Theoretical Analysis of Recent Changes and Expectations in Intelligent Robotics

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Abstract. This paper deals with the current trend towards moving from industrial robots to the service or social robotics era. The time when robots populated the environment 'alone' is over and networked robotics and the acquisition and understanding of crowd-sourcing is fully supported by the trends in Computer technology.

Cloud Robotics is a new phenomenon supported by Cloud Computing and the main challenges question how these new trends change the tools of Artificial Intelligence and the forms of its contributions to human behavior simulation. The challenging question within this domain is the quality of Human-Robot and Robot-Robot interactions in a general environment or industrial scenario.

The role of emotions seems to be increasingly important and the impact of synthetic robotic emotions on humans is essential to human performance and productivity or entertainment in everyday life. The paper also emphasizes the importance of tele-monitoring, linked with tele-operation, as an important part of the knowledge acquired in cloud robotics and crowd sourcing. The paper draws together certain theoretical predictions on the future of intelligent robotics domains.

1 Introduction

The first glimmer of robotics began when the mankind came up with mechanical copies of biological organisms like animals, humans, etc. History proves these examples began with the Archytas of Tarentum [1] who, in 350 B.C., constructed the 'artificial mechanical Dove' which used some form of compressed air to be able to fly rather high. History is very rich with similar, yet more advanced mechanical constructors, including Leonardo da Vinci in the 15th century who designed a mechanical machine that looked like a soldier or a knight with armored protection. He also had certain engineering ideas of machines similar to helicopters and hang-gliders.

In 1505, he published the work and his drawings confirmed his ideas. Since that time, there is no verification whether it was actually constructed, but it was a very

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good inspiration for technical motivations toward later inventions and practical contribution for mankind.

Later, in the early 18th century in Grenoble, Jacques de Vaucanson had an extreme passion for automation and mechanical systems. Thus, in 1738, he designed an automated Flute and Tambourine Player and a mechanical DUCK that was able to imitate the behavior of real ducks; all these inventions used to entertain local Royalty and higher society [2].

Very important step toward computers was made in 1801, when Joseph Jacquard invented punch cards and used them to control a textile machine. Later, this technology was used and supported by the work of Charles Babbage and much later by IBM for their first computers.

Tele-operations advanced dramatically in the field of robotics in 1898. In this year, Nikola Tesla utilized radio waves to control a boat and confirmed the importance of radio-waves in the remote operation of objects at a distance from human control. This philosophical approach is very important even today when and all aspects of tele-operations are not yet fully solved. Tesla's role [3] is not as appreciated as much as it should be and the importance of this innovative man is enormous.

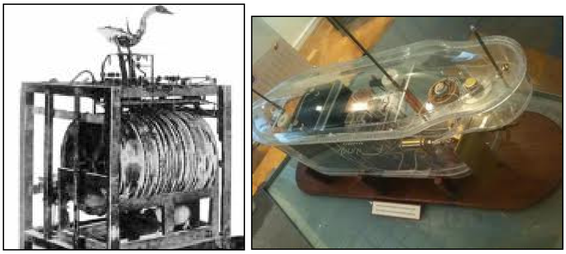

Fig. 1. Vaucanson's design of musical Automata and mechanical Duck. Tesla's tele-operated ship.

The introduction of the word 'Robot' came from Central Europe when a Czech writer Karel Capek and his brother Jozef used it in Karel's 1921 play 'R.U.R.,' an acronym for 'Rossuum's Universal Robots.' [4] Robot derives from the Czech word 'Robota' which means 'compulsory job'. Just a few years later, in 1926, Fritz Lang made the movie 'Metropolis' in which 'Maria,' a female robot, played a role.

The convergence of the development of robotics and computers is evident, thus, the contributions of Allan Turing and John von Neumann are extremely important – first with Turing's tests of computer/robot intelligence and also with von Neumann's architecture for computer hardware. Later, in 1940, Issac Asimov in his series 'A Strange Playfellow' called Robbie an artificial person. In 1950 'I, Robot', a popular novel, was written. Asimov is well known for his popularization of the term 'Robotics' as well as for claiming three robotics laws (later adding a Zero-th Law) that are very important in present times. The community of lawyers is beginning to consider the implications of robots and the significance of their existence, ownership and autonomy.

The Rockefeller Foundation set aside a special grant to fund an Artificial Intelligence seminar for selected people in 1956. In the same year, John McCarty and Marvin Minski established an Artificial Intelligence Lab at MIT, but later McCarty moved to Stanford and Minsky dominated the MIT AI Lab. The Stanford AI Lab, coordinated by McCarty, became an important AI research destination in the early 1960.

In 1961, the MH-1 Mechanical Hand was developed at MIT and, in 1962, a new robot made by the UNIMATE Company was used on General Motors Assembly Lines to replace repetitive and laborious operations. Following on in 1966, the Stanford Research Institute (SRI) established the Shakey robot with a degree of intelligence and sensors. In the same year, MIT, led by Joseph Weizenbaum, began the project ELIZA for dialog engineering that could be fully used in robot-human communications.

