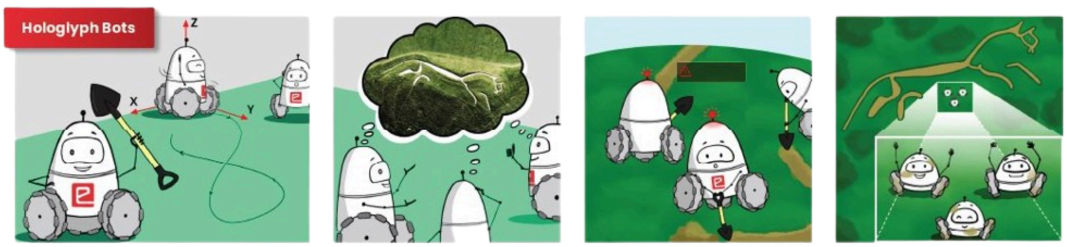
e-Yantra Robotics Competition 2023-24

Hologlyph Bots



Rulebook

Welcome to the ultimate document for the Hologlyph Bots Theme of eYRC 2023-24!
This document summarises the theme and defines the rules for this theme.

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1. Introduction

Before we get to the technical details of this them, here's the story behind the name of this theme.

In the years when flying aircraft and spacecraft have become super affordable, a large number of new geoglyphs are being discovered by explorers. **Geoglyphs** are large designs or motifs that are difficult to see or even identified on the ground but are easily appreciated when seen from the sky. The mysteries of these newly discovered geoglyphs have created a new excitement across the population of humankind! Due to this new hype around geoglyphs, multiple teams of engineering enthusiasts have decided to build robots to create bigger than ever, more intricate than ever and modern versions of geoglyphs.

In this theme, we prepare for this future by doing the same in an 8ft x 8ft arena and an overhead camera to assist these autonomous robots!

To enable the robot to do more complex and interesting glyphs, the teams will explore an exciting type of mobile locomotion, known as holonomic drive. To draw glyphs of such large dimensions autonomously we will surely need more than just one robot. And thus we shall have a team of three holonomic drive robots for the job.

And thus the name **Hologlyph Bots**,
a theme about a team of *three* **Holo**nomic drive **glyph**s drawing ro**Bots**!

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2. Theme Description

In the next section, we shall look at the detailed description of the final task of this theme!

Engineering Motivation & Journey so far

The technical challenge proposed in this theme are many and can be desribed as folows:

- To design and fabricate a team of three holonomic drive robots
- To implement a centralised controller using only an overhead camera for feedback
- To collaboratively plot desired shapes or drawings

Through stage 1 of this theme, we explored many different aspects of the challenge by working on a simulated setup in Gazebo with ROS2.

- In Task 0 and 1A, we started by setting up and getting familiar with the tools we will need in our journey of tackling this challenge.
- Next, in Task 1B we understood how to autonomously control a "sliding block on a surface", to go to goal pose with control inputs (v_x, v_y, ω) given ideal localisation (from simulator).
- In Task 2A, we took a step closer (from simulator) to the real implementation by using a simulated overhead camera for feedback and working on the kinematics of a three-omni-wheeled robot [(vx, vy, ω) $\longrightarrow$ (v1, v2, v3)] and controlling wheel velocity (v1, v2, v3) as the control input instead of giving velocities to "sliding block on a surface"
- Finally in Task 2B, we simply multiplied this to three robots without thinking about concepts like task allocation and collision avoidance and scheduling.

With that Stage 1 comes to a wrap and we begin with the hardware based tasks in Stage 2!

