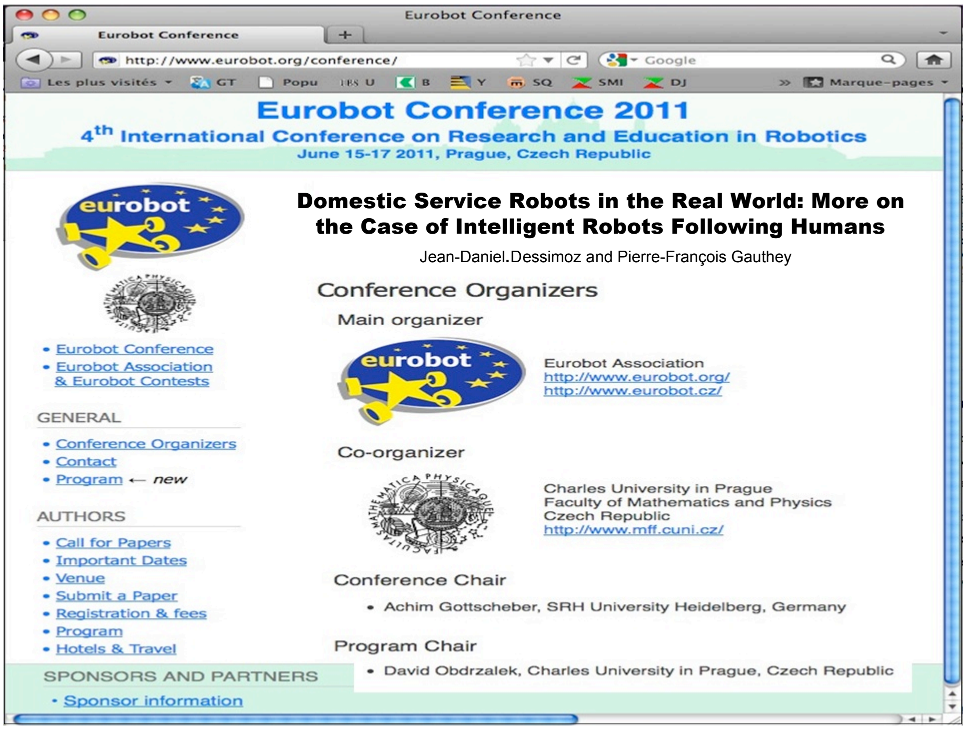

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Domestic Service Robots in the Real World: More on the Case of Intelligent Robots Following Humans

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Eurobot 2011 – Internat. Conf. on Robotics Research and Education, Prague, Czech Republic, 15-17 June 2011

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Keywords: , knowledge, cognition, cognitics, ontology, information, model, memory, service robotics, domestic applications, following and guiding, standardization

Content

1. Introduction 1 of 4

- Robotics and AI: from research to applications
- Required functionalities of robots are varied and complex; standards should help
- Special areas of interest for us:
  - AI, cognition, cognitics
  - Cooperative robotics
  - Human interaction in domestic environment
  - Go quantitative ! Analogy: height of a wall to pass over
- Intelligence is a property exclusively implemented in humans? No; re. MCS.

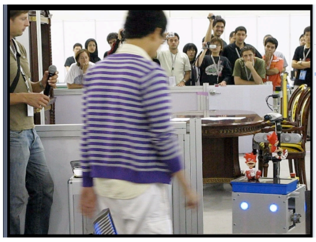
1. Introduction 2 of 4

- **Goal: cooperative robotics and human interaction for the domestic environment**
- **"Robocup", in particular "At-Home" : excellent environment for testing and validation**
- **More specifically, "following humans", basic and necessary capability of domestic service robots:**
  - **"Follow and Guide"(2007), "FastFollow"(2008), and "Follow Me" (2009, 2010 with the new concept of "checkpoints"); etc.**

