Social Dependability: a proposed evolution for future Robotics

This paper deals with a possible scenario that could become common in a future robotics-assisted society. Robot applications are affected by dependability, reliability, safety concepts owing to the intelligence and the autonomous capability of advanced robots not only to carry out tasks without any man intervention, but also to establish whether a task must be carried out or not, depending on a high level evaluation of the environmental context. The interaction among different robots and among them and the human society is likely to increase in the future; transient Robot Societies, whose behavior cannot be foreseen with the tools we have today, are expected to generate and will pose management problems. This will demand the development of a methodology able to define the degree of dependability of a robot. The following discussion tries to address this problem by putting some ideas on the table for a possible technological, but also scientific challenge

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Introduction

Robot Dependability (RD) is generally accepted as an extension of the Dependability concept, widely used in many of the common devices of our automation society. Dependability has been defined as a methodology able to define both a confidence index between man and the machine and a set of tools able to increase this index during the machine design and within its lifetime. Born in the frame of computing science, the Dependability concept has been applied in many areas, ranging from airplanes to electronic devices. Car Dependability is perhaps one of the most diffused examples of the importance of the concept: with a total amount of about 50,000 deaths (Eurostat source) each year, only on the European roads, the need to cope with the dependability of a modern, high technology car becomes of utmost importance for a car manufacturer.

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There are Companies (i.e., J. D. Powers) that are charged by car manufacturers to carry out yearly Dependability studies on existing models worldwide.

This need is mandatory not only to comply with the safety rules imposed by public administrations, but also to support the market position of manufacturers with a safety image that has to be also as much attractive as possible.

At present, dependability in the market robots has not the same relevance than in the car market, but in consideration of the increasing interaction between robot and human population's dependability is already playing a significant role.

For instance, this is happening in working environments, where the interaction of building, handling or servicing robots with workers that are not always enough prepared to safely manage these relatively complex production tools is turning into a working safety problem.

This means that robotics is increasingly becoming a horizontal technology, and its applications are embedded in a large number of common technologies. The car itself can be considered as a robot thanks to its many automatic functions.

At present, robots directly interacting with humans, such as the "robot companion" concept, are rather a laboratory experiment than a social phenomenon, but this could change all of a sudden if the robot technology for home and in general human-conceived environments will become more affordable and economic.
ENEA has recently started to study the application of a large number of cooperating robots, performing their tasks both inside and far from the human environments [1][2][3][4][5].
In particular we have addressed a class of tasks generally oriented to the surveillance of the coastal sea bottoms. The concept we are developing is based on the exploitation of underwater ships designed and composed by cheap and easily deployable vehicles endowed with the capability to communicate with a very high bandpass owing to a new concept we have introduced in our work (see the artist view in Figure 1).
The general architecture implies coordination among many subsystems at a high complexity level and a considerable part of the development is expected to be devoted to the control of the multirobot system from the remote operator.
One of the elements arising from this preliminary work is the conceptual problem of how to cope with the control and the management of groups of autonomous or semiautonomous machines (we could call them non-human groups or, in the most wild dreams, "societies") with respect to human individuals or groups. This is a new fundamental challenge.
The basic point that represents a qualitative difference between a "robotic society" and any other group of machines is the ability to define and perform actions independently from the direct control of a human and, moreover, the relative unpredictability of these actions also by the same performers in case of unforeseen interactions.
In the daily life, anyone can lose the control of a tool (or of a machine), causing damage and hence the need to manage the situation to recover the consequences. In case of interaction with non-intelligent machines, the reciprocal influence and the unwanted behaviours of many different devices may also cause more or less severe damage, but this increases if the interacting systems operate at global dimension where damage is probably to be more severe and with more serious consequences. In this regard, specific statistical methods like FMECA [6] have been developed to evaluate the real rate of failures / faults of complex systems.
In the case of robots, these "unwanted behaviours" become the "rule of the game", that is autonomous robotic systems are always performing actions not completely controlled or foreseen by their human owners. In these situations, the human operator is completely off-guard with respect to unexpected events caused by unwanted interactions between different robots.
Our conclusion is that a new mathematical approach to the Dependability concepts should be developed to overcome these situations, and we suggest to call it "Social Dependability".

