UNIVERSIDAD DE MÁLAGA

Navigability Analysis of Natural Terrains with Fuzzy Elevation Maps from Ground-based 3D Range Scans

Jorge L. Martínez, Anthony Mandow, Antonio Reina,
Tomás J. Cantador, Jesús Morales, and Alfonso García-Cerezo

Dpto. Ingeniería de Sistemas y Automática
University of Málaga (Spain)

OUTLINE

1. FUZZY ELEVATION MAPS
2. NAVIGABILITY ASSESSMENT
3. EXPERIMENTAL RESULTS
4. CONCLUSIONS

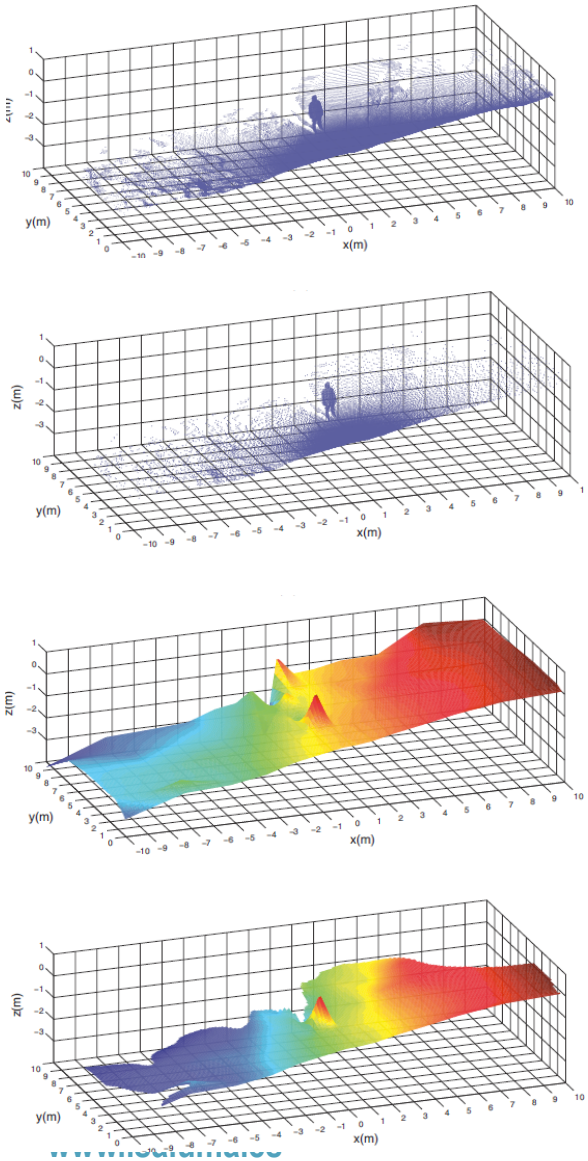
UNIVERSIDAD
DE MÁLAGA

1.
FUZZY ELEVATION MAPS

3D Terrain Modeling

- **Natural environments**
  - *Search & Rescue*
- **Onboard 3D scanner**
  - *Huge amount of data*
  - *Resolution decreases with range*
  - *Need for compact representation*
- **Fuzzy Elevation Maps (FEM)**
- **Navigability**
  - *Reliable data*
  - *Admissible inclination*

Local Fuzzy Elevation Maps (FEM)



Raw 3D Point Cloud

Subsampling

Reduced 3D Point Cloud

ANFIS Learning

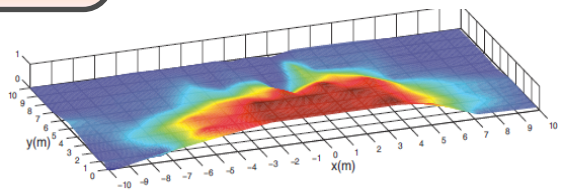
Fuzzy Elevation Map

Occupancy Binary Matrix

ANFIS Learning

Fuzzy Reliability

Reliable Fuzzy Region



- *Filter noisy data*
- *Interpolate missing data*
- *Continuous representation*

UNIVERSIDAD
DE MÁLAGA

2.
NAVIGABILITY ASESSMENT

FEM Inference

- **Standard Fuzzy Partition (SPF)**

$$\sum_{\forall i,j} \omega_{ij}(x,y) = 1$$

  - *Firing strength:*

$$\omega_{ij}(x,y) = \mu_{F_i}(x)\,\mu_{F_j}(y)$$

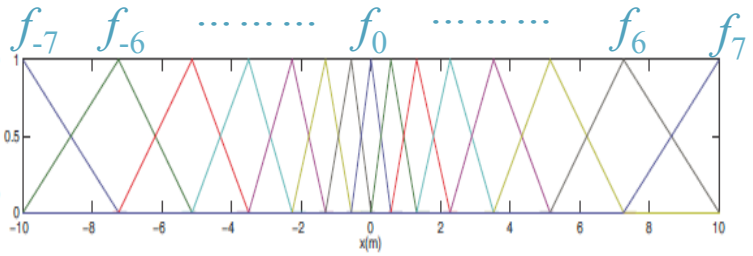
- **Zero-order Sugeno inference**
  - *Consequents:*