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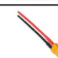
Components List (Provided in Kit)

Hardware Provided in Kit:

Sl No	Component Name	Qty	Image
1	ESP 32	3	
2	USB Camera (OV2710)	1	
3	USB Extension Cable (5m)	1	
4	Omni Wheel 38mm	9	
5	MG995: 360 continuous servo	9	
6	MG90s: 180 servo	3	
7	Water Brush and Metallic Brush Pen	6 + 3 = 9	
8	Buck Converter XL4015	3	

Sl No	Component Name	Qty	Image
9	Orange 11.1V 2200mAh 30C 3S Lithium Polymer	3	
10	Li-Po Battery Charger	1	
11	1-8S Lipo Battery Voltage Tester	1	
12	XT60 cable	3	
13	Bolt & Nut (15mm - M3)	40	
14	Micro USB Cable	2	
15	40 Pin Burge Strip Male	1	
16	Jumpers (10 pin male to female jumper wires , 10 pin male to male cable and 10 pin female to female cable)	30	

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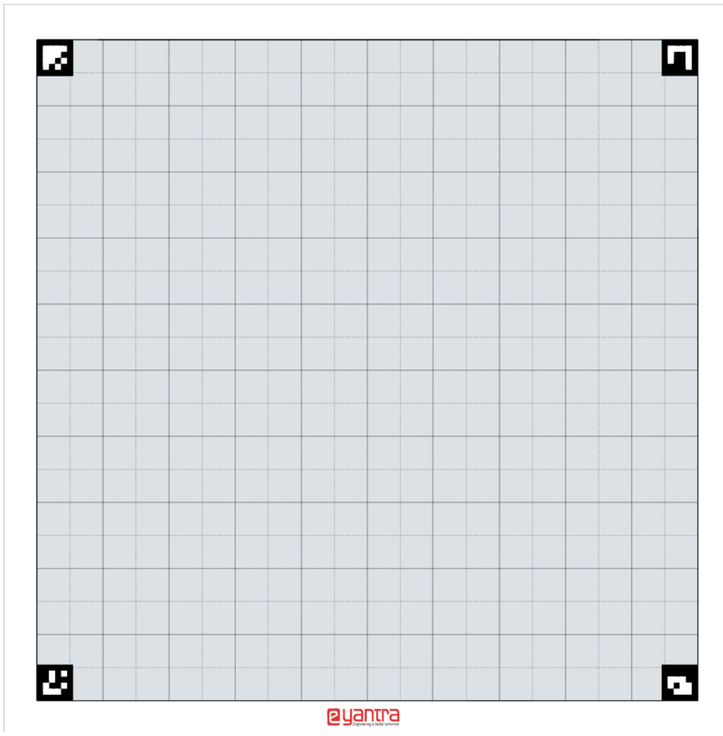
Arena/Setup

Arena as shown in the image below was provided in Task 3B for the teams to print, to practice on and to do final task on.



As described in Task 3B, the arena must be printed on the glossy side of a 8ft x 8ft flex sheet. The dimension of the grid (drawing area) is 220cmx220cm and is divided into 10 unit of 22cm each in both x and y directions. Note that 1 unit on the grid correspond to 22cm on the arena which also correspond to 50 pixels on the feedback image (and in goal points description - explained further in Task Description).

The Arena setup involves:

- **Four Aruco markers** printed in the arena defines the drawing boundary. Note that the outer edges of the aruco align with the corner of the Arena. These aruco markers must be used to calibrate the feedback. This is important to ensure the position and orientation of the overhead camera doesn't affect the scaling, orientation and the centering of the images drawn. The Manual Drawing Evaluation (mentioned in scoring formula) will involve using the grid printed on the arena to ensure the same.
- **Waveshare OV2710 camera** must be mounted at a height of about ~2.5m ideally facing perpendicular to the ceiling (facing down), making sure all the four markers are comfortably within the frame, so that the the aruco are not distorted/cut-off after camera calibration.

An important term that must be introduced here is:

- **"Home Pose"**: The positions of the three robot's pen's start position will be defined/given along with the desired shape/function (explained in Task Description Section). There are grids on the arena that will be used to define this position.

That is it! Quite a simple arena with hardly any elements. But for a Holonomic Art Bot, all we really need is a blank canvas and that is what the arena is. Next, let's have a look at the robots that will be creating the masterpiece!

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Robot Description

The robot we will be building and using in this theme are **Three Three Omni-wheeled robot** (that is not a error ofcourse).

Think
For the "think" part of the "sense-think-act" of the robot, a.k.a. the brain of the robots we will use **three ESP32 development boards**. This is quite a perfect match for this project because it can interface with our hardware ofcourse and additionally it is supported by micro-ROS, which is perfect for establishing communication with the laptop/PC running ROS2 (and is connected to the overhead camera).