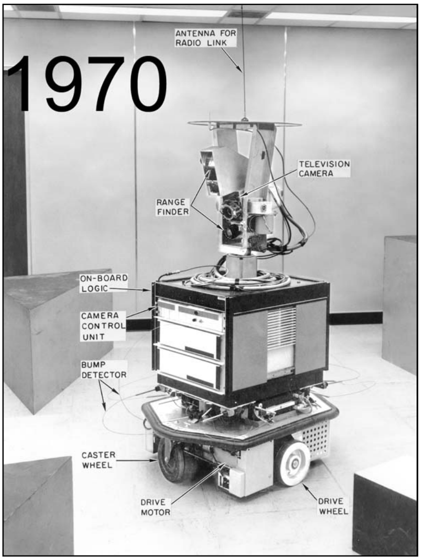

Fig. 2. The Shakey Robot from Stanford University, constructed in 1970 [5]

1.1 Computer Technology versus Robotics

The development of Computer technology was very influential to the development of robotics. The relationship between computers and robotics anchors the basic understanding of whether all processing for robots will be done on-board the robot or follow a remote-brain approach as promoted at the University of Tokyo in the early 90s, providing full ‘off-board processing’. This is a crucial question in autonomous systems that include the distribution of computer power for both ‘on and off board’ robots.

Computer trends clearly favor Cloud technology [6] and its advantages seem to outweigh such disadvantages and negatives of Cloud computing as security as well as others, currently being solved. The importance of wireless technology is enormous both in information and command transmission as well as in powered wireless transmission, critical in many areas, including robotics. In general, it is believed that wireless connectivity will rapidly improve around the globe in the sense of its speed and reliability.

All of the above technologies of cloud and wireless environments fully support the idea of progress in manual tele-operations and an almost autonomous use of robots where humans serve supervisory roles. Tele monitoring and tele-control are not yet solved by the current available technology if we consider the globe as an opportunity for robot operation and human/robot collaboration. This goal must include a crowd sourcing know-how and learning process in general. Learning procedures will change, influenced by computer technologies, big data solutions and the increased speed of computers in general.

1.2 Human-Computer/Robot Interaction

The previous problem is linked to the level of Human-Computer Interaction (HCI) and Natural Computer Interaction (NCI). There is huge progress in speech (mainly English) human machine interaction as well as the movement detection achieved mainly by the NATHAL/KINECT project [7]. Multimodal interface is the future of human-robot interaction. This also allows emotions to be incorporated between human – computer – robot interactions.

Much cross-disciplinary research on affective computing, emotional technology and emphatic computing has been investigated and a number of results from psychological emotional model implementation to NCI are underway. This interaction seems to be more and more psychologically and socially plausible, therefore, we are heading toward robots that will be companions or co-workers with humans. That means that humans can be replaced by robots and other people can work with them (robots). An interesting example is the early BAXTER project that would cooperate with and/or replace humans at assembly lines in industrial environments.

1.3 Legal Issues and Robotics

Legal Issues and Robotics [8] is a completely new area, but legal issues connected with technology are pretty well-known cases in history. What is important to understand is that this is the main legal issue concerning the reliability of a machine guaranteed by the machine/robot producer. The problems concerning more robots among humans will be very similar to having more cars in society, but this will become more and more complicated if mankind allows robots without a proper owner's and producer's guarantee. The problem is who decides whether and how robots can harm people. These are very complicated questions that can slow down the practical use of robots in everyday life.

2 Cloud Computing and Its Impact on Robotics

Cloud computing is very important to present trends in computing. It saves money, makes computing a service that is fully scalable and provides complete solutions for users who don't care about the technicalities of the task. But the problem must be specified and the requirements of the task must be defined.

Cloud Computing and Cloud Robotics are linked with the basic technology as eternally linked systems (ELS). Cloud Robotics [9] was first mentioned by James Kuffner from CMU and all efforts have been focused on creating a framework for Cloud Robotics with various types of robots, regardless of their inputs and abilities to acquire knowledge. Good examples of such projects are the RoboEarth and similar projects of that type.

The major question is if Cloud Robotics will change core approaches to Artificial Intelligence, with learning being the major and key challenge. Crowd Source learning, data and knowledge acquisition lead to Big Data and Data Discovery issues important to robotic systems.

