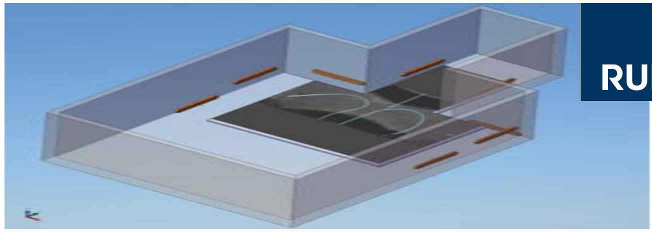


RUHR-UNIVERSITÄT BOCHUM

PHASE DIFFERENCE BASED RFID NAVIGATION FOR MEDICAL APPLICATIONS

ANDREAS WILLE
INSTITUT FÜR NEUROINFORMATIK

RFID 2011

Outline

Medical Navigation

What is medical navigation ?

1. **Take images** (MRI/CT) of a patient in advance.
2. **Plan** a procedure on these images.
3. During surgery **register** the images with the patient.
4. **Track** medical instruments.
5. **Visualize** their **position** relative to the planning.

Why use RFID localization ?

- no line of sight required
- small equipment
- multi tag support

RUHR-UNIVERSITÄT BOCHUM
Introduction Experimental Setup Localization Process Results Conclusions

Medical Navigation

What is medical navigation ?

1. **Take images** (MRI/CT) of a patient in advance.
2. **Plan** a procedure on these images.
3. During surgery **register** the images with the patient.
4. **Track** medical instruments.
5. **Visualize** their **position** relative to the planning.

Why use RFID localization ?

- no line of sight required
- small equipment
- multi tag support

PHASE DIFFERENCE BASED RFID NAVIGATION FOR MEDICAL APPLICATIONS RFID 2011 | A.Wille 3

RFID Localization

Several different approaches:

- Time of arrival
- Identification grid
- RSSI
- Phase differences

because:

- simple hardware setup
- less affected by noise than RSSI

Special requirements/features of medical applications:

- high accuracy required (0.1 mm - 1 m)
- high reliability essential
- limited operating range (≤ 5 m)
- no electromagnetic noise
- limited set of obstacles

RUHR-UNIVERSITÄT BOCHUM
Introduction Experimental Setup Localization Process Results Conclusions

RFID Localization

Several different approaches:

- Time of arrival
- Identification grid
- RSSI
- **Phase differences**

because:

- simple hardware setup
- less affected by noise than RSSI

Special requirements/features of medical applications:

- high accuracy required (0.1 mm - 1 m)
- high reliability essential
- limited operating range (≤ 5 m)
- no electromagnetic noise
- limited set of obstacles

PHASE DIFFERENCE BASED RFID NAVIGATION FOR MEDICAL APPLICATIONS RFID 2011 | A.Wille 4

RFID Localization

Several different approaches:

- Time of arrival
- Identification grid
- RSSI
- **Phase differences**

because:

- simple hardware setup
- less affected by noise than RSSI

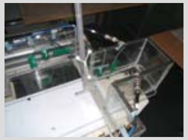
Special requirements/features of medical applications:

- high accuracy required (0.1 mm - 1 m)
- high reliability essential
- limited operating range (≤ 5 m)
- no electromagnetic noise
- limited set of obstacles

Hardware

PRPS Prototype (amedo)

- 8 receivers / 1 reader
- passive tags (868 MHz)
- 16 measurements of phase differences
- Update rate: 1 Hz

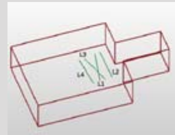


Experimental Environment

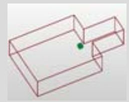
- plastic basin (50 cm $\times$ 90 cm $\times$ 20 cm)
- no obstacles
- CNC device for tag movement (0.1 mm accuracy)

Series of Measurements

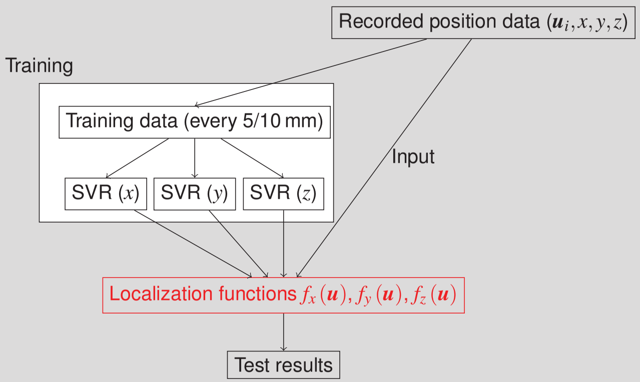
- Line data:
  - 4 linear paths with 20 cm length
  - each line with 200 positions
  - 1 mm distance between positions
  - 20,000 measurements in total



- Volume data:
  - box (20 cm $\times$ 1 cm $\times$ 1 cm) with 20,000 positions
  - cube (27 cm^3) with 35,000 positions
  - 1 mm distance between positions
  - 500,000 / 900,000 measurements in total



Data Processing



Support Vector Regression

Kernel based supervised learning algorithm

Input: l training examples $(\boldsymbol{u}_i, y_i) \in U \times \mathbb{R}$, $l = 1, \ldots, l$