$$G_{ij}(x,y) = a_{ij}$$

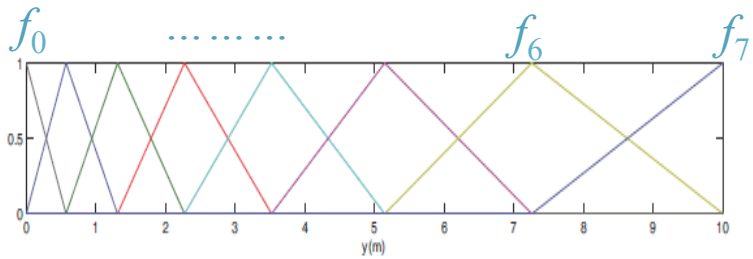
- **Terrain elevation:**

$$z = H(x,y) = \sum_{\forall i,j} \left(\omega_{ij}(x,y)\,a_{ij}\right)$$

X (sideways) membership functions:



Y (forward) membership functions:



f_i : peak values

Computing Terrain Inclination

$$z = H(x,y) = \sum_{\forall i,j} \left(\omega_{ij}(x,y)\, a_{ij}\right)$$

- **Gradient of terrain elevation points:**

$$\nabla H(x,y) = \begin{pmatrix} \frac{\partial z}{\partial x} \\ \\ \frac{\partial z}{\partial y} \end{pmatrix} = \begin{pmatrix} \sum_{\forall i,j} \left(\frac{\partial \mu_{F_i}(x)}{\partial x} \mu_{F_j}(y)\, a_{ij} \right) \\ \sum_{\forall i,j} \left(\mu_{F_i}(x) \frac{\partial \mu_{F_j}(y)}{\partial y}\, a_{ij} \right) \end{pmatrix}$$

where

$$\frac{\partial \mu_{F_i}(u)}{\partial u} = \begin{cases} \frac{1}{f_i - f_{i-1}} & \text{if } f_{i-1} \le u < f_i, \\ \frac{-1}{f_{i+1} - f_i} & \text{if } f_i \le u < f_{i+1}, \\ 0 & \text{otherwise.} \end{cases}$$

- **Gradient magnitude:**

$$|\nabla H(x,y)| = \sqrt{(\partial z/\partial x)^2 + (\partial z/\partial y)^2}$$