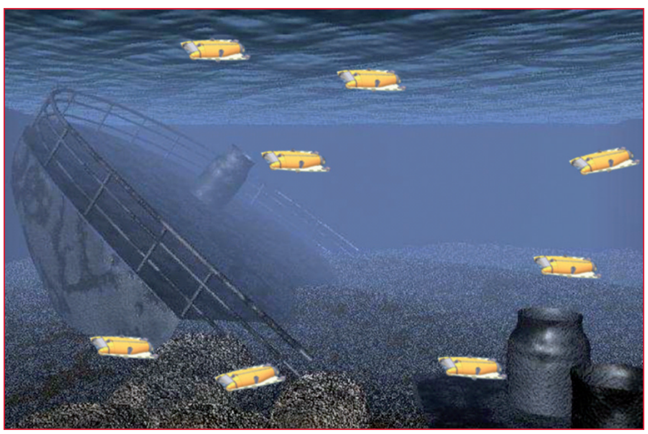

FIGURE 1 Artist view of the coastal exploration Swarm

Related works

The work that Jean-Claude Laprie has been carrying out since 1980 introducing the term of Dependability in Computer Science and the many important methods in the following years are of fundamental importance to this proposal [7][8]. Dependability applied to robotics is becoming a peculiar research field inside the active international Research Field and this has been pushed by several organizations (among these, CNRS-LAAS and IARP).
Important results were presented by TKK Automation

Technology Laboratory, Helsinki University, by Prof. Halme and his group, who have been working since 1993 on the specific theme of Robot Societies [9][10]. Some of the ideas of the current paper come, in fact, from the work of this group, especially focused on underwater group cooperation.
Recently, Ceng Xian-yi, Li Shu-qin and Xia De-shen of Nanjing University and of Jiangsu University performed interesting studies on self-organising models of robots, where many of the concepts here reported can be derived [11][12].
Also important contributions to this line could be derived by the work of Olson and Goodrich and by the analysis carried out by Crandall et al.[13][14]

Need for new definitions

The most widely accepted approach to Dependability [7][8] involves the evaluation and the mutual relationship of six system attributes. Qualifying the level of dependability of a system demands to define some categories that contribute to its definition. They are: attributes, a way to assess the dependability of a system; threats, to understand what can obstacle the dependability of a system; and correct process, that means defining what can be done to prevent or remedy the problems. Each of these categories have some features. To give some examples for Attributes, they are: Reliability, Availability, Safety, Confidentiality, Integrity, Maintainability (see Figure 2). Each one of these variables (hereinafter referred to as "state variables") can be represented by one or more values that can be generally considered as statistical variables.
Safety, for instance, can be defined under many different aspects depending on the consequences that we consider, and it is generally accepted as the inverse of the probability that a certain risk will take place.
Therefore the "safety" parameter depends on many elements beyond the specific considered risk and cannot be defined without including in the state variable the definition of the surrounding environment and its relevant typical characteristics. Some general ideas about the safety of a multirobot team could be found in [15]. In the considered literature, the terms Robot Group Robot Swarm, Robot Team, and Robot Society are used with similar and often overlapped meanings. Generally speaking, researchers of the field use these terms to make reference to some organised group of robots endowed with common purpose, with more or less developed sensing capabilities and, possibly, communication systems. Therefore the first thing we will try to do is to define a tentative, very simple, taxonomy of robot organisation in order to have the possibility to apply more articulated concepts and methodologies.

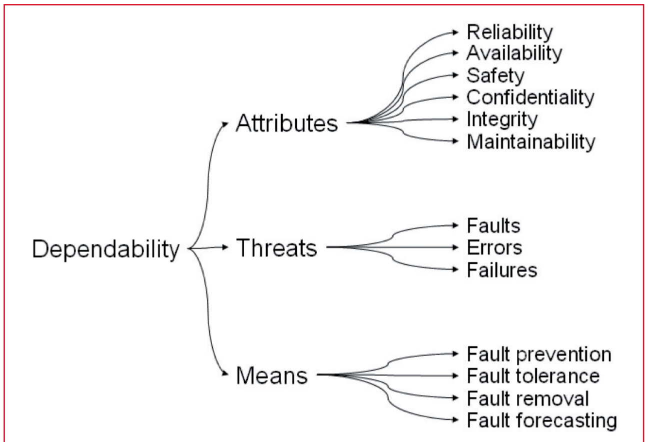

FIGURE 2 Dependability tree following Laprie et al.

