Towards proactive robots for elder care

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Towards proactive robots for elder care

Barbara Bruno

Jasmin Grosinger
The take-home message

Robot technologies

1. Big expensive robots can help elderly people
2. They will come as an ecology of devices capable of proactive behavior
3. AI provides key enabling tools
Line of argument today

1. Assistive robotics: the ecological approach
2. A realization: Robot-Era
3. Toward proactivity: WearAml
4. WearAml: eliciting context
t1. WearAml: deciding actions
   Finale
Assistive robotics: “Big Robot” approach

- Build a highly competent, general purpose “robot assistant”
Assistive robotics: “Big Robot” approach

- Difficulties with this approach

  Technological
  - understand the human
  - recognize objects
  - grasp
  - dexterous manipulation
  - safe navigation
  - ...
  - ...
  - ...
  - ...
Assistive robotics: “Big Robot” approach

• Difficulties with this approach

Technological
– understand the human
– recognize objects
– grasp
– dexterous manipulation
– safe navigation
– ...
– ...
– ...

Socio-economical
– would you accept this object?
– would you accept these services?
– how much would it cost?
– can be customized to your needs?
– can be expanded?
– ...
– ...

[Image of a robot assisting a person]
Assistive robotics: “Ecological” approach

- Build a highly competent, general purpose robot assistant?
- Build an ecosystem of robotic devices around the human!
Robot Ecology: the concept

• Many specialized, pervasive “robotic” devices
  – sensors, tagged objects, appliances, robotic tables, ...
  – complex abilities achieved through cooperation
Robot Ecology: the concept

- Complex abilities achieved through cooperation
  - Dynamic ad-hoc coalitions
    - depending on the task
    - depending on the available devices

Where is Johan?
Open the door!
The milk has expired!
The “Robot Ecology” approach

- Better suited for real deployment?

Technological
- understand the human
- recognize objects
- grasp
- dexterous manipulation
- safe navigation
- ...
- ...
- ...

Socio-economical
- would you accept this object?
- would you accept these services?
✓ how much would it cost?
✓ can be customized to your needs?
✓ can be expanded?
- ...
- ...
- ...

[Care-o-bot image]
Robot Ecology: needed functionalities

- Middleware
  - inter-operability of robots, WSN, tags, ...
Robot Ecology: needed functionalities

- **Middleware**
  - inter-operability of robots, WSN, tags, ...
  - dynamic addition and removal of devices

IoT: platforms
Robot Ecology: needed functionalities

- Middleware

- Dynamic self-configuration
  - automatic connection of devices to perform a given task
Robot Ecology: needed functionalities

- **Middleware**

- **Dynamic self-configuration** ➞ **AI: planning**
  - automatic connection of devices to perform a given task
  - re-configuration whenever needed
Robot Ecology: needed functionalities

- Middleware
- Dynamic self-configuration
- **Information sharing**
  - among heterogeneous devices

Robotics: sensor fusion

AI: ontologies
Robot Ecology: needed functionalities

• Middleware

• Dynamic self-configuration

• Information sharing

• Context awareness
  – understand the environment
  – understand the humans

Per is cooking for guests

Robotics: state estimation

AI: activity recognition
Robot Ecology: needed functionalities

- Middleware
- Dynamic self-configuration
- Information sharing
- Context awareness
- **Proactivity**
  - generate own goals
  - act toward own goals
Robot Ecology: realizations

- Middleware
- Dynamic self-configuration
- Information sharing
- Context awareness
- Proactivity

Robot-Era project (2012–2015)
WearAml project (2015–2017)
Robot Ecology: realizations

- Middleware
- Dynamic self-configuration
- Information sharing
- Context awareness
- Proactivity

Robot-Era project (2012–2015)
WearAml project (2015–2017)
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<thead>
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Line of argument today

1. Assistive robotics: the ecological approach
2. A realization: Robot-Era
3. Toward proactivity: Wearable context
4. Wearable: eliciting context
5. Deciding actions
6. Finale
The Robot-Era project (Jan 2012 – Dec 2015)

