Report on the

First IARP/IEEE-RAS Joint Workshop

Technical Challenge for Dependable Robots in Human Environments

May 21-22, 2001

Séoul, Korea

Chong-Won Lee, KIST, Korea
Zeungnam Bien, KAIST, Korea
Georges Giralt, LAAS-CNRS, France
Peter Corke, CSIRO, Australia
Munsang Kim, KIST, Korea

1. Workshop framework

Considering the similarity of interest and objectives, the International Advanced Robotics Programme (IARP) and the IEEE-Robotics and Automation Society (IEEE-RAS) have signed a Memorandum of Understanding agreeing to technical cooperation to foster advances in the fields of Robotics and Automation.

Both organizations recognize the importance, within the broad domain of Human Centered Robotics, of current frontline technical issues and developments in Service, Assistive and Personal Robotics.

Accordingly, within the framework of this agreement, they have decided to jointly organize a first Workshop co-located with ICRA 2001 in Seoul, Korea, on “Technical Challenge for Dependable Robots in Human Environments”.

2. Workshop objective

Robotics opens today, at the turn of the Century, a large perspective for seminal scientific and technical achievements well articulated to a highly challenging broad host of novel applications.

Central to those developments stressing the paramount role, in its various themes, of Machine Intelligence, there is the highly challenging domain of human-centered robotics where machines have to closely interact with humans.

Within these R&D directions, the application cases encompassed by public-oriented service, assistive and personal robotics emphasize the human-machine interaction where the person may be either a non-professional user or a by-stander, or both.

This clearly points out to the critical questions of Physical Safety and Operating Robustness. Both aspects can be captured by the concept of **Dependability**.

Unlike in the industrial robotics domain where the work space of machines and humans can be segmented, service and personal robots cannot but have contact interaction. The safety aspect entailed is, of course, already an important challenge addressed to Robotics research.

Still we believe a more difficult and far reaching challenge concerns Operating Robustness. Here, the issues are central to the very concept of “Intelligent” robots.

Indeed Machine Intelligence is a necessity as soon as we consider applications not strictly related to a sole and very simple task. Task diversity in not completely engineered environments and in the presence of non-professional users, implies necessarily significant levels of Robot Autonomy and sophisticated, efficient, robust, machine intelligence based friendly interfaces.

The objectives of the WS stressing the concept of ROBOT DEPENDABILITY and aiming to outline the subject contents and directions were many folded:

- to review the field technical challenges and research issues,
- to assess the research opportunities central to future critical developments,
- to foster research activity and international cooperation,
- to consider mid term and long term market product perspectives.

3. Scope of the workshop

The initial topics given to enlighten the themes encompassed by the workshop included, without being limited to pure conceptual and technical issues, system requirements, study cases, and market and societal impact aspects:

Mechanical design for human interaction
Reliable sensing and control
Fault tolerant behavior
Operability diagnosis
Fault location and isolation
Decisional autonomy and exceptional cases handling
User-robot communication robustness
Networked operation
Legal and liability issues
Standards and their role today
Interaction with impaired (blind, partially blind, deaf, mentally impaired) human beings
A variety of applications cases where robots closely interact with humans Surgery, rehabilitation, personal assistance
. Robotic guides and public oriented services
. Cleaning and house keeping
. Hospital delivery

4. Sponsoring and organization

Sponsorship

<u>IARP</u>

8 IARP countries jointly with the host country, Korea, sponsored the Workshop with the respective country representatives engaged in its direct support: Australia (Peter Corke), France (Georges Giralt), Germany (Tomas Martin), Italy (Claudio Moriconi), Japan (Kazuo Tanie), Russia (Valery Gradetsky), UK (Geoff Pegman), US (Elbert Marsh).

<u>IEEE-RAS</u>

The sponsorship comprised:

- the direct support of the Society Administrative Committee represented by its President, Steve Hsia,

- the engagement and the support of ICRA 2001 to host the Workshop.

Organizing institution

The Workshop general arrangements and logistics were carried out by the Korea Institute of Science and Technology (KIST) with:

- financial support provided by the Ministry of Science and Technology of Korea through the national project on Service Robot and Human-Friendly Welfare Robot System Engineering Research Center,
- the assistance of ICRA 2001 which contributed with workshop resources and logistic support.

