

## Appendices of the paper:

Jean-Daniel Dessimoz and Pierre-François Gauthey, "Domestic Service Robots in the Real World; the Case of Robots Following Humans", Domestic Service Robots in the Real World Workshop, SIMPAR-2010 Second International Conference on Simulation, Modeling and Programming for Autonomous Robots, November 15-18, 2010, Darmstadt, Germany, (accepted for publication).

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For a longer, integrated version, of above paper, please refer to the following website: <http://lara.populus.ch/rub/3>

### Appendix A The need for path programming - why to follow; whom to follow whom; and what to follow.

To bring domestic service robots into the real world to address the most relevant problems, one pressing requirement is the need for path programming; e.g. how to specify a robot the way from the TV set in the living room to the fridge in the kitchen. In traditional programming, trajectories can be defined textually as a set of locations in a script, or clicked with a mouse on a map. But it is far more convivial just to guide the robot once through the path.

Fig. App.1 presents two examples in Suzhou (China) of Robocup 2008: 1. FastFollow challenge, with RH3-Y following its guide, then crossing another team, and finally successfully finishing first the walk through home; and 2. RH-Y as a cooperating caddie.

**Fig. App.1.** *Examples of use of the human-following capability (on the left, FastFollow).*



This point is addressed below: the need to teach pathways is discussed first, then successively refined into finer questions: why to follow, whom to follow, and what to follow.

### **AppA.1 The need for path programming**

Robotics include many capabilities, such as AI or vision, which also make sense on their own. But 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.

It is therefore no surprise that to control robots, some kind of path programming must be performed by users.

In general, the path is mostly determined by its end, and in this sense, the details of the path are not critical. 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, it is obvious that straight lines can validly be traveled only for small path increments. At medium to large scales, trajectories must be more complex, and largely unpredictable intermediary constraints must be brought into account. To some extent, robots may autonomously explore space and progressively learn what are the constraints, but for complex cases like for humans in Suntec City, Singapore, to have other humans guiding the way from @Home2010 area to ToysRUs test place is quite a necessity.

### **AppA.2 Why to follow**

In domestic applications, trajectories are relatively complex, and the current location and the desired final goal intermediary constraints must be brought into account.

It is interesting to see how the problem is handled in the case of humans. Two cases are considered. 1. The traditional and most comfortable way to define a path for a human is to have another human guiding him or her. In cognitive terms, the task is quite demanding, implying on the order of 15 bit per second of information that must be acquired (re. detailed estimation in Sect.4.1) while classical psychometric studies indicate that humans can consciously process a maximum of 30 bit/s. 2. When a path is extremely deterministic, constant for a long time, and useful for many, maps and topographic indications are usually worked out; this approach has a rather high initial cost (both for the elaboration of directions and for the training of agents using them); however, over time and as many people use the developed tools, it can become competitive with guiding.

For robots, schematically two classes of solutions may develop: in the first case, programming is performed in a more or less declarative way by programmers; and the alternate type of solutions calls for something similar to the human way. Whenever possible, the first class of solutions should apply, to load humans as little as possible; nevertheless, as for humans, the ability to learn a new path just by following potentially brings the most convenient type of solutions, especially in complex and dynamically changing home environments.

In recent years in the Robocup-at-Home competitions, a priority has been set on robots being able to follow humans, rather than on humans to guide robots. This priority may be useful from the perspective of fostering advances in technology. However, in the long term and for general use in society, in authors' view the final responsibility must shift again to the human guide in this context; robots should make

guiding a simpler exercise by following humans as conveniently as possible, but the main responsibility for successful path following should in no way lie on their side.

### **AppA.3 Whom to Follow**

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 particular, a question commonly addressed in the context of the “Follow” task refers to the ability of robots to recognize a specific human as the guide.

In our approach, the tasks of human identification and of following are schematically split.

In the first case, human identification, traditional solutions for humans call for keys; in recent times and the advent of digital society, PINs, passwords and code numbers are widespread. In special contexts, ID-cards, passports, RFIDs or biometric tests provide the proper answers. Robots are machines that include computers and are more and more connected to networks; therefore, all of these solutions can similarly be envisioned for making robots capable to identify potential guides.

In the second case, following a human, it is sufficient to ensure the continuity in time and location of the perceived guide’s path. With RH-Y (re. Fig. 1) resources, the location of the guide can be estimated 10 times per second, with an accuracy of about 1 cm. This is sufficient to guarantee also guide’s ID continuity.

### **AppA.4 What to Follow**

The paradox of learning trajectories, and consequently of following humans, is that dynamic changes and long-term stationarity are assumed at the same time. Unfortunately, there are still many other factors that behave in between and create disturbances.

Learning implies here that new trajectories are desirable, which are yet unknown for the robot. In these circumstances, it is appropriate for humans just to walk about to teach the robot by guiding.

However, learning trajectories also implies that in the future those trajectories will keep their adequacy, i.e., the domestic environment will be essentially stable.