“Implementation and integration of advanced Robotic systems and intelligent Environments in real scenarios for the ageing population”

• The Robot-Era consortium

<table>
<thead>
<tr>
<th>Elder experts</th>
<th>Italy</th>
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<tr>
<td>Istituto nazionale di riposo e cura per anziani</td>
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<td>YOUSE</td>
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<td>STMicroelectronics srl</td>
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<td>TechnoDeal</td>
<td>Italy</td>
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<th>End users</th>
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<tbody>
<tr>
<td>Municipality of Peccioli</td>
<td>Italy</td>
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<tr>
<td>Lansgarden Fastigheter</td>
<td>Sweden</td>
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</table>

• ”Taking care of the elderly... from home to town”
The concept: 3D robotic services

- Ambient Intelligence Infrastructure
- Domestic Robot
- Residential Robot
- Outdoor Robot
The concept: 3D robotic services

• In the apartment
  – Objects transportation, Reminding, Communication, Cleaning, Surveillance, Escort

• In the building
  – Objects transportation
  – Laundry assistance, Food delivery

• In the town
  – Shopping delivery, Garbage collection
  – Outdoor walking support
The system: architecture
The system: functionalities

- Middleware: PEIS Middleware
- Dynamic self-configuration
- Information sharing
- Context awareness
- Proactivity
The system: functionalities

- Middleware
- Dynamic self-configuration
- Information sharing
- Context awareness
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The system: functionalities

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**Evaluation: methodology**

- **Two loops**
  - Technology development
  - First experimental campaign (controlled experiments)
  - Technology development
  - Second experimental campaign (uncontrolled experiments)
  - User requirements elicitation

- **Two experimental sites**
  - Town of Peccioli, Italy
  - Ängen residential facility, Sweden

- **140+ elderly subjects involved**
- **700+ hours of tests**
Evaluation: sample runs

Object transportation
- “You are thirsty. Call Doro to bring you a bottle of water.”
Evaluation: sample runs

Laundry assistance
- “You need to make your laundry. You can use the robots to bring your clothes to the laundry room, and bring them back to you after cleaning.”

speed x2
What is missing?

- Middleware
- Dynamic self-configuration
- Information sharing
- Context awareness
- Proactivity

| Robot-Era project (2012–2015) | ✓ | ✓ |
| WearAml project (2015–2017) | ✓ | ✓ | ✓ | ✓ | ✓ |
|------------------|----------------------------------|-------------------------------|-----------------------------|
| • Middleware     | ✓                                | ✓                             | ✓                           |
| • Dynamic self-configuration | ✓ | ✓ | ✓ |
| • Information sharing | ✓ | ✓ | ✓ |
| • Context awareness | ✓ | ✓ | ✓ |
| • Proactivity    | ✓                                |                               |                             |
Line of argument today

1. Assistive robotics: the ecological approach
   - A realization: Robot-Era

2. Toward proactivity: WearAml
   - Eliciting context

3. WearAml: deciding actions

4. Finale
The WearAml project

• "Progetto Grande Rilevanza" PGR02714
  – Italy – Sweden cooperation

• Objectives
  – exploit information from wearable and ambient sensors
  – to recognize the inhabitant's activity
  – allowing robots to take better decisions
Line of argument today

1. Assistive robotics: the ecological approach
2. A realization: Robot-Era
3. Toward proactivity: WearAml
4. WearAml: eliciting context
data
5. WearAml: deciding actions
6. Finale

COFFEE BREAK

OREBRO UNIVERSITY
WearAml: eliciting context

- Dynamic self...
- Information
- Context awareness
  - understand the...
### Human activities: which ones?

