IEEE RAS Micro/Nano Robotics & Automation (MNRA) Technical Committee

Mobile Microrobotics Challenge 2014

OFFICIAL RULES

Version 1.2
December 16, 2013

1. THE EVENTS

Events Overview

The 2014 RAS MNRA Mobile Microrobotics Challenge will consist of two events:

1. Autonomous Mobility
2. Microassembly

In the Autonomous Mobility Challenge, a microrobot must navigate a randomly prescribed course through a planar track in the fastest possible time. The Microassembly event requires a microrobot to assemble multiple micro-scale components in a narrow channel. This event will simulate manipulation challenges found in *in vivo* medical applications, such as operation inside a human blood vessel, and assembly-based nanomanufacturing.

Each competing team must furnish its own microrobots. Each microrobot must fit within a virtual cube that is 500 μm on a side with two faces parallel to the arena and conform to the requirements listed in Section 3.

Each team must also furnish its own micro-arenas, which must conform to the requirements listed in Section 3.

Equipment used to power, operate, and control microrobotic devices must be furnished by the competing teams, and must interoperate with the competition equipment as described in Section 2. Each team must set up their equipment for each event within a 10-minute window, and must take down their equipment in 5 minutes.

Autonomous Mobility Challenge

The arena for the Autonomous Mobility Challenge will consist of a 3.1 mm × 2.2 mm region that includes six 200 um diameter posts in which three arbitrarily prescribed paths for the robot to traverse will be specified at the time of each run. The combination of walls and posts in the workspace creates nine possible gates for the robot to traverse through. (See Section 2 for a full

description.) At the start of each of the three trials, the team will place a microrobot so that its entire body lies in the starting (leftmost) region. The referee will supply the team with the prescribed path for this specific trial. At this time, the team will have 5 minutes to program their robot and have it traverse the path. The microrobot will autonomously traverse the prescribed path through the 6 gates in the prescribed order, returning to pass through the last gate back into the starting region. The robot must then come to a complete stop in a position where its entire body lies in the starting region. The trial is complete when the microrobot has come to a complete stop as identified by two consecutive frames of a competition-supplied digital camera. Each team will perform three trials of the Autonomous Mobility Challenge, which need to be completed in 30 minutes of running time from when they enter the competition area.

The microrobot's **finish time** for a trial of the Autonomous Mobility Challenge will be measured with digital video at 100 fps or greater. The time will be measured from the last frame in which the microrobot is stationary after the referee's start signal to the first stationary frame after the robot has completed all 6 gate passes (in order).

If the microrobot misses a gate, moves out-of-bounds (See Section 2) or does not complete the task within the allotted time, the trial will be scored as a foul. Any trial of the Autonomous Mobility Challenge that results in a foul will be assigned a finish time of 5 minutes.

The three arbitrary paths prescribed for each team may be different but will be constructed so that the total length of the paths for each trial run are the same for each team ($L_{total} = L_1$, L_2, and L_3). (See Section 2 for more information). The microrobot's score for the event will combine the total time to navigate all three paths, T_{total}, and the largest dimension of the robot in microns, D_{max}. The scoring metric is the following: Score = T_{total} x (D_{max}/500). This encourages teams to minimize the size of their robots for this event. Lower scores beat higher scores.

Microassembly Challenge

The arena for the Microassembly Challenge will consist of a 1.75 mm × 2 mm starting region, connected to a narrow channel having dimensions of 2 mm x 0.75 mm. A set of triangular microfabricated components is placed in the starting region with the microrobot(s). Upon the signal of the referee, the microrobot begins assembling the components into the far end of the channel. Components must be densely packed, so that no gap between components, or between components and the channel wall, is larger than 50 μm. The trial ends after 2 minutes, or when the team informs the referee that they are done.

The assembly components are to be furnished by the competing teams, and must be in a right triangular shape. The long leg of the component must be 500 μm while the short leg must be 200 μm. The components can be no more than 500 μm high, and must be clearly visible with high contrast to the surrounding area under an epi-illuminated white light microscope.