1. Introduction 3 of 4

- **Publications made, in particular:**
  - **"MCS", in a book, about cognitics, quantitative cognition and thinking machines;**
  - **re. SCPR'08 about standards.**
  - **Complements recent publication [SIMPAR'10], including a taxonomy in 5 classes of human-following capabilities, based on distance and force considerations.**
- **More information given here:**
  - **need for path programming**
  - **implementing security measures**
  - **for Class 1 human-following case, the main application of human-following at home: to guide a robot for training it in new grounds, without contact between guide and robot, and a typical distance of about 1 meter between them**

1. Introduction 4 of 4



Successful examples of use of the human-following capability in @Home context *(on the left, "FastFollow*" and "Robotized Caddy"; on the right, "WalkAndTalk*")*

**** official competitions***

re. videos on http://rahe.populus.ch

Content

1. **Introduction**
2. **The need for path programming - why to follow; whom to follow; and what to follow**
3. **Implementing security measures and functional capabilities**
4. **Conclusion**

2. The need for path programming - why to follow; whom to follow; and what to follow 1 of 3

How to specify a robot the way from the TV set in the living room to the fridge in the kitchen?

- **2.1 The need for path programming**
- **2.2 Why to follow**
- **2.3 Whom to Follow**
- **2.4 What to Follow**

2.1 The need for path programming 1 of 3

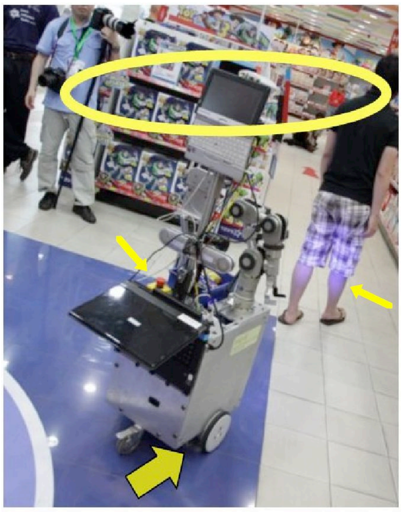
- **Robotics include many capabilities:**
  - **Some make sense on their own :**
    - **AI, vision, etc.**
  - **From a scientific and technical point of view, robotics is most specifically motion:**
    - **Robots have many joints, which require coordination.**
    - **For example, Nao humanoids have more than 20 motors to control.**
- **Targets must be devised for the coordinated joints over time; this is path programming**

2.1 The need for path programming 2 of 3

- **At least, path is determined by its end.** (usual solutions consist of interpolating in joint space for industrial robots and limb motions; and to move in straight lines for mobile robots)
- **In domestic applications**
  - Straight lines can validly be traveled only for small path increments. At medium to large scales, trajectories are more complex, and largely unpredictable
  - To some extent, robots may autonomously explore space and progressively learn the constraints, but for complex cases human guiding is appropriate
  - Ex. 1: Guiding humans in Suntec City, Singapore.
  - Ex. 2: Guiding robots in @Home2010 test at ToysRUs

2.1 The need for path programming 3 of 3

- **Ex. at ToysRUs**



2.2 Why to follow 1 of 2

- In domestic applications, trajectories are relatively complex. Between current location and desired final goal intermediary constraints must be brought into account
- Case of humans:
  - 1. Tradition and comfort: human guides another human
    - Demanding cognitive task: 15 bit/s required (details later) while 30bit/s is the upper limit for human capabilities
  - 2. Alternative when constant, deterministic, standard paths: Maps and topographic indications
    - High initial cost: elaboration of communication support and training of users

2.2 Why to follow 2 of 2

- Path programming - Case of robots:
  - 1. Traditional, declarative programming
    - Possible for simple and repetitive tasks
  - 2. Similarity to human cases:
    - Elaborate models, maps and topographic indications
      Adequate for stationary aspects, but requires expert programmers
    - Follow a guide; typically, follow a human
      Guiding is a most natural technique for humans to define locations and itineraries; implicit path programming
  - 3. Priority on the role of the follower or of the guide??

