National Institute of Standards and Technology
U.S. Department of Commerce

NIST Mobile Microrobotics Challenge 2011

Official Rules

Version 1.3
September 27th, 2010
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1. THE EVENTS

Events Overview

The 2011 NIST Mobile Microrobotics Challenge will consist of two events:

1. Mobility
2. Microassembly

In the Mobility Challenge, a microrobot must navigate a 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 600-μm-diameter sphere and conform to the requirements listed in Section 3.

Each team must also furnish its own micro-arena, 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.

Mobility Challenge

The arena for the Mobility Challenge will consist of a 3.5 mm × 2 mm region in which a prescribed course is divided into three regions by the presence of two walls, each of which has two gates. (See Section 2 for a full description.) The team will place a microrobot so that its entire body lies in the first (leftmost) region. Upon the signal of the referee, the microrobot will traverse a figure-eight course through the four gates in a prescribed order, returning to pass through the first gate a second time. The robot must

then come to a complete stop in a position where its entire body lies in the second (middle) 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 Mobility Challenge.

The microrobot's **finish time** for a trial of the 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 five gate passes (in order).

The required order of the gate passes will be: [1, 2, 3, 4, 1]. Gate numbers and the required directions are identified in Figure 1 and listed in Table 1 below:

Number	Position	Direction
1	Top-Left	Region 1 → Region 2
2	Bottom-Right	Region 2 → Region 3
3	Top-Right	Region 3 → Region 2
4	Top-Left	Region 2 → Region 1

Table 1: Mobility challenge gate positions and required directions.

If the robot misses a gate, it must return to the starting side of the gate, and move through it in the correct direction before any other gate traversals will be counted toward completion of the trial.

If the microrobot moves out-of-bounds (See Section 2) or does not complete the task within 2 minutes, the trial will be scored as a foul.

The microrobot's **score** for the event will be the root mean square of its finish times on each of the three trials. Lower scores beat higher scores.

Any trial of the Mobility Challenge that results in a foul will be assigned a finish time of 2 minutes.

Microassembly Challenge

The arena for the Microassembly Challenge will consist of a 1.5 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 are 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 30 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 triangular in shape when viewed through the competition microscope. The longest in-plane edge of any component can be no longer than 500 μm. The shortest in-plane edge of any component can be no longer than 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 largest continuous length of assembly channel, in micrometers, that has been **densely packed**, as shown in Figure 2. A segment of the assembly channel is densely packed if no region between two adjacent components (or between a component and the channel wall) is big enough to accommodate a 50-um-diameter circle in the image plane. 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 quadratic 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 2 minutes. 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.

Mobility Challenge Arena Dimensions

Any arena used for the Two-Millimeter Dash must be a flat rectangular surface nominally 3.5 mm in length by 2 mm in width. The height of the surface (relative to the competition optics) must vary by no more than 1000 micrometers across its area.

Boundary lines should have a nominal width of 50 micrometers, and must be between 40 micrometers and 60 micrometers 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 by two vertical lines, such that the nominal lengths of the regions are 750 µm, 2 mm, and 750 µm, from left to right. Each dividing line will have two gaps ("gates") each having a nominal width of 600 µm. The gates will be separated by a nominal distance of 500 µm.

The dimensions of the arena do not include boundary lines. Specified dimensions are as follows:

Width of Arena:	2000 µm ± 20 µm
Length of Region 1:	750 µm ± 20 µm
Length of Region 2:	2000 µm ± 20 µm
Length of Region 3:	750 µm ± 20 µm
Width of Boundary Lines:	50 µm ± 10 µm
Width of Divider Lines:	50 µm ± 10 µm
Length of Top Divider Lines:	150 µm ± 10 µm
Length of Top Gates:	600 µm ± 10 µm
Length of Middle Divider Lines:	500 µm ± 10 µm
Length of Bottom Gates:	600 µm ± 10 µm
Length of Bottom Divider Lines:	150 µm ± 10 µm