The microrobot's **trial score** is the number of **densely packed** components in the assembly channel. Components are densely packed if no region between two adjacent components (or between a component and the assembly channel wall) is big enough to accommodate a 50-um-diameter circle in the image plane. For example, in Figure 2 there are 5 densely packed

components, earning a trial score of 5 points. If a trial ended with just the triangle labeled 1 densely packed against the right wall of the channel, a trial score of 1 will result. If just the triangles labeled 1 and 3 were in the positions shown, that is a score of 2. However, if the trial results with only a single triangle in the assembly channel and not closely packed to any of the walls (like the position of the triangle labeled 4), the trial score would be zero.

Any component that moves out-of-bounds during the course of the trial will be counted as a gap in its final position at the end of the trial. If a robot moves out-of-bounds during the course of the trial, the trial will be scored as a foul.

Any trial of the Microassembly Challenge that results in a foul will receive a trial score of 0. The microrobot's **score** for the event will be the mean of its trial score on each of three trials. Higher scores beat lower scores.

Event Timing

Each trial will be filmed using a digital camera at 100 fps or greater. The trial will begin upon a verbal signal from the referee, and will end either when the team informs the referee that the trial is complete, or when the maximum time has elapsed, whichever comes first. When the trial has ended, the referee will stop the camera. The maximum time for each trial is 5 minutes and 2 minutes, respectively, for each event. Teams need not use all the available time.

Competition video of each trial will be captured beginning approximately 3 seconds prior to the referee's verbal start signal. The elapsed time for each trial will begin at the last stationary video frame before the microrobot begins moving, provided that this frame occurs within 8 seconds of the first video frame. Otherwise, the elapsed time will be measured from the first video frame. The end of the elapsed time will be measured at the first stationary frame after the robot has ceased moving.

2. THE ARENAS

The arenas will be provided by the competing teams, and must conform to the contest specifications described here. Arenas that are shown to not conform to these specifications will be disqualified from use in the competition. For this reason, teams are strongly encouraged to track all nominal dimensions as closely as possible to ensure their ability to compete.

It is recommended that arena boundaries be fabricated in such a way that they physically prevent microrobots and manipulated objects from going out-of-bounds, in order to avoid fouls.

Autonomous Mobility Challenge Arena Dimensions

Any arena used for the Autonomous Mobility Challenge must be a flat rectangular surface nominally 3.1 mm in length by 2.2 mm in width. The height of the surface (relative to the competition optics) must vary by no more than 500 μm across its area.

Boundary lines should have a nominal width of 50 μm, and must be between 40 μm and 60 μm wide. Boundary lines must be clearly visible with high contrast to the surrounding area under an

epi-illuminated white light microscope. The length of the arena will be divided into three regions, such that the nominal lengths of the regions are 750 µm, 1.8 mm, and 750 µm, from left to right. Six posts with a nominal diameter of 200 µm are situated in the middle region. The height of the posts should nominally be the same height of the arena walls, sized appropriately to ensure that the robot can't drive over the gate or over the walls and out-of-bounds. The spacing between each of the posts and the walls is a nominal distance of 600 µm. The dimensions of the arena do not include boundary lines. A schematic of the arena dimensions are shown in Figure 1. The specified dimensions are as follows:

Width of Arena:	2200 µm ± 20 µm
Length of Starting Region:	750 µm ± 20 µm
Length of Post Region:	1800 µm ± 20 µm
Length of Turn-around Region:	750 µm ± 20 µm
Width of Boundary Lines:	50 µm ± 10 µm
Diameter of Posts:	200 µm ± 10 µm