5. Chairmanship and International Program Committee

Honorary Chairs:

Norman Caplan, IARP President (USA)
Steve Hsia, IEEE-RAS President (USA)

General Chairs:

Chong-Won Lee, KIST (Korea)
Zeungnam Bien, KAIST (Korea)
Georges Giralt, LAAS-CNRS (France)

International Program Commitee:

Chair: Peter Corke

Co-chair: Munsang Kim

David Barnes
Antonio Bicchi
Raja Chatila
Henrick Christensen
Ruediger Dillmann
Martin Fischer
Valery Gradetsky
Oussama Khatib
Dong-Soo Kwon
Jean-Claude Laprie
Nikos Papanikolopoulos
Geoff Pegman
Art Sanderson
Shigeki Sugano
Antonio Tornambe

6. Final program

The final program attempted to comply with the central technical and operational objectives of the Workshop:

- outline the concepts, methods and tools which define the Robot Dependability domain
- assess the state of the art and characterize the main research issues and directions.

To this aim, the Workshop comprised four salient features:

Position papers

The eight position papers selected aiming to domain assessment and large open discussion comprised:

- a first key note paper introducing the concept of Dependability in the field of Computer Systems: Fundamental Concepts of Computer System Dependability (cf. annex 1),
- seven thematic papers covering generic aspects and reflecting on the many folded impacts of dependability concepts.

Regular papers

Fifteen papers reported on current work, both covering generic aspects, study cases and market perspectives.

Two special short presentations highlighted on-going advanced developments in Entertainment Robotics (SONY, see annex 2), and in anthropomorphic ultra-light arms and articulated hands (DLR, see annex 3).

Thematic panel sessions (see annex 1)

The two thematic panels were set to provide opportunity and room for assessment and open discussion in a first phase on key aspects of the WS domain. Both included in a first phase the presentation of regular papers with the speakers joining with other panelists in the completing second phase.

The themes of those two panel sessions are, we believe, worth to be mentioned here:

- Dependability and Decisional issues and Architectures,
- Dependability: industry technical issues and market perspectives.

Concluding general round table

This Round Table, an essential feature for an IARP Workshop, had the charge to conclude the two days presentations and discussions. It provided the opportunity for sharp exchanges as well as the material to summarize the workshop contributions, the recommendations and conclusions that are reported in section 8.

To open the Round Table, the main issues discussed and the conclusions reached during the two panel sessions were reported by the two chairs, respectively R. Chatila and H. Christensen. The general discussion was further introduced by short presentations from J.C. Laprie, C.W. Lee and K. Tanie (see section 8).

7. Participants

The Workshop was attended by 60 participants (see list in annex 4) pertaining to the following categories :

- Organizers, chairs and IPC members.
- Session and panel chairs, speakers (papers/panels).
- IEEE-RAS invitees.
- IARP invitees.

8. Concluding general round table, WS summary and recommendations

8 .1. Panel composition and floor contributors

8.1.1. Panelists

Chair : G. Giralt
R. Chatila, H. Christensen, reporting as chairs of the corresponding panel session
J.C. Laprie, C.W. Lee, K. Tanie

8.1.2. Floor contributions

Following the panelists presentations, the floor outstandingly contributed with statements, comments and sharp debate with the panelists. We shall specially mention by alphabetic order: A. Bicchi, G. Conte, H. Inoue, O. Khatib, C. Moriconi, C. Thorpe, T. Wang.

8.2. Panelists contributions

8.2.1. R. Chatila

R. Chatila divided his presentation of the panel session “Dependability and decisional issues and architectures” in two parts. The first one, briefly sets the session framework and its objectives. The second part attempts to provide a comprehensive summary.

<u>Panel session framework</u>

Dependability

- Availability: readiness for service.
- Reliability: continuity of service.
- Safety: non catastrophic consequences.
- Integrity: no system state alteration.

- Maintainability: undergoes repair, evolution.

Dependable robot system

- Mechanics, sensors, processors: *hardware design*.
- Data processing, noise reduction, compliant control: *sensory processing and control, software development.*
- Perception, interpretation, representations: *Algorithms, environment and task context*. N. Pears
- Decision making, task achievement*: safe behavior, logical deduction, situation assessment, situation anticipation, diagnosis*. B. Graf
- System organization, architecture: re*al-time system, networking, global robustness*. F. Ingrand
- Human interaction: *unambiguous interpretation, anticipation, intentions.* B. Graf

Discussion issues

- In robotics, improving dependability through:
  - design,
  - perception algorithms, sensor fusion,
  - compliant control,…
  - obstacle avoidance,
  - reactive control architectures,
  - diagnosis/error recovery (supervision, AI).
- Design methods and tools ? Development cycle.
- Validation methods and tools: temporal/logical ; adequacy to task/context ?
- The role of task context and semantics ?
- Is dependability only possible at global system level ?
- Typical MTBF ; existing satisfactory systems?