- **Activities of Daily Living (ADL)**
  - specific daily-life tasks
  - used to assess level of autonomy

<table>
<thead>
<tr>
<th>Activities</th>
<th>Independence (1 Point)</th>
<th>Dependence (0 Points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Points (1 or 0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BATHING</td>
<td>(1 POINT) Bathes self completely or needs help in bathing only a single part of the body such as the back, genital area or disabled extremity.</td>
<td>(0 POINTS) Need help with bathing more than one part of the body, getting in or out of the tub or shower. Requires total bathing.</td>
</tr>
<tr>
<td>Points:</td>
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</tr>
<tr>
<td>DRESSING</td>
<td>(1 POINT) Get clothes from closets and drawers and puts on clothes and outer garments complete with fasteners. May have help tying shoes.</td>
<td>(0 POINTS) Needs help with dressing self or needs to be completely dressed.</td>
</tr>
<tr>
<td>Points:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOILETING</td>
<td>(1 POINT) Goes to toilet, gets on and off, arranges clothes, cleans genital area without help.</td>
<td>(0 POINTS) Needs help transferring to the toilet, cleaning self or uses bedpan or commode.</td>
</tr>
<tr>
<td>Points:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRANSFERRING</td>
<td>(1 POINT) Moves in and out of bed or chair unassisted. Mechanical transfer aids are acceptable.</td>
<td>(0 POINTS) Needs help in moving from bed to chair or requires a complete transfer.</td>
</tr>
<tr>
<td>Points:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTINENCE</td>
<td>(1 POINT) Exercises complete self control over urination and defecation.</td>
<td>(0 POINTS) Is partially or totally incontinent of bowel or bladder</td>
</tr>
<tr>
<td>Points:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEEDING</td>
<td>(1 POINT) Gets food from plate into mouth without help. Preparation of food may be done by another person.</td>
<td>(0 POINTS) Needs partial or total help with feeding or requires parenteral feeding.</td>
</tr>
<tr>
<td>Points:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Points:</td>
<td></td>
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</table>

Score of 6 = High, Patient is independent.  
Score of 0 = Low, patient is very dependent.
How to detect them?

- **Activities of Daily Living (ADL)**
  - specific daily-life tasks
  - used to assess level of autonomy

- **Wearable sensors**
  - info about movement of body parts
  - allow to infer **executed motions**
How to detect them?

- **Activities of Daily Living (ADL)**
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  - used to assess level of autonomy

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- **Ambient intelligence sensors**
  - info about people location
  - info about usage of objects
  - allow to infer *execution context*
How to detect them?

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  - specific daily-life tasks
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- **Ambient intelligence sensors**
  - info about people location
  - info about usage of objects
  - allow to infer *execution context*
Detection of motion primitives

- **Assumption:**
  - stereotyped motion can uniquely identify an activity
Detection of motion primitives

Training data set

Raw data filtering

Feature extraction

GMM models

- Gravity - x axis
- Gravity - y axis
- Gravity - z axis
Detection of motion primitives

Run-time data stream

Raw data filtering

Feature extraction

GMM models

Comparison

Recognized motion primitives

[ Bruno et al, RAM 2015 ]
[ Bruno et al, IPMU 2014 ]
Detection of motion primitives

- Assumption:
  - stereotyped motion can uniquely identify an activity
  - but not always!
Integration with ambient sensors

- **Sensors in the environment**
  - in the environment: PIR, light, temperature, ...
  - attached to objects: RFID tags, accelerometers, current, ....

- **Temporal models**
  - relate events to activities

- **Recognition**
  - given sensor data
  - infer likely explanations

- **Include detected motions**
  - work in progress

[ Pecora et al, JAISE 2012 ]
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4. WearAml: deciding actions

Finale
WearAml: goal generation

- Dynamic self
- Information
- Context awareness
- Proactivity
  - generate own goals
  - act toward own goals

Work by: Jasmin Grosinger  <jasmin.grosinger@oru.se>
A proactive robot: bring the pills

Johan has not taken his pills yet. He will be sick if he doesn’t. He will now go and visit his children. I’ll bring him the pills!

