Robotics

APPLICATIONS FOR TODAY AND TOMORROW

(PART 2 OF 2)

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N.Ed.: Dr. Andrew Goldenberg is the 2016 recipient of the IEEE Canada McNaughton Gold Medal, the highest award given by IEEE Canada.

There are numerous applications of robotics in a wide range of sectors. Most of the robots offered on the market are product lines that need to be adapted to the desired applications. In some cases, when the complexity of requirements cannot be met with standard off-the-shelf products, custom robots are developed and used.

Most robotic businesses are focused on specific lines of products, ex. medical robot. A minority of businesses offer products over a range of applications including customized products.

This article introduces a selected number of applications originated in the company I founded. These products have reached their development maturity, and further work is now focused on enhancing the products by embedding modern technology such as Artificial Intelligence (AI). AI provides methods and tools that enhance the products in terms of their usability, reliability and performance.

The products that would be enhanced are Mobile, Security and Personal Robots, which would embed autonomous navigation capability. Industrial and Collaborative Robots would be enhanced by embedding image recognition capability as applied to identification of parts and objects near the robot. Face and Voice Recognition are technologies that would further enhance the Personal Robots.

Security Robots

MOBILE ROBOT FOR EXPLOSIVE AND ORDNANCE DISPOSAL (EOD)

Police, Military, Emergency Response Team (ERT), Fire, Nuclear, and other hazardous response personnel require remote controlled equipment for stand-offs in dealing with explosives, ordnance, and other hazardous materials. The remote-controlled equipment consists of a mobile platform, video equipment, a robot arm mounted on the platform, and a series of auxiliary operational tools such as firearms, disrupters, x-ray units, etc. and associated means of attaching them to the arm or platform. In addition, such a system includes an operator control unit (OCU) that includes cable and wireless communication with the platform, video monitors, means of controlling the platform and arm, as well as activating the operational tools. The communication covers data, video, and audio links.

The platforms and arms come in various sizes. The platforms are usually anywhere from 60 to 135 cm in length, and from 45 to 66 cm in width. The arms can have a reach from 0.8 cm to 2-3 m. The payload capacity varies from 5 kg to over 75

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kg depending on the configuration of the arm. The total weight varies from 25 kg to 350 kg. The speed of the platform varies from 2 Km/hour to more than 10 Km/hour.

This class of robots is subdivided in three major groups: small, medium, and large. There are commercial suppliers for each category. The small category is mainly used for reconnaissance, and surveillance. It is usually not used with an arm. The large category addresses large payloads, ammunition firing, and other hazardous tasks involving heavy payloads. The medium category is used for a mix of operations, some pertinent to the small robots, and others to the large ones.

These mobile robots could be used for surveillance, reconnaissance, handling of hazardous items, manipulation of suspected packages, neutralizing and handling such items as Improvised Explosive Devices (IED's), Hazardous Chemicals, and Radioactive Materials. They are all-weather, all-terrain mobile robots that can be used in both indoor (buildings, public institutions, airports, homes, etc.) and outdoor environments (terrain cluttered with obstacles, ditches, gravel, snow, mud).

The mobile robots are fitted with different means of traction: some use only wheels for traction, others use tracks, yet others use quick-removable tracks that can be mounted or dismounted very easily. The tracks, permanent or removable, are necessary for climbing stairs and obstacles.

Other features are related to precise independent joint control, high dexterity of arm, long reach, high payload, open computer architecture for integrating bio-chem sensors, and options for autonomous navigation. In terms of control, the operator has the option to control the arm in joint or task space. The platform is always controlled in task space, by coordinating the motion of the wheels. Typically, the platform has two motors, actuating two wheels, one on each side. The other wheels are rotated by chain or other means of transmission.

The robots are remotely controlled by a wireless or cable link; cable link has an on-board automatic winding cable system, or an independent reeled cable system. Two-way data and audio and one-way video links are usually available. Up to four cameras and a microphone provide the operator with images and sounds of the environment. A surveillance camera can be mounted on the arm (low to the ground, high in the air, close or far from the gripper) or on a separate articulated boom (usually positioned vertically up).

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Mobile Robots

Articulated track mobile robots have mechanical means activated by remote control or autonomously that change the shape of the tracks. These robots also have arms that are fully modular with self-contained electronics. The arms have up to six joints, a medium size gripper and a variety of operational tools and accessories. The robots are all-weather and can operate indoor (buildings, public institutions, airports, homes) and outdoors (obstacle-cluttered terrains).

The arm modules are plug-and-play. The arms have distinctive features, enabling them to access hard to reach areas in airplanes, subways, buses, buildings, homes, airports, and train stations. The main functionalities and applications of the articulated track mobile robots are:

- Handling a wide variety of payloads and security mission tools operated by ERTs, Special Weapons and Tactics (SWAT), Fire Department Personnel, Hazardous Goods Response Units and Emergency Measures Units
- Handling a wide variety of payloads and security mission tools for Surveillance, Reconnaissance, Manipulation of hazardous items, Handling of suspected packages, Neutralization of security concerns
- Handling and manipulating security concerns:
  - Explosive Ordnance Disposal (EOD)
  - Explosive Ordnance Removal (EOR)
  - Improvised Explosive Device (IED)
  - Hazardous Chemicals, Radioactive Materials, Biochemical Waste (CBRNE/HAZMAT)
- Remote Control of handling and manipulating operations:
  - Handling of payloads over large workspace
  - Visual assessment, measurements and clean-up in hazardous environments.

