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RH3-Y – Toward a Cooperating Robot for Home Applications

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Abstract. RH3-Y is the third version of an autonomous robot designed for home applications, in Robocup-at-Home context. The family is characterized by numerous original elements, of hardware, software, and cognitic (automated and cognitive) nature. Innovative technologies include systemic aspects, our proprietary Piaget programming and control environment as well as some physical components. Research focus is on automated cognition, cognitics, with applications in home robotics and in manufacturing. A particular area of interest is in the quantitative assessment of cognitive entities. Reusability is ensured by classical means, such as publications or licensing, but also by the use of COTS. A simulation environment has also been created, to be possibly made publicly available in close future. RH3-Y can be applied in real world in several ways: interaction with physical world; in robust and fully autonomous way; with the goal of solving well-defined, socially relevant tasks, at home.

1 Introduction

RH3-Y is the name of our current autonomous and cooperating robot, designed for domestic help and participation in Robocup-at-Home (RAH) world competition 2008 in Suzhou, near Shanghai [1, 2]. It is also the name of our team. Our current robot is the most recent evolution of our RH-Y robots, which themselves inherited key components from previous robots of our ARY family. We shall not describe again here in full details what has already been presented in other publications [e.g. 3, 4]. Instead, we focus below on additional data as recommended in RAH guidelines.

The paper is organized as follows. Section 2 presents an overview of RH3-Y. Section 3 gives additional information in terms of innovation, research focus, resource sharing and applicability. Late changes in size limit allow us also to disseminate some of our key research and technology results in App.A.

2 Brief overview of RH3-Y

RH3-Y is described below under three angles: hardware, software, and cognition.

In short, and from a hardware perspective, RH-Y robots are typically about 50x50x100cm large, weight about 30 kg, consist in a mobile platform including 70W active wheels, arm, end-effector, power units and energy storage (batteries), many sensors and control units interconnected with Ethernet, TCP-IP technology.

In terms of software, RH-Y robots are programmed in our original Piaget, multi-agent, real-time environment, mostly implemented currently in C++ with Windows; but in fact control is hierarchically organized with various resources matching specific needs in terms of reactivity, robustness, and global optimization; therefore Linux and IEC61'131, for example, are also present in some of RH-Y components.

Cognitive capabilities of RH3-Y are numerous, including, to a very good degree for an embedded system: visual recognition, vocal dialogue, 2D-distance perception, pose management and trajectory planning, joint coordination, learning, extensive modeling and simulation capabilities, prehension and manipulation, hierarchical and distributed control, and expertise in most of Robocup-at-Home test domains: "Fast-Follow" a person, autonomously "Navigate" through home locations, "FetchAnd-Carry" an object, recognize WhoIsWho, etc.

Our lab has also designed various test systems with other, classical AI, techniques (expert systems, neural networks, fuzzy logic, genetic algorithms, etc.). This is useful for education purpose, but for contexts as demanding as RAH, such techniques are not found to globally provide the required level of cognitive/cognitic performance.

3 Points of particular interest, in the context of RAH guidelines

At Robocup, specific guidelines have been established for the "at-Home" League, which require a special attention for innovation, research, resource sharing and applicability. These aspects are considered below in sequence.

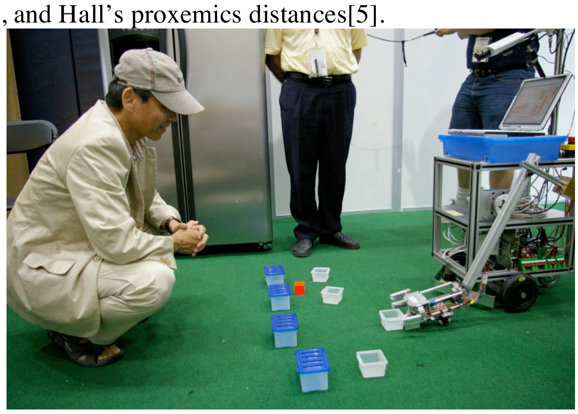
3.1 Innovative technology

Innovative technology will be discussed here in several points, ranging from market-mature solutions to prototype-level contributions.

In terms of strategy, our team favors (re-)using available solutions, whenever possible. In particular and obviously, a lot can be found on the market. We had been advocating for many years computer-based automation and Ethernet/TCP/IP as valid solutions for communication and control in most manufacturing contexts. Now this has become very common in practice. Similarly, since more than 10 years computer-based supervision and since 5 years an Ethernet hub are the key components for communication within ARY/RH-Y robots. Small-size, portable computers, as well as Ethernet-compatible PLC, cameras, and motor controllers have been integrated as soon as available on the market. A key property for motion control is additionally the possibility to parameterize motion laws and to ensure good synchronicity. In another respect, we are now using "subversion" technology for collaborative development.