Act
For the actuation we shall use **three x three MG995 360 continuous servo motor** coupled to the **three x three 38mm Omni wheels**, arranged such that the Kinematics equation that defines the matrix representation of the transform from (vx, vy, ω) ⟶ (v1, v2, v3) is an invertible 3x3 matrix. (The obvious arrangement being: all the 3 wheels tangent to a single circle, 120º between the axes of any two motors).

Additionally we shall use **MG90s 180 servo** to achieve "pen-up", "pen-down" operation. The servos shall be coupled to the **brush pens** provided in the kit. The *water* brush pens are for practice and the *metallic* brush pens are for the final run.

Sense
For the "sense" part of the "sense-think-act" of the robot, we shall have no onboard sensors (except the one inside the servo motor)!! So where is the sensing? It's of course the overhead **Waveshare OV2710 camera** mentioned in the Arena Setup.

> IMPORTANT: The position of the Aruco Marker on the Robots and the x,y, position of where the brush pen makes contact with the arena, w.r.t the center of the chassis (intersection point of the motor axes) must be taken into consideration while drawing to ensure there are no offsets caused by this.

Power
Three **2200mAh 3S 30C (11.1V) Lithium Polymer Battery Pack** is provided in the kit for powering the robot.

⚠️ LiPo Battery Maintenance ⚠️

LiPo Battery maintenance is a **VERY critical matter** and should not be taken lightly both for safety reasons and for longer life. For this a Battery Checker and Balance charger is provided in the kit. Please read about LiPo battery maintenance before using the LiPo Batteries (Explained in Task 3C Hardware Testing).

Chassis, Circuit Board and other miscellaneous components
The design and fabrication of the chassis and circuit board is left to the teams and are encouraged to take into account *functionality*, *reliability*, *ergonomics* and *aesthetics* while designing the robots. *This will directly or indirectly affect the score in the finals.* Scoring Formula is explained in the last section of the rulebook.

For the chassis, teams could explore for example 3D Printing, Acryllic/wood sheet laser cutting etc.. For the circuit board, the teams could explore for example perf boards, ferric chloride etching, CNC etching etc..

Coupling motor to the wheel is super easy and self explanatory. We have provided nut and bolts that may be helpful (optionally) to mount the motor to the chassis.

XT60 cable is provided in the kit to connect the circuit board to the battery. Jumpers are provided in the kit just for hardware testing and we would NOT recommend using jumpers and bread boards (not in kit) while designing and building their bots.

Teams are allowed to use additional components for the purpose of ergonomics and aesthetics like switches, LEDs, buzzers etc.. But ofcourse it is mandatory to use only the componenets listed by us for the essential functionality of the bot (Sense-Think-Act-Power of the robot.

💡 **IMPORTANT:** We would like to encourage the teams to think of the task of designing and fabrication of the robot as building a product for a customer. Going the extra mile beyond functionality will be rewarded by the Scoring Formula. Since this is a very subjective score it will be introduced only in the finals at IIT Bombay and not in Stage 2.