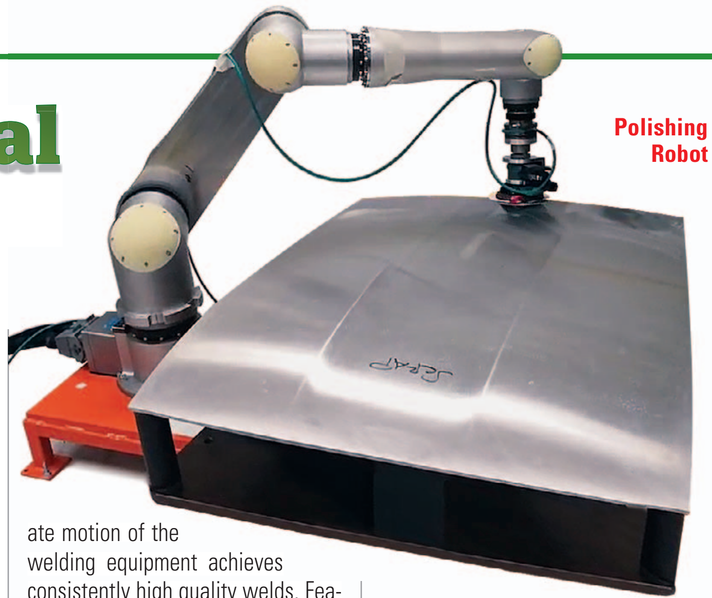
The technology includes the following features:
Arm: High dexterity arm can be configured to perform grasping and manipulating objects, aiming disrupters, pushing payloads, reaching under cars or through car windows, breaking windows, inserting a car key to open car doors.

Precise Motion: To approach, hit and handle a sensitive target with high accuracy. Programmable in task space coordinates.

Dexterity: Gripper can rotate continuously, Shoulder, elbow and wrist joints are rotary and allow large ranges of motion.

Modular Design: Arm can be easily disassembled and re-assembled for repair and maintenance. Multiple Payload Mounting: Disrupter, shotgun, X-ray unit, biosensors and radiation sensors, window breaker, charge drop assembly. ■

Industrial Robots



Polishing Robot

POLISHING ROBOT

The advent of modern polishing techniques emerged in the early 1900s. Advances in automation technology have allowed equipment builders to develop automated equipment to process more complex shape parts.

In the 50s, 60s and 70s, some automated polishing applications were implemented, but only the simple shape applications could be accomplished. More complex shaped parts required many media processing heads, each head working on a specific part area.

The development of robotic technology has further improved automation of finishing applications for both simple and complex shape parts. The robot with its six axes of motion can maneuver complex shaped parts, and with the proper head and tooling design can successfully polish six sides of most part surfaces.

The industrial robot can replicate the motions a human would make during the manual finishing process. Robots, while lacking the human senses of sight and touch, do possess the ability to replay their programmed path with a great deal of repeatability. Through the implementation of force control a constant polishing pressure can be applied to the work piece.

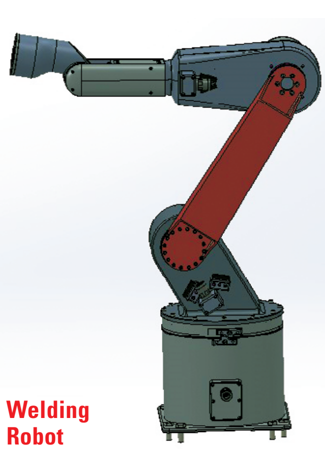
Last but not least, robots produce consistent, high-quality finishing with greater throughput while reducing the exposure of workers to the contaminants, noise and monotony of grinding, polishing, buffing and sanding processes.

WELDING ROBOT

The robot is for automatic arc welding or spot welding applications. The robot arm moves the welding gun over the surface to be welded while maintaining a proper distance, speed, and orientation relative to the surface. The smooth and accurate motion of the welding equipment achieves consistently high quality welds. Featuring lightweight aluminum alloys, the arm integrates welding wire feed cabling and mounting holes for the welding gun in proximity of the welding location. This allows effective welding process control. The controller includes easy-to-use arc welding and spot welding functions. The system has high accuracy positioning and path tracking, arm dexterity for complex welding processes, and is easy to program. Possible usage in other application areas are dispensing and cutting.

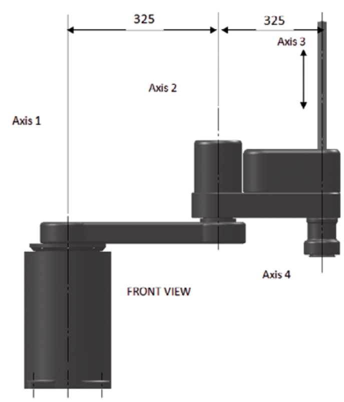
SCARA ROBOT FOR ASSEMBLY MANUFACTURING

The SCARA robot consists of base, first axis joint, link arm, second axis joint, link arm, third axis and fourth axis joints. The arm is for small-footprint, light-payload applications where high precision, high speed, and high performance are required. It has a modular design including: single-joint modules, compliant joints and has high payload/weight ratio.



Welding Robot

The robot is configured out of four modules: a large joint module, a medium size module, and a two-joint wrist module. An "extended" SCARA robot can be configured with five joints by adding one more joint to the wrist to allow tilting of the end-effector that does not exist in the standard SCARA robot. Other configurations are possible as well.



SCARA Robot

The modular joints are controlled by an embedded fully digital servo drive. By connecting several modules together one obtains a robot. The robot can be used for assembly manufacturing, and can work side-by-side with a human. The robot is light weight, and has high speed, high accuracy, small footprint, integrated force/torque sensor interface for force and impedance control and integrated vision sensor interface for visual servoing.