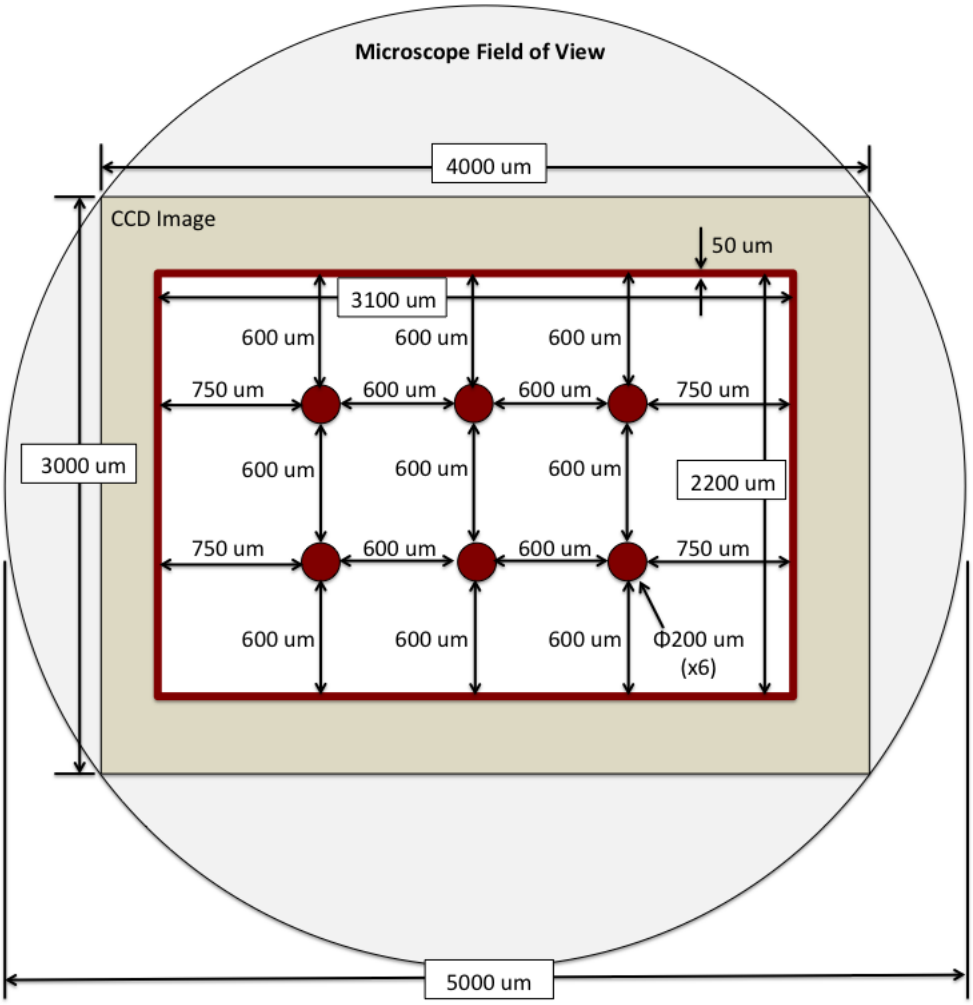

Figure 1: Arena Dimensions for the Autonomous Mobility Challenge (*note: 3100 um width should read 3300 um*)

Prior to each trial run, once the robot is placed in the starting region, the team will be given a gate sequence. The gate sequence will consist of six gate numbers in order that the robot must

traverse through. See Figure 2 for labeling of the arena gates. The robot will always sequentially navigate through one gate per each column of gates in the arena. For example, the first gate in the sequence will either be 1, 2, or 3. The second gate in the sequence will either be 4, 5, or 6, etc. The path length for a particular sequence is calculated using the sum of the Cartesian distances between the gates for the path. Therefore, the horizontal or vertical distance between adjacent gates is of length 1. Figure 3 shows three sample gate sequences, paths, and path lengths. Each team will receive different gate sequences with different path lengths. However, the total (L_{total}) of the individual path lengths (L_1, L_2, and L_3) for each set will be a constant value among all teams. Therefore, when comparing the total time to navigate the paths for each trial, all robots will have travelled the same nominal distance.

