Cooperative robots in people guidance mission: DTM model validation and local optimization motion.

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Overview

- Motivation.

- Modelling people’s motion.

- Modelling the motion space.

- Local Optimal Robot Task Assignment for the Cooperative Mission.

- Model Validation

- Implementation results.

- Conclusion.
Motivation

- Guiding people in urban settings using several mobile robots.

(Work performed under the European Project URUS)
Motivation (ii)

- **Robot tasks:**
  1. Robot leader, it guides the group of people.
  2. Shepherd robot:
     1. It has to look for people that can potentially escape from the crowd formation and regroup.
     2. It has to go behind the people in order to push them.
Model Description

Discrete-Time-Motion Model

Discrete-Motion Component

Robot behavior

Discrete-Time Component

Representation of the Environment

Estimation of future states: PF

People Motion
Modeling People’s Motion (i)

Perception of the Situation and Environment

Personal Aims and Interests

Information Processing

Results: Decision

Physical Tension: Motivation to Act

Physical Realization: Behavior Change

Stimulus

Physiological and Mental Process

Particle Filter

Reaction
Modeling the Motion Space

- Modeling the whole environment.
- Estimating the position and velocity of each individual.
- Key element: Discrete-Time-Motion Model (DTM)
  - Evaluates the estimation data in discrete time instance, every $k$ units of time.
- DTM’s components:
  - Discrete Time Component
  - Discrete Motion Component
Characterization of people and robot tensions:

- People and robots are characterized by:

\[
\{(\mu_x, \mu_y), (\sigma_x, \sigma_y), \nu, \Theta, T\}
\]

- The tension for people and robots is:

\[
T_p (\mu_p, \Sigma_p)(x) = \frac{1}{|\Sigma_p|^{1/2} (2\pi)^{n/2}} \exp\left(-\frac{1}{2}(x-\mu_p)^T \Sigma_p^{-1} (x-\mu_p)\right)
\]
Characterization of the obstacle tensions:

- A set of a Gaussian functions collocated at regular intervals around their boundaries. \( X=\{(x_1, y_1), \ldots, (x_n, y_n)\} \)
- By the set: \( \{(\mu_x, \mu_y), (\sigma_x, \sigma_y), T\} \) for \( i=1, \ldots, n \).
Local Optimal Robot Task Assignment for the Cooperative Mission

Cost Function

Robot work motion

Human work motion

Dragging Work

Traversing work

Pushing work

Optimal Robot Task Assignment
Robot Work Motion

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Optimal Robot Task Assignment
**Robot Work Motion (iii)**

- **Robot work motion:**

- For each robot $i$, we consider:

  \[ f_{i}^{\text{mot}} = m_{i} a_{i} \]

  \[ W_{i}^{\text{mot}} = f_{i}^{\text{mot}} \Delta s_{i} \]

  - Mas of $i$-th robot
  - Acceleration of $i$-th robot
  - Space traversed by the robot to achieve its goal

  Goal dynamic

  \[ \Delta s_{i} \]
Human Work motion

Cost Function

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Optimal Robot Task Assignment
Three types of forces on this kind of interaction:

- Dragging force
- Pushing force
- Crowd intrusion force

Effect of robots on people as forces:

- Leader Robot: attractive force (dragging)
- Shepherding robot: Repulsive force (pushing / traversing)
Human Work motion

Cost Function

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Optimal Robot Task Assignment
**Dragging Work**

- **Dragging force:**
  - Necessary when the leader robot guides the group.
  - Attractive force

- **Force applied by robot leader** \( i \) **to each person** \( k \):

  \[
  f_{ij}^{\text{drag}}(t) = -C_{ij}\vec{n}_{ij}(t) = -C_{ij}\frac{x_i(t) - x_j(t)}{d_{ij}(t)}
  \]

  \[
  d_{ij} = \|x_i(t) - x_j(t)\|
  \]

  \[
  W_{\text{drag}} = \sum_{\forall \text{ person } j} f_{ij}^{\text{drag}} \Delta s_j
  \]