Navigability can be checked against h, an admissible inclination threshold

UNIVERSIDAD
DE MÁLAGA

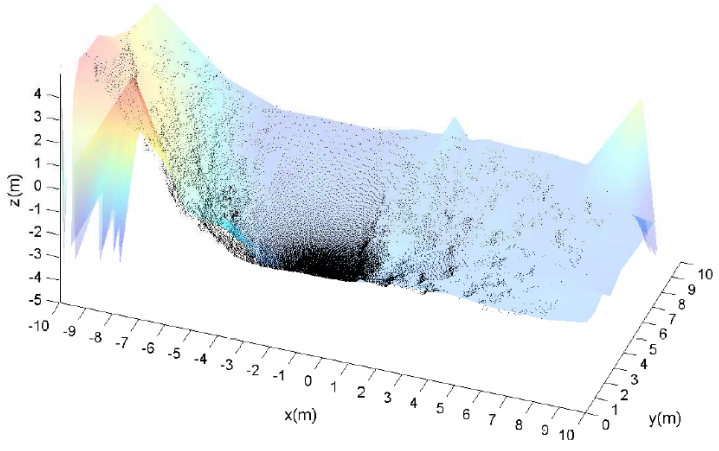
3.
EXPERIMENTAL RESULTS

Experimental Setup

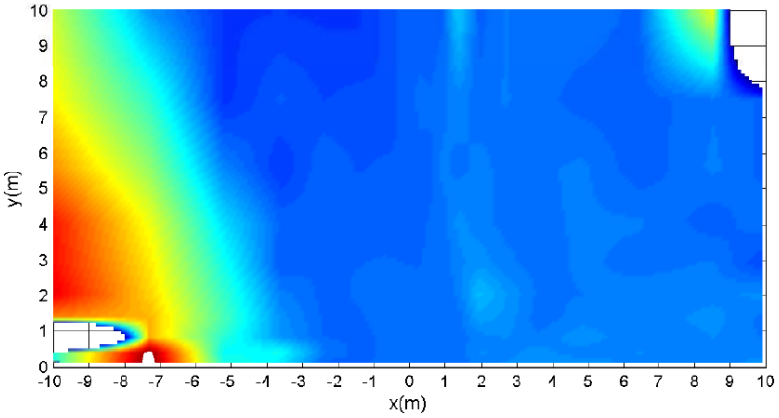
- **UnoLaser 3D Scanner:**
  - *30m range*
  - *0.7 m above ground*
- **FEM**
  - *Subsampling resolution δ = 0.1m*
  - *20x10 (meter), 19x10 Rules*