- **Proactivity requires**
  - Awareness of current state
  - Prediction of future states
  - Knowledge of undesirable states
  - Awareness of available actions

- **Let’s formalize this!**
Formally ...

- A system $\Sigma = (S, U, f)$
- With desired states $Des$
Formally – dynamics

- **Nature**: free run behavior \( F^k \)
- **Robot**: action schemes \( \{ \alpha_1, ..., \alpha_n \} \)
Formally – beneficial action schemes

- Some actions are *applicable*
- Some are *beneficial* – $Bnf(\alpha_1, s)$
Formally – opportunities

- This is an "opportunity to act"!
- \( \text{Opp}(\alpha, s, 0) \) iff \( s \in \text{Undes} \wedge \text{Bnf}(\alpha, s) \)
Formally – opportunity

- Which are "opportunities to act" in the future?
Formally – opportunity

- **Six types of opportunity**

\[
\begin{align*}
\text{Opp}_1(\alpha, s, k) & \iff s \in \text{Undes} \land (\exists s' \in F^k(s) : \text{Bnf}(\alpha, s')) \\
\text{Opp}_2(\alpha, s, k) & \iff s \in \text{Undes} \land (\forall s' \in F^k(s) : \text{Bnf}(\alpha, s')) \\
\text{Opp}_3(\alpha, s, k) & \iff \exists s' \in F^k(s) : (s' \in \text{Undes} \land \text{Bnf}(\alpha, s')) \\
\text{Opp}_4(\alpha, s, k) & \iff \forall s' \in F^k(s) : (s' \in \text{Undes} \land \text{Bnf}(\alpha, s')) \\
\text{Opp}_5(\alpha, s, k) & \iff (\exists s' \in F^k(s) : s' \in \text{Undes}) \land \text{Bnf}(\alpha, s, k) \\
\text{Opp}_6(\alpha, s, k) & \iff (\forall s' \in F^k(s) : s' \in \text{Undes}) \land \text{Bnf}(\alpha, s, k)
\end{align*}
\]
From opportunity to proactivity

• Proactivity:
  - Generate own goals
  - Act toward own goals

• When there is no opportunity: equilibrium
  - Above algorithm: "Equilibrium maintenance"
Equilibrium maintenance at work

Model of system $\Sigma$

- $S = \text{Des} \cup \text{Undes}$
- Transition relation $f$
- Action schemes $A$

Current state $s \in S$

Equilibrium Maintenance

State Estimation

Plan-based Executive

Sensors

Humans

Robots

Assess current state
Find opportunities
Select opportunities

Enact opportunities
Equilibrium maintenance at work

Anna lives in a smart home. Sensors detect her activities.

**Equilibrium Maintenance**
Anna will have lunch soon. Will she take her pills then? → *Opportunity* to remind! soon...
Q1: Are the chosen actions good?

Theorem 1. Let \( \sigma \) be the action selection function defined by \( EqM(K) \). For any state \( s \in \text{Rec}(\Sigma, r) \), with \( r < K \), there is a \( t \leq K \) such that \( \text{Reach}^t(s, \sigma) \subseteq \text{Des} \).
Q2: Can we have degrees?

- This is an "opportunity to act"!
  - To a degree 0.7

[ Grosinger et al, SMC 2017 ]
Q3: What’s missing?

- Integration of context recognition and equilibrium maintenance
- User evaluation
Line of argument today

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4. WearAI: deciding actions

Finale
The take-home message

Robot technologies

1. Big expensive robots can help elderly people
2. They will come as an ecology of devices capable of proactive behavior
3. AI provides key enabling tools

I'd better bring Johan his pills.
Thank you!

The Robot-Era team
- Federico Pecora
- Maurizio Di Rocco
- Subhash Sathyakeerthy
- Julien Bidot
- Chittaranjan Swaminathan
- Ali Abdul Khaliq

The WearAmI team
- Antonio Sgorbissa
- Barbara Bruno
- Fulvio Mastrogiovanni

The proactivity guru
- Jasmin Grosinger