Robot Group (RG)

In our selected literature there is no definition for Robot Group. This is quite obvious if we consider that a Robot Group has poor specific properties.
Our definition proposal is:
Robot Group: Non-cooperating system, intended like a casual, non-pre-planned, number of individual robotic units, having different own objectives to achieve. Each single robotic unit (or Team or Swarm) is supposed to have, anyway, behavioural rules aimed at avoiding damage or dead-lock situations in the interactions with external agents.
As an example, we can consider human people in a pub.

Robot Swarm (RSw)

Literature selected definition: "A set of dynamical mechanisms whereby structures appear at the global level of a system from interactions among its lowerlevel components. The rules specifying the interactions among the system's constituent units are executed on the basis of purely local information, without reference to the global pattern, which is an emergent property of the system rather than a property imposed upon the system by an external ordering influence" [16].

Things are in this case reasonably intuitive and we just tried to give a short and manageable definition that can collect all of the basic properties already identified by Bonabeau and others.

Our definition proposal is:

Robot Swarm: Cooperating system of individual robots, endowed with single and social rules defining a common group behaviour, without an "a priori" defined Hierarchical or Networked structure.

As an example, we can consider from nature biology a bee swarm.

Robot Team (RT)

Literature selected definition:

"The Robot Team is an interim formed and tight relation set by individual robots. It can be regarded as an autonomous zone. The team leader who has the ability of organization is the centre of the organization. The team leader has the right to divide and allocate the tasks to the members of the team without negotiation. The team leader represents the united intention of the team. Only the team leader can communicate and cooperate with the other team. And the team leader is dynamically changeable." [12]

Our definition proposal is:

Robot Team: Cooperating system of individual robots endowed with a common purpose and with a defined Hierarchical or Networked structure of coordination & communication.

As an example, we can consider in human society a Team of construction workers.

Robot Society (RS)

Literature selected definitions:

"Robot society: the robot society is organized by all of the individual robots and robot groups that have connections, which is a large group with organization." [10] *and also* "Robot society is an organised society. There is a control centre of the society members called society leader. Society leader can be the low level society or team's leader or an individual robot. The robot team can be regarded as the sub-organization of robot society"

From [12] *Our definition proposal is*:

"A Robot Society is an organised structure of individual robots with a defined structure of coordination & communication that can be lacking of common purposes in terms of jobs, short term actions or communication with human beings."

At this point we may complete the definition of RS with the concepts we have outlined in the introduction of this article concerning Dependability, and we can say that a Dependability Robot Society (DRS) is a RS having a behaviour inspired, among others, to some human "ethic-moral" behaviour rules, having the aim to "well" behave with respect to an external society or individuals. The concept of Robot Ethics has been discussed by other Authors and we do not wish to enter in it in this paper, which we want to be more focused on the mathematical aspects of the matter.

In our definition of RS and hence DRS, we stressed the possible lack of common purpose in the different elements of this society. The common purpose is a feature of almost all the natural societies, including the human one. The human society is a very complex society, which embeds many type of societies. In fact, as members of the human society we can observe that generally a society or any societal groups work better when a common aim is shared by the largest number of its members. The smaller and less defined is the common aim, the more a society has internal problems or even its same survival may be at risk.

RSws and RTs are also a Society, since they may work in many situations where space will be shared among humans and servicing robots. In the DRS, the robots form a Society shaped on the basis of some human-centred needs to achieve a dependable behaviour, also in case of different aims. In particular, the relatively narrow space creates the needs for coordination, communication and identification of the most suitable solution to simplify conflict resolutions.

Similarly to an RG, but contrary to the RT and RSws, an RS may lack a common purpose in its different robot members. However, albeit not always finalised to a common purpose, an RS (or better, a DRS) having the aim of service towards another external society or individual, has a fundamental set of behaviour rules that may recall the human ethical rules.

