MAD76 Vision

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September 20, 2025

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Contents

1 Agenda

- Print and place the AruCo markers for computer vision (see Section 2)
- Mount, adjust and calibrate the Raspberry Pi camera (see Section 3)

2 AruCo Markers

MAD76 applies AuUco markers in computer vision for detecting and tracking cars. This section explains

- how to generate and print the markers (see Section 2.1),
- how to place the coordinate frame markers (see Section 2.2),
- how to place the car markers (see Section 2.3),

2.1 Marker Generation

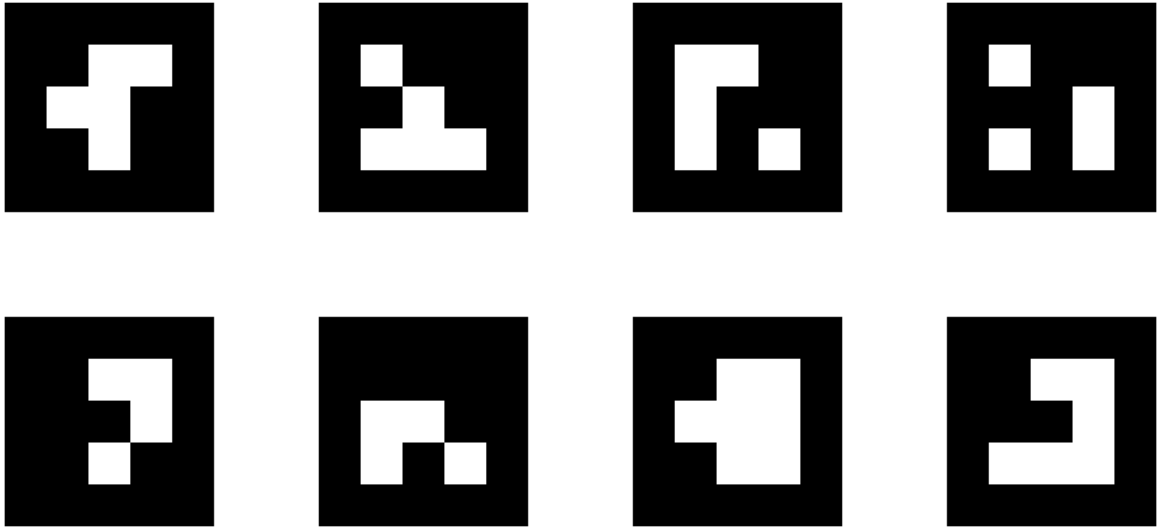

Figure 1: AruCo markers for cars and coordinate frame.

- The cars are tracked by ArUco markers [1].
- Computer vision computes the Cartesian coordinates and the yaw angles of the cars.
- The markers are generated with the OpenCV ArUco library.
- A custom ArUco dictionary of 8 markers with a size of 3x3 bits is used to increase the reliability of computer vision.
- The PNG image of the 8 markers can be optionally created by

```
cd ~/src/mad2/mad_ws
install/mbmadvisionaruco/lib/mbmadvisionaruco/create_board --bb=1 -d=17 -w=4 -h=2 -l=200 -s=100 markers.png
```

- The markers IDs are from 0 to 7, 0 to 3 in the first row from left to right, and 4 to 7 in the second row.
- Print the markers in Fig. 1 on a snow-white, 80 grams paper.
  - Make sure to configure high quality printing.
  - Scale the printing such that the black area of the markers have a height and width of 21mm each.
- Cut the markers as squares including approx. 5mm boundaries.
- Note the marker IDs before cutting with a thin pencil on the boundaries, because you will need these IDs later on.