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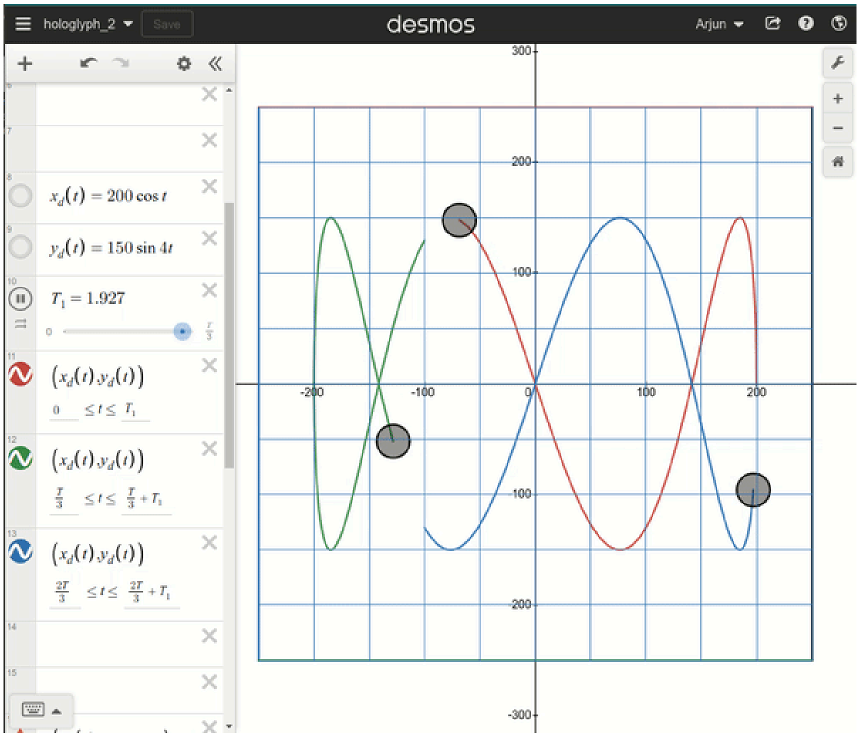
Task Description

The Task has one simple objective: Draw shapes using the three holonomic drive robot with maximum “Accuracy” and minimum “Time”.

There are two modes of the task, defined by how the desired shapes are given to the teams:

- **Function Mode**: Drawing a shape defined by parameterised function, x(t), y(t), θ(t) as t goes from 0 to T (some positive real constant).
    - Where units of x and y are in pixels (to make it easy to compare with feedback of pose which is in pixels - from overhead camera).
    - (x,y) = (0,0) is the centre of the image/arena.
    - x(t) and y(t) lie in the range {-249, ..., 250} and θ(t) is 0 for all t,
- **Image Mode**: Drawing a shape defined by the contours of a black and white image of dimension 500*500. Which ofcourse has the same ratio as the dimension of the arena 1:1.

Task Mode	Example gif/image
Function Mode	 an example function is described in the desmos plot. x_d(t) and y_d(t) (on the left panel) describe the function as t goes from 0 to T=2π. This task is divided among the three bots by spliting [0,T] into three intervals.
Image Mode	 an example of image mode described by a 500px x 500px black and white image

This task must be accomplished by the robots defined in Robot Description. For feedback the team will use an overhead camera connected to a laptop/pc (as described in Arena Setup) which is wirelessly communicating with the robots. The robots must start at "home pose"s which will be provided along with the desired shape.

IMPORTANT:

- The teams will be given the desired functions and/or the b/w image of desired shape a short period before the runtime (for finalists) or the given deadline (for final task online submission). So the teams must be able to switch between modes and enter the desired input to the system in short notice.
- The teams will be asked to demonstrate either one or both of the modes in a single run therefore must be designed to switch between modes autonomously.

- The teams must make sure the shapes are perfectly to scale, position and orientation on the arena. For this the teams will need to use the 4 aruco markers on the arena to calibrate (to centre and straighten the camera feed) the image processing/feedback system quickly and reliably. The teams must also take into account the offset caused by pen position on the bot.

There are many different challenges that will arise while doing this task:

- task allocation: among the robots: who does what part of the drawing.
- control strategy: for example, go-to-goals vs pure pursuit.
- collision avoidance: for example, trajectory tracking/scheduling/synchronizing vs dynamic obstacle avoidance with no synchronizing.

These topics are discussed in Task 4 (and onwards) of this theme. Teams are free to choose their approach to solving the general problem of drawing shapes with a team of three robots.

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3. Theme Rules

Theme Run

Theme Run/Play

Before the start of the run:

- the teams must place the robots at the defined "Home Poses" (refer 2.2.2 Arena/Setup)
- the teams must run the evaluator provided. This is used for automated calculation of Accuracy Score and Time of Run.
  - the evaluator will display Status: `Set Robots @ Home Position` in red if the bots are not at home positions.
  - as described in the task description section, the position of the pen tip in pen down position and zero orientation, must be at the home position of each of the robot.
  - make sure your feedback node is publishing the position of the pen to the `\pen1_pos` `\pen2_pos` and `\pen3_pos` topic.
- once the bots are placed at the respective home positions with zero orientation, the evaluator will display Status: `Robots Set @ Home Position` in green.
- now the teams can proceed to run their controller(/s) to start the run.