HIGH PAYLOAD ROBOT

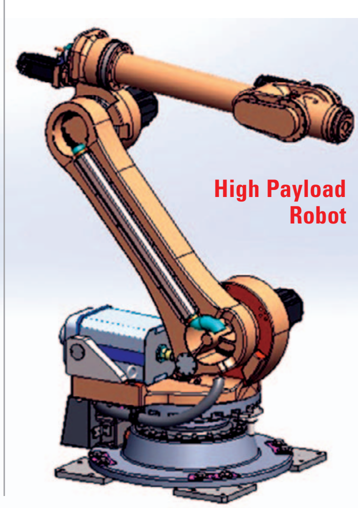
Applications of the high payload robot are in machine tending, palletising, packaging, part transferring, pick and place, grinding, deburring, and polishing. The arm has large payload, large working space, high speed, high accuracy, and integrated force/torque sensor interface for force and impedance control, integrated vision sensor interface for visual servoing.

The robot achieves high strength and agility with high payloads without sacrificing speed and accuracy. It consists of base, turret, shoulder tilt, upper link, elbow tilt, lower link, wrist, first roll, wrist pitch and wrist second roll, and gripper.

Turret and shoulder have the same internal layout, motor, input gear and reducer. The rotation of elbow joint is realized through a servomotor with a fixedly attached input gear to drive a reducer directly.

The wrist assembly consists of three joints: wrist-first roll, pitch, and second roll. Three identical motors are used for the three joints of the wrist assembly. They are mounted on the back of the upper link to conveniently maintain and ease the balancing of the robotic system. However, it is a challenge for the mechanical design to transmit the motion and torque of the three motors to the wrist.

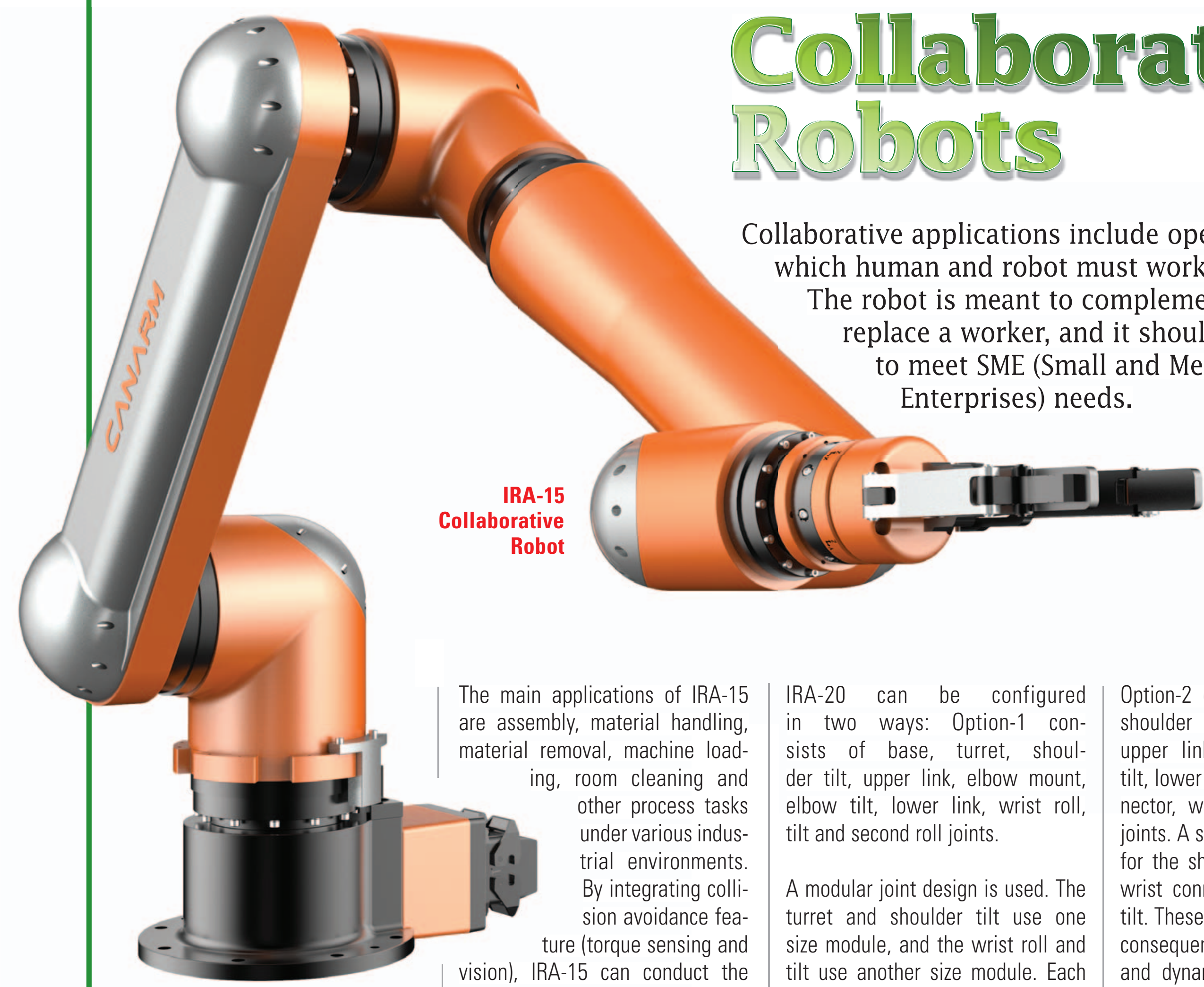
A counterbalancing system is used to compensate the load moments of each axle such that the axle drive is not overloaded statically, thus it can provide the maximum moment available for the acceleration of the axle. The balancing device is arranged to counteract a gravitational force upon relative movement of the robot arms. ■



High Payload Robot

Collaborative Robots

Collaborative applications include operations in which human and robot must work side-by-side. The robot is meant to complement and not replace a worker, and it should be flexible to meet SME (Small and Medium sized Enterprises) needs.