Panel summary

The first and following part integrally reproduces the slides presented. In the second part, aspects orally developed and stressed are selected and briefly reported.

a) Slides presented

Ìnteraction with humans

- Levels of interaction induce different dependability needs.
- Analysis of human error.
- Acceptability by users and harmless in design, better than human in function.
- Predictability of behavior.
- Visualization, explanation.

Networked robots: intrusion, confidentiality

Task context

- Robots are not dependable because they are not capable. Precise operation conditions are not specified.
- Specifications are not as clear for robots as for computer systems.
- Robustness w.r.t. Environment variations.

Natural uncertainty characterizes (adverse) natural events. Robotics has to live with it.

- Environment cannot be engineered
- Procedures can be designed
- Logistics around the robot

System

- Formal methods, systematic approaches for development and validation.
- Diagnosis (residuals, fault analysis)
- Architecture. Dependability at the global level: well defined limits of each sub-system, exception handling by global system (supervision, diagnosis, recovery).

Metrics

- Envelop (bounds in the state space)
- Degree of satisfaction. Reversibility (entropy)
- No single metric. Discrete scale, classes and measurable properties

b) Salient issues orally highlighted

Along with the presentation, oral comments stressed the following salient issues and open topics:

- Interaction with humans puts emphasis in human trust of robot behavior. This entails a number of features among which Predictability which encompasses aspects such as action preview and, at some level, action explanation. The user should not be “surprised” by robot behavior when proceeding with a practical task (a noticeable difference for entertainment robots).

- Task variability impacts a lot on robot dependability:
  - capacities are largely impaired by over claiming and actual bad system specification
  - robustness of performance strongly depends on sensor data (e.g.: lighting conditions for vision)
  - since the environment cannot be completely engineered, natural uncertainties lague robot behavior. Nevertheless, robots are not alone: procedures and environment logistics can be devised to compensate in part
    - → Those last two aspects clearly define the key differences between computer dependability and robot dependability.

- Dependability has to be considered at the level of a global system which includes: robot(s), environment, human(s) -user(s) plus bystanders.

- Exception handling would not be possible at subsystem level and has to be taken care at the global level with recursion to the subsystems in order to effectively implement diagnosis and recovery.

8.2.2. H. Christensen: Panel Industry summary

<u>Panel session framework</u>

Participants:

- Fujie: Serv. Robotics; Casucci: SW sys.; Hamel: hazardous mat.; Lohnert: Robotics/Humans; Lee: Price/Performance

Issues:

- Verification/analysis/cost
- Interaction with humans
- The (acceptable) cost of dependability ?
- The cost/dependability is specified by "regulator"
- Dimensions & Scale of Dependability

Panel summary

The first and following part integrally reproduces the slides presented. In the second part, aspects orally developed and stressed are selected and briefly reported.

Slides presented

Dependability of Mechanisms

- Formalisms must be studies/acquired
- Also studies by others: IFIP, IEEE-CS, INCOSE,…

Robustness of dialogue with humans

- Human factors, dialogue systems
- Different from many other areas
- Domain/task(s)/… influences design significantly

Mechanical Design

- Passive compliance/Active compliance
- Design redundancy, ex kinematic redundancy, or structural redundancy ; x quadruped vs biped