  Helbing et. al

Definition of people’s vital territory
Pushing work

Cost Function

Robot work motion

Human work motion

Dragging Work

Traversing work

Pushing Work

Optimal Robot Task Assignment
Pushing Work (ii)

- Pushing force:
  - Done be Shepherding robot for regrouping people (or the broken crowd) in the main crowd formation
  - Repulsive force
  - It is due by intrusion of robot in people’s living space
- Force applied by robot leader $i$ to each person $k$:

$$f_{ij}^{push} = A_i \exp((r_{ij} - r_{ij})/B_i) \vec{n}_{ij} (\lambda_i + (1 + \lambda_i)^{1 + \cos(\varphi_{ij})})$$

$$W_{push} = \sum_{\forall \text{ person} \in \Omega_i} f_{ij}^{push}(t) \Delta S_j$$

$A_i$: interaction strength

$r_{ij} = ri - rj$, usually 1.5m

$B_i$: parameter of repulsive interaction

$\lambda < 1$

$\varphi_{ij}$: angle of the directions

$\Omega$: people affected by pushing force
Traversing work

Cost Function

Robot work motion

Human work motion

Dragging Work

Traversing Work

Pushing work

Optimal Robot Task Assignment
Traversing Work (ii)

- **Pushing force:**
  - Forces applied by robots when they traverse the formation.
  - Repulsive force
  - For security reasons, its value is considered as infinity

![Diagram showing people escaping, leader robot, and shepherd robot.](image)
Optimal Robot Task Assignment

Cost Function

Robot work motion

Human work motion

Dragging Work

Traversing work

Pushing work

Optimal Robot Task Assignment
Optimal Robot Taks Assignment (ii)

- Total cost function for robot $i$:

$$W_i = \delta_{mot} W_{i mot} + \delta_{drag} W_{i drag} + \delta_{push} W_{i push} + \delta_{trav} W_{i trav}$$

Where,

$$\delta_k = \begin{cases} 
1 & \text{if this task is assigned} \\
0 & \text{if this task is not assigned} 
\end{cases}$$

Finally, the task assignment for robots will be the one that minimizes the cost required

$$C = \text{argmin}(W_{total}(C)), \forall \text{ configuration } c$$
Data Collection

- Data collection:
  - Camera Network mounted on Barcelona robot Lab
  - 21 interconnected cameras
- People behavior
  - The group follows the instructions of the guides.
  - A person who is being led, if he goes away from the group one of the guides has to regroup him.
  - Several people escape at the same time in opposite directions.
  - The group stops and moves again,
Data Collection

- Data collection process:
  - Video sequences were registered.
  - Each frame was rearranged in order to synchronize the complete sequence.
  - Complete path was registered by 15 cameras.
  - Position of people was annotated manually
  - 10,000 images were labeled.
  - The trajectory of every person has to be taken into account in the complete path.
  - This trajectories are compared against the estimation obtained using DTM model.
Validation Process

- **Two cases were studied:**
  - The motion behavior of robots:
    - Shepherd robots
    - Leader robot
  - Motion behavior of the guided people.
- **Robots’ analysis:**
  - A comparison of the real motion and simulated motion is performed in different scenarios
- **People analysis**
  - A comparison of estimation motion and real motion is performed.
  - Via quadratic error:
    \[
    error_k = \sqrt{(y_k - \hat{y}_k)^2}
    \]
Simulations
Simulations
Simulations
Results

- **Corridor:**
  - People
  - Leader Robot
  - Shepherd Robots
Conclusions

- We have presented a new model to guide people in urban areas with a set of mobile robots working cooperatively.
- In contrast to existing approaches, DTM model can tackle with more realistic situations.
- Various results in different situations have been presented.
- In all simulations robots can act early enough to guide the group of people through a path computed previously.

- What’s next?
  - Increase the number of robots.
  - Develop real experiments
Thank you!
Discrete Time Motion Model for Guiding People in Urban Areas Using Multiple Robots

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