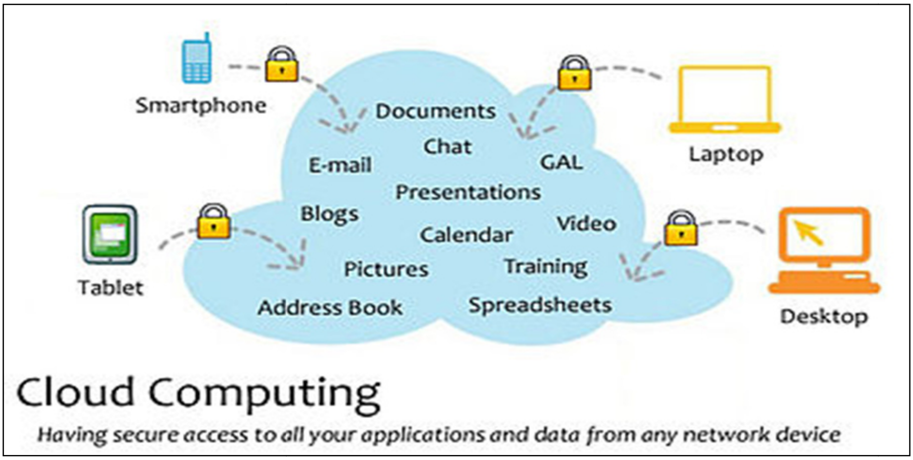

Fig. 3. Basic Concept of the Cloud Computing Paradigm which is becoming more and more financially advantageous over classical computing approaches [10]

2.1 Cloud Robotics and Crowd Source Knowledge Acquisition

Cloud Robotics has an important impact on knowledge acquisition and still more crowd based approaches are being used to build a global knowledge base [11], used and sourced by robots. A good example of such an approach is building a large fuzzy rule database. Certainly it is not an easy approach, since we have a twin-structure database. One part is the assumption portion of a rule and the second is the consequence portion. Both must be sequentially and incrementally consistent with all rules to build a large database.

If numerous machines and/or people can build knowledge bases in the form of IF-THEN rules, then numerous machines can use them. So we are applying well-known tools of Artificial or Computational Intelligence in the Cloud Computing / Robotic environment and a key question is how this technology will influence the core methods and approaches to AI and Computational Intelligence.

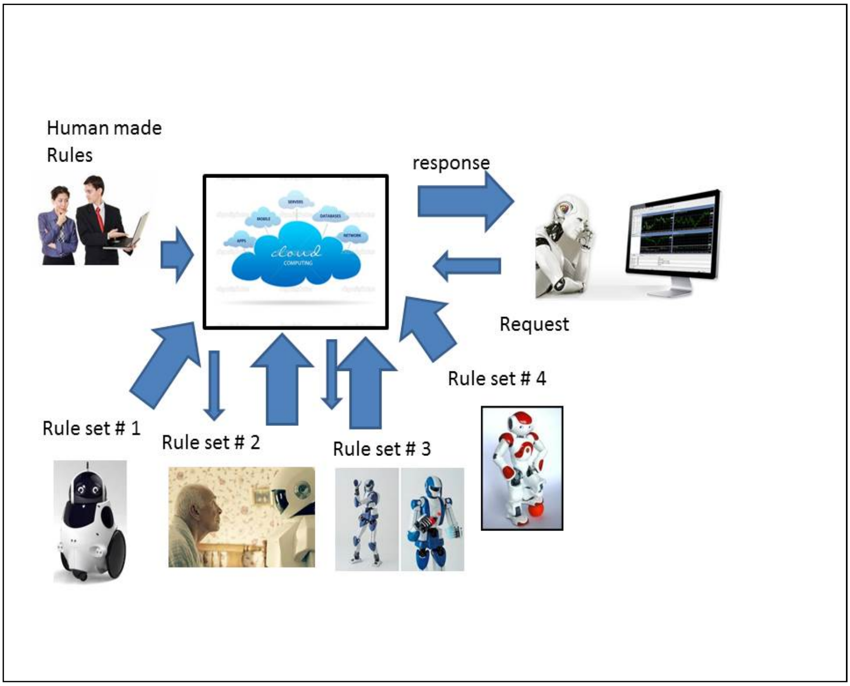

Fig. 4. Implementation of a fuzzy rule-based system in the Cloud Robotics environment

2.2 Towards World Universal Knowledge

Universal World Knowledge has been the dream of many generations and was featured in a number of sci-fi movies and analyzed from the technological point of view [12]. In the movie 'I, Robot', a VIKI computer (Virtual Interactive Kinetic Intelligence) played the role of the World Universal Knowledge. There is a number of projects related to Cloud Robotics and a universally fused knowledge base, as in project RoboEarth [ ] and a number of others. The concept of Cloud Robotics varies. One approach is that there will be virtual robots in the cloud and once the personalization of user preferences is done and a personal user switch on the robot profile is downloaded from the cloud, an actual robot for personalized human computer interaction will be accomplished.

2.3 AI Bricks as Important Parts of Cloud Robotics

The software agents for Cloud robotics with modular concepts can be useful tools for the future of crowd-based artificial intelligence powered by many people. The Agent is a virtual model of a robot or some particularly well and clearly defined procedures based on Artificial Intelligence (AI bricks) used by other agents. The scope of the problem is device and problem dependent. The concept of cloud robotics is under rapid development and concentrated technological innovation will exert a major influence on Cloud Robotics technology including wireless tele-robotics, learning and other important issues related to robotics [13].