Towards a social dependability

Let's consider now which is the cost of the applicability of the Dependability concept to a Robot Society.
In the simplest situations, when the final objective is to derive a final characterization of a device with respect to the operator, the quantification of the Dependability in its different attributes can be relatively easy to calculate and define.
On the other hand, when we move towards more complex systems, where the final value of each single state variable depends from the interactions among many subsystems or components, calculating the total Dependability can become a process quickly divergent in terms of complexity and costs.
It's important to point out that, in case of Groups, Swarms/Teams or Societies of advanced and autonomous robots, an interaction among them could be considered under the Dependability aspect for the reasons presented in the Introduction, but the cost of this process, if carried out following the current methods, could be too high and the required time too long (almost impossible to derive in fact). Moreover, this approach could be conceived only in the case of multirobot systems (or swarms), designed for specific applications: those groups, in fact, could be considered as a single entity.
In the case of random "Robot Societies" sharing common work places, as in the former definition we gave, the calculation procedure to derive the group Dependability could not either be proposed since the composition of the group is not known a priori. Examples of random "robot societies" can be represented by different robots performing different domotic tasks, by service robots separately operating in common environments (like civil construction sites) and by other similar aggregations. The Society composition can be modified for the most different reasons, and new individuals can join in every moment to the "society" whereas others can leave, modifying both the interactions and their intensity. By the term "Intensity" here we mean the level of the action and some additional characteristics, including the physical area in which the interaction itself can take place.
Very preliminary analyses of these phenomena led us to consider that the behaviour of the whole system could be modelled following the chaos mathematics, where the interaction types and relevant frequencies identify typical attractors inside the model itself.
Other approaches during our first discussions led to propose a modification to the Dependability definition, developing a new one in terms of rules that, starting from building up different classes of interactions (i.e., physical, logical, sensorial, etc.) leads to derive a procedure to combine the single Dependability features.
Some comments are needed to clearly understand the meaning of Figures 3, 4 and 5. The classical architecture of Dependability [Figure 2] proposes the "attributes" in terms of probabilities, the "threats" in terms of events related to the "attributes" calculated probability, and the "means" in terms of methods suitable to modify those probabilities or to recover the unwanted event.
Social Dependability cannot be approached exactly with the same logical organisation since probabilities are not a fixed "attribute" of a device, but can be viewed more as continuous modifications of event probabilities depending on variables bounded to tasks, members and interactions among members, that can take place in a defined piece of space-time.
Either means partially change their meaning, adding to classical time-invariant means to prevent threats (we have not reported them into the figure for clarity reasons), further Real-Time measures, needed to cope with Social modifications.
This will be better explained in the following.
Accepting this assumption, for each class of the original definitions (attributes, etc...), we have characterised tasks, members and interactions with items that, following our first conclusions, can affect the probability of "Threats". In other words Reliability, Safety etc… became functions of *t* and of the identified parameter, and can be derived like in the following formulas in Figure 6.
Being:
Power = Sum of the power requested for a specific task (affecting the cost of threats consequences)
Speed = speed of the robot (generally a function of the task and of the single robot capabilities)