Major innovative components of our own include those visible at systemic level: software and hardware architectures (Piaget environment, multiple distributed heterogeneous agents, communication topology and protocols) ; the key idea is to match specific agility and technology solutions to specific elementary requirements at all levels, in a variable yet coherent approach.

Other aspects relating to Piaget environment consist e.g. in 1. the capability in this context, to a very advanced degree, to dynamically tune up the level of simulation versus real-world implementation of the application (re. also §3.3); 2. to efficiently parametrize cognitic processes, 3. the unique capability to perform "programming" tasks at 4 different levels of complexity as well as 4. numerous cognitive components, such as e.g. 4a. possibility to map object locations from image coordinates to robot and home coordinates; or 4b. possibility to efficiently manage vocal dialogues along with all other robot functions, and Hall's proxemics distances[5].



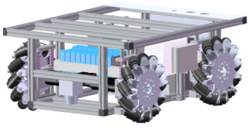


Fig.1 RH3-Y (left, with new platform in development), and a view in Atlanta of Robocup competition 2007: CopyCat task, with RH2-Y replicating motions shown by Prof. Minoru Asada (right, photo Th.Wisspeinter)

Innovative components can also be found in physical domain. First let us propose an analogy: trains might have other wheels. Instead of the old technology whereby wheels feature a special shape (large lateral disks) in order to be kept within rails, one could consider orientable (direction-adjustable) "flat" wheels and to control the latter by digital processors along with appropriate sensors. But in fact centering feedback control can classically be performed in the physical domain: current wheels can be seen as performing parallel, closed-loop proportional control with the elastic property of metal yielding a lateral acceleration force which is proportional to instantaneous trajectory error. In a similar way, our end-effector is much more sophisticated than a fast glance might tell. In addition to 1. encoder and limit sensors directly connected to an active device, with current, voltage, acceleration, speed, and position control capabilities, the "hand" includes 2. a Swedish wheel which ensures a secure minimal distance to ground, 3. a support plate, for relatively high payload, 4. three fingers in a classic centering capability, 5. augmented by a passive fourth one, in order to allow for grasping of small objects and 6. finger joints adjustable by hardware in opening range and force/torque capabilities.

For what concerns the arm, our concept is to consider it as inheriting platform dof's. Thus in addition to the capability of the platform to be posed according to 3 coordinates in the plane, the arm includes now a motorized shoulder joint, for hand motion in a fourth, vertical coordinate. (Work is also progressing in order to replace our platform by a new one featuring 4 mecanum wheels; this would yield a different tradeoff between economical cost and robot capabilities). Another point relates to human safety: in order to deal with small torques so as to avoid pinching hazards and yet to be able to handle interesting payloads an early design was featuring a balancing pendulum and a clutch. Now adjustments have been made on gear ratio and current limits may vary for motor drive, which suppresses the need of gravitational balancing device.

3.2 Focus of research (research interests)

The context of RAH League is precious for us in several ways relating to research. Very specifically, we are interested in automating cognitive processes, i.e, in the science and techniques of automated cognition; cognitics. Another interest is in the design of autonomous, cooperating *system* technologies, for domestic applications, but also for manufacturing goals.

Cognitics is a new field. When addressing a scientific field, the first thing to do is to build up a clear model, a theory with its proper objects and laws. For that, RAH context allows us to proceed schematically in three ways: in one direction, to test how useful our current proposals can be ("MCS" theory); in another direction, to possibly identify new requirements, which would call for theoretical revision and development; and in the third way we hope to be in a place where the benefits of our MCS theory can be recognized and widespread. Our current conclusion is that the MCS approach easily allows to estimate amounts of cognitive properties and to point at where the main cognitive components lie (in as much as users are familiar with classical modeling and information estimation); quantitative cognitive/cognitic estimation as been systematically performed for our solutions to RAH 2007 tests and challenges. So far we do not see a necessity to revise MCS; progress in having the theory widely recognized, and taken advantage of, becomes a top priority[1]. See also App. A.

Another area of interest for our research is the design and operation of complete autonomous cooperating *systems*, and in this sense, it is very interesting for us (and for society) to identify and integrate, especially in critical areas, the best partial solutions developed at world level. Domestic applications are a focus domain for us, and as a byproduct, progress made in RAH context can be, in addition, also transferred to manufacturing environments; we are part of the (Swiss component of) European "Manufuture" platform [6, 7].