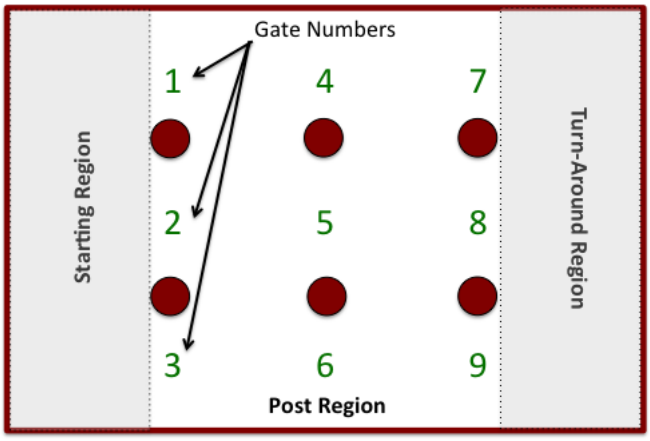

Figure 2. Arena Regions and Gate Numbering for Autonomous Mobility Challenge

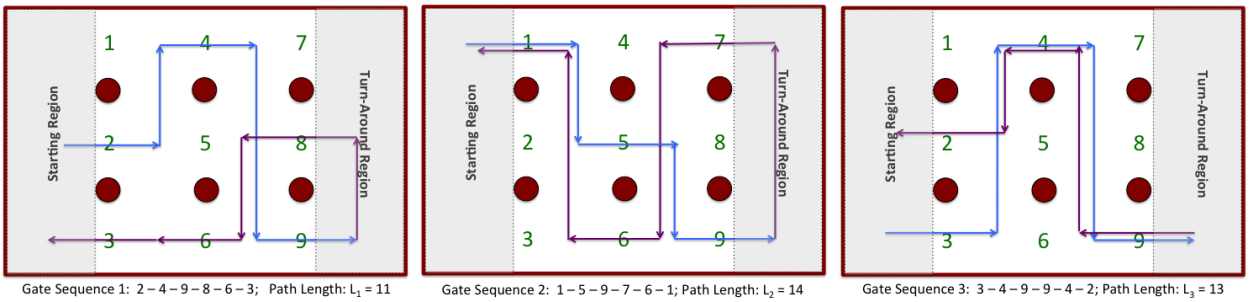

Figure 3. Example Trial Runs for Autonomous Mobility Challenge

The microrobot's score for the event will combine the total time to navigate all three paths, T_{total}, and the largest dimension of the robot in microns, D_{max}. D_{max} is defined as the diagonal across a rectangle that completely contains the robot. E.g. if the robot can be fully contained in a 500 µm x 500 µm footprint, then $D_{max} = (500^2 + 500^2)^{1/2} = 707$ µm. The scoring metric is: Score = T_{total} x (D_{max}/500). This encourages teams to minimize the size of their robots. Lower scores beat higher scores.

Microassembly Event Arena Dimensions

Any arena used for the Microassembly event must be a flat rectangular surface nominally 3.5 mm in length by 2 mm in width. The height of the surface must vary by no more than 1 mm across its area, relative to the microscope optics.

Boundary lines should have a nominal width of 50 µm, and must be between 40 µm and 60 µm wide. Boundary lines must be clearly visible with high contrast to the surrounding area under an epi-illuminated white light microscope. The length of the arena will be divided into two regions, having nominal lengths of (in left-to-right order) 1.75 mm and 2 mm. The left hand region defines the allowable starting area for the microrobot and assembly components, and the right hand region defines the channel in which the components must be assembled. Boundary sidewalls for both regions should have a nominal width of 50 µm, with a specified tolerance of ±10 µm. The dimensions of the arena do not include boundary lines. Specified dimensions are as follows:

Length of Arena:	3500 µm ± 35 µm
Length of Starting Region:	1750 µm ± 20 µm
Width of Starting Region:	2000 µm ± 20 µm
Length of Assembly Channel:	1750 µm ± 20 µm
Width of Assembly Channel:	750 µm ± 10 µm
Width of Boundary Lines:	50 µm ± 10 µm
Length of Triangular Component Long Leg:	350 µm ± 10 µm
Length of Triangular Component Short Leg:	200 µm ± 10 µm

