Next Generation Robot Workshop 2005
Templates of Identified Needs

August 23, 2005
Organized by the Robotic Industries Association (RIA) and the Manufacturing Engineering Laboratory of the National Institute of Standards and Technology (NIST)
NIST Campus
Gaithersburg, Maryland, USA

This was the organizational meeting to initiate a standards development effort to define the safety and performance requirements for the Next Generation Robot. The NGR is envisioned as a circa 2010 machine incorporating inherent safety design and benign operating features which enable and promote lean manufacturing. The meeting offered multiple stakeholders the opportunities to identify and target promising new technologies; establish requirements for interdisciplinary research efforts; and relationship building for the formal standardization effort. This meeting was an open brain-storming session with out-of-the-box thinking encouraged. Sponsored by the Robotic Industries Association, this meeting was hosted at the NIST facilities in Gaithersburg, Maryland. For more information contact Jeff Fryman at the RIA jfryman@robotics.org; (734) 994-6088.

Here is a thought-provoking list of subjects that was discussed:

1. Plant floor clothing, gloves and hats, which protect from injuries, without restricting mobility, dexterity and comfort.
Possible candidates are micro/nano technology composite garments, gloves and hats.
2. Embedded sensors which identify the presence and identity of machine operators.
These could be sensors embedded in human garments and/or robot skin, which constantly search for human presence and identity in the machine restricted area.
3. Impending injury warning systems.
Similar to sensors described in (2), which are now looking for close proximity to moving objects, high temperature or high voltage surfaces, etc.
4. Human vital signs monitoring systems.
Systems which will detect extreme biological state signs and then trigger alarms and provide the location and identity of the injured individual.
5. Safety sensing vision systems.
6. Force/motion sensing
7. Trajectory prediction/monitoring
8. Access permission
9. Force dynamics/limitations/testing
10. Servo motor/control development
11. Safety physiology
12. “Smart” materials/composite technologies
13. Tactile response
14. Scanning technologies
15. The regulatory environment

NIST Templates of NGR Needs:

1. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Research that will enable to prove and certify the safety of NGR**
Economic Significance	High
Technical Barriers	Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Safety Testbed
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	The best safety equipment will not be good unless the regulatory agencies are convinced that it performs adequately. There is need for research that will enable to move to regulatory change. This could include computer simulations, tests with instrumented dummies, etc., which can be used to validate safety claims and perhaps even rate robots according to their accident prevention capability.

2. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Classify safe robots (validate safety claims)**
Economic Significance	High
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	Quantify Safety Risk
Potential Solutions	Safety Testbed
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	The level of operating safety of a robot cannot be currently recognized from their external appearance and that can expose people to great danger. There is a need to classify robots according to their ability for safe operation and to clearly communicate that information to anyone approaching a robot. The safety classification claim must be validated.

3. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**NGR safety credibility for regulators, managers and labor unions**
Economic Significance	High
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	Quantify Safety Risk
Potential Solutions	Safety Testbed
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	The finest standards and safety validations will not be worth very much if the regulators, managers and labor unions do not accept and promote them. A parallel path should be followed where these important players should be engaged and involved in the development of the NGR concept and technology.

4. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Easy lock out**
Economic Significance	High
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	Detection of the presence, location and ID of personnel inside the restricted space
Potential Solutions	Distributed micro/nano sensors and RFID
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	Ideally we would like to make lock out as easy as pulling a gate plug, which will increase the level of safety significantly. This work will involve the participation of robot integrators.

5. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Alternatives to initiating an immediate stop (E-Stop) (varying speed, direction, proximity)**
Economic Significance	High
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	Detection of impending undesirable operation
Potential Solutions	Distributed micro/nano sensors and RFID, Sophisticated controllers
Potential Providers to Solutions	

Role for NIST if Any	
Government Role if Any	
Discussion	When the robot emergency stop (E-Stop) is activated it generates significant amounts of stress on the robot and the tools, which are suspended or in contact with the robot arm. A more intelligent robot, which is aware of its environment and the human presence might be able to interact in a more gentle manner, which maintains safety and induces the minimum amount of damage possible.

6. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Intelligent robot response to safety emergencies (slow down, change path, notify)**
Economic Significance	High
Technical Barriers	Research
Where Barriers Appears	R&D
Measurement-Problems	Detection of the presence, location and ID of personnel inside the restricted space
Potential Solutions	Distributed micro/nano sensors and RFID, Sophisticated controllers
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	Present robot controllers stop robot motion abruptly during an emergency. Future robots could detect approaching individuals and slow down or move to another direction in an emergency.

7. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Flexible servo drives**
Economic Significance	High
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Sophisticated controllers
Potential Providers to Solutions	

Role for NIST if Any	
Government Role if Any	
Discussion	One possible option for the design of safe NGRs is to build them with inherently weak servo drives, which generate enough torque to perform the desired work, but not enough to injure humans. This might be accomplished with a flexible servo drive, which adjusts the maximum torque it can generate according to the needs of the assigned job. Some die-casting robots have a servo float mode, which can control the maximum possible torque that they can apply. How do you measure this torque and classify it according to safety?

8. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Position verification**
Economic Significance	High
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	Measure the position and orientation of a 3D moving object even when it is obstructed from direct line of sight view in an industrial environment
Potential Solutions	Arrays of metrology sensors
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	The position and orientation of most robot arms is determined with sensors mounted on the back of the joint drive motors. These sensors can become loose and malfunction and then the arm will move into an unexpected position and orientation. Perhaps an independent sensor or calibration test can prevent an unwanted and unexpected robot arm motion.

9. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Collision detection**
Economic Significance	High
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	Proximity and Contact force between 3D moving objects and between objects and humans
Potential Solutions	Distributed micro/nano sensors
Potential Providers to Solutions	

Role for NIST if Any	
Government Role if Any	
Discussion	Currently used collision detection devices are designed to prevent collision with hardware. Perhaps they should be redesigned to include human collision detection capability. These could include omni-directional cameras, guaranteed safety coverage sensors and safety deployment devices, like air bags.

10. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**NGR cost should be a consideration**
Economic Significance	High
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Use of light weight prefabricated micro/nano material composites
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	The present cost of safeguarding equipment is approaching that of the robot itself. It is hoped that a significant portion of that cost can be used for building an NGR, which requires less floor space and safeguards. The long-term benefit of such a change should offset any increase in the cost of the robot itself. A significant increase in the robot cost could be counterproductive.

11. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Robot-human pain interface (current knowledge from IEEE and Japanese data)**
Economic Significance	High
Technical Barriers	Research
Where Barriers Appears	R&D
Measurement-Problems	Quantification of pain and injury
Potential Solutions	Bio medical experiments
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	The Japanese have used human subjects in order to collect impact pain data. Similar experiments would be difficult to conduct in the USA.

12. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Personal protective equipment (PPE) enabler**
Economic Significance	High
Technical Barriers	Research
Where Barriers Appears	R&D
Measurement-Problems	Evaluate human reaction to emergencies
Potential Solutions	Pressureless enable switches
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	It is desirable to have garments or sensors, which alert the robot controller of the identity, presence, location and health condition of a human who has entered its restricted space. Can we though rely on humans to always choose to wear PPE? This is similar to the automobile safety belts regulations problem. This could be an enabler for NGRs.

13. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**High performance which has a safety component**
Economic Significance	Medium
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Integrated sophisticated controller and safety sensors
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	The NGR design objective should be high performance, which has an embedded safety component.

14. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Improve control capability with safety in mind in an unstructured environment**
Economic Significance	Medium
Technical Barriers	Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Integrated sophisticated controller and safety sensors
Potential Providers to Solutions	

Role for NIST if Any	
Government Role if Any	
Discussion	The automobile manufacturers plan to make gradual improvements to vehicle controls, which sometime in the future might lead to autonomous driven vehicles. The current scope of the improvements though is to increase automobile safety, like for example collision warning, safe lane change, etc. This could be a model for the evolution of industrial robots to an ideal NGR. Since many robot controllers will be connected to a network it is important to maintain secure and safe network operation.

15. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**High accuracy, cleanliness and variable foot print**
Economic Significance	Medium
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Sophisticated controller and modular design
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	The size of products a company produces can range from macro scale to meso and micro scale, like for example the glass screen of large size and small size displays. It would be advantageous if a single high accuracy robot can dandle these different sizes and have adjustable foot print size in order to save floor space.

16. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Differentiate between humans and objects**
Economic Significance	Medium
Technical Barriers	Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Sophisticated imaging analysis, RFID human recognition
Potential Providers to Solutions	

Role for NIST if Any	
Government Role if Any	
Discussion	Users of industrial robots have been asking for sensors, which can identify the nature of obstacles in the robot workspace. In the case of a human the robot can react differently than in the case of a box. 3D vision could be designed to make this distinction with what is called a "Safe Vision System." Humans could be given devices, like RFID or scanner arrays, which advertise their presence and may perform a similar function. Since there should be no blind spot in the restricted space, perhaps a combination of various sensors should be used.

17. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Identify the presence, identity and the intentions of humans**
Economic Significance	Medium
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	RFID human recognition and voice instructions understanding
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	The department of defense is funding the development of mobile robotic platforms, equipped with weapons and robotic arms. Currently these systems are operated under manual control (tele-operated), but the plan is to become more autonomous in the future. In an autonomous mode they will have to recognize the presence and location of humans and to identify them as friend or foe. Similar techniques could be used by manufacturing robots in order to better interact with humans.

18. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Redundant sensors**
Economic Significance	Medium
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Small inexpensive arrays of micro/nano sensors with integrated signal conditioning, processing, communication capabilities
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	Mechanical stop switches are used in order to limit the travel of robots and protect human operators. We should perhaps replace mechanical switches, which wear out and are prone to failure with human presence and position detecting sensors. Dual redundant sensing might be required.

19. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Better cooperating mode (IAD)**
Economic Significance	Medium
Technical Barriers	Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Sophisticated controller, which can accept commands from human body touch, voice, eye, brain, etc. and can recognize the presence and identity of humans
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	IAD is an intelligent assist device, which is widely used in manufacturing today. An IAD is manually driven by a human operator through some kind of handle equipped with force or other sensors, which prevent the IAD from moving in the direction of the operator. We would like the NGR to have similar cooperating capabilities.

20. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Better slow speed control (validation) testing**
Economic Significance	Medium
Technical Barriers	Research
Where Barriers Appears	R&D
Measurement-Problems	Measure the tool pose even when it is obstructed from view
Potential Solutions	Integrated sophisticated controller and tool pose sensors
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	Slow speed testing is used for attended program verification (APV) purposes, because robot operators may come close to the robot operating space. Unfortunately when the operating speed of the robot is increased its performance might change significantly. Some robot manufacturers have chosen to program the ATP speed to be below the required 250 mm/s. Such a slow speed frustrates the operators, who abandon slow speed testing and run APV at high speeds. This is an unsafe practice.

21. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**NGR=A machine does all (Modular robots)**
Economic Significance	Low
Technical Barriers	Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Use of light weight prefabricated parts, standard interfaces
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	A typical industrial plant has a variety of different industrial robots and consequently has to maintain a large number of spare parts. Besides the cost of the spare parts the plant has to train robot operators and maintenance workers to take care of this diverse population of robots. A NGR which can replace these diverse robots, through perhaps modularity, commonality in parts and training, is going to be very helpful.

22. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**NGR manipulation at different scales**
Economic Significance	Low
Technical Barriers	Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Promote the development of manipulators at the meso-micro-nano scale
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	Future industrial applications might require manipulation of objects through a wide range of scales. An example could be the assembly of mm or smaller size parts to a larger size device, like a computer hard disk, which will have to be assembled tested and packaged. Such an industrial operation could be performed by a multitude of different size manipulators and automation systems or a single NGR at a much lower cost.

23. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Easy robot-to robot interaction**
Economic Significance	Low
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Sophisticated controllers, proximity and force sensor arrays, vision system arrays, etc.
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	Industrial robots have become very versatile. Instead of bringing the parts to robots we now have robots perform that work. Robots pickup transport and deliver parts to other robots. It is thus important that this interaction becomes as simple and safe as possible.

24. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Define the application and identify the problem**
Economic Significance	Low
Technical Barriers	Standards and Research
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Comprehensive study of robot design needs based on applications
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	The application should drive the design of the robot safeguards. The best example of that is the KUKA robo coaster, which is used as an entertainment robot. KUKA designed this robot to comply with a DIN standard for entertainment machinery and they did open their manufacturing plant to a relevant approving agency, which directly supervised the casting and serializing of the parts. Part of the design was a study of the human endurance to g forces.

25. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Safety networks based on software**
Economic Significance	
Technical Barriers	Standards
Where Barriers Appears	R&D
Measurement-Problems	
Potential Solutions	Reliable software and secure communications
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	One big advantage of software control programming is flexibility. A recent trend is to program dedicated processors to safeguard industrial robots through "Safety Networks." This could be taken a step further where 3D software representations of the permitted workspace are used in order to restrict robot motions instead of mechanical stops, which are difficult to implement in a complex restricted workspace.

26. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Standards should not impede competition at the international level**
Economic Significance	
Technical Barriers	Standards
Where Barriers Appears	
Measurement-Problems	
Potential Solutions	Harmonization of national robot standards
Potential Providers to Solutions	Past experience has taught us that it is better to first develop a national standard and then try to promote it as an international standard. The establishment of an international standard should make it easier for national products to compete in international markets. Another reason to move from national to international standards is to level the playing field. This will reduce the possibility for a company to move robot manufacturing to a country that does not comply with safety standards for the purpose of reducing production cost.
Role for NIST if Any	
Government Role if Any	
Discussion	

27. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Shift of liability to the robot manufacturer**
Economic Significance	
Technical Barriers	Standards
Where Barriers Appears	
Measurement-Problems	
Potential Solutions	
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	In the case of a robot vehicle the degree of human supervision could vary from 100% (fully supervised manual control) to 0% (fully autonomous automatic control). If the vehicle causes an accident the degree of responsibility varies accordingly from the operator to the manufacturer. Similarly responsibility for an NGR accident can shift to the manufacturer for fully autonomous operation.

28. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Crisp on scope of application**
Economic Significance	
Technical Barriers	Standards
Where Barriers Appears	
Measurement-Problems	
Potential Solutions	
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	Robots are expanding their applications outside the industrial manufacturing environment, like for example, medical care, military, etc. For this reason we should be careful to clearly specify the scope of the application of any NGR standard, since it might not be applicable to all future applications of these robots.

29. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Determine robot stop distance**
Economic Significance	
Technical Barriers	Standards
Where Barriers Appears	
Measurement-Problems	
Potential Solutions	
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	In the past we used to bring the parts to the robots, now we increasingly have the robots coming and picking up the parts. This brings the robot increasingly closer to humans makes more important the correct knowledge of emergency stopping distances.

30. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Reduce cost increase scope**
Economic Significance	
Technical Barriers	Standards
Where Barriers Appears	
Measurement-Problems	
Potential Solutions	
Potential Providers to Solutions	

Role for NIST if Any	
Government Role if Any	
Discussion	One of the main competitors of robots is all the other forms of automation. As we decreased the cost of robots and extended their range of applications we have seen a significant increase in the volume of sales. It is now cheaper to move parts with robots than to build specialized transport conveyors.

31. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**How do we get access to accident information?**
Economic Significance	
Technical Barriers	Standards
Where Barriers Appears	
Measurement-Problems	
Potential Solutions	
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	Near misses are more frequent than robot accidents and they have a lot to teach us regarding the level of safety of a robot design. Perhaps a reporting mechanism for near misses should be established similar to that of airline pilots. A Japanese company reported that they have a requirement for reporting any manual intervention with a robot, and then they used the information to design out the cause of the intervention. They considered the cause a design fault.

32. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Use accident and near misses to guide NGR research**
Economic Significance	
Technical Barriers	Standards
Where Barriers Appears	
Measurement-Problems	
Potential Solutions	
Potential Providers to Solutions	

Role for NIST if Any	
Government Role if Any	
Discussion	OSHA does track industrial accidents, but does not have a separate robot accidents category, that would allow to better understand the nature of this type of accidents. Industrial manufacturers do not want to share their robot accidents information. The United Auto Workers Union is the only reliable source of robot accidents information. Perhaps an independent mechanism of robot accidents data collection should be established, which should maintain confidentiality, but also help with the research of NGR development.

33. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Robot control adaptivity in order to reduce floor space**
Economic Significance	
Technical Barriers	Standards
Where Barriers Appears	
Measurement-Problems	
Potential Solutions	
Potential Providers to Solutions	
Role for NIST if Any	
Government Role if Any	
Discussion	Currently the safeguarding installation is usually established at the time of the robot installation and it is rarely modified. We need a robot controller and safeguarding means, which adopt to the robot operation and reduce the floor space they occupy depending on the nature of the operation.

34. Technology at Issue	Next Generation Robot (NGR)
Technological Need	**Safety embedded programming**
Economic Significance	
Technical Barriers	Standards
Where Barriers Appears	
Measurement-Problems	
Potential Solutions	
Potential Providers to Solutions	

Role for NIST if Any	
Government Role if Any	
Discussion	The controller programs must be structured in such a way that they are cognizant of human operations in the restricted space and react in a safe fashion. The control interface must be designed so that it allows for the easy selection of the various safe related control settings.