2.3 Whom to follow 1 of 1

- In domestic applications, many tasks must be done. Yet to have a chance to master them, consideration should be focused progressively on each task.
- In the context of the "Follow" task : ability of robots to recognize a specific human as the guide?
- In our approach: split identification and following:
  - Identification: key, PIN, password; ID-card, RFID, biometric tests
  - Following: ID garantee by continuity in time and location of guide (1 cm accuracy with 0.1s update rate)

2.4 What to follow 1 of 2

- A paradox of learning trajectories (following humans): dynamic changes or long-term stationarity? Unfortunately, many factors behave in between and create disturbances.
- Learning implies here that new trajectories are desirable. In these circumstances, it is appropriate for humans just to walk about to teach the robot by guiding. The domestic environment is assumed essentially stable

2.4 What to follow 2 of 2

- Following a human naturally leads to **track the environment**
- Differences: **motion versus stability**
- **Many other cases, in between**:
  - Doors (open or closed)
  - Chairs often moved
  - Humans may stand still, talk, watch television, or sleep for hours
- =>Robots to acquire more than trajectories. **Full success impossible**. Requirement of security. measures necessary

Content

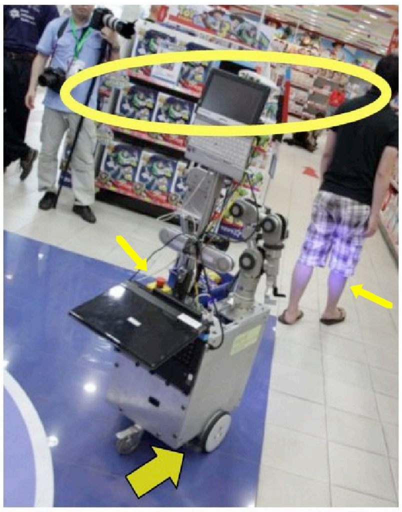
1. Introduction
2. The need for path programming - why to follow; whom to follow; and what to follow
3. Implementing security measures and functional capabilities
4. Conclusion

3. Implementing security measures and functional capabilities

Overview of some security measures *(in the Mall)*:

1. **warning blinking light;**
2. **coordinated blocking;**
3. **unidirectional blocking capability**
4. **maximal radius of influence;**
5. **emergency stop**

Others items: distance continuity, close control



3. Implementing security measures and functional capabilities

3.1 Requirements
3.2 Overview of solution
3.3 Possible close interaction to prevent crossing
3.4 Blue blinking as a discrete warning signal
3.5 Close interaction for accuracy in complicated trajectories
3.6 Blocking in a coordinated way
3.7 Unidirectional blocking
3.8 Coping with path-cutters
3.9 Maximal radius of influence
3.10 Emergency Stop and other factors

3.1 Requirements 1 of 2

- **Before attempting to implement a function: review the main requirements.**
- **it is critical to go quantitative; cognitive aspects (modeling, information, knowledge K, expertise E)**
- **speed on the order of 1 m/s**
- **positional accuracy on the order of 1%, e.g., of about 10 cm in a 10 m range**
- **a trajectory can be viewed as a sequence of locations in a 2-dimensional space**
- **=> Input information amounts to about 15 bit per second**

$$n_i = 2 \cdot \log_2(10/0.1) \cong 15[bit]$$

- **Considering a similar accuracy in the plane (1%, 3 coordinates, e.g. x,y, and orientation) about 21 bit of control, output information, must be elaborated**

3.1 Requirements 2 of 2

- **Consequently:**

$$K = \log_2(n_o \cdot 2^{n_i}) = \log_2(21 \cdot 2^{15}) \cong 20[lin]$$

$$E = K/\Delta t = 20/0.1 \cong 200[lin/s]^*$$

- **Other requirements: smooth (versus time) and fast motions**

** re forthcoming B-Prize*

3.2 Overview of solution 1 of 7

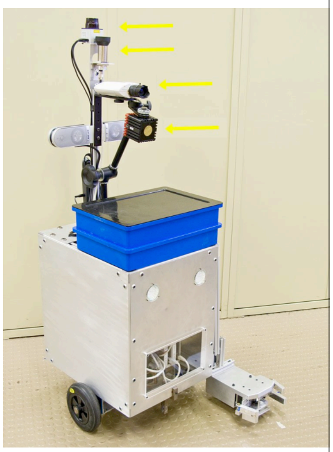
-For the perceptive capacity estimated above, and for the “Follow a person”, vision instruments or rangers are adequate; an alternative, albeit slower mode, might rely on compliant motion, i.e. on a kind of force and torque perception. In all cases, a complex hierarchy of functions and devices are necessary