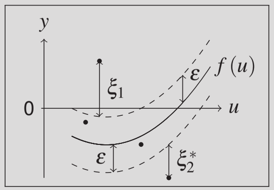
Output:

$$f(\boldsymbol{u}) = k(\boldsymbol{w}, \boldsymbol{u}) + b \qquad \boldsymbol{w} = \sum_{i=1}^{l} \alpha_i y_i \boldsymbol{u}_i$$

by solving:

$$\min_{w,\xi,\xi^*} \frac{1}{2} ||\boldsymbol{w}||^2 + C \sum_{i=1}^{l} (\xi_i + \xi_i^*)$$

$$\text{subject to :} \quad y_i - f(\boldsymbol{u}_i) \leq \varepsilon + \xi_i$$
$$y_i - f(\boldsymbol{u}_i) \geq -\varepsilon - \xi_i^*$$
$$\xi_i, \xi_i^* \geq 0$$



Parameters: ε, C, kernel k

RUHR-UNIVERSITÄT BOCHUM RUB
Introduction Experimental Setup Localization Process Results Conclusions

Support Vector Regression

Kernel based supervised learning algorithm

Input: l training examples $(\boldsymbol{u}_i, y_i) \in U \times \mathbb{R}$, $l = 1, \ldots, l$

Output:

$$f(\boldsymbol{u}) = k(\boldsymbol{w}, \boldsymbol{u}) + b \qquad \boldsymbol{w} = \sum_{i=1}^{l} \alpha_i y_i \boldsymbol{u}_i$$

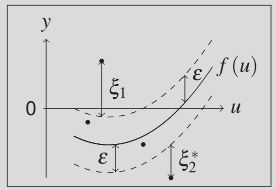
by solving:

$\varepsilon = 0.1\,\mathrm{mm}$

$k(\boldsymbol{u}_i, \boldsymbol{u}_j) = \exp\left(-\gamma ||\boldsymbol{u}_i - \boldsymbol{u}_j||^2\right)$

$$\min_{w,\xi,\xi^*} \frac{1}{2} ||\boldsymbol{w}||^2 + C \sum_{i=1}^{l} (\xi_i + \xi_i^*)$$

$$\text{subject to :} \quad y_i - f(\boldsymbol{u}_i) \leq \varepsilon + \xi_i$$
$$y_i - f(\boldsymbol{u}_i) \geq -\varepsilon - \xi_i^*$$
$$\xi_i, \xi_i^* \geq 0$$



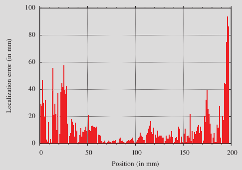
Parameters: ε, C, kernel k

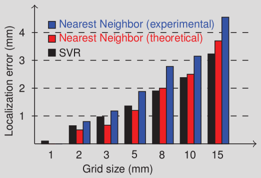
PHASE DIFFERENCE BASED RFID NAVIGATION FOR MEDICAL APPLICATIONS RFID 2011 | A.Wille 8

Line Data

Basic properties:

- SVR results strongly depend on position
  $\Rightarrow$ Use central parts only !
- Training accuracy: 0.1 mm (as requested)
- General accuracy: depends on grid size





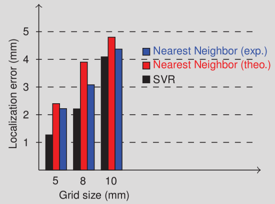
Successful localization but:

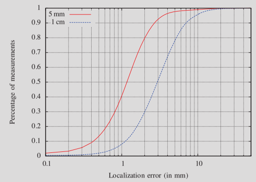
- high variance in accuracy
- limited systematic miscalculations
- best benefit for coarse grids

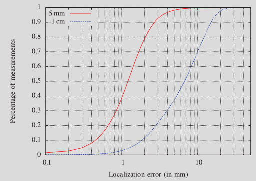
Volume Data

Improved situation:

- reduced border effects
- almost independent of position
- reasonable scaling with grid size
- training accuracy still 0.1 mm







General Results

Comparison of accuracy

General RFID localization:	$\approx$ 0.3 m
Polaris (optical):	0.1 mm
PRPS (alpha version):	3.8 mm (no interpolation)
PRPS + SVR:	1.6 mm (volume, 5 mm grid)

Learning positions from RFID phase information with 2 mm accuracy is currently no problem

- with oversized 10 mm one-dimensional grid for volumes of room size.
- with 5 mm three-dimensional grid for small volumes.

More optimized SVR training offers potential for even better accuracies (at cost of decreasing reliability).

Conclusions

RFID is ready to be used in medical application for

- medical instruments count / patient identification
- coarse scale patient/device placement
- **addition to optical navigation**
- **stand-alone navigation in volumes with special focus**

Still left to do:

- Solve multipath problems
- Perform measurements inside the human body
- Improve accuracy to < 0.5 mm
- Reduce calibration time and efforts

Thank you for your attention !

Phase Difference Based RFID Navigation for Medical Applications

Andreas Wille

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds für regionale Entwicklung
INSTITUT FÜR NEUROINFORMATIK