IRA-15 Collaborative Robot

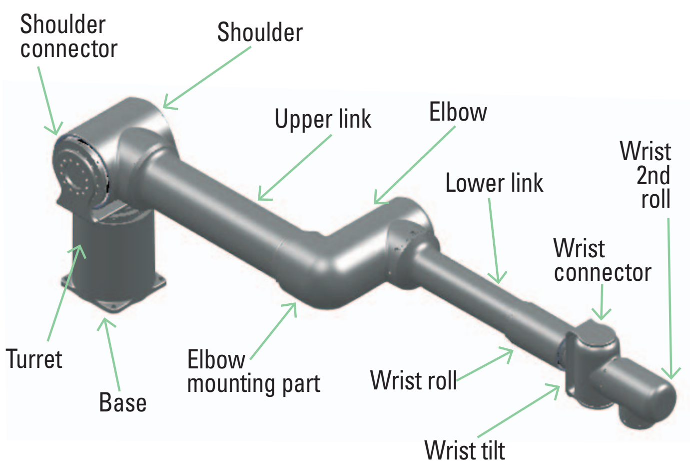
COLLABORATIVE 1-JOINT MODULES ROBOTS

IRA-15 is designed for collaborative applications where the required safety, dexterity and flexibility are very demanding. IRA-15 is a 6-DOF collaborative robot arm with single-joint modular modules. The compact and modular design of the IRA-15 ensures the lightweight, ease of installation and maintenance of the robot.

The IRA-15 uses combo actuators, which contain output bearings, gearhead, servomotor, encoder and brake all in one assembly. In addition, these components are hollow structured and that is very convenient for cable harness routing. Due to the use of combo actuators, the entire robot structure of joint and arm is very compact, and the total weight is lower than products on the market at the same payload level.

The main applications of IRA-15 are assembly, material handling, material removal, machine loading, room cleaning and other process tasks under various industrial environments. By integrating collision avoidance feature (torque sensing and vision), IRA-15 can conduct the above tasks collaboratively with humans.

IRA-20 is a 6-DOF modular arm comprising of single-joint compliant modules, reconfigurable, with a high payload to weight ratio (payload = 20 kg), suitable for collaborative human-robot operations.



IRA-20 (Option 2) Configuration

IRA-20 can be configured in two ways: Option-1 consists of base, turret, shoulder tilt, upper link, elbow mount, elbow tilt, lower link, wrist roll, tilt and second roll joints.

A modular joint design is used. The turret and shoulder tilt use one size module, and the wrist roll and tilt use another size module. Each module is composed of harmonic drive, brushless motor, brake, encoder, motor drivers, interface boards, and peripheral components. These features make the IRA-20 installation or replacement easier during operation or service. The harness passes through the inside of the links and through the center of the joints.

Option-2 consists of base, turret, shoulder connector, shoulder tilt, upper link, elbow mount, elbow tilt, lower link, wrist roll, wrist connector, wrist tilt and second roll joints. A shoulder connector is used for the shoulder and turret, and a wrist connector for wrist roll and tilt. These would have only minimal consequences for the kinematics and dynamics due to the change of the offset from the base to the upper arm and from elbow to wrist second roll.

Option-2 would be slightly heavier than Option-1 because of two connectors' weight. However, Option-2 kinematics and dynamics are simpler. Also, the stiffness and deformation of shoulder and wrist tilt joints in Option-2 would be easier to control.

Option-1 turret and shoulder would use same size module, and wrist roll, tilt and second roll would use same module. Option-2 would not use same size modules.

The main features of the robot are: (i) active compliance: force and impedance control; (ii) passive compliance: built-in joint compliance; (iii) small footprint; (iv) lightweight; (v) high dexterity; (vi) integrated force/torque sensor interface for force control; and (vii) integrated vision sensor interface for visual servoing.

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Personal Robots

Personal Security Robot

THIS ROBOT is for execution of full or partially autonomous patrolling of dwellings and support to personnel in various security operations.

The application is focused on public and private security services in both indoor and outdoor environments, such as schools, office buildings, private rental and condominium dwellings, hotels, stadiums, bus and train stations, ports and airports. The robot moves through programmed routes independently: it will call and enter elevators; it will do reconnaissance in underground parking garages, detect objects and issue emergency signals related to fire-sensors and human-detecting sensors. It can be mounted on various mobile platforms.

The robot provides the following functionalities and applications:

- Mobile navigation in private premises
- Remote viewing, inspection of surroundings, transfer of images
- Auto docking and power charging with operation of more than 6 hours
- Automatic detection of obstacles and automatic stop for safety
- Mobile video surveillance
- Detection of intruder, fire, smoke, water, gas and chemicals
- People detection and tracking
- Parking garage vehicle plate scanning and licence checking
- Scheduled patrolling of private premises.

VIDEO CONFERENCING AND TELEPRESENCE ROBOT

THE VIDEO TELECONFERENCING and telepresence robot has a wide range of active and passive applications: office-to-office communication, remote business-to-business communication, remote viewing, inspection of environment, transfer of images, and other.

The user can listen, talk, see and be virtually seen.

It provides access to locations by remote control, and it provides feedback to the operator through video, audio and data. Typically, the robot APM can be mounted on various mobile platforms (MP).

The main functionalities and applications are:

- Office-to-office communication, remote business-to-business communication
- Remote viewing, inspection of environments, transfer of images
- Auto docking and power charging with operation of more than 6hrs.
- Automatic detection of obstacles and automatic stop for safety
- Local touch-screen display
- Application in commercial, public and private environments.