- At lower levels, depending on the considered test phase (following mode or navigation), either the position or speed controls provide the best solutions, either positional accuracy or smooth motions.

3.2 Overview of solution 2 of 7

General view of RH5-Y. **From top, the yellow arrows successively point at**

1. a planar laser ranger;
2. an ultrasonic distance sensor;
3. a color camera; and
4. a 2-D time-of-flight ranger, i.e. a 3D camera.



From the top down, the hierarchy of controls is described here in five steps

3.2 Overview of solution 3 of 7

1. the linear and rotational robot motion commands are elaborated as speed targets based on the walker's location relative to the robot. Two parallel controls are in operation.

   Attention is also given to possible overall mode commands: "sleep", "follow", or "observe and interpret remote gestures".

   Distance discontinuities are monitored for possible path cutting,

   Excessive errors are monitored to guarantee orderly phasing out.

   Perception is best done with a planar ranger (240 degree aperture, 10 Hz refresh rate, about 700 radii between 0 and 400 cm, with 1 cm accuracy).

   Nevertheless, other modes are feasible (eg.3D), and some have been performed in competition (e.g., color vision or ultrasonic sensors, with much less aperture though, less angular resolution and lower distance reliability). Multi-agent approaches, e.g. with our original Piaget environment [e.g. 6], and vocal channels also act in parallel to help prevent errors and cope with them when they occur

3.2 Overview of solution 4 of 7

2. a MIMO stage performs inverse kinematics, providing the necessary joint commands (wheel 1 and 2) based on the linear and rotational speed targets naturally expressed in world, Cartesian or polar coordinates.

   In particular, a parameterized gain matrix is used.

   The functions described in points 1 and 2 are implemented on a supervisory computer (typically, an embedded laptop).

3.2 Overview of solution

3. Then, the **motion law stage** is entered , and parameterized “constant” accelerations are used for interpolating speed target values.

3.2 Overview of solution

4 The wheel velocity control is accomplished with two independent PID **closed loop controllers** with encoder management.

Coordination is implicitly ensured by simultaneous commands and appropriate respective acceleration and speed targets.

Information between the laptop and servo-controllers is conveyed via **Ethernet with the TCP-IP mode**

3.2 Overview of solution

5. **Finally (level 5), amplifiers manage the motor currents, ensuring that limits are not transgressed (two on/off action, closed-loop controls).**

3.3 Close human-robot interaction to prevent crossing

- **Guides should adapt their walking speed to the circumstances**
- **In our classical solutions, the speed evolves as the distance between guide and robot**
- **(re. [6-SIMPAR-2010]).**

3.4 Blue blinking as a discrete warning signal 1 of 3

- Customary for vehicles to have some warning signals:
  - when visibility poor,
  - risk of collisions high,
  - possible consequent casualties high.
- In our mobile robots, we have always had a blinking signal:
  - composed of LEDs of various powers and colors
  - initially meant for informing team members that operations and, in particular, parallel processes were running correctly.
  - after the 2nd year at @Home, this signal has increased in visibility and is currently a freely programmable double blue light, which typically blinks as a discrete warning signal during following tasks.

3.4 Blue blinking as a discrete warning signal 2 of 3

- Even though the objective risks are typically small and should remain so, laypersons are often afraid of machines
- To communicate clearly and early about presence and activity however reduces the possibility of surprise.
- This measure appears experimentally useful and may, in particular, contributes to increase awareness and confidence among laypersons. Because cooperative robots in domestic environment interact with people, such a measure should become a normal custom.