3.3 Re-usability of the system for other research groups

Re-usability of our results is addressed in many ways. Traditional approaches such as publications, education, possibly patents are normal ways to ensure that. We also maintain a website, train interns from other institutions and participate in demonstrations and fairs. Even a priori, our strategy calling for a maximal use of available resources, from the market (COTS) or from the general community, makes the whole transfer yet easier for other users and teams.

Our RH3-Y robot could be replicated relatively easily (IPR could be rather symbolic for non-commercial use, in RAH League), but nevertheless it would have to

[1] A B-Prize is being considered

include a lot of different hardware and software resources. Much easier, the Piaget environment could be transferred, possibly with some minimal IPR restrictions, and with the goal of having it working in simulation mode. At the moment, we are considering releasing a special version of our environment, exclusively for simulation mode; the gain would be that it would thus *not* require installation of various drivers, code, and actual devices necessary only for running in the real world, and thereby our RHn-Y application would be easy to install, program and use by other parties; to experiment to a large degree solutions for RAH and similar applications; a noticeable advantage of this approach is the completeness of the description and the inspiration one might get from it. Only prerequisites: C++ Borland and Windows.

Another approach would be to transfer Piaget to other environments (we have done such transfers into C /Piaget-light, and Pascal implementations; with DOS, and RTDOS on an integrated PC - re. Beck). This is relatively easily done in the sense that our Piaget kernel does not include that many lines, but the challenge might be to find out on the new implementation target all of the capabilities we now make use of, provided by Borland components and especially Windows OS.

3.4 Applicability of the robot into the real world

RH3-Y can be applied into the “real” world in several senses. Comments follow in an order going from the broader sense to a more restrictive one.

The statement is true in a first sense, where real means “physical” world: we do not only have a theory or a simulation in a non-physical world, but indeed, our robot is acquiring data from the physical world with sensors, and acting with forces and other physical means on the physical world.

The statement is true also in a more restrictive sense, as the system is autonomous, can behave in real-time, and in particular can react to unforeseen events.

To a large extent, RH2-Y is even applicable to the real world in a more restrictive sense yet, robustness: it includes mostly industrial-grade components (re. motors, chassis, PLC, ultrasonic sensors, etc.) and components encapsulated in robust devices (laptop, batteries, Fiveco controllers, camera, etc.). There remain some elements however which may be functionally satisfactory in the context of RAH competitions, but would require some more effort in terms of proper packaging and certification (e.g. non-protected circuits, cables, bumpers and hand); this is however typical of production and market relating problems - industrialization.

Finally the most debatable point is whether any final user might benefit from using RH3-Y. Here we meet the essential goal of our RAH league; in as much as we collectively succeed in defining socially relevant tasks, and RH3-Y passes the tests, we must conclude that RH3-Y is successful in the quality of being applicable into the real world. The answer cannot be just Boolean, but should be assessed in a finer way. In 2007 in Atlanta, RH2-Y ranked second after technical tests, and 4th in final ranking.

4 Conclusion

RH3-Y is a most recent occurrence of our ARY line of robots, and specifically the third version of an autonomous robot, designed for home applications, in Robocup-at-Home context. The family is characterized by numerous original elements, in terms of hardware, software, and cognitic nature. Innovative technologies include systemic aspects, our proprietary programming and control environment (“Piaget”) as well as some physical components. Research focus is on automated cognition, i.e. cognitics, in home robotics and in manufacturing applications. A particular area of interest, for our group, consists in the quantitative assessment of cognitive entities. Reusability is ensured by classical means, such as publications or licensing, but also by the strategic use of COTS components. Possibly, a simulation environment will be made available to other RAH teams in a close future. RH3-Y can be applied in the real world in many ways: interaction with the physical world; in a robust and fully autonomous way; with a goal of solving well defined, socially relevant tasks, at home.

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Appendix A – Requirements, and elements of solution, in the field of automated cognition – cognitics; quantitative cognitics.

This appendix is organized in three parts relating to the science and technology of automated cognition, cognitics: requirement to go quantitative, summary of classical prerequisites, overview of the so-called “MCS” theory.

A.1 Requirements

When attempting to automate cognitive processes, the first step is to clearly define the essential entities in the field (i.e. in the old and classical sense, the related ontology). In particular, the definition of a metric system is required.

Consider as an analogy the mechanical aspects of the task, for a human, to jump over a wall. In such a context, reference to some notions of height, and length unit, are obviously beneficial.

It turns out that, for most humans, jumping over a 50 cm-high wall is easily performed. And over a 5 meter wall, such an action is totally impossible. Just a decade change in quantities makes a critical difference for feasibility.