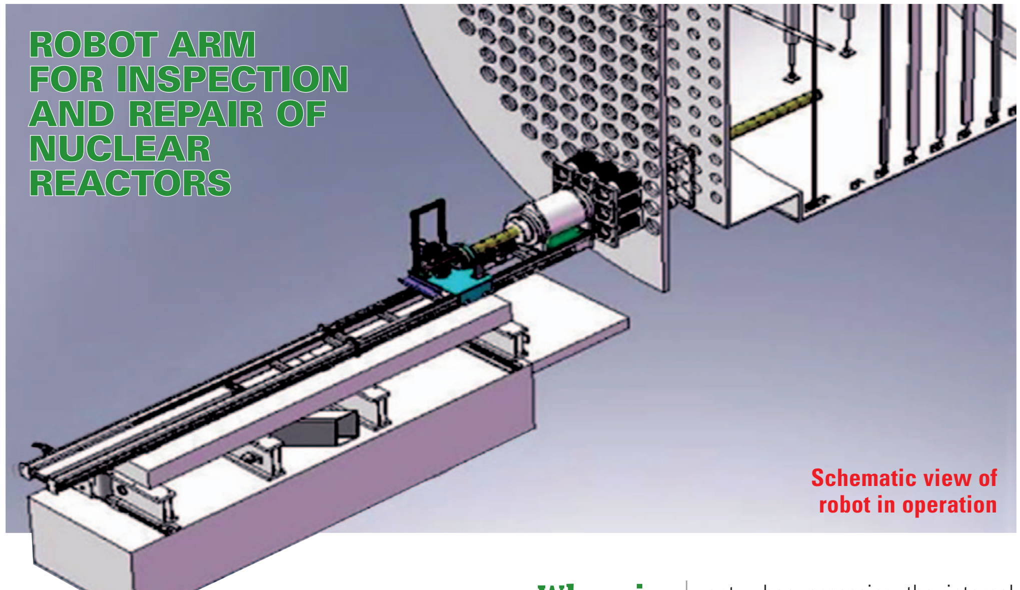
HEALTH ASSISTANT ROBOT

This robot can meet many care receivers' health and security needs in non-acute health care environments such as elderly care centres, rehabilitation centres and home elder care.

It can manage massive personal information, enabling autonomous ward rounds. It has intelligent care receiver indentification capability, fetching in care databases including medication and meal schedules. It can also monitor and collect health indicator data, e.g., heart rate, blood pressure, body temperature and blood glucose. Immediate warning is given of abnormal situations and remote help sought. ■

Nuclear Plant Robots

Nuclear robots enable maintenance procedures to be conducted without risk to human health. Their capacity for very precise movement also ensures that delicate tubing is not damaged during the process.



Schematic view of robot in operation

At the core of CANDU (CANada Deuterium Uranium) nuclear reactors is the Calandria vessel. It contains a network of horizontal tubes for fuelling the reactor. After several decades of service these fuelling tubes must be replaced in a process known as "re-tubing" of the reactor. It is of utmost importance that during this operation no debris or foreign matter remains inside the Calandria.

With robots for such operations the user can pick up and remove any debris, and can also inspect the interior of the nuclear reactor core. A robot system for operation inside the Calandria vessel is used for both visual inspection and hardness inspection. The robot is also a contingency tool to be used to collect foreign material created during the re-tubing process. The robot is inserted through a lattice sleeve tube in the shielding wall of the reactor after the fuelling and pressure tubes have been removed.

The Calandria Vessel Inspection (CVI) robot consists of a long two joints boom with a manipulator arm attached to its end. The robot is equipped with radiation-hardened camera system for visual inspection and guiding of the robot arm, a vacuum nozzle for removing of small shavings and dust-like debris, and a gripper for removing larger items – up to approximately 1 kg. The arm is fitted with an ultrasonic hardness tester.

When in operation, the tool built-in shielding mitigates and essentially eliminates the "open channel of radiation" that is inherent when accessing the internal portions of the reactor.

The arm is constructed of radiation hardened material and components. When in operation, the tool built-in shielding mitigates and essentially eliminates the "open channel of radiation" that is inherent when accessing the internal portions of the reactor. The arm comes with a modular end-effector that can be used to pick up small debris visually located during the inspection process.

The robot enters the Calandria vessel through any of the fuel channels. Servo-controlled boom extension and roll combined with robot manipulator elbow rotation and front link extension allow the end-effector to reach any point within the Calandria vessel. The robot arm is controlled by a combination of electric and pneumatic actuators that incorporate force control and position feedback. The elbow joint is driven by a radiation hardened stepper motor. The forearm is extensible with a pneumatic cylinder through a range of 400 mm. The position of this link is monitored with a custom magnetic encoder. The end-effector is comprised of a pneumatic gripper and a vacuum nozzle. Smaller debris are removed by vacuuming; larger debris can be picked up with the gripper and dropped into a shielded flask mounted directly in front of the tube sheet. The boom is designed to provide radiation shielding during the operation of the robot system. ■

Biotechnology and Laboratory Automation Robots

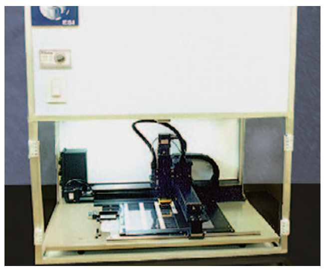
DNA MICRO-ARRAYER

DNA array is a generic name covering different molecular biology products and techniques. It can be described as a manifold of DNA fragments (spots) of oligonucleotides at low, medium or high density. DNA arrays are used as research and diagnostic tools. The array of DNA fragments on a solid surface allows detection of the expression of thousands of genes in a single experiment. Gene array technology is becoming one of the most common techniques used in all molecular biology laboratories.

The advantages of DNA array technology are: simultaneous analysis of many genes in a single experiment; quantitative and reproducible results; speeding up basic biological research and disease diagnosis; reduction of time, cost, and risks associated with discovery and development.