2.2 Frame Markers

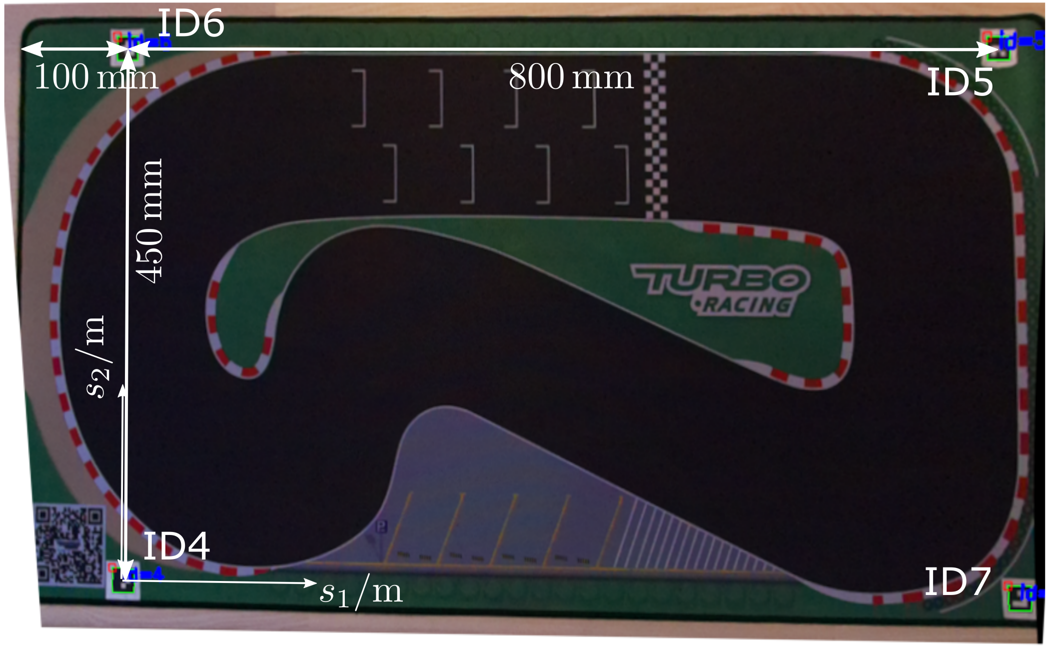

Figure 2: Track with 4 coordinate frame markers.

- 4 frame markers define the coordinate frame of the track.
- All coordinates of cars and track are measured in meters.
- The frame origin $(s_{01}, s_{02}) = (0\mathrm{m}, 0\mathrm{m})$ is at the center point of marker ID4.
- Place frame markers with IDs 4, 5, 6, 7 at corners of board as depicted in figure.
  - It is recommended to place the markers with high accuracy in the 1mm range. Otherwise, the control functions of the MAD76 driving stack will loose precision.
  - Although modified distances may be later configured in the ROS2 package `mbmadvisionaruco`.
  - The distances are measured at the marker center points.
  - The markers must form a rectangle.
  - The sequence of the marker IDs is essential.

2.3 Car Markers

Figure 3: Red car with marker ID 0.

- Each car has its individual marker.
- The following configuration is recommended:

Marker ID	Car
0	red orange
1	green yellow
2	blue
3	white

- If you have fewer than four cars, please start with ID 0 in any case.
- Each marker's center point must be placed exactly at the car's rear axle center point.
- The horizontal orientation of the marker must match to the forward direction of the car.

3 Camera

This section explains

- how to mount the camera (see Section 3.1),
- how adjust focus and aperture (see Section 3.2),
- and how to calibrate the Raspberry Pi camera using ChArUco boards (see Section 3.3).

3.1 Mounting Camera

- The camera must be mounted above the MAD76 track for bird's eye view.
- The camera lens should be at a height of approx. 106cm above the track.
- The ideal position is above the center of the track.
- If the camera is mounted on a tripod next to the track, a tilt in one direction is necessary, which should be as small as possible.
- In all other directions, the camera should be aligned in parallel to the track and not be tilted.

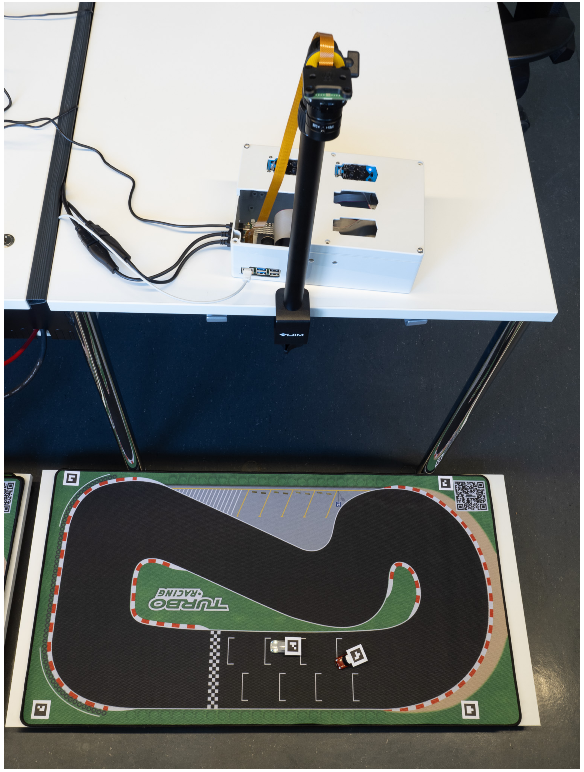

Figure 4: Mounting camera above the MAD76 track.

- Place the track as close as possible to the tripod, such that
  - the camera can capture the entire track without any obstruction,
  - the whole track area is as close as possible to the camera for higher pixel resolution,
  - and is in the focal plane of the camera
- For adjusting the position and tilt of the camera, run the following ROS command

  ```
  ros2 launch mbmad madpiman.launch
  ```

  This opens a window with the camera image as depicted in Figure 2
- All 4 frame markers and track borders shall be visible.
- The lower and upper track borders shall be in parallel to the image borders.
- The lower track border shall be a as close as possible to the lower image border if the camera is titled.