Software Components

- Redundant systems, state monitoring

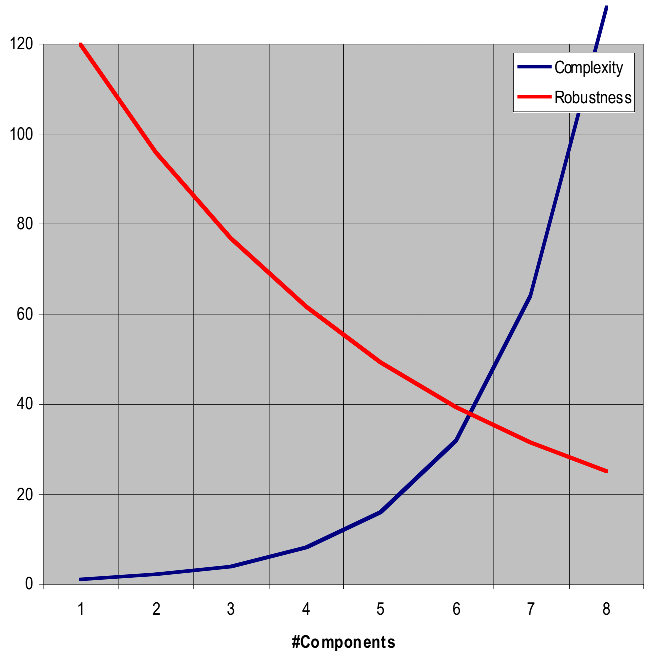
Method of composition

Considered for:

- Availability, reliability, safety, integrity, & Maint.

What is feasible ?

- Increased complexity
- Increased need for verification/analysis
- The cost is obviously task dependent (?)
- Where is the "best" compromise ?



Salient issues highlighted

- **Industrial perspectives**: it is not obvious whether or not the new industrial sectors are of interest for, or going to be taken up by the "traditional" robotics industry. This is due to several aspects:

  - The market sectors are very different for many of the new types of robots like the elderly care and toys. Thus the established companies might not be major market players in these new areas. One might expect a gradual change where some of the existing robotics companies become component / OEM providers to companies that have a stronghold in these new market sectors.

  - The current robotics companies are directed at professional customers. The new robotics markets are often associated with consumer markets, which require differences in customer support, sales channels, ... It is not obvious that existing robotics companies have the dynamics (or desire) to move into these new sectors as the demands are very different.

  - The traditional robots are based on high quality low maintenance constructions, where price is "secondary" in the sense that uptime is a major sales factor. In the consumer sector price will be alpha and omega and this requires a very different approach to design and manufacturing of such products in very high volumes. i.e. today ABB is manufacturing ~9000 robots per year. Sony is manufacturing the same number of AIBOs per day.

- Tools dependability assessment: we have well established paradigms and analysis methods for industrial machinery. We should build on it ("not to reinvent the wheel") to face the jump in complexity brought in by human factors.

- Complexity/system analysis cost: attached cost may raise to be higher than actual development. What is an acceptable cost and who will pay for it ? In hazardous material domain, there is a "regulator" that determines the amount of effort to be put in dependability aspects. It seems likely that in the new robotics industry (e.g. entertainment, assistive robots,...) insurances will be the "regulator".

- "Design to purpose": it is OK, if a toy moves in a funny way, for a vacuum cleaner robot, the user will consider it to be broken or at best not to be reliable/useful.

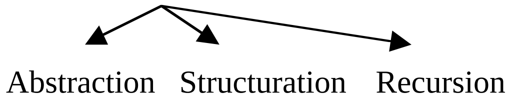
8.2.3. J.C. Laprie

Jean-Claude Laprie used, as the first two panelists, text slides to support his contribution to the concluding general round table.

Slides presented

*** General**

Definition(s)
- Minimum set of concepts
- Other formulations and synonymous exist (see Tableau 1)
- At stake: complexity mastering



*** Design for dependability**

- Not a feature that can be added afterwards
  . Dependability research must go along with functional research
- Role of assumptions in design
  . Validation: design given assumptions + assumptions vs reality

*** Measures of dependability for quantification**

- Not a single measure, several related to (some) attributes
- Important, relates to fault forecasting
- Fault prevention, removal and tolerance are (at least) as important and difficult

*** Robotics** (with apologies for potential naiveties)

- Environmental uncertainties in addition to faults for robots in non-professional environments
  . Misformulation of uncertainties: design fault?
  . Safety policy(ies) for robotics
- Fail stop vs continuity of service
  . "Intrinsically safe": jargon for fail stop
  . Acceptance of continuity of service: social process for concerned community(ies), for reaching trust and confidence (e.g., fly-by-wire, from Concorde to B777, via A-320).
- Diversity