In terms of the technology used to make DNA arrays, there are three methods: (i) photolithography method that is based on-site oligonucleotide synthesis; (ii) micro-spotting with quill pins; and (iii) ink jetting. The spotting tools are: split/quill pins, solid pins, piezoelectric pins, capillary, ring-and-pin systems. The support used for DNA arrays can be: nylon membrane, polypropylene membrane, or glass slides. The methods of DNA binding to the support are based on electrostatic and hydrophobic interactions with covalent links. For detection of gene expression, complementary DNA (cDNA) is spotted first onto the slides, then the target DNA is hybridized with the cDNA, and the expression is identified through probe labeling: radioactivity (33P) and fluorescence (CY 3 and CY 5), and subsequent detection (reading of color intensity).

Robot spotters have been developed for DNA spotting on glass slides. A spotter has a large spotting surface (75 or 126 slides), modular & reconfigurable structure, able to spot up to 83,000 spots per 25 mm x 75 mm slide, and capable of performing other bio-laboratory tasks such as arraying, gridding, re-arraying, and pipetting. The robot system is based on a high quality three axis gantry robot, with 1.25 µm resolution of motion along each axis, and impedance control to avoid high impact forces at the contact between the slide and the pin.

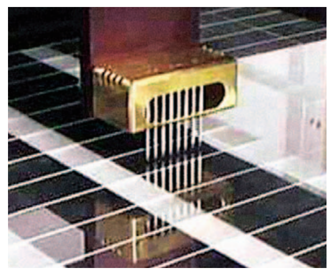


DNA Microarrayer

The system has a repeatability of 2.50 µm, and high bandwidth communication with the controller. There is no heating, vibration, and the speed is 1 spot/slide/pin (61,000 genes are spotted in 3.5 h). The slides can be of 25 x 75 mm, 25 x 25 mm, or 50 x 75 mm. 1 to 8 micro-titter source plates and 1 to 6 small membrane holders can be used along with up to 126 slides. The cleaning of the pins between loads is done in a water bath that uses active water pump for cleaning.

The robot is designed to collect DNA from 96-well and 384-well source plates. 1 to 48 pins can be used simultaneously. Each pin collects 250 nl of solution and spots 0.6 nl per dot on 75 to 126 microscope glass slides. The center-to-center distance is 120 µm.

A vacuum chamber is used to dry out excess material from the quill pins, and dry off the water after washing them. A blotting pad is used to eliminate excess material from the pins before spotting. The quill pins have long life (1,000,000 spots). They generate 75 or 90 µm diameter spots. Each pin can be replaced individually, and up to 250 dots per sample/one dip can be obtained.



Manifold of up to 48 quill pins

Environmental control is provided with a positive pressure HEPA Fun Filter and PPHC humidity controller (limits evaporation and fast drying of the spots).

The motion controller is based on an embedded PC-104/Pentium. A Graphical User Interface is used to program the spotter and monitor the execution. The host computer is based on Pentium/Windows NT. The host controller module can be at a remote location. The Graphical User Interface is intuitive and Windows-based for easy control of number of slides, rows, columns, array pattern, dots per row or column, speed, spotting order, type and direction of source plate or membranes, number of pins, etc. Simple robotic language is used for programming the robot.

ROBOTIC CELL SAMPLE PREPARATION OF LIQUID SCINTILLATION ANALYSIS

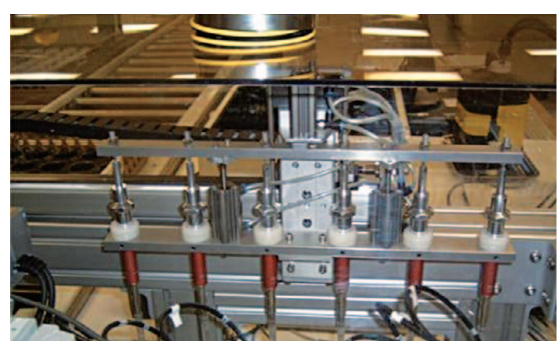
Managing employees who work at nuclear power stations presents some unique challenges. One of the issues that requires close monitoring is employees' exposure to radiation. Quick and accurate detection of any anomalous radiation exposure can improve the health and safety of the employees as well as the operational safety of the power station.

One of the common methods of monitoring radiation exposure is performing a daily scintillation count of an employee's urine sample. A precise amount of sample is mixed with a known chemical for analysis. This process is tedious and time consuming.

Typically, the amount of sample is in the 1000 µl range and the cocktail is in the 8ml range. While these volumes are not unduly small, they are too small to dispense accurately into the vial without proper laboratory equipment.

A turnkey robot system was developed for the bioassay sample preparation, handling and analysis. The robot takes a very small quantity of the sample from a container, puts it into a sample vial, adds reagents, caps and seals the vial, mixes it, and places it into a cassette for analysis. More than 500 samples per day can be processed.

Processing laboratory vials



Picking up samples from vials

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Security Robots continued from page 15 »

MOBILE ROBOT FOR IN-GROUND MINE DETECTION

An articulated remote controlled mobile manipulator has been developed to scan autonomously off-road and unstructured terrain for buried landmines and explosives. The robot consists of a dual-arm manipulator mounted on a six-wheel mobile platform, mine or explosive detector, range sensors, terrain mapping software, and hardware and software for communication, data transfer and control. The platform can also be used with tracks mounted over the wheels. The tracks help climb steep slopes, and move over very rough terrain. The platform can be operated in remote control, semi-autonomous, and autonomous modes. The terrain map is generated with respect to a range sensor frame to minimize the computational load in real-time. Sensors scan and measure the range with respect to the terrain and relative to the reference coordinate frame. Also, the normal direction to the terrain is computed in real-time. Based upon the terrain map that is generated in real-time, the mine detector's position and orientation is controlled such that a desired (constant) separation and orientation with respect to the terrain is maintained.