3.4 Blue blinking as a discrete warning signal

- In RH-Y robots, the light management in performed in several steps:
  - 1. Asynchronous commands given in Boolean mode independently on both lights (right and left) by the “strategy” agent of our proprietary, “Piaget” environment.
  - 2. For dynamic behavior, the task is handed over to a parallel Piaget agent, occasionally with parameters, and is asynchronously decided by the “strategy” agent. Steps 1 and 2 occur on the supervising computer.
  - 3. A PLC receives through Ethernet and a TCP-IP channel the instantaneous Boolean orders, and on this basis autonomously elaborates and provides robust output controls.
  - 4. Variations are possible, whereby the PLC is ordered to modulate output signals in specified ways and/or R-G-B lights replace the blue lights of Fig. 2.

3.5 Close interaction for accurate positioning in complex trajectories

- As mentioned in Sect. 3.1, guides should adapt their walking speed to circumstances:
  - complicated trajectories may require a lower speed than the average
  - a lower speed decreases the requirements for expertise.
  - a complex trajectory has higher requirements in terms of local perception by definition (re. [6-SIMPAR-2010]).

Example

RH-Y in @Home 2010, Singapore. ***Left to right, top to bottom*: The robot starts, its light starts blinking, and it follows the official guide (1), then turns and passes the wall (2), detects a path cutter and consequently announces it will stop for 3 seconds (3); when the time is elapsed, however, the guide has gone beyond limits and the robot stands still, observing the maximum safety radius (4).**

3.6 Blocking in a coordinated way

- **In the real world, many disturbances occur unavoidably.**
- **Therefore, additional, appropriate failure management procedures must be devised for situations when the main task, following the guide, cannot be achieved (re. [6-SIMPAR-2010]).**

3.7 Unidirectional blocking

- **As guides drive robots, errors occur and sometimes robots collide with hard to move obstacles, such as heavy pieces of furniture (re. [6-SIMPAR-2010]).**

3.8 Coping with path-cutters

- **As a consequence of measures advocated in Sect.3.3 and Sect.3.4, no one should attempt to cross the path between a robot and a guide. However, people, and especially children, like to play; therefore, it is tempting for many to ignore warnings and common sense and to explore what happens when a driving path is cut. Thus, paths may be cut, and appropriate measures should be devised in anticipation (re. [6-SIMPAR-2010]).**

3.9 Maximal radius of influence

- **As the distances between the robot and the guide increase, the risk also increases that they miss each other. To prevent problems, it is wise to define a maximal radius of influence (re. [6-SIMPAR-2010]).**

3.10 Emergency Stop and other factors

- **Seven measures for security listed above for robots to safely follow a guide. Some other considerations are mentioned here: additional examples, including some approaches already conducted in a @Home context.**
  - **The ultimate measure, to cut power:**
    - **measure already enforced in the @Home context;**
    - **tradeoffs between a completely hard-type power breaking approach and a completely software-based emergency management approach should be considered ;**

3.10 Emergency Stop and other factors

- **The ultimate measure, to cut power (continued):**
  - **In most of our proprietary mobile autonomous robots ("ARY" family), the circuit-breakers only affect the power circuits of the wheel drives (power remains in resources that do not directly affect the lowest structural stages: the robot maintains some ability to act);**
  - **for low-power elements, (e.g. Katana arm, or NAO humanoid), an emergency stop not mandatory, risks of casualty low. As a general guideline, a safety limit in the range of 10 W seems appropriate for this mode. More formal, international standards have come (ISO 10218-1, 2006; ISO 10218-2, 2010 and 2011).**

3.10 Emergency Stop and other factors

- **Another trend for security is to limit as much as possible power, speed and force (for arm motions, the Katana arm of RH5-Y is already certified in this regard).**
- **A similar feature is offered by compliant control. The latter principle may provide an alternative to the paradigm of "following". Inherently, the compliant approach ensures minimal distance and contact between the robot and the guide.**
- **In reverse mode, a low, constant, linear speed is provided for safe and easy motions. Implementation is most simple when the ability already exists to follow humans. This is done in our case in speed servo mode, with constant acceleration speed changes**