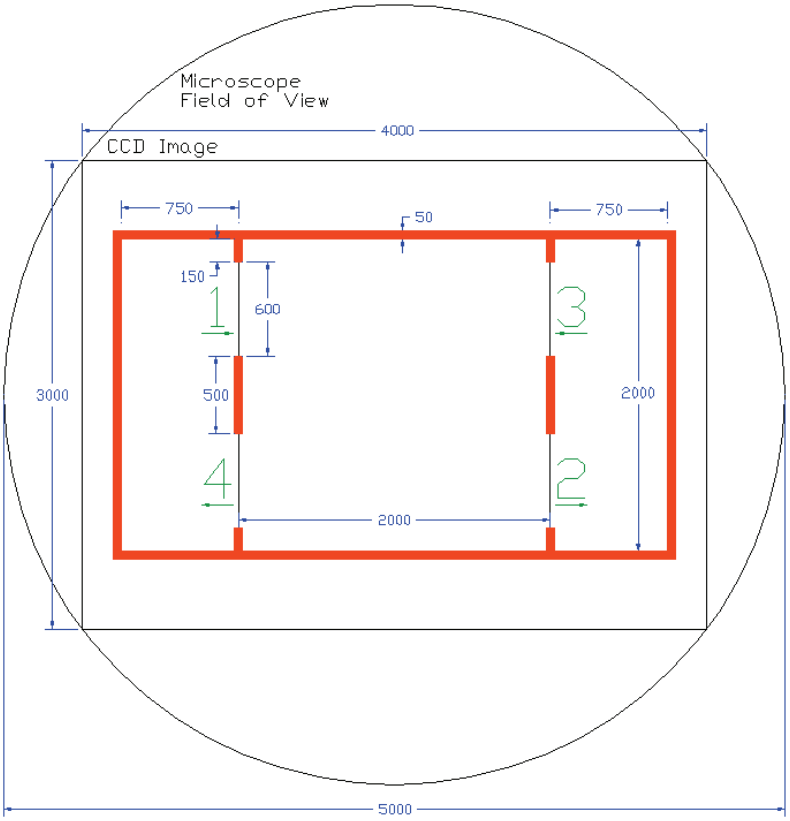

Figure 1: Arena Dimensions for the Mobility Challenge

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 micrometers, and must be between 40 micrometers and 60 micrometers 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) 1.5 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 micrometers, with a specified tolerance of ±10 micrometers.

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 Component Major Edge:	<= 500 μm
Length of Component Minor Edge:	<= 200 μm

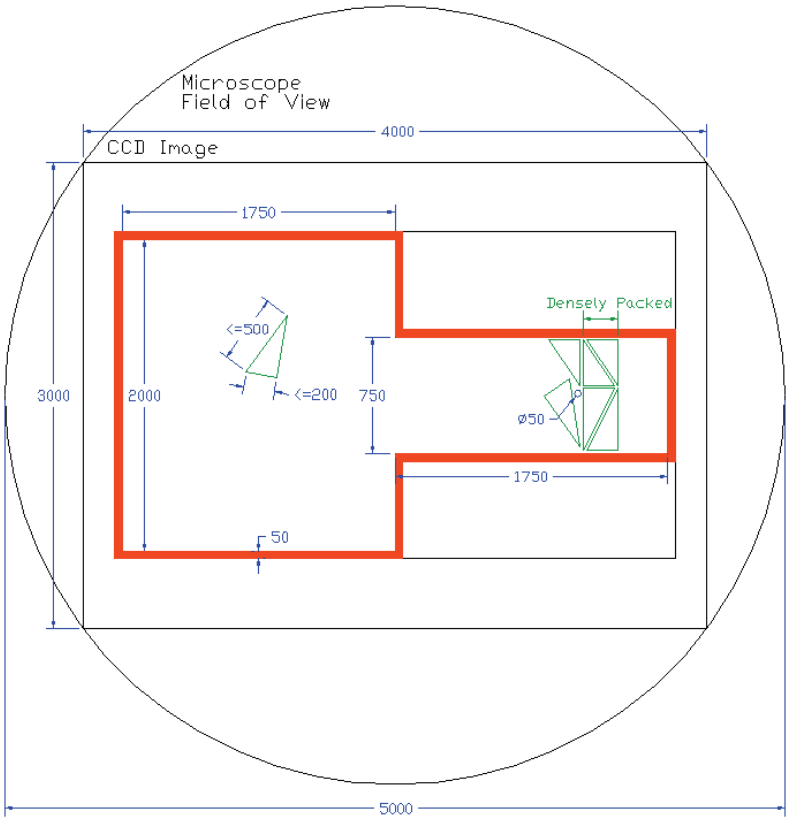

Figure 2: Arena Dimensions for the Microassembly event

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. 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 be sit below the bottom of the microscope to avoid interaction with the microscope.