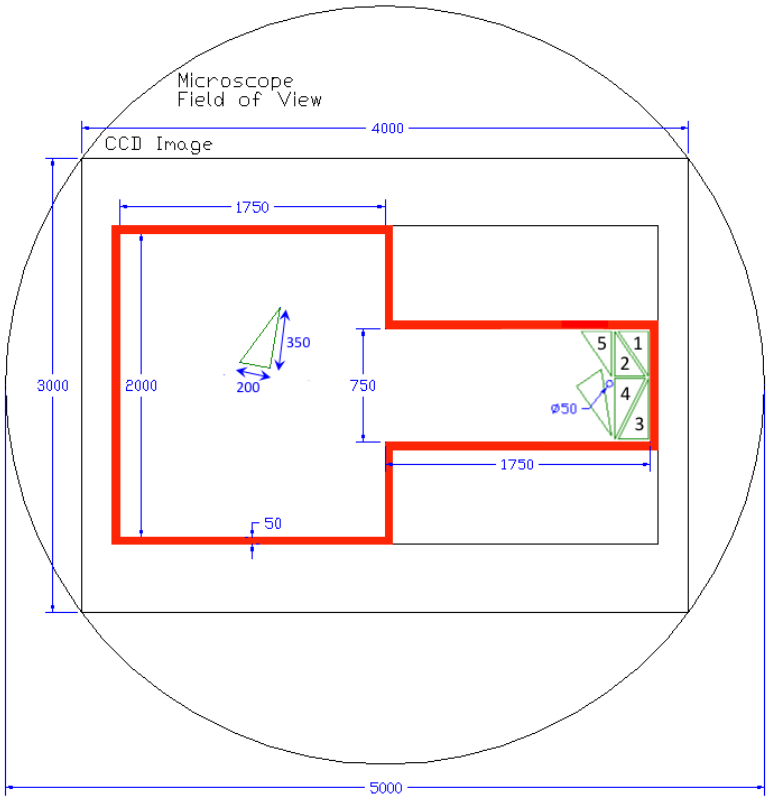

Figure 4: Arena Dimensions for the Microassembly event

THE OPTICS

The Microscope

An upright microscope is used to observe the motion of the microrobots and provide visual feedback for closed-loop control. The microscope is a simple zoom microscope with a magnification range of 0.58X to 7X. It is mounted on a microscope stand, which consists of a base and a post on which the microscope is attached. A manual XY motion stage is mounted on the base and sits below the microscope. Competitors' equipment must conform to the dimensions and specifications for the microscope, as outlined here.

The working distance, WD, of the microscope is approximately 95 mm when the field of view has a diameter of 5 mm. The distance between the bottom of the microscope and the motion stage, D, has the following range: 95 mm < D < 300 mm. These parameters are shown on the following figure. All equipment used by the competitors must sit below the bottom of the microscope to avoid interaction with the microscope.

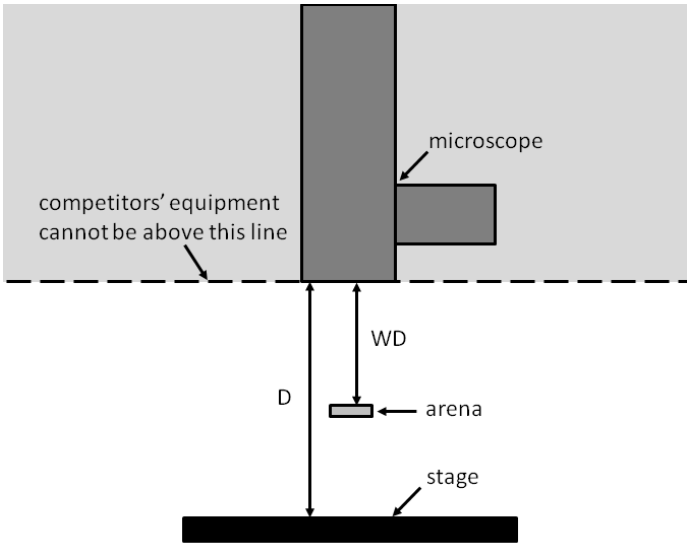

Figure 5: Front view schematic of the microscope and microscope stage

The top plate on the motion stage measures 200 mm wide and 200 mm deep and has an array of tapped M6 holes for mounting equipment (see following figure). Arenas, associated packaging and actuation hardware should be attached to this top plate with M6 screws. Mounted hardware may not protrude past the back edge but it can protrude over the other three edges. Based on the range and kinematic constraints of the motion stage, an imaging region has been mapped out, as shown in the following figure. Teams must ensure that their arenas sit in this region so that the microrobots can be observed during the competition.