3.10 Emergency Stop and other factors

4 of 6

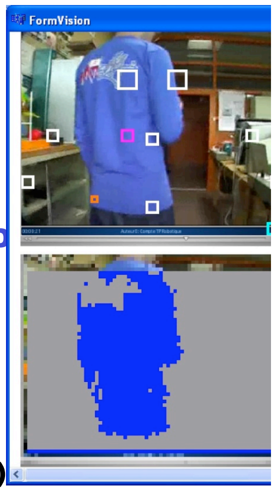
- **It should be mentioned again that in as much as circumstances allow, guides should take their leading role actively and not just expect that robots are smart enough to solve all difficulties on their own; thus more is typically achievable, in results and safety.**
- **As can be judged from professional guides of tourist groups, a special visibility feature, such as an umbrella, may help to safely increase the influence radius introduced above.**

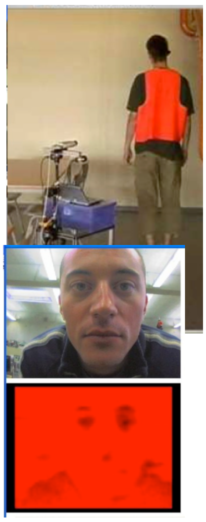
3.10 Emergency Stop and other factors

5 of 6

•Other possible, vision-based, safety measures:

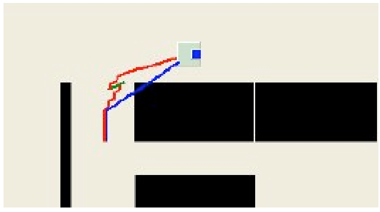
- **left, following techniques with "one of nine" optimized colors (@Home 2006) (now improved, with SbWCD classification).**
- **using high-visibility guide attire (*top right*);**
- **user identification, based on SbWCD correlation (*bottom right*)**





3.10 Emergency Stop and other factors

- Additional explored methods include the use of **lateral ultrasonic sensors** to avoid lateral obstacles, and map-registered environment properties for the same purpose. In the latter case, the guide position may be reached, while avoiding a table by **adapting behavior to map-based constraints**.



4. Conclusion

- "Robocup", and in particular the "**At-Home**" league, provide an excellent environment for focusing research in robotics and AI
  - Excellent for testing the abilities of domestic service robots.
  - **Following humans has long been recognized as a basic capability** in this context.
- Following humans allows for **convenient path programming**, and although the cognitive requirements quite high, all humans usually proceed in this same way.
- The **environment is dynamic** => disturbances occur => may cause **errors**...

