ASSIGNMENT

5

DECEMBER 12, 2021

Submitted to: Prof. Dr. Kemalettin Erbatur

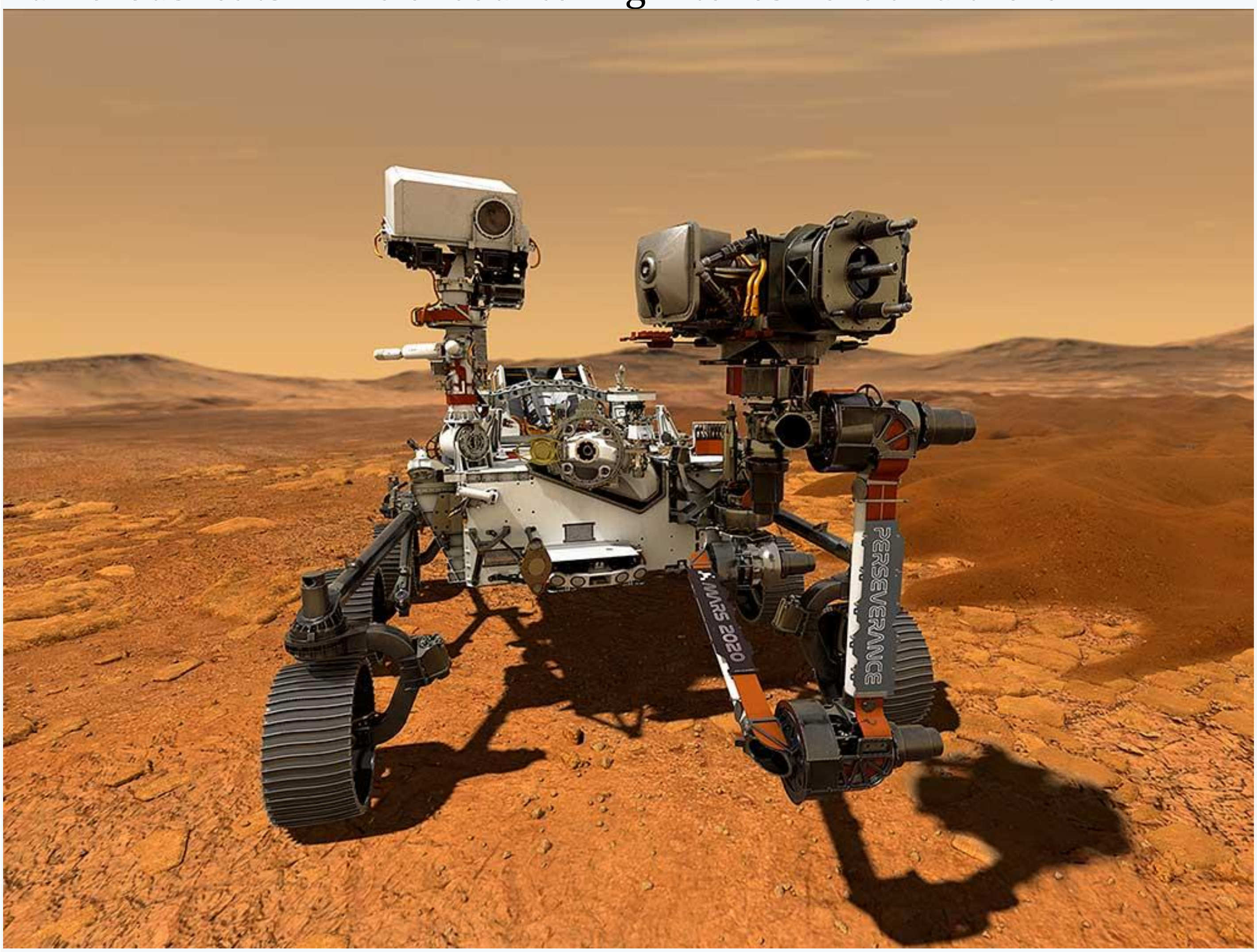
Name of Student: Moses Chuka Ebere
Student Number: 31491
Course: Autonomous Mobile Robotics (ME 525)