The run will **start** (as per the evaluator):

- when ANY of the robot leaves the "home pose" (as a result of the team starting the run from their "base station").
- after which the system must run completely autonomously with no manual intervention in any part of the system.
- Status will change to `Run in Progress...` in blue.

During the run:

- the teams must publish to the `\pen1_down`, `\pen2_down`, and `\pen3_down` topics when they wish to do pen down.

- the teams must publish to the `\pen1_pos`, `\pen2_pos`, and `\pen3_pos` topics the x,y position of point where the pen tip makes contact with the arena,.

- the evaluator will take the coordinates published in pen pose topics into account for accuracy score calculations only when the respective pen down topic is enabled.

- Penalties:
    - Each manual intervention of any kind of single or multiple bots will incur one penalty count. A maximum of 3 interventions will be allowed.
    - Every collision between two robots will incur penalty points.

The run will **stop**:

- when the team terminates the run by calling a service provided by the evaluator OR
- when the total time of T_max seconds runs out.

At the end of the run:
The evaluator will display the team's Team score and Accuracy score based on, time of run and a comparison of the robot pose trajectory published by feedback (when pen down is active) and the desired pose trajectory. Rest of the scores described below will be evaluated by the e-Yantra team (or Jury) manually.

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Scoring Formula

$$\left(\frac{E_{MAX}-E}{E_{MAX}} \times 200\right) + \left(\frac{T_{MAX}-T}{T_{MAX}} \times 200\right) + (MDE) + (100 - P \times 30 - C \times 30)$$

Accuracy Score	Time Score	Manual Drawing Evaluation	Reliability Score

Accuracy Score: ((E_MAX - E)/E_MAX)×200

- E_MAX: a constant provided along with the desired shape to roughly indicate the worst error possible.
- E: the error estimated by the evaluator by comparing the robot pose and desired pose trajectories.

Time Score: ((T_MAX - T)/T_MAX)×200

- T_MAX: a constant provided along with the desired shape that defines max time given to complete the task.
- Run Time (T): Time of Run
    - Timer starts at 0 when the run "starts" and stops at value T when the run "stops". ("start" and "stop" defined in Theme Run section)
    - T value is automatically maxed out (implying time score of 0) if the Accuracy score is calculated to be less than a threshold that defines a valid run.

Manual Drawing Evaluation (MDE) (Max: 100)

A score given by the Theme Developers after manual evaluation of drawing created by the robot or the visual inspection of the robot's movement during the run. Parameters taken into consideration while scoring:

- Accuracy
    - Scale, orienatation
- Completeness
    - Is the drawing drawn without breaks?
    - Is the pen-down operation operating as expected?
- Smoothness
    - For ex: if the desired shape is a circle, does the drawing appear to be a circle or an n-sided polygon (smaller n implies a poorer score in smoothness)?

- Continuity
    - If we imagine a continuously flowing ink, then to avoid blobs/spots of ink we would need to maintain constant velocity while drawing.
    - So, to score high in the continuity parameter, the teams must try to maintain constant velocity or minimum acceleration/deceleration or jerks.

Reliability Score

A fixed 100 points is awarded to all teams (this is the Reliability Score if there are no penalties incurred).

Penalties:

- Penalty of 30 points is incurred for every reposition, adjustment of single or multiple bots, or any other manual intervention during the run time. A maximum of 3 interventions are allowed.
- Penalty of 30 points is incurred for every collision between two robots.

Design Score, DS (100) A design score is awarded by the evaluator based on the design and fabrication of the robot. Since the Functionality and Reliability of the design are already represented in the above scoring parameters, in this score we shall mainly focus on parameters like Creativity, Ergonomics and Aesthetics of the design and fabrication. Since this is a subjective score it will be introduced only in the finals at IIT Bombay and not in Stage 2.

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Important Note

In case of any disputes/discrepancies, the e-Yantra decision is final and binding. e-Yantra reserves the right to change any or all of the above rules as we deem fit. Any changes to the rules will be duly notified to the participating teams.