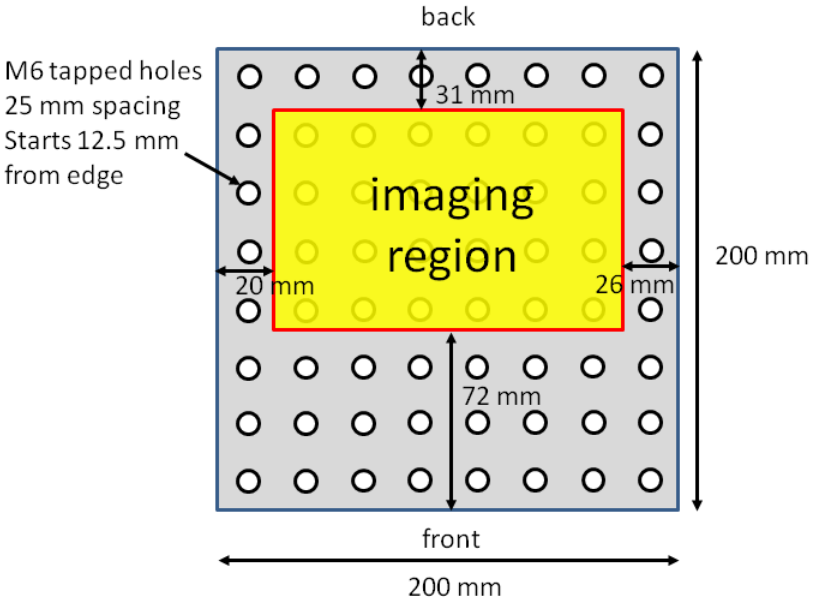

Figure 6: Top view schematic of the microscope stage with a highlighted area indicating the region in which samples can be imaged

The two events will be observed with a magnification of 1.5X. When using a ½" CCD camera with 1392 x 1040 pixels the field of view is approximately 4.1 mm W x 3.2 mm H and the pixel resolution is 2.95 μm/pixel. At the lowest magnification (0.58X) the field of view is approximately 10.66 mm W x 7.5 mm H.

The Camera

Each team will provide its own camera system as needed for machine vision capability. The camera must be compatible with the C-mount on the microscope and it should have a ½" sensor (CCD or CMOS) so that the field of view is the same for the competition camera and the team camera. The camera must weigh no more than 1 kg.

3. THE MICROROBOTS

Safety

Microrobots are to be provided by the competing teams. Microrobots and any associated equipment must not pose a danger to contest participants, spectators, or contest equipment. Any participating team whose equipment is deemed to be unsafe will be disqualified from the contest until such time as it can demonstrate to the contest organizers that the safety hazard has been eliminated.

Dimensions

At the start of each event, the entire microrobot must fit within a virtual cube that is 500 μm on a side with two faces parallel to the arena. The microrobot may separate or expand outside of this volume as necessary once the event has begun.

It is the team's responsibility to demonstrate compliance with the size requirement, and conservative choice of microrobot size is recommended. Teams can demonstrate compliance by imaging their micro-robot with its longest dimension perpendicular to the optical axis, provided that it can be shown that the longest dimension is perpendicular to within 5 degrees. A suitable size reference should be present in the image. It is also acceptable to image the microrobot in its operating orientation, and determine the peak height using a focal distance measurement.

Control Systems

A robotic system may include a machine vision subsystem to be mounted on the competition microscope. Power and instructions may be provided to the robot through any means that does not physically tether the microrobot. Off-board computers may be used to process data generated by these systems, and to generate signals to the microrobots and the competition timing system.