TABLE OF CONTENTS

WHEELED PLANET EXPLORATION ROBOT

MARS 2020 PERSEVERANCE ROVER

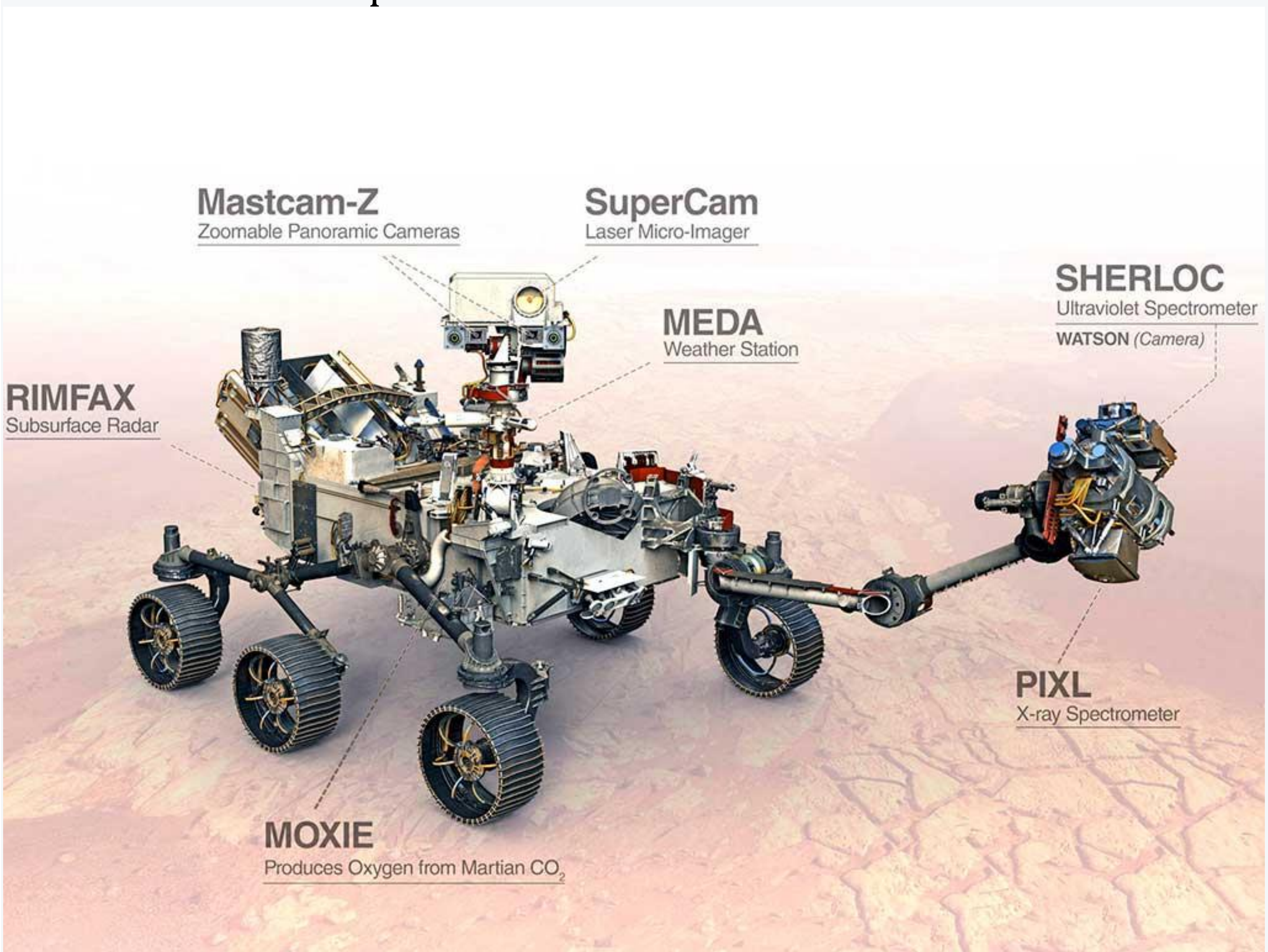
Perseverance is one of five robotic vehicles (also knowns as rovers) that have so far been sent to Mars by NASA. Manufactured by the Jet Propulsion Laboratory, Perseverance is a semi-autonomous rover tailor made for exploration of the planet, Mars. The robot is around the size of a small car, and it is loaded with high-end scientific equipment with the goal of seeking evidence that gives credence to past microbial life on the red planet. Launched on July 20, 2020, and landed on February 18, 2021, the robot has so far achievement numerous feats while encountering hitches here and there.



I consider this robot state-of-the-art for the following reasons:

- While it took Curiosity more than 8 months to reach Mars, the perseverance rover made the same trip in about 7 months.

- It also has a total of 23 cameras which is five more than its predecessor – Curiosity - and is equipped with a pair of microphones.
- The rover is replete with seven state-of-the-art science instruments to perform different tasks.