To a large extent, the ability to follow a human can naturally lead to the ability to follow the environment; but there are also major differences, for example, in principle the human guide keeps moving, while the environment is stable.

In fact, there may be numerous other cases, e.g., doors will sometimes open or close, chairs are often moved, and humans may stand still, talk, watch television, or sleep for hours. To cope with all these phenomena requires the robot to acquire, while following a person, much more than just the trajectory; anyway, it is most probably impossible to achieve full success in all cases; occasional failures are bound to happen. Therefore, it is also important to devise appropriate security measures.

## **Appendix B Blue blinking as a discrete warning signal**

It is usual for vehicles to have some warning signals, especially when visibility is poor or the risk of collisions and consequent casualties is high. In our mobile robots, we have always had a blinking signal composed of LEDs of various powers and colors that were initially meant for informing team members that operations and, in particular, parallel processes were running correctly. After the 2<sup>nd</sup> 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.

Even though the objective risks are typically small and should remain so, laypersons are often afraid of machines (we are not aware of systemic and formal studies on this though). To communicate clearly and early about presence and activity however can reduce the possibility of surprise. This measure appears experimentally useful and may, in particular, contribute to increase awareness and confidence among laypersons. Because cooperative robots in domestic environment interact with people, such a measure should become a normal custom.

In RH-Y robots, the light management is performed in several steps: 1. Asynchronous commands can be given in Boolean mode independently on both lights (right and left) by the “strategy” agent of the Piaget environment. 2. For dynamic behavior, such as blinking, 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 R-G-B lights replace the blue lights in Fig. 2.

## **Appendix C Emergency Stop and other factors**

Seven measures for security are listed above. This list is not exhaustive though and some other considerations are briefly mentioned here.

The ultimate measure for stopping robots is to cut the power. This measure is already enforced in the @Home context.

In reverse mode, a low, constant, linear speed is provided for safe and easy motions.

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.

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.

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).

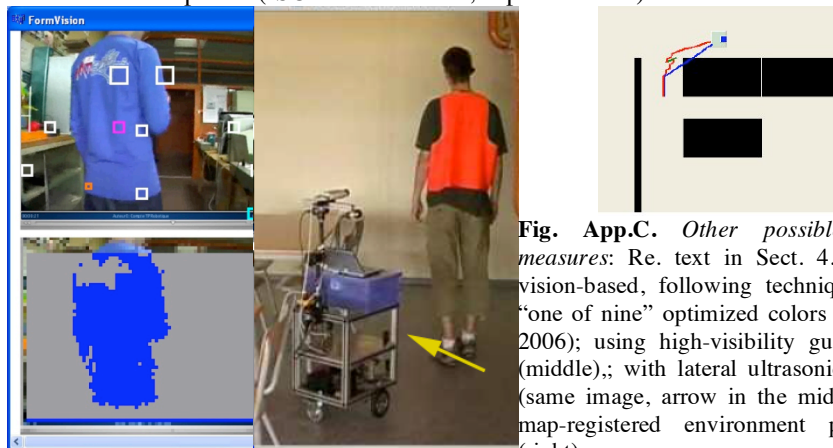
A similar feature is offered by compliant control. The latter principle may provide an alternative to the paradigm of “following”. Inherently, the compliant approach ensures minimal distance and contact between the robot and the guide.

Continuous recognition of the guide may be an advantage, even if not strictly required. In @Home 2010, in a checkpoint the guide was asked to get out of robot sight for a while. To recognize him or her, our RH-5 robot was given an original, robust, visual, saturation-based weighted color difference correlation capability [12].

The next paragraph, which discusses the implementation, gives additional examples of ways that robots can safely follow a guide, including some other approaches that have already been conducted in a @Home context.

Cutting power can be viewed in several ways. In particular, the tradeoffs between a completely hard-type power breaking approach and a completely software-based emergency management approach should be considered. In most of our proprietary mobile autonomous robots (“ARY” family), the circuit-breakers only affect the power circuits of the wheel drives, and power remains in resources that do not directly affect the lowest structural stages, which ensure that the robot maintains some ability to act.

For low-power elements, such as for the Katana arm, or the NAO humanoid, the question of an emergency stop is not mandatory because the risks of casualty are 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 102181-Part 1, 2006) or are under development (ISO 102181-Part 2, expected 2011).



**Fig. App.C.** *Other possible safety measures:* Re. text in Sect. 4.10. Left, vision-based, following techniques with “one of nine” optimized colors (@Home 2006); using high-visibility guide attire (middle); with lateral ultrasonic sensors (same image, arrow in the middle); and map-registered environment properties (right).

Fig. App.C. illustrates yet some other possible safety measures: In the context of vision-based following techniques, safety may be improved with robust vision approaches, such as the SbWCD (saturation-based, weighted intensity and hue, color differences) correlation, which is documented in a separate paper [12] and/or by using high-visibility guide attire, such as the vests that are worn on high-speed roads . 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.