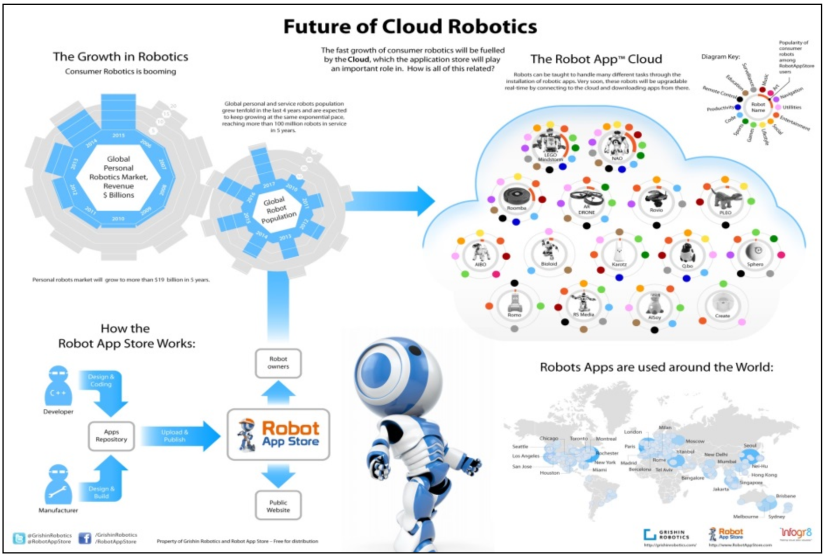

Fig. 5. Basic concept of Cloud Robotics, designed by Grishin Robotics, Ltd. of New York

2.4 Evaluating the Contribution of Cloud Robotics

There is extensive discussion whether Cloud Robotics is mostly a hype or a breakthrough technological revolution. That poses the question of how we measure the contribution of cloud technology to robotics as well as the efficiency of knowledge fusion and its utilization of the integrated knowledge by numbers of robots or robot-like entities. The basic parameters to observe are time, incremental stages, replication and impact of so-called Crowd Learning Systems on the knowledge base for robots.

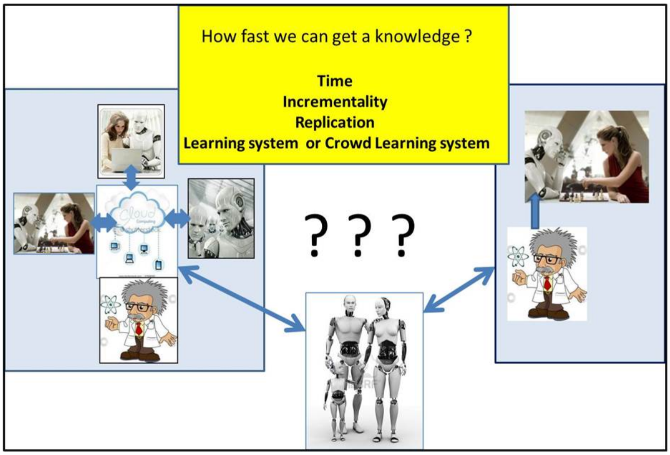

Fig. 6. The Principle for measuring the effectiveness of Cloud Robotics approaches

2.5 Tele-Scope and Cloud-Based Technology for Monitoring and Tele-control

Tele-monitoring seems to be a very important and progressive method for leading tele-operation towards assisted tele-operations and the autonomous behavior of robots under the supervisory role of humans. There is a number of active tools in this field of tele-monitoring and tele-operation. The Center for Intelligent Technologies is one of them.

Telescope is an integrated system with the ability to connect, access and join devices with different programming and user interfaces. It also allows to control, share and work with a device within a single user interface. Programmers are able to work with the device using uniform JavaScript and C# API.

By device we mean every single mechanism or gear (software or hardware) that has the ability to communicate and its current state can be read or changed. Considering this definition, devices might be different sensors or motors as well as more complex systems such as robots, mobile devices or software.

As a result, Telescope systems can communicate with a device but also provide communication between devices. For instance, controlling of a motor based on data from a speed controller can be simply achieved using this feature. The main features of Telescope systems are:

- System availability anywhere. This means both geographically and technically, with availability on PC and mobile devices using a web browser
- System availability within different web browsers
- System runs in real-time using WebSocket technology[1]
- Scalability, meaning the system's ability to deal with large amounts of connections. For this purpose we used the Redis database system[2] and its cluster mode.

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[1] `http://www.websocket.org/`

[2] `http://www.redis.io/`

System Telescope Consists of 2 Larger Parts, as May Be Seen (Fig. 7):

- Back-office service – Event server:

The essential part of back-end is the Event server which is designed to communicate and cooperate with other event servers. The server uses Python language and WebSocket technology used for communication. On the other hand, faster data storage and communication is achieved by using a Redis NoSQL Server that creates a cluster and mediates the communication between user and device based on a unique identifier.