Concept	Dependability	Survivability	Trustworthiness
Goal	1) ability to deliver service that can justifiably be trusted 2) ability to avoid failures that are more frequent or more severe, and outage durations that are longer, than is acceptable	capability of a system to fulfill its mission in a timely manner	assurance that a system will perform as expected
Threats present	1) design faults (e.g., software flaws, hardware errata, malicious logics) 2) physical faults (e.g., production defects, physical deterioration) 3) interaction faults (e.g., physical interference, input mistakes, attacks, including viruses, worms, intrusions)	1) attacks (e.g., intrusions, probes, denials of service) 2) failures (internally generated events due to, e.g., software design errors, hardware degradation, human errors, corrupted data) 3) accidents (externally generated events such as natural disasters)	1) hostile attacks (from hackers or insiders) 2) environmental disruptions (accidental disruptions, either man - made or natural) 3) human and operator errors (e.g., software flaws, mistakes by human operators)
Reference	"Fundamental concepts of dependability" 1	"Survivable network systems" 2	"Trust in cyberspace" 3

1. A. Avizienis, J.C. Laprie, B. Randell, "Fundamental concepts of dependability", March 2001.

2. R.J. Ellison, D.A. Fischer, R.C. Linger, H.F. Lipson, T. Longstaff, N.R. Mead, "Survivable network systems: an emerging discipline", Technical Report CMU/SEI-97-TR-013, November 1997, revised May 1999.

3. F. Schneider, ed., *Trust in Cyberspace*, National Academy Press, 1999.

Tableau 1

Salient issues highlighted by the speakers

- **Dependability**: We are interested in a minimal set of definitions since what is really at stake is mastering complexity. Sole solution first, good abstraction, i.e. realistic, that can be used ; second, structuration; dependability is fundamentally a recursive function. Fault is definitely a recursive function too: whatever mechanism you devise to be a checker has to be self-checking, to be fault tolerant, recovery points have to be stored in stable memory.
The Dependability concept opens the way to master complexity with tools of abstraction, structuration and recursion.
- Dependability is not a feature that can be added **after** functional design. Evidence from other fields shows it always fails which strongly implies that research for dependability must go along with research for functionality in Robotics.
- Validation: the first half of the job is validation in respect to a set of assumptions, the other half is validation of the assumptions in respect to reality. There is an important trade off: the weaker the assumptions the easier the validation but the weaker the assumptions, the more complex the design. The more complex the task and the over design.
- Remarks regarding robotics
- high complexity due to uncertainties, e.g. environment, added to faults and miss-formulations (design faults ?),
- implications are that is part of design for dependability to formulate safety policies

which have to be general/global enough but realistic as well (Assimov's laws are general enough but not realistic enough !!).

- Intrinsically safe is jargon for fail-stop. The real problem is fail stop versus continuity of service which is an unavoidable feature for realistic robotics.
- **Trust** will come in a long way of experiences with continuity of service (e.g. fly-by-wire for pilots).

8.2.4. C.W. Lee

I think Dependability has different implications for different perspectives of robots as I hear from the presentations. I can recognize at least three different types of machines. The first one is a robot as a generic machine. It does not matter which kind (e.g. automobile), the machine has to be reliable or dependable. J.C. Laprie has a good presentation of what machines should be regarding reliability and operability and so on.

Also I hear of a robot as an automatic machine. Then, a robot has to be in full control as in all real time operations. In that view, dependability is like a controllability.

That is why we can hear, for those two cases, that a robot has to be simple and stupid. This view is valid as long as the environment is well structured. When the environment is not structured and variable, this view is not as valid anymore.

The third one is an Intelligent Machine. The dependability of an intelligent machine does not comply with the aspects we considered so far. This is what we should further discuss during this round table session.

In machine centered perspectives, I think we were talking about levels of system interaction but when the robot is working in a human environment, I think we have to classify as well the type of humans that robots have to interact with. For instance, we are talking about service recipients but we have other perspectives to design for. We have to design within these perspectives considering the operator specificities. For instance, in medical robotics, we have to account for multiple different operator perspectives.

I am interested in the human robot interaction and see what dependability means to them, operator and human. For instance, for the designer reliability or dependability can be the built capacities of the robot but for the actor that uses the service robot, dependability can be a good man-machine interface. Otherwise he cannot carry out a good operation.

That is why I contend we need a good classification of the human side in Human-Robot interactions.

8.2.5. K. Tanie

K. Tanie’s presentation includes the four slides printed in the next page completed by the statements and comments briefly reported here below.

In the task to design dependability functionalities, key issues relate to the many folded problem of how to find dependable functions that satisfy the user requirements.