Results: Fuzzy Elevation Map

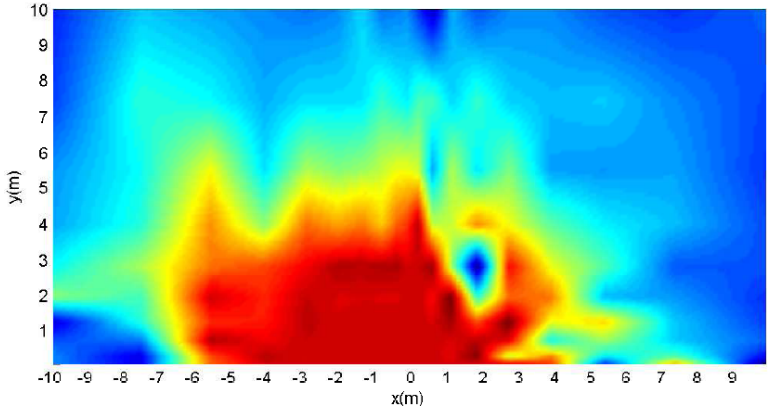
- Point cloud + FEM



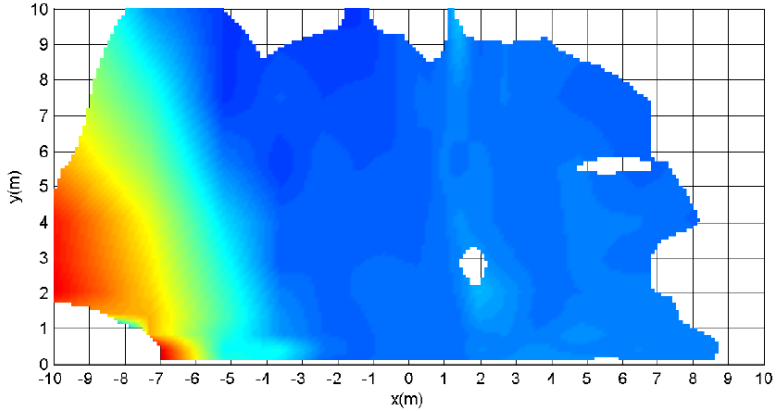
- FEM



- Fuzzy Reliability $v \in (0,1)$

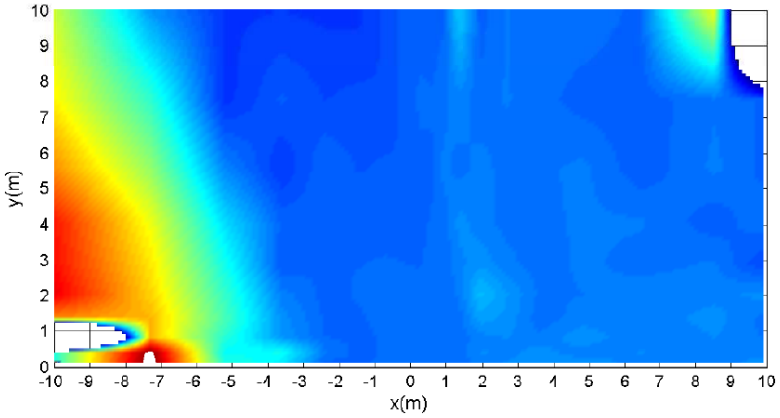


- Reliable FEM, $v(x,y) > 0.1$

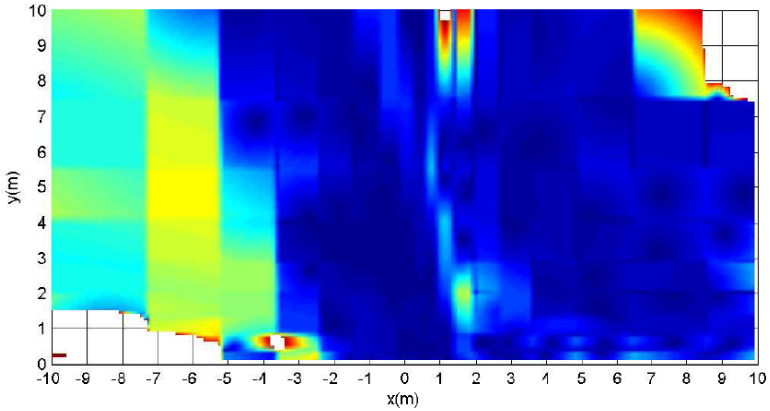


Results: Navigability Assessment

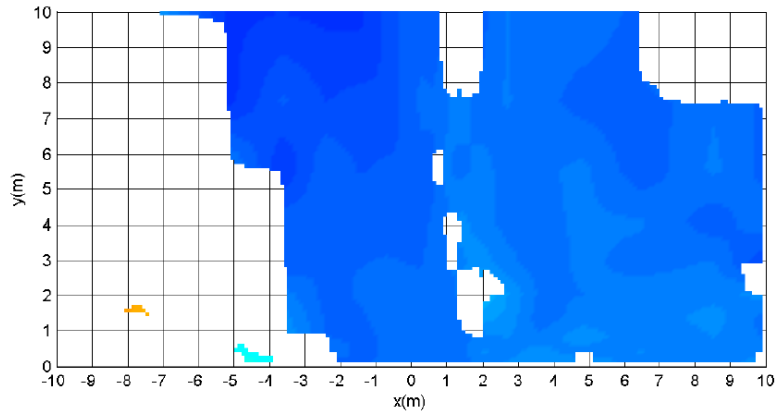
- FEM



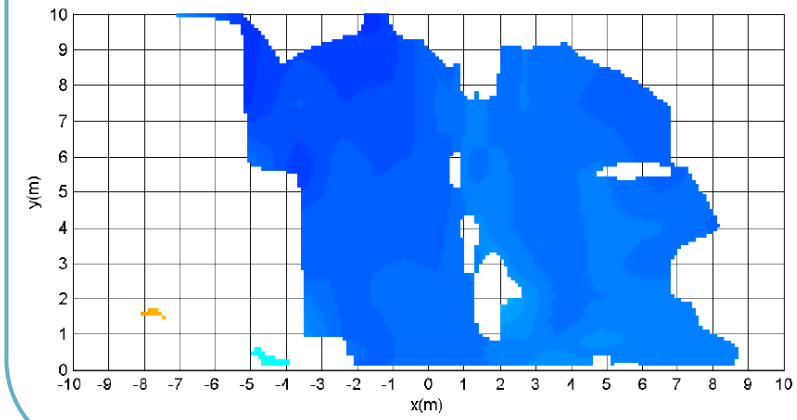
- FEM Gradient



- FEM with $|\nabla H|<0.5;h=26.6°$

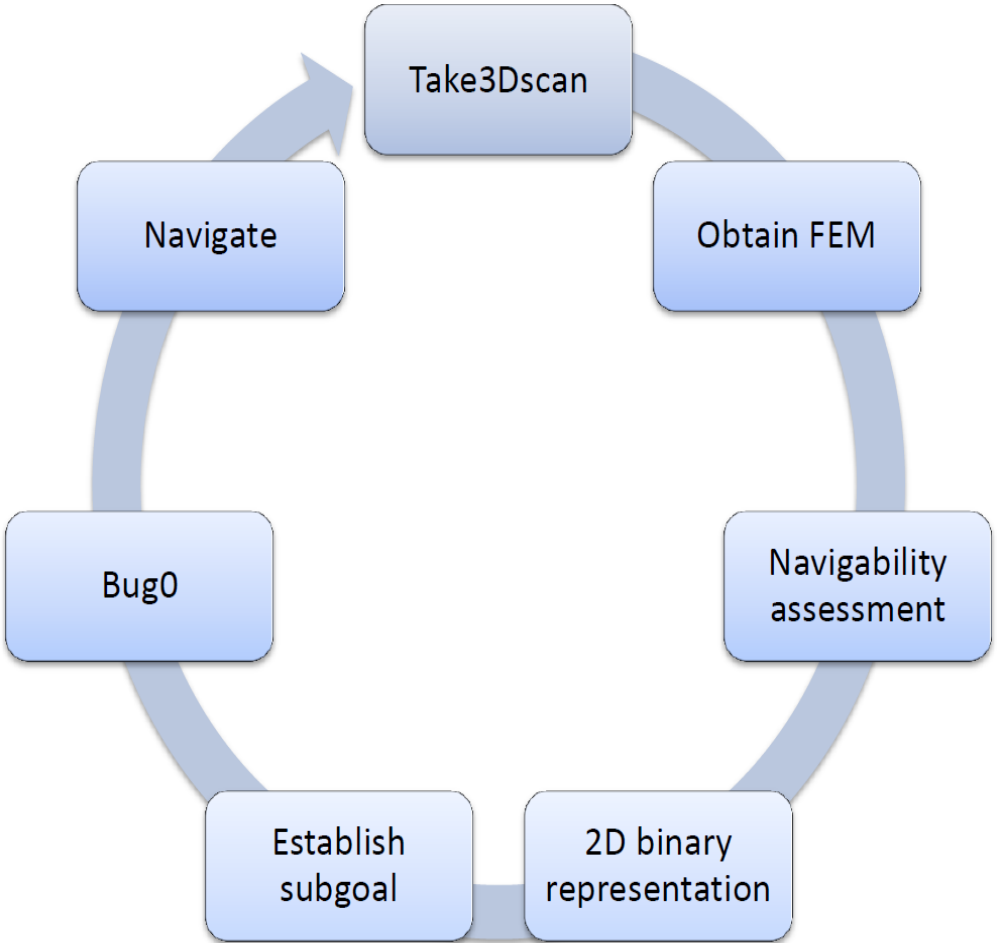


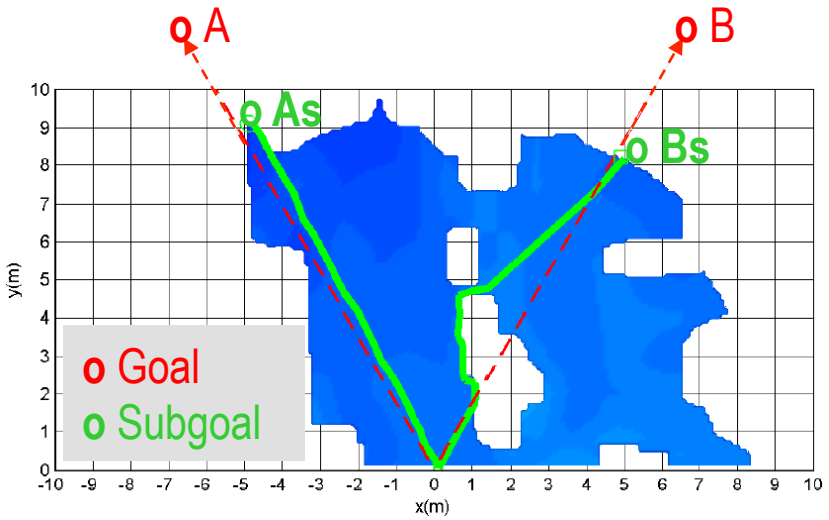
- **Navigable FEM:** grad.+reliab.

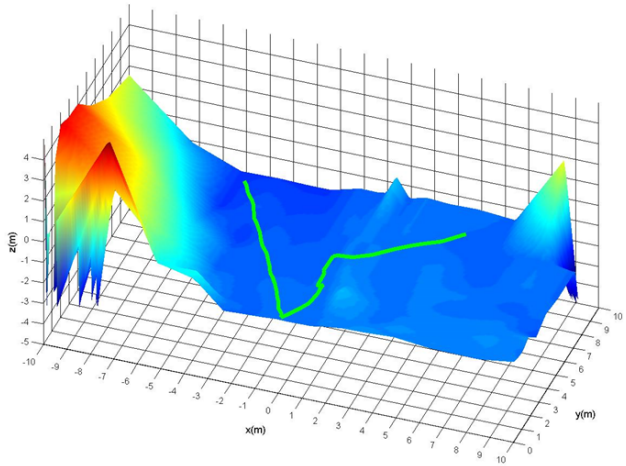


Results: Application of Bug(0)

- **Example: local paths to two different goal points**







UNIVERSIDAD
DE MÁLAGA

4.
CONCLUSIONS

Conclusions

- **Natural terrain modeling from 3D point clouds.**
- **Fuzzy Elevation Maps**
  - *Compact*
  - *Continuous*
  - *Manages noisy and missing data.*
- **Navigability assessment:**
  - *Reliability*
  - *Admissible terrain inclination*
- **Local path planning applicability**
  - *Bug(0) examples*
- **Work in progress**
  - *Navigation with Quadriga robot.*
  - *Dealing with overhangs (e.g., tree tops).*

UNIVERSIDAD DE MÁLAGA

Thank you!　　ありがとう！

www.isa.uma.es/amandow