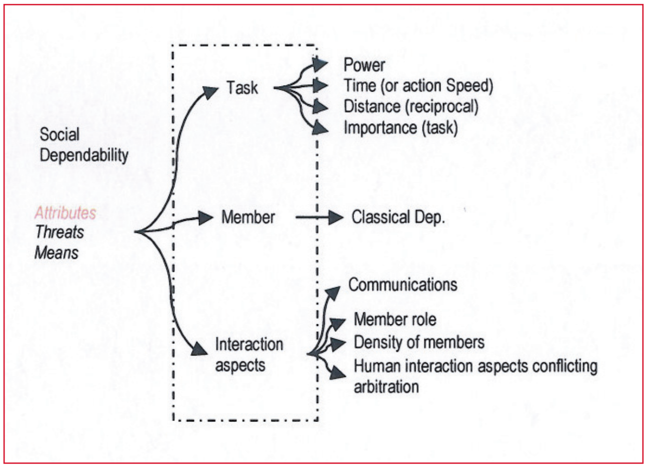

FIGURE 3

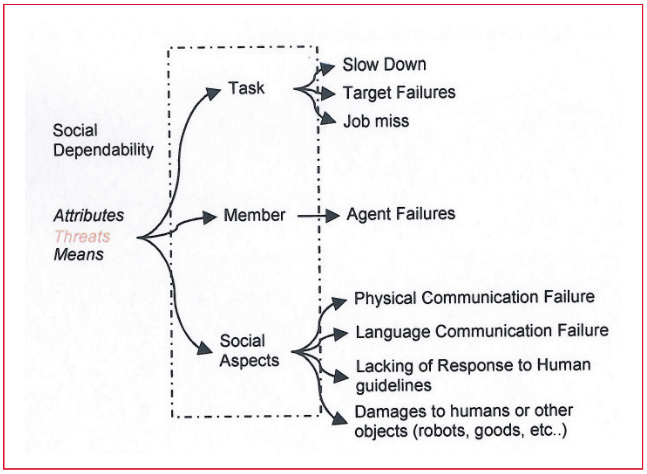

FIGURE 4

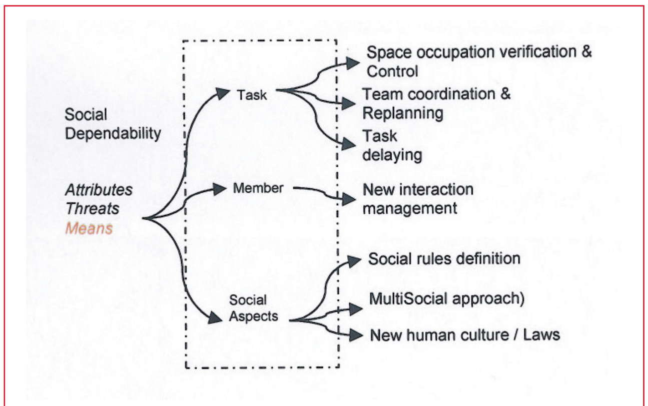

FIGURE 5

$$\text{Reliability} = R\left(t, Power, Speed, Density, \sum_i w_i CDM\right)$$

$$\text{Integrity} = I\left(t, Comm, \{Role_i\}, Density, \sum_i w_i CDM\right)$$

$$\text{Maintenability} = M\left(t, Density, HRI, \sum_i w_i CDM\right)$$

FIGURE 6

Density = density of robots in a specified area
CDM = Classical Dependability of each Member
$\mathbf{w_i}$ = Member weight (function of t), not necessarily in relationship with the role of the members
Role = Memberi role/rank in the Society
HRI = Human Robot Interaction Intensity (can be a task feature but also a function of t)
Comm = Communication Intensity (function of t)

What we have presented here is not supposed to be in any way a consolidated result, but just a possible line of application of the idea.

Keeping that in mind, what we would address and discuss here is the importance of the development of a discipline that could lead to the identification of "Social Dependability Parameters" (SDP) and to a metrics allowing the relevant management.

In a practical situation the "Social Dependability parameters" could be applied through a manageable mathematics procedure by the intelligent agents themselves (we used here a more general definition than robots), when they are operating in a common area, generally with humans.

The application of this approach could prevent potentially dangerous individuals from accessing to a specific area (provided that their relevant work is not a very high priority task), or avoid to abandon, from the same area, a society member if the consequences of the work interruption are not too serious. The evaluation of all the possible choices could be carried out by either following autonomous procedures or submitting the choice to the evaluation of a human authority after giving him all the calculation results. This latter case could be applied and is especially helpful in private houses,

where the owner can manage the associated risks.
Many elements need to be defined before trying to develop a functional concept, including the definition of a common Social area: in fact the influence area, that is the area where Social Relationships take place, can be a different variable characteristics for each individual of the "Society" and the definition of this parameter, crucial to the identification of the "Society" members, seems not to be an easy task.