- Front-office service – Telescope user interface,

Telescope is a WEB-based system covered by web service available for PCs, mobile devices (smartphones iOS, Android) and smart TVs. After connecting to the Telescope Web Service[3], CloudFlare[4] technology responds to user requests and guarantees the availability of static content anywhere in the world. Dynamic content is provided by PHP server which allows the users to login. Subsequently, JavaScript code takes control over communication with the server that processes the events and the actual data from the device is displayed.

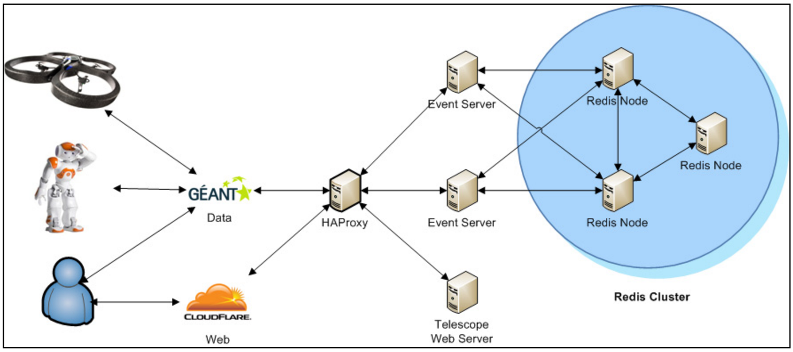

Fig. 7. Telescope system architecture overview

Overall communication within the Telescope system is joint in a single node, handled by a powerful HAProxy proxy server[5], and directs communication to the dedicated nodes.

[3] www.telescopesystem.com

[4] www.cloudflare.com

[5] http://haproxy.1wt.eu/

2.6 Monitoring and Analyzing Real-Time Data Using Telescope System

As mentioned before, the Telescope system uses WebSocket technology that provides access to real-time data. For example, we chose robot NAO[6] from a French company Aldebaran Robotics.

The basic requirement for connecting the robot to the Telescope is a wrapper program that translates communication between the robot and Event server. Telescope system also offers a security mode with user authorization using a unique ID and allowing users to share devices among each other.

Back to the NAO, the first thing to do is authorize yourself in the Telescope system using your personal ID. Only after that the system will provide a list of devices available to your account and relevant information such as online status, name or identifying number. The main requirement for monitoring data from the robot is the ability to retrieve data from the robot in real time, which can be achieved in 2 different ways. One is to regularly request specific data from a robot in a loop. The second is to wait for a value to be changed and handle each event.

We chose the first option, so the program will request data from the robot in specific time sequences. In addition, NAO robot supports 2 different return values from one motor – an actuator value and a sensor value. The first represents information that controls the motor behavior and the second displays the actual value. Comparing these two, we can easily analyze correct movements. As shown in Fig.8, the application monitors the real-time data displayed in the graph in the right area and evaluates conformity of both the movement and the motor. Evaluation in itself is a rule-based system which premises are average relative error and change of error. After evaluation, the system sorts its current state into 1 of 3 categories:

- OK (green), everything seems okay, changes of error are not too large and the average relative error is not higher than the threshold. Green also includes an option where the relative error is higher than threshold, but change is negative
- Warning (orange), change of error may be too high or average error is balancing around the threshold value
- Error (red), means a serious problem

This diagnostic system is based on an approach that connects NAO from everywhere on the planet to everywhere on the planet without the necessity of having a public IP address for a NAO robot. This improves the security and portability of the system. This is also a Cloud-ready solution, tending to become a software as a service provided through the warranty and post-warranty periods as an aftercare policy of the producer or robot owner.

[6] https://community.aldebaran-robotics.com/nao/

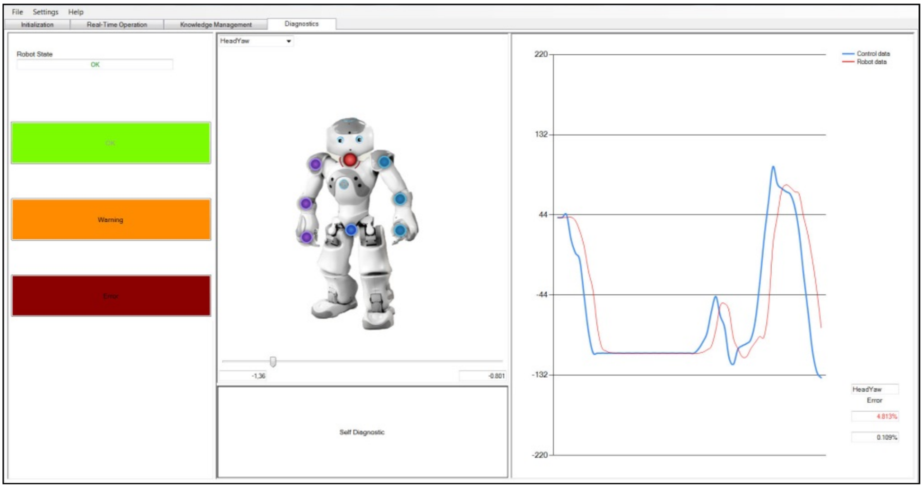

Fig. 8. NAO diagnostic system using Telescope system

3 Finding a Way towards Learning Machines

There in a number of approaches for creating an intelligent Machine. Learning is essential for this process and depends on learning goals. Learning tools can be divided into 3 categories:

1. Learning from data – mainly based on neural networks
2. Learning from humans in the form of experience – rules – Fuzzy Inference Machine
3. Learning by demonstration, using Kinect or other approaches for learning from human manual tele-operation and dividing data into functional blocks that can be reused in other tasks given by humans to robots.

Figure 8 shows the understanding of the U.S. IROBOT Company of creating an intelligent machine using tele-operation and engaging learning procedure into the process. The application potential of this approach is rather large, since a number of autonomous machines are expected to appear on the market in the near future.

One of the major problems related to Intelligent Machines are the difficulties in measuring the autonomy of the system. For the most part, there is no universal approach to this problem. We can state that it is a task or mission oriented approach and therefore we write it as:

$$GTI = HTI + MTI \tag{1}$$

Where

GTI (Global Task Intelligence) is always value 1, is a sum of Human Intelligence „HTI (Human Task Intelligence) from interval <0,1> and Machine Intelligence MTI

(Machine Task Intelligence) from interval <0,1>. Also, we can define a Machine Task Intelligence Autonomity“(MTIA) as follows:

$$\mathbf{MTIA = MTI / HTI} \tag{2}$$

So, when MTIA is 0, we are describing a manual, fully human-made process, since HTI is 1 and MTI is 0. If MTIA is a very large number, HTI is very small close to „0“ and MTI is close to „1“. This can be considered as an autonomous mission where a human is the only observer. The further consideration of MIQ Machine Intelligent Quotients related to machines have been studied in the past []. The MIQ should be domain-oriented and could be used in future for commercial advantage by selling various machines to humans.

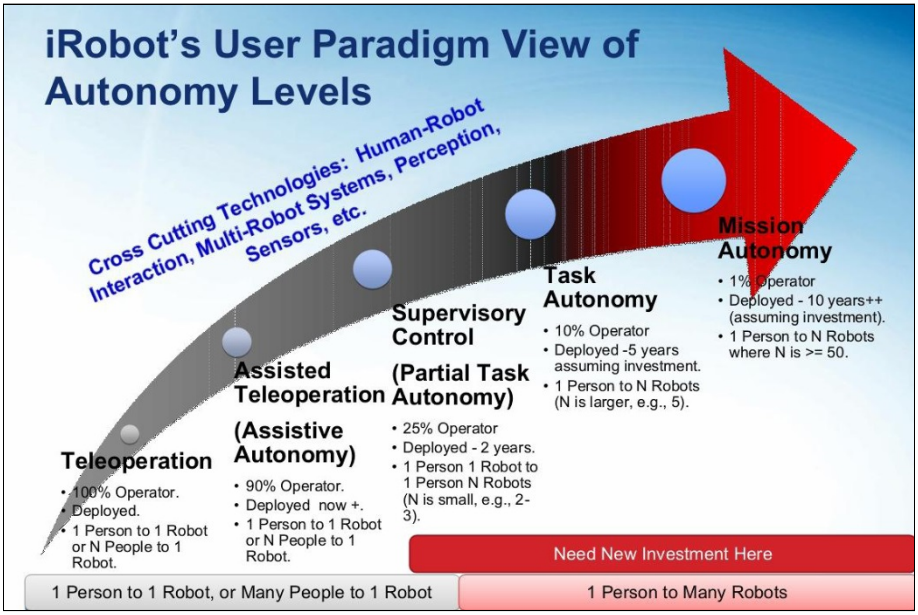

Fig. 9. The approach of Tele-operation toward Mission Autonomy operation [14]

4 Emotions and Robots–A Part of the Human Robot Interaction

4.1 Theory of RIEM (Robotic Integral Emotional Models)

The proposed theory of RIEM comes from social observation and interactions among people. The notions of Internal Emotional State and External Emotional State form the Theory of Integral Emotional Model of the Robot.

Just as in human beings, our biological systems have internal emotional states that depend on random input, environment and persons in those environments. External Emotional States could be, but are not necessarily, the same as Internal Emotional

States. External states are fully device/robot-dependent and, on the other hand, Internal Emotional States could be device/robot-independent.

The output of the RIEEM is a Social Robot Behavior based on the relationship between IEM and EEM within an Integrated Emotional Model. These relationships are characterized by weights “w11”…”w1m” up to “wn1”…”wnm” and describe intensity and connectivity which can be a personalization factor. Thus, each social robot can be emotionally set up for the convenience of a human co-worker in the sense of better performance regarding their collaboration.

