OA_i} + \mathcal{N}_{1_i} \cdot (\mathbf{u}_{RA_i} + \mathcal{N}_{2_i} \cdot \mathbf{u}_{GTG_i})$

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