One of the dual-arms (Detector Arm – DA) holds the mine or explosive detector (e.g. metal detector, Ground Penetrating Radar source, or a nuclear quadrupole resonance instrument) that is manipulated autonomously. A plurality of mine detectors can be mounted on the DA. The autonomous motion of the DA is synthesized and controlled on-line based on a 3D map of the terrain. The map is generated in real-time by fusion of sensory data acquired from a scanning laser rangefinder, an array of four ultrasonic sensors, and joint encoders of the dual arm.

The rangefinder, a motorized scanning mirror, and ultrasonic sensors are mounted on the other articulated arm (Sensor Arm – SA). The SA has a pan joint allowing it to be positioned relative to the DA such that it always scans "ahead" of the DA.

The rangefinder, a motorized scanning mirror, and ultrasonic sensors are mounted on the other articulated arm (Sensor Arm – SA). The SA has a pan joint allowing it to be positioned relative to the DA such that it always scans "ahead" of the DA.

The DA holds and maintains the detector at a desired constant vertical distance from the ground irrespective of undulations of the a priori unknown terrain profile. As well, the DA can maintain the detector orientation constant with respect to the unknown terrain. ■

Collaborative Robots continued from page 17 »

COLLABORATIVE 2-JOINT MODULES ROBOT

IRA-10 is a two-joint compliant modules modular, reconfigurable, high payload/weight ratio robot arm for collaborative human-robot operations. The robot is a 6-DOF robot arm that can be reconfigured in multiple ways.

The robot manipulator comprises turret, shoulder, elbow, first wrist roll, wrist tilt and second wrist roll. The robot includes two links, the upper-arm, and the forearm.

The robot has modular shoulder, elbow, and wrist whereby each module is composed of two rotary joints with their motor drivers and their interface boards installed in the module housing. These features make the robot installation or replacement easier during operation or servicing. Another feature is the internal cabling design, in which all cables pass through inside of the links and through the modules. The upper link connects the shoulder module to the elbow module, and the fore link connects the elbow module to the wrist module. The two-joint module robot provides a compact structure and is lightweight.

The shoulder module has tilt – pan joints. It could be reversely installed to become tilt – roll and then a turret module (pan joint) can be added to become a 7-DOF arm. The tilt output side and its opposite side are designed to connect to a fork-type mechanical interface. The pan joint is designed to connect to the base of an arm. Two motor-drivers are located inside the module. All cables are internal to the module.

The elbow two-joint module has tilt-roll joints. The tilt joint output and mechanical interface assemblies on the opposite side of the housing connect to the upper arm. The roll joint output connects to the forearm. Two motor-drivers, two electronic interface boards and all wirings are located inside of the module. To keep consistent with robot shapes, this module has the same shape as the wrist module.

The use of frameless motors is to reduce weight and size; other features are similar to IRA-20. ■

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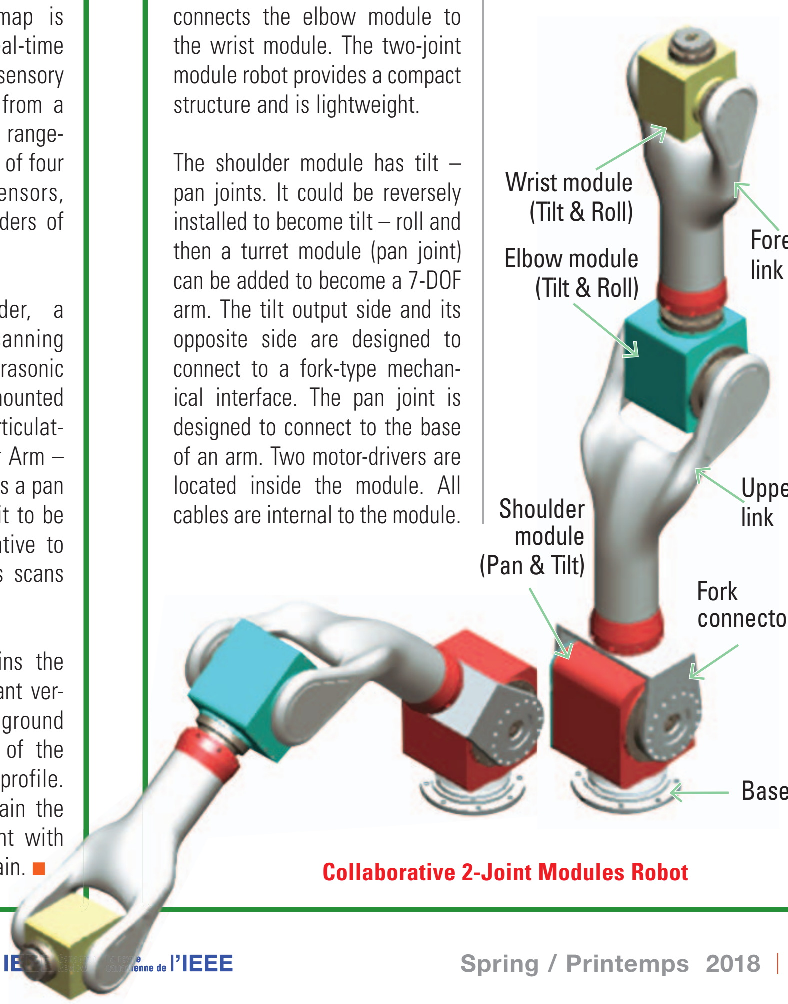


Collaborative 2-Joint Modules Robot

All personnel are issued a unique barcode for their samples. These samples are collected in bar-coded trays distributed throughout the power station. Each evening these trays arrive at the health physics laboratory for analysis. An operator simply should place these trays on the input conveyor section of the robot system and the robotic cell takes care of the rest.