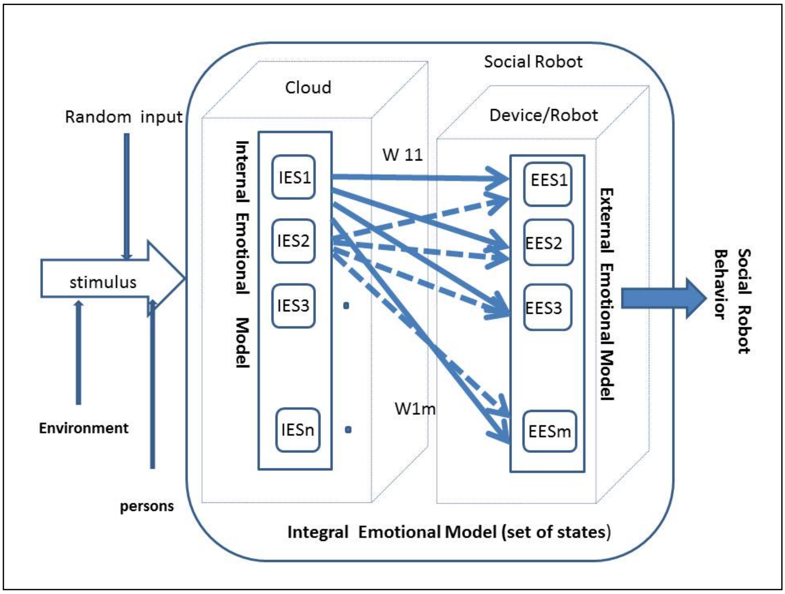

Fig. 10. Theoretical Model of Robot Integral Emotional Model

The above figure represents a model of RIEM that is based on fuzzy approaches to the set of Internal Emotional States and External Emotional States. Also, the time dimension of IES and EES is a very important factor of the Emotions, which means we have 2 fuzzy sets if we consider:

$$IES(t) \rightarrow IEM(t+q), \;\; EES(t) \rightarrow EES(t+q) \tag{3}$$

so in fact we can get a set of fuzzy sets related to time “t”.
so we have set

$$IEM = (\, IES_F(t), IES_F(t+1), \ldots, IES_F(t+q) \,) \tag{4}$$

the same is for

$$EEM = (\, EES_F(t), EES_F(t+1), \ldots, EES_F(t+q) \,) \tag{5}$$

Following these definitions, we state the following fuzzy sets for IEM set and EEM sets as follows:

If we say that fuzzy set A(t) = IESF(t), then

$$A(t) = ([IES1(t), \mu_A(IES1(t))], [IES2(t), \mu_A(IES2(t))], \ldots, [IESn(t), \mu_A(IESn(t))]) \tag{6}$$

also

$$A(t+1) = ([IES1(t+1), \mu_A(IES1(t+1))], [IES2(t+1), \mu_A(IES2(t+1))], \ldots, [IESn(t+1), \mu_A(IESn(t+1))]) \tag{7}$$

And the last member of IEM set is a fuzzy set

$$A(t+q) = IES_F(t+q) \tag{8}$$

Similar situation is on the side of EEM, so, if we assume that fuzzy set

$$B = EES_F(t)$$

then

$$B(t) = ([EES1(t), \mu_B(EES1(t))], [EES2(t), \mu_B(EES2(t))], \ldots, [EESm(t), \mu_B(EESm(t))]) \tag{9}$$

also

$$B(t+1) = ([EES1(t+1), \mu_B(EES1(t+1))], [EES2(t+1), \mu_B(EES2(t+1))], \ldots, [EESn(t+1), \mu_B(EESm(t+1))]) \tag{10}$$

And the last member of IEM set is a fuzzy set

$$B(t+q) = EES_F(t+q) \tag{11}$$

The relation between real sets IEM and EEM or better set of fuzzy sets

$$A = (A(t), \ldots A(t+q)) \tag{12}$$

and set of fuzzy sets

$$B = (B(t), \ldots B(t+q)) \tag{13}$$

as follows :

$$B\ (t) = \text{function}\ (A(t), W(t), \text{Stimuli}) \tag{14}$$

where

A(t) is fuzzy set IESF(t), W(t) is matrix of weight between A(t) and B(t) and Stimuli is integration persons, environment and external random input, see Figure 9.

This general model of Theory of Integrated Emotional Model of Robot is model-free, so in fact the IEM can be represented with some well-known models and the EEM part also has the same possibility. As it is well known, the emotional states of humans were under research observation of psychologists and they have set up number of models beginning with the Ekman model [15], Izard model [16], the very popular Plutchik model [17] and many others, including PAD (Pleasure, Arousal, and Dominance). The emotional model proposed by Lovheim [18], the Lovheim Cube of Emotion, in fact takes into consideration the Mehrabian Worker Satisfaction Scale (WSS) to achieve a comfort level for humans working with robots (or machines in general). The concept of IEM and EEM and the fully weighted connection between these layers can present a personality model of a human model behavior. Hence, the EEM depends on the robot device and its ability to express emotions.