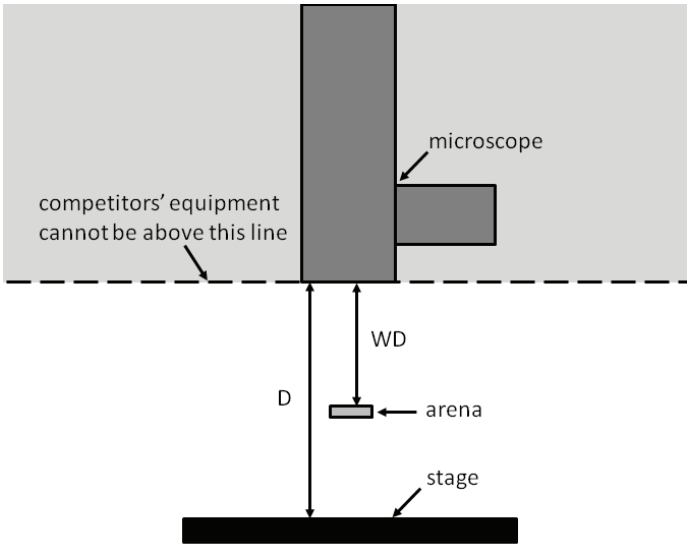

Figure 3: Front view schematic of the microscope and microscope stage

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.

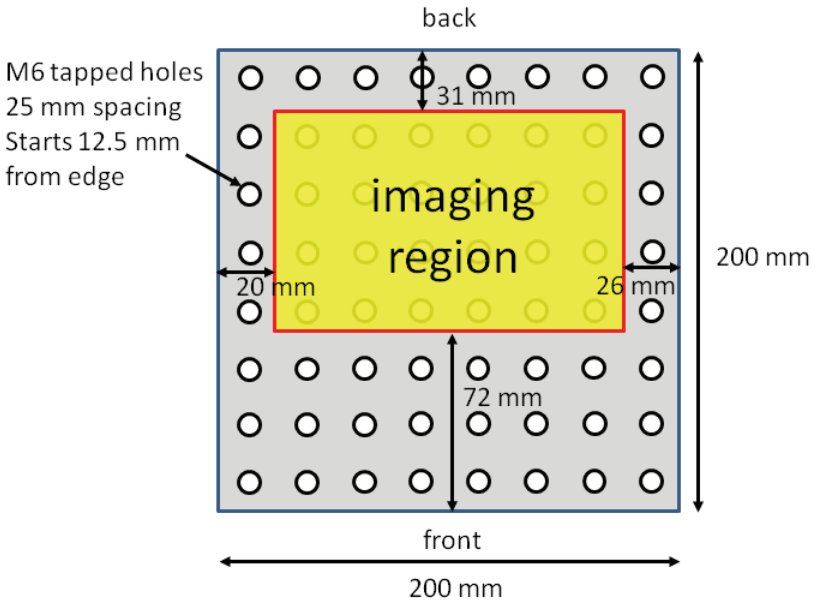

Figure 4: Top view schematic of the microscope stage with a highlighted area indicating the region in which samples can be imaged

The first 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 field of view for the third event will set according the size of the associated arena.

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 600-μm-diameter sphere. 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. The microrobot must then fit in a box with a 600-μm diagonal.

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.
- Provides a report of each trial to the Technical Committee, to include trial times, scores, and any disqualifications.

All decisions of the referee are final.

5. QUALIFICATION

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

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

Team Proposals

To apply to the NIST Mobile Microrobotics Challenge, submit a proposal by December 1st, 2010. The proposal may be submitted by electronic mail to microrobotics2011@nist.gov, or by post to:

NIST Microrobotics Challenge, 2011
c/o Craig McGray
National Institute of Standards and Technology
100 Bureau Dr., MS 8120
Gaithersburg, MD 20899

The proposal must identify:

1. The individuals contributing to the team.
2. Contact information for exactly 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 within two weeks of receipt.

Video Submission

Teams whose proposals are accepted must demonstrate satisfactory progress on developing their microrobotic system by submitting a short video of their microrobot in motion. Videos must be submitted on CD or DVD to the address above by March 15th, 2011.

The qualification video must contain a demonstration of the team's microrobot crossing a distance of 2 mm. The microrobot must begin from a stationary position, traverse the 2 mm distance, and come to a complete stop. The distance from the front of the robot in its starting position to the back of the robot in its stopped position must be no less than 2 mm and no more than 2.5 mm. Videos must be time stamped showing that the traversal is completed in less than 2 minutes.

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

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 videos become the property of the National Institute of Standards and Technology.