For each sample the robotic cell performs the following basic operations:

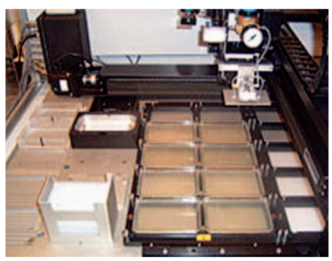
- Reads the barcodes on the incoming bottles containing urine samples
- Transfers a measured amount of sample material from sample bottle into an empty scintillation analyzer vial
- Adds measured amount of liquid scintillation cocktail into the vial
- Seals the vial and thoroughly mixes the contents
- Deposits the vials into the scintillation analyzer cassette
- Provides the data relating the sample code to the location of the vial

HIGH-DENSITY COLONY REPLICATOR

The High-Density Colony Replicator is a dispensable, very high density bio-sample array replicator as an attachment to colony picking robots.

Experimental work conducted in biotechnology laboratories requires replicating large numbers of yeast colonies. The colonies are grown in regular arrays on standard gel plates. One task of the experimental process involves transferring an array of samples from a library plate onto a mating plate, followed by transferring of another array of samples from a bait plate onto the same mating plate, in such a way that the samples in the corresponding locations overlap. Another task requires creating "copies" of sample arrays: cells from each colony on the source plate are transferred onto one or more target plates.

The common process of replicating large numbers of yeast colonies is relatively inefficient. The density of yeast colony array is limited primarily by the accuracy and repeatability of the equipment used to manipulate the samples. The commonly used "bed-of-nails" print heads can reproduce an array of 768 colonies on a standard gel plate. There is a need to increase the array density by increasing the number of metal pins in a print head. However, the pins in such print heads need to be considerably smaller, positioned more accurately, and machined with more precision. Therefore, the print head is much costlier to manufacture and difficult to maintain. Moreover, metal pins need to be washed after every transfer, which requires additional time and equipment, and introduces the risk of sample cross-contamination.



High density replicator attached to colony arrayer robot

A new print head was developed that would use disposable replicating pads. Such a print head can replicate high-density arrays and does not require washing of the surfaces that encounter sample material. In addition, disposable pads with density, pin-tip size and pin configuration corresponding to the currently used metal-pin print head have also been developed.

HIGH-PERFORMANCE AUTO-SAMPLER FOR MASS SPECTROMETRY

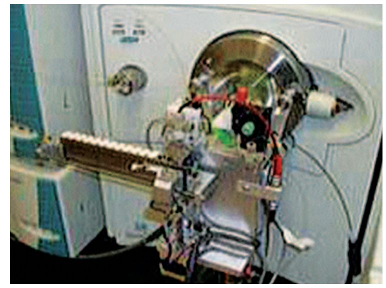
Mass Spectrometers (MS) in biotechnology and pharmaceutical laboratories are used to process large numbers of protein samples. They operate 24 hours a day, 7 days a week. It is necessary to automate the process, so that unattended operation over an extended period is possible.

Auto-Samplers can automatically pick up samples from vials, or from 96-well plates; however, the sample loss is very high, as these instruments cannot efficiently handle very small (20 to 50μl) quantities.

Auto-Samplers can operate in two modes: full-loop and partial-loop injection. Only partial loop injection is suitable for small samples. However, even in this mode sample loss can be as high as 50% due primarily to large dead volume (approximately 40μl) on the intake side of the sample loop. Although manufacturers provide dead volume compensation procedures, in practice a significant part of each sample is lost because of fluid dynamics and protein absorption in the intake line, as well as other factors.

The accuracy of MS measurement is also affected by high protein absorption inside the stainless-steel sample loop, and relatively large dwell volume between the buffer pump and the column.

An auto-sampler for very low-loss automatic injection of samples into the mass spectrometer column was developed. The system is placed directly in front of the mass spectrometer. It includes a compressed air supply system and control system. It is based on a micro-cross assembly mounted on an X-Y-Z positioning mechanism. The mechanism is used to manually adjust the position of the column tip in front of the MS opening. The required range of adjustment is approximately ±3 mm for each DOF. Positioning accuracy is 0.2 mm.



Mass spectrometer with the mounted auto-sampler

An Injection Head Assembly is mounted on a vertical linear actuator. The actuator inserts the injection head into the sample vials, or into the waste line coupler. The injection head has two sealed ports: one for the 100μm liquid line that connects the injection head to the micro-cross, the other one for the compressed air line.

The method of sample injection into the column assumes that the sample will not flow into the line connecting the micro-cross to the buffer pump. If significant backflow into the buffer pump line is found, a cut-off valve installed on the pump line next to the micro-cross prevents it.

A Vials Handling Mechanism is used to position the selected sample vial or the waste line coupler underneath the injection head. The vials sit in the matching nests in the vial blocks. The blocks will provide necessary mechanical support when high pressure is applied to a vial. ■

About the Author

Dr. Goldenberg is the founder of the field of Robotics at the University of Toronto where he has been since 1982 as a Professor of Mechanical and Industrial Engineering (now Emeritus), cross-appointed in the Institute of Biomaterials and Biomedical Engineering, and formerly cross-appointed in the Department of Electrical and Computer Engineering. He has supervised to date many graduate students, 46 PhD and 64 MASc. From 1975-1981 he has been an employee of SPAR Aerospace Ltd., of Toronto, working on the development of the first Space Shuttle Remote Manipulator System (Canadarm).

Dr. Goldenberg is also the founder of Engineering Services Inc. (ESI) established in 1982 and operating in the development of robotics-based automation. Under his leadership, the company has achieved significant growth and a global leading role in a wide range of industrial sectors. In 2015 ESI has been acquired by a Shenzhen-based Chinese consortium, and as of November 2016 the company become public listed in Hong Kong. Dr. Goldenberg is the CTO of the public company.