Similarly, a task with cognitive components such as "Following a human", or "Playing chess" must be critically qualified with adequate units and metric values before any forecast on feasibility can seriously be made. Indeed in Robocup-at-Home (RAH) league some standard tests have been defined, with associated points, and similarly in chess world, so-called Elo units have been created. But these units are very much application-specific. Now it is the goal of the "MCS" theory to define essential entities and associated metric units for the field of cognition – meaningful as well for man-based as for automated, i.e. machine-based tasks. The MCS theory is providing a universal solution, in the same sense as the length unit may be used both to qualify chessboard sizes and clearance distances between robots and guides.

A.2 Classical prerequisites

MCS is relying on well-established notions, especially the one of "information". Everyone has heard about metric units specifically defined for information, such as the fundamental "bit" or some of its alternative instances: byte, megabit, etc.

Now it turns out that most people are NOT familiar with the techniques to estimate information quantities in general (consider for example: how much information is required to "follow a human"?). Therefore this paragraph discusses the process of estimating an information quantity and may be useful to some readers. Two difficultties typically arise. The first one relates to information theory: how much information is conveyed by a message, by a signal? The second is yet another crucial prerequisite, modeling: how do I go from the real world to a (set of) message(s), or signal(s)?

Essential definition for information quantity. Fundamentally, a single equation does it: $Q=\log(1/p)$. The amount of information in a message is given by the logarithm (typically, the logarithm is computed in base 2 , in which case the unit is the "bit" – BInary digiT) of the inverse probability of occurrence of this message.

Modeling. No matter how focused and constrained a domain is, reality is always mostly out of reach; it should be viewed as impossible to be exhaustively described: in practice the "complete" message has a "zero" probability of occurrence; an "infinite" amount of other messages are similarly possible. Therefore we have to select a goal to reach; to retain only the minimum amount of information necessary to reach that very specific goal. (Sometimes people say that a key quality of experts is that they are good at ignoring non-critical aspects; their guts focus very selectively on critical dimensions.)

Example. Let's take an example similar to the "Follow a human" task in robocup-at-home competition. How much information, Qf, is required to make a step? First, some modeling is required: what is that "to follow"?, what is "a human"? The goal is described in the rulebook and is critical in narrowing down requirements. It appears (guts, remember? – or experience; training; brain storming; trial and error; etc.) that to perceive distances between a robot and a neighboring object (a human) in a horizontal plane, at torso level, with a 10 cm resolution in an area of say 2m by 2m in front of the robot is sufficient to take the proper decisions for the locomotion process. In such a model, 400 positions are considered as possible, and if we further consider them all as equiprobable (modeling again), the answer to the question is the following: Qf=$\log_2(400)$, i.e. 8.6 bit of information.

Other remarks. The notions seen so far – information, and model- though classical, may deserve some more remarks.

- Beware of their highly subjective and dynamic nature. It is a fact that the very same message delivered to different receivers, or to the same receiver at other points in time, may carry a different amount of information! For they may be expected with different probabilities; according to models that are in frequent updates (in formation). In the previous example, 1/400 is the probability of presence of the human in any of the possible regions in front of the robot *before* perception. After perception, this probability typically changes to 1 for one specific location, and zero for all the 399 other ones.

- Remember that modeling is a necessity; a model is always false in the sense of incomplete with respect to reality; typically, it may however be good, in the sense that it helps to reach a chosen goal. So in practice to create a model, the critical question must be: for what goal? And to assess the merit of an existing model, here again the background question should be: for what purpose was this model set-up?

A.3 Quantitative estimation of cognitive properties

When the reader is familiar with classical prerequisites, it is rather straightforward to understand and use the MCS theory [e.g. 4]. I shall comment here what are probably the main cognitive entities originally defined in MCS: knowledge, K and expertise, E.

$$K = \log_2\left(n_0 \cdot 2^{n_i} + 1\right) \text{ [lin]}; \qquad E = K / \Delta t \text{ [lin/s]}$$

Knowledge. In short, knowledge is the property of delivering the right output message (n_o bit of information), spontaneously, or as a reaction to an incoming message (n_i bit of information). Intuitively the corresponding quantity may be viewed as a function of the size of a memory (table) containing all possible answers, for all possible situations. But this is just for reference, for experience shows that we can easily reach, today, K values far beyond what such a table, implemented with all (known) universe resources, i.e. ca 10^{125} protons, would ever allow.

Expertise. Expertise takes into account knowledge, but also, critically, the time necessary to deliver the output message (Δt). Synonyms: know-how, skill, competence, etc.