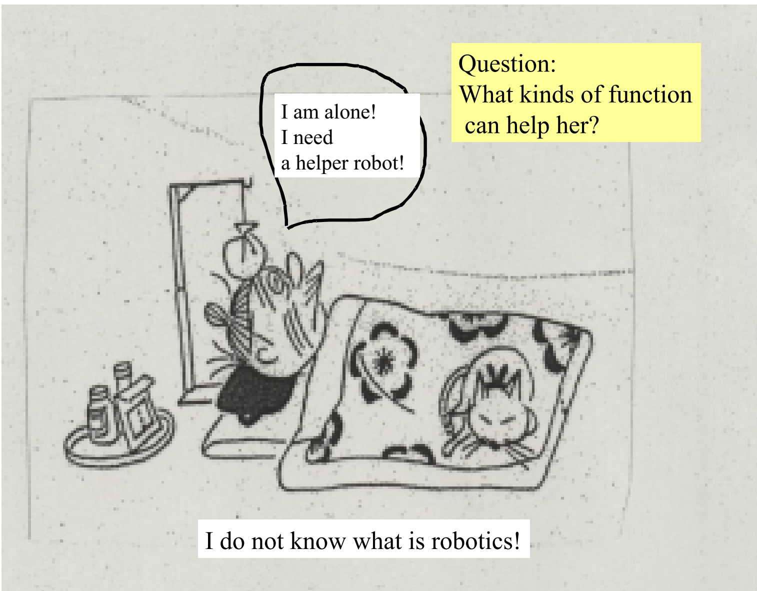
Human-Friendly Robotics is directly and foremost concerned by methodologies, possibly depending on the very nature of the application, to answer these questions.

Several key issues and ideas regarding current and future research in the domain shall be further precised here:

- Difficulty to understand user requirements and to meet them with dependable functionalities.
- Need to develop methodologies possibly based on specific application cases to achieve sufficient levels of Safety, Reliability, Maintainability,...
- Design and realization of dependable robots for human environments is a Grand Challenge roboticists have to meet.

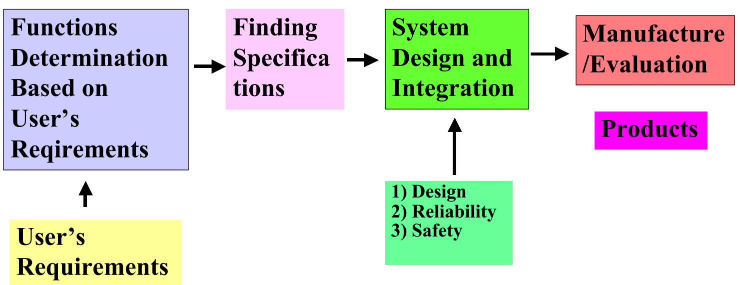
To conclude, we contend in summary that :

- to find functions which satisfy user requirements is the central problem for robotizist to devise dependable robots,
- we shall consider the concept of Dependability as seen by the **user** rather than by the designer.

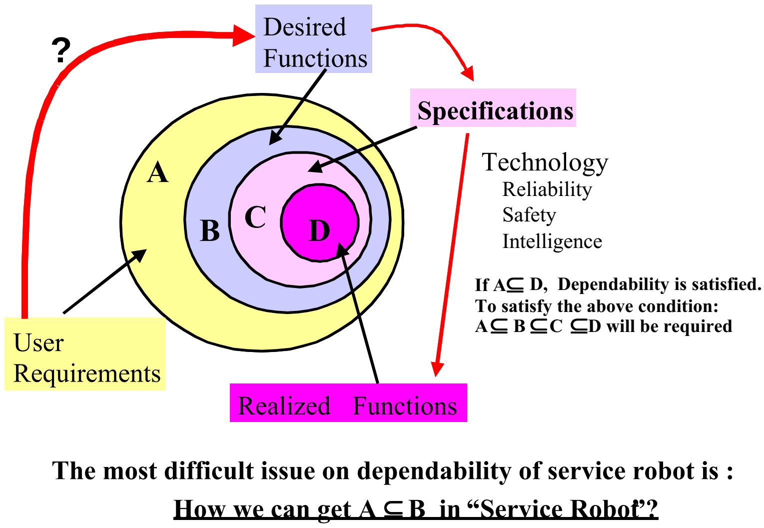


slide #1

Process of Developing Practical Products



slide #2



slide #3

slide #4

8.3. General discussion highlights

The discussion was actively engaged with salient contributions by seven intervenants from the floor (see 8.1.2) and the panelists. We have largely used for the following notes the chronological order wishing to keep the flow of questions and debates rather than a more elaborate thematic structuration.