3.2 Focus and Aperture

- In MAD76, the camera acquires images with a frame rate of 40 frames per second (fps) (or a sampling time of $25\mathrm{ms}$)
- The MAD76 SW sets the exposure time to a fixed value of $2\mathrm{ms} = 1/500\mathrm{s}$ to avoid motion blur.
- The focus of the lens must be adjusted to ensure that the entire track area is in sharp focus.
  1. Fasten the screw for aperture adjustment (`OPEN<>CLOSE`).
  2. Loosen the screw for focus adjustment (`NEAR<>FAR`).
  3. Adjust the focus by turning the focus ring until the entiretrack area is in sharp focus.
     – You may zoom in by hitting the menu button + of the camera image window.
  4. Fasten both screws.

- The aperture must be adjusted to the small value (large f-stop number) to achieve a large depth of field.
  1. Fasten the screw for focus adjustment.
  2. Loosen the screw for aperture adjustment.
  3. Adjust the aperture by turning the aperture ring, such that all 4 frame markers are reliably detected.
     – The detection is successful if all 4 frame markers are highlighted in the camera image by green bounding boxes.
     – A darker image is better than a brighter image for reliable detection and greater depth of field.
  4. Fasten both screws.

3.3 Camera Calibration

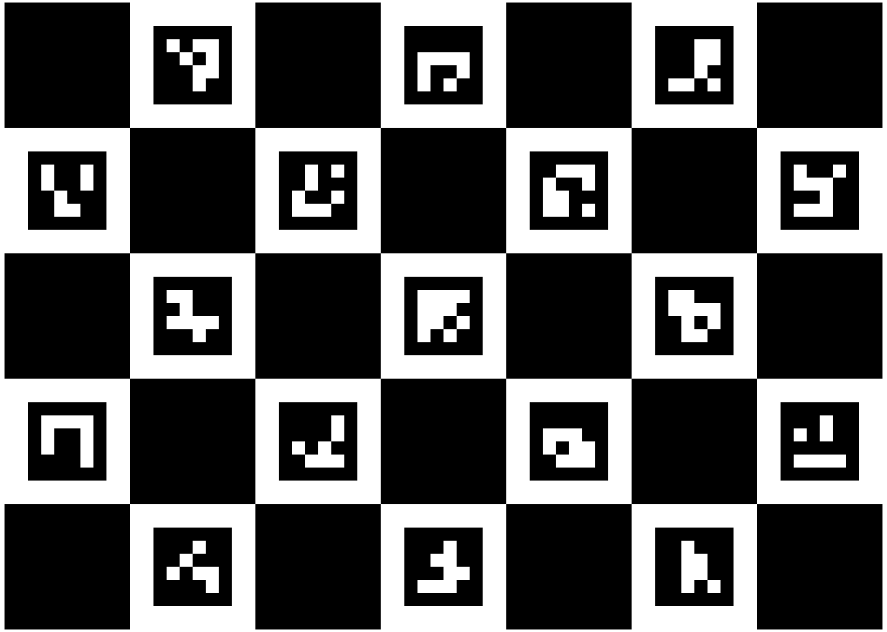

Figure 5: ChArUco board for camera calibration.

The Raspberry Pi camera must be calibrated, so that the MAD76 can undistort the camera image frames [2]. The calibration is performed applying an ChArUco board, which is an augmentation of a chess board by AruCo markers for higher precision. Follow the following steps for calibrating your camera:

- Print the marker board in Fig. 5 on a snow-white DIN-A4 paper. Use high-quality printer settings.
- This PNG image can optionally be created by

```
cd ~/src/mad2/mad_ws
install/mbmadvisionaruco/lib/mbmadvisionaruco/create_board_charuco -d=0 -w=7 -h=5 -ml=500 -sl=800 charucoboard.
   png
```

- Fix this paper on a cardboard.
- Measure the side lengths of the squares and the AruCo markers (not including the white boundaries) in meters.
- Calibrate the camera by running the following command:

```
ros2 run camera_calibration cameracalibrator --pattern=charuco --size 7x5 --square 0.036 --charuco_marker_size
   0.022 --aruco_dict 4x4_50 image:=/mad/camera/image_raw camera:=/mad/camera camera/set_camera_info:=/mad/
   camera/set_camera_info
```

- After successful calibration the camera matrix and distortion coefficients are stored in the file

```
~/.ros/camera_info/imx296__base_axi_pcie_120000_rp1_i2c_88000_imx296_1a_800x600.yaml
```

or similar.

- This calibration data file will then be automatically loaded by the MAD76 computer vision for undistorting camera frames.

References

[1] OpenCV. *Detection of ArUco Markers*. Accessed: 2025-02-05. 2025. URL: https://docs.opencv.org/4.x/d5/dae/tutorial_aruco_detection.html.

[2] ROS. *How to Calibrate a Monocular Camera*. Accessed: 2025-02-05. 2025. URL: https://wiki.ros.org/camera_calibration/Tutorials/MonocularCalibration.