Dependability metrics

In the previous chapter we addressed a conceivable procedure to achieve a possible metrics to evaluate an actual Robotics Society Dependability situation.
Many proposals have been studied and reported in literature to represent different parameters of an RS (Efficiency, Safety, Human-Robot interaction, others) under different definitions of this RS "ensemble" [17][13][12][14]. Unfortunately all these attempts are not adequate for our situation, mainly because they address parameters that can be considered, at least in the mean values, relevant to a stationary state.
The Dependability application we are more interested in is instead a dynamic state that could be represented through the mentioned SDP.
The expression shown in Figure 7 is not supposed to be an assessed definition, but is a reasonable approximation of what SDP could be.
Where k is ranging along all the considered SDP.
They could be considered as a number of vectors in a multidimensional space. The SDP set identifies a volume in this multidimensional space and we need to choose a procedure for understanding whether this volume is compatible or not with a Dependable Robot Society behaviour.
A conceptually "easy" solution in this representation can be envisaged in the definition of a number of Dependable Hypervolumes (DH) surrounding (hopefully) the SDP volume.
Therefore DH is a geometrical definition that could change in relation to practical situations. In other words, Dependable Hypervolumes could be the equivalent of security laws that can be applied to some situations (i.e., accident preventions on the

$$\mathrm{SDP}_k = SDP\left\{t, Comm, HRI, \{Role_i\}, Power, Speed, Density, \sum_i w_i CDM\right\}_k$$

FIGURE 7

job), but must be modified to be effective in different human world locations (home safety or school safety rules or others).
SDPs are modifiable entities, changing their space "giacitura" as a function of time and, in a quite large area. In a reasonable time extent, a sort of "pulsing" behaviour is expected, trying to maintain the total volume inside of the Dependable Hypervolume.
When the SDP volume inflates beyond their relevant DH (Laws violation), a serious probability for some Threat happening is expected and using a Real Time Means (Law enforcement) becomes necessary.
The former frame description is far from being complete and exhaustive and, even at this very general level, it is not formalised enough. For instance, the problem of definition of the Social Areas is still existing. In our model, in fact, Areas are defined in terms of both space and time, but it is not clear in general how the boundaries must be chosen, and how they must be defined in the general case.
Since robots have a definite work space operation, also in the case of mobile units, as an example, an Area could be the union of the Working Spaces around a centroid possibly defined by the most important task of that Area (see Figure 3).
In most situations, boundaries are well defined in terms of space (e.g., in houses) whereas in others in terms of time/space (e.g., civil construction sites), but there are many situations where the Areas (like in public places) are physically always crowded due to the simultaneous presence of people, other machines (e.g., cars) and possibly autonomous working machines (i.e., robots). In these situations Tasks can arise and end frequently in different, but physically close places, and consequently an efficient definition of the Area becomes a really difficult affair.
In these cases, Areas lean towards fuzzy and transient

entities and their management with the concepts of Social Dependability could become more difficult, demanding a strict definition and assessment of the mathematical tool.

In general anyway we assume that Areas can be kept separated or can be transformed into a suitable space where they actually are not overlapped.

Of course this is exactly the situation where an effective metrics becomes of the utmost importance to avoid threats (accidents in fact).

Another interesting approach we found in literature to achieve the realisation of an efficient metrics could be based perhaps on the work of Tucker [18] [19], but in any case, once the evaluation of the efficiency (driven by diversity) of robot societal structures has been chosen, we can have a powerful tool to obtain at least a partial social Dependability. Nevertheless the need to define a procedure for the management of Social Dependability still remains open and an appropriate methodology, different from the one we envisaged, must be defined.

Conclusions

Whatever model shall be chosen to cope with the problem defined in the present paper in the future, the problem shall be afforded to define the conditions that ensure a "safe", "reliable", "maintainable", or in a word, "dependable" interactions between the "robot society", that offer services, and the "human society" (or simply the human person), that takes advantage of their services. In our vision, it is crucial to avoid that a social rejection adverse the robotics technology can take place in case of accidents, with large impact on the public opinion (and of course to avoid or limit accidents as much as possible). Robots (or other artificial beings) will share the human space in the next future, supporting humankind. Therefore the capability to ensure the application of "Social Dependability Parameters" or an equivalent procedure, aimed at predicting the Robot Society behaviour and the consequent possible threats, will be of fundamental importance to exploit such "creatures" in our social tissue.

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