4. Conclusion

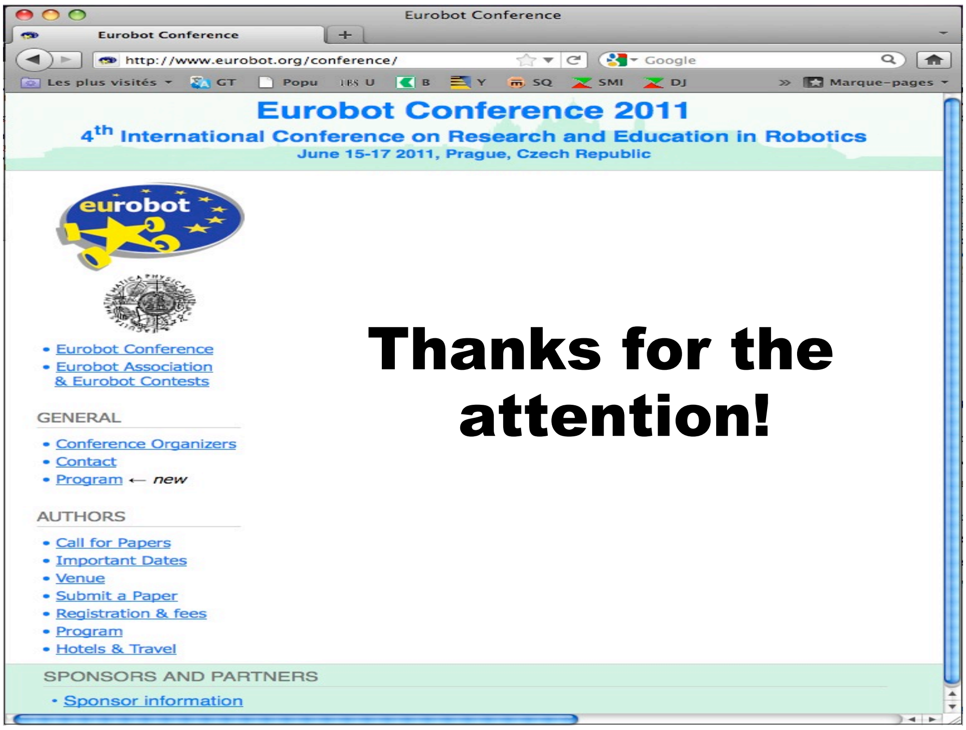
- **Safety measures must be devised, in particular,**
  - **close human-robot interaction to prevent crossing**
  - **light signals as discrete warnings**
  - **close interaction for accurate positioning in complex trajectories**
  - **coordinated, unidirectional blocking**
  - **vocal warnings and the ability to stop while people cross the path between the robot and the guide**
  - **maximal radius of influence**
  - **emergency stopping capabilities**
  - **robust vision-methods**
  - **map-based obstacle avoidance.**
- **At the most abstract semantic level, about 15 bits per second of information must be perceived. Particular sensors:**
  - **color camera, planar laser range scanner, 3D-ranger, ultrasonic sensors, and joint sensors.**
- **Smooth and stable real-time behavior by 5-level control in different technologies (computers, PLC, servo controllers, etc.).**

4. Conclusion

- **Experience in @Home context confirms a general phenomenon by which perception is crucial in mapping some of the infinitely complex reality to a much simpler, useful cognitive representation. In the typical case discussed above, it allows for an abstraction index higher than 1'000, thereby very significantly extracting the necessary application-oriented, semantic essence, as used as starting point in the quantitative cognitive assessment of Sect. 3.1.**
- **According to our opinion, above proposed methods are the best of the time and in the context of @Home the factor the most critical for success has appeared to be the ability of the guide to make use of robot capabilities.**

4. Conclusion

- Concerning the help at home, progress is regularly achieved, in a modest and incremental way, which can be translated in much use for society. For achieving results somehow similar or better than nowadays home helpers though, the @Home league will probably take a time similar to the soccer league in their effort. Their goal – to beat humans in world level competitions - is set in time for the year 2050.
- The paper complements publication [6], each summarizing, or respectively developing different aspects.
- The authors wish to acknowledge the useful suggestions of referees, numerous contributions of past RH-Y team members, as well as HESSO and HEIG-VD for their support of this research.



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Taxonomy of human-following capability and associated topics

Class 1: human-following at home is to guide a robot for training it in new grounds

Class 2: with closer interaction, possibly with contact (e.g. arm, or dedicated steering device)

Class 3: pushing people (or robots) in a compliant way

Class 4: following from a larger distance

Class 5: progressing possibly incognito or searching for a person in a crowd

Taxonomy of human-following capability and associated topics

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Other standards related to robotics

- Appropriate distances depend on circumstances (e.g. for a first encounter, according with Hall's proxemics etc.)
- Other aspects :
  - Affordance: awareness is growing of the importance of affordance, i.e. usability and ergonomy
  - Autonomy : for stable and fast behavior, autonomy must sometimes be granted to robots
  - and user's responsibility: for typical cases, the responsibility must remain on user's side (the guide), and therefore the latter must be given the possibility at all time to adjust the degree of control he or she retains, versus granting autonomy to robots.
  - Beyond body trajectory, limb configurations may also be pertinent.