Auxiliary Equipment

The microrobotic system may include auxiliary equipment to control the ambient environment of the microrobot, to perform off-board computation, to generate electromagnetic signals, or for other necessary functions. This equipment must fit either on the stage of the competition microscope, or to the side of the microscope. Equipment placed on the microscope stage must fit in a box 25 cm long by 25 cm wide by 15 cm high. Equipment placed to the side of the microscope must fit in a box 80 cm long by 80 cm wide by 80 cm high. The nearest edge of the available area to the side of the microscope will be no more than 150 cm away from the microscope stage. Connections between these two areas may be made with tubes and wires whose combined cross section does not exceed 25 cm^2.

Manipulation of Objects

Only the microrobot is allowed to manipulate objects within the arena during the competition events. If an object is manipulated by any other means during any event trial, the trial will be scored as a foul.

4. THE REFEREE

The Authority of the Referee

Each trial will be controlled by a referee who has full authority to enforce these rules and award scores to competitors.

Powers and Duties

The referee:

- Enforces these rules.
- Controls each trial in cooperation with any assistants.
- Starts each trial as described in these rules.
- Stops a trial if a situation is deemed to be unsafe to participants.
- Stops a trial if a situation is deemed to be unsafe to spectators.
- Stops a trial if a situation presents a hazard to competition equipment.
- Stops a trial if competition equipment is not operating correctly.
- Assigns scores for each trial, and for each event.

All decisions of the referee are final.

5. QUALIFICATION

Teams intending to compete in the RAS MNRA Mobile Microrobotics Challenge must qualify by:

1. Submitting a written proposal to participate.
2. Submitting video demonstrating controlled microrobot motion as identified below.

Team Proposals

To apply to the RAS MNRA Mobile Microrobotics Challenge, submit a proposal by **December 15, 2013**. The proposal may be submitted by electronic mail to RAS_MMC_Organizers@googlegroups.com

The proposal must identify:

1. The individuals contributing to the team.
2. E-mail, telephone, and postal contact information for one individual who will serve as a Primary Contact.
3. The facilities available for fabrication, operation, and characterization of microrobots.
4. An overview of the microrobot design.
5. An overview of the intended capabilities of the microrobot.
6. An overview of the fabrication process to be used.

The purpose of the proposal is to convince the contest organizers that the team has a credible plan for bringing operational microrobots to the competition. Proposals will not be shared outside of the event organizers before the competition without express permission of the Primary Contact. After the competition, all proposals may be shared with others at the organizers' discretion, and may be used by the organizers for publicity or other purposes.

Proposals will be accepted or rejected by December 31st, 2013.

Video Submission

Teams whose proposals are accepted must qualify for live competition by submitting a short video that demonstrates the functionality of their microrobotic system. Videos must be submitted by March 15th, 2014. Videos may be submitted by e-mail or by posting on an accessible web location controlled by the team. Videos submitted by electronic mail must be no more than 5 Mb in size.

The qualification video must show the team's microrobot performing the following task:

Tele-operated Mobility Task: The microrobot must traverse one of the representative gate sequences shown in Figure 3. The path traversed must be between traversed on an arena meeting the competition specifications. Videos must be time stamped showing that the traversal is completed in less than 2 minutes. The robot can be directed by a user via tele-operation.

The qualification video must be accompanied by a demonstration that the microrobot meets the dimensional requirements of Section 3.

Teams invited to compete in the 2014 Microrobotics Challenge will be selected based on the video submissions. Microrobotic systems shown completing higher-numbered tasks from the above list will be selected prior to those completing lower-numbered tasks.

The qualification videos will not be shared outside of the event organizers before the competition without express permission of the Primary Contact. *After the competition, qualification and competition videos become the property of RAS Micro/Nano Robotics and Automation Technical Committee.*

Travel Funds

For the past three years, the National Science Foundation in the USA has provided funding to support the travel costs of up to two participants for each qualifying US team. The funds covered the ICRA registration, hotel stay, and transportation (airfare). Students from all US-based institutions are eligible. We are hoping to arrange for the same travel funding this year. Stay tuned for information if/when travel funds are available and if so, how to get reimbursed. Typically, students submit receipts for all reimbursable costs to the competition organizers to be eligible for reimbursement. European or Canadian teams have also received travel support from their home organizations, and we encourage every team to pursue local sources of funding for this event.