Although we have attempted to be true to the ideas expressed, the authors of the report take sole responsibility for memory inaccuracy, misinterpretation and text shortcomings.

A first intervention addressed the issue raised by H. Christensen's panel about cost and complexity, in a two-folded way:

. technology and methods development make the "crossing points", rather the optimizing

compromise, to move over the time,
. living entities solve the problem differently relying on learning, adaptation and evolution.

Therefore the question was raised about the role and perspective of using learning for Intelligent-Machines complexity issues.

Considering the domain of robots that interact with humans, users and by-standers, it seems obvious that an Human-Friendly design is necessary -a lot of work is going on around the world on these new technologies.

It would be a real setback for Robotics if we had to suffer of a serious accident -this is something to be kept in mind.

For Human-Friendly Robot design, the issue is to have soft materials, mechanisms and kinematic structures more flexible, more compliant and not only putting a new gear and believing this realizes the mechanisms and kinematics of an human like structure.

Robot arms, any mechanical linkage in general, is a real danger we have to face not only with compliance but with realistic **soft mechanisms**. Materials people must be directly and urgently involved.

The Research efforts around the world on Service and Personal Robots suffer of too limited funding. Consequently, to attract the interest of industry appears to be of the utmost importance in spite of cost efficiency questions to make progress beyond the sole scientific issues. Hardware developments are of the utmost importance for this "new robotics" (see e.g. the PC success story).

Considering what happened for dependability and user trust for other machines (e.g. 20 years ago no electronics in cars), the following statements were made:

- Verification is so costly ; verification after is hopeless.
- We should proceed with design for dependability.
- In order to proceed in a well structured way, knowing what you are doing, theoretical tools are necessary.
- Dependability has to be verified by statistic results.
- A good theory, making steps verifiable, is necessary for Robot Dependability by design.

Caution was also advised regarding the misleading opposition: "Theory versus Experiments". New Robotics definitely needs both.

The perspectives opened by Robots designed as Intelligent Machines were without contest considered to be scientifically sound and very attractive, conceptually accommodating high level features such as Learning, Dependability,...

An intelligent system will have, by definition, multiple evolutions -although not all of them restricted to structure evolutions. This is another merging point between Advanced Robotics and Dependability concepts. Thus, we can go further and structure the problem into :

- the functional properties,

- the meta-functional properties, i.e. the dependability properties that can be schematized . From that on, the distinction between different evolution aspects can be made. A good way of thinking is, here too, to use recursion.

Robot perception rightly generated, by its impact in global performances, a large debate.

It was first commented that to understand a situation, there is a lot of capabilities behind perception that we do not have and on which very little work, unfortunately, is done.

Further comments pointed out that:

- the problem raised implied many levels of scenes analysis and recognition for which work was carried out in the field of cognitive vision,
- the issues above could not be considered in any way as relevant of sound high level sensing but pertained in fact to Machine Intelligence in full breadth since the robot had to understand its world which in fact happens to be, in the application domains of this WS, in an ever increasing part our own world !

Laws, shape, functions,... are the ingredients we need to make robots begin to work in a variety of situations. This is where Robotics interleave with the notion of dependability. Actually, all the robot research work currently done in many domains is just trying to make robots dependably work on these domains, e.g. to account for changes in light conditions. It is actually the basic research which is done. The point is that if the notion of dependability is considered in terms of assessing it in a more quantitative way, this will help to better master the complexity of the systems which are being built and to define exactly where the situation stands now and how to do better. That is not a far fetch view. This applies to the global system since as long as only one issue or element is considered, progress will never reach very far in global system Dependability, Machine Intelligence, ...

Regarding the safety aspect of dependability, a comment came back to the fail stop concept putting forward the more elaborated concept of "passive transition to an universally safe situation", i.e. a state where the robot exhibits, up to some extend, a safe behavior: transitions and final state being necessarily realized by design concurrently with the regular functionalities.

When considering leading projects in the field of Human-Friendly Robotics, one can see that the dependability aspect is not included so far. Research efforts are currently focused on many other very difficult questions but the subject will come soon enough on time to be taken over.

In an everyday environment, the most important feature for a robot is the capacity to be used continuously, which is very different from laboratory uses where you do not expect all day operations.