So, at the end of the day, we can set up a model of emotional behavioral activity of a human or, by adapting in sense of Reinforcement learning, a W(t) matrix where a criteria function is set by a human. Thus, it may enhance a control adaptability of weights for its own benefit and conformability for collaboration purposes between human and machine. Very interesting feature of the Lovheim PAD model is that it also has a response to managers and commercial community to achieve the optimum productivity of humans. In the near future we may talk about a human-machine community instead of a human community. The theoretical backgrounds for the PAD Emotional State Model have been proposed by Mehrabian [19].

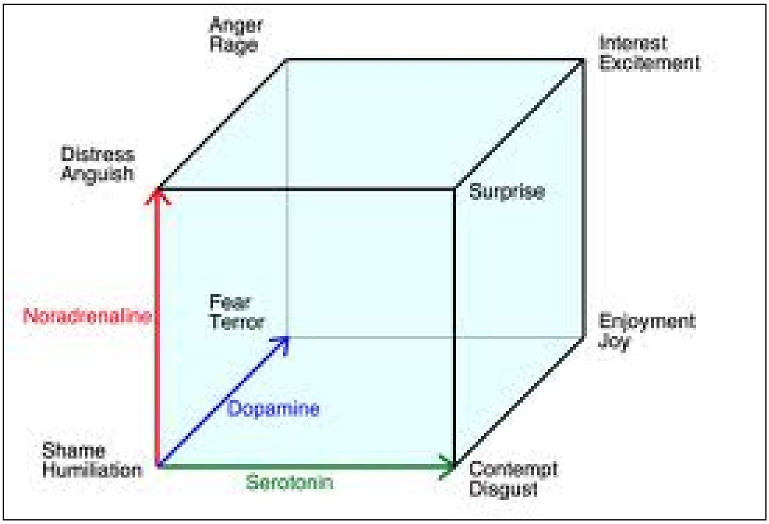

Fig. 11. Lieheim Cube of Emotion

‘Pleasure-displeasure’ defines a positively-negatively affected quality of emotional states. ‘Arousal-nonarousal’ defines a mental state that describes a mental involvement of a human/machine in a present situation and ‘dominance-submissiveness’ determines the terms of master control versus lack of control or slave-like control.

Very interesting is the distribution of emotions based on a PAD scale range from -1 to +1: e.g. angry (-.51, .59, .25), bored (-.65, -.62, -.33), curious (.22, .62, -.01), dignified (.55, .22, .61), elated (.50, .42, .23), hungry (-.44, .14, -.21), inhibited (-.54, -.04, -.41), loved (.87, .54, -.18), puzzled (-.41, .48, -.33), sleepy (.20, -.70, -.44), unconcerned (-.13, -.41, .08), violent (-.50, .62, .38). What is particularly interesting is that all those numbers can be a matter of personalization and could be adapted according to the Human Companion.

4.2 Consequences of RIEM to Human Robot Interaction

The application of this theoretical approach can have a number of implications. Creating a number of robots with similar IEM and different EEM (or vice versa) can create a very interesting situation where various robots may have a different IEM and similar EEM. Then, certain implications arise for other states of EEM, while maintaining the different IEM. The logic of these theoretical layouts can be intriguing and lead to a number of interesting personalization effects which are hidden in the adaptations of weights between IEM and EEM.

These adaptations can be set up for the user in a mirroring way (who likes to collaborate with machines that have similar emotions as the user) or simply setting up emotional responses of the machine for user's convenience and regarding the task in which the user collaborates with the robot.

5 Estimating the Future of Intelligent Machines

Generally, there is a number of communities driving intelligence and machines towards autonomous systems. The impact of the technology is enormous and it enables core and fundamental research including the basic principles of Artificial Intelligence and Ambient Intelligence in general. We expect the the following factors will influence the development of intelligent machines:

1. Needs of the market and legal issues related to Autonomous systems;
2. Computer network connection speed and wireless network development including wireless power transmission;
3. Cloud technology development and integration of cloud-based virtual robotic rooms as a pre-sale for renting specific tools for case-based operations. Cloud robotics will be a very important factor in service and social robot development;
4. Social robotic needs of society and human acceptance of robots as companions;
5. Building of a general knowledge-base will be a matter of commercial relations based on domain-oriented pieces of knowledge for robots or groups of robots;
6. Human-robot interactions will be multimodal, less language-dependent and introduced into everyday life. Communication with machines in every form will be natural and essential.

We are approaching an exciting era that will be influenced by technology, financial profit and human society's ability to accept negative impacts of machine-human coexistence. Will humanity embrace such increase in the quality of life in the name of harmony, prosperity and its benefits to human society?

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