An actual robot has many parts and components and it is very difficult, indeed, to keep high levels of Safety, Availability, Maintenability,...

That is why when the research objective becomes robots to be used continuously by everybody -let us think about computers-, then in some sense Dependability will be the most important aspect and to be kept in mind when considering all other features from appearance to functionalities.

Dependable Robots for Human Environments is a very demanding subject. Such research advances call for repetition, multiple iterations on old projects by new ones that will improve the performances.

To claim improvements means to have some metrics, some way to represent the property: scale, matrix,...

This issue is a fundamental one for an ample development of efficient reasearch in Robot Dependability:"last did.... next will...".

8.4. Conclusions and recommendations

The WS in all its aspects, session, panels, general round table, has demonstrated the pertinence of the rich concept of Dependability in respect to today front-line research in the field of Service, Assistive, and Personal Robots where Humans and Robots have to closely interact.

Safety, one of the major components of Dependability, has been largely considered both as a firmly established part of industrial robotics and one of the important factors considered in several new robotics domains, e.g. surgical robots. Most naturally, it appears as important to further built on existing results and tools.

One of the most salient aspects in considering Dependability in relation to Human-Friendly Robotics relates to the multi-faced interactions between the human and the machine (dialog, contact,...). Here, we need to encompass very difficult issues, some of them key conceptual factors different from the ones captured by Dependability in computing systems.

A large debate about Dependability by Design concluded to the imperious necessity to concurrently design for system dependability and robot functionalities. This is certainly one of the major facts we have learnt from other fields.

The WS participants expressed a large interest for renewed contacts and exchanges in the field. We strongly recommend in consideration of this and the front-line nature of the subject to organize a second WS as early as possible.

ANNEX 1

Workshop Program

Contents

May 21, 2001

N. Pears, J. Austin and J. McDermid

(Panelists)
Felix Ingrand (LAAS-CNRS, France), Yoji Yamada (Toyoda, Japan)
Birgit Graf (IPA, Germany), Chuck Thorpe (CMU, USA), Nick Pears (U. of York, UK)

May 22, 2001

Panel Session V (9:00 – 10:30) Chair : H. Christensen

How To Commecialize Service Robots in the 21st -- V-1
M. Fujie
Embedded Software Technology --- V-2
M. Casucci

(Panelists)
Marco Casucci (CEO of INTECS-ACTIA), Frieder Lohnert (Daimler-Chrysler)
Hans Skoog (ABB), William R. Hamel (UTK/ORNL), M. Fujie (Hitachi),
Sukhan Lee (Samsung)

Coffee break (10:30 – 10:40)

Session VI (10:40 – 12:20) Chair : K. Tanie

10:40 - 11:15 **Dependable Medical/surgical Robots --- VI-1**
R. Taylor
11:15 - 11:50 **Dependability in Biomedical Robotics: Critical Issues and Main ------ VI-2 Challenges**
P. Dario, C. Laschi and E. Guglielmelli
11:50 - 12:05 **Compliant Design for Intrinsic Safety: General Issues and Preliminary Design --- VI-3**
A. Bicchi, S. L. Rizzini, and G. Tonietti
12:05 - 12:20 **A Wheelchair Robot System and its Various Interface Methods for the Disabled Persons --- VI-4**
Z. Bien, W. Song, D. Kwon, M. Chung, P. Chang, H. Park, D. Kim, J. Kim, and K. Lee

Lunch time (12:20 – 13:20)

Session VII (13:20 – 15:30) Chair : M. Kim

13:20 - 13:55 **Dependability Aspects of Multimodal Man/Robot Interaction ---------- VII-1**
R. Dillman
13:55 - 14:30 **A Consideration toward Human/Robot Dependability Based on the Current Techniques of Securing Human Safety for Human/Robot Collaborative Conveyance Tasks --- VII-2**
Y. Yamada, T. Morizono, and Y. Umetani
14:30 - 14:45 Coffee break
14:45 - 15:00 **Observer-Based Fault Diagnosis for Robotic Systems -------------------- VII-3**
F. Caccavale and B. Siciliano
15:00 - 15:15 **Special short paper**
G. Hirzinger (DLR, Germany)
15:15 - 15:30 **Special short paper**
M. Fujita (Sony, Japan)

Final Session VIII (15:30 – 17:00) Chair : G. Giralt

Others annexes are available in the Workshop Proceedings