- The SuperCam is a combination camera, rock-vaporizing laser, and spectrometer that can identify the composition of rocks and soil.
- The robot is powered by two lithium-ion rechargeable batteries as a standby for times of peak demand.
- In order to charge the batteries, an on-board Radioisotope thermoelectric generator which converts heat from plutonium-238 into electricity is used.

- To mitigate the possible adverse effects of radiation, the central processor (underlined by PowerPC 750 Architecture: a BAE RAD 750) is specially radiation-hardened.
- Durable materials like aluminum and titanium are used throughout the robot.
- As a measure against negative factors, the electronics are housed in insulated surfaces.
- Particularly impressive is the large robotic hand attached to the robot. As seen in the last figure, the end of the arm is equipped with a large turret with a coring drill and other scientific gadgets.
- The hand turret has five degrees of freedom.

Actuators

- Rotary actuators in the arm
- Steering motors
- Drive motors
- Actuators for sampling handling
- Actuators for liquid pumps

Sensors

- Ground contact sensors
- close-range microscopic camera and spectrometer
- ground-penetrating radar
- sensors to measure temperature, pressure, humidity, wind speed and direction, and atmospheric dust characteristics, etc.
- Cameras

Challenges

Due to the unfamiliar terrain of the red planet, the Perseverance rover has been faced with multiple challenges, some of which include:

- Protecting the sensitive on-board equipment against strong Martian winds and dust.

- Withstanding large temperature variations of about 170 degrees within a 24-hour time frame.
- Mitigating the effect of the dust on the cameras.

Achievements

- Perseverance has so far been able to test all its scientific equipment.
- The rover has driven about 2 miles on Mars while taking tens of thousands of photos.
- With its arm, the rover has been able to collect the first set of rock samples.
- The attached helicopter, Ingenuity, has also flown on multiple mission covering as much as 60% of a kilometer in one flight.

MATLAB CODE

Calculation for Pixel Coordinates

The projection matrix containing the intrinsic parameter matrix, rotation matrix, and translation matrix would be need for this task.

The focal length in pixels is not expressly given; however, it can be computed by obtaining a scaling factor from the image frame (in pixels) and the image plane (in mm). In this case, it will be (1000/24) `[pixel/mm]`.

For this assignment, I used two different methods to calculate the pixel coordinates of the point. **The first method utilized the equations below while the second method uses some computer vision toolbox inbuilt functions like cameraInstrinsics() and worldToImage().**

$$\begin{bmatrix} \lambda u \\ \lambda v \\ \lambda \end{bmatrix} = \begin{bmatrix} kf & 0 & u_0 \\ 0 & kf & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix}$$

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix} + \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} = \begin{bmatrix} R & | & T \end{bmatrix} \cdot \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}$$

METHOD 1

m-file name – findPixelCoordinates.m

```
clear all; close all; clc

% Define the Intrinsic Parameters
image_frame = 1000; % in pixels
image_plane = 24; % in mm

principal_point = [image_frame/2; image_frame/2]; % (u0,v0)
in pixels
focal_length = 30; % in mm
scale_factor = image_frame/image_plane; % k in pixel/mm
effective_focal_length = scale_factor*focal_length; % in
pixels

theta = 12*pi/180; % in radians

% Coordinates of Point in World Frame
Xw = 0.05; % in meters
Yw = 0.03; % in meters
```

```
Zw = 0.3; % in meters
point_in_world = [Xw; Yw; Zw];
H_world = [point_in_world; 1]; % Homogeneous World
Coordinates

% Extrinsic Parameters
T = [0.1; 0.2; 1]; % Translation vector

% Obtain the coordinates of the point with respect to the
camera center
% using the rotation and translation vectors.
rotationMatrix = [cos(theta) -sin(theta) 0;
                  sin(theta)  cos(theta) 0;
                  0              0      1];

point_in_camera = [];
point_in_camera = rotationMatrix * point_in_world + T;

% Define lambda which corresponds to the depth (Z_camera)
lambda = point_in_camera(3);

% Create the intrinsic parameter matrix, K
K = [effective_focal_length            0
principal_point(1);
     0                     effective_focal_length
principal_point(2);
     0                                 0
1];

% Concatenate the columns of the rotation matrix and the
translation
% vector.
pixel_coordinate_unscaled = K * [rotationMatrix T] *
H_world;
% OR pixel_coordinate_unscaled = K * point_in_camera;

homogeneous_pixel_coordinates =
1/lambda*pixel_coordinate_unscaled;

% Final pixel coordinates (a 2x1 vector)
pixel_coordinates = [homogeneous_pixel_coordinates(1);
homogeneous_pixel_coordinates(2)];
```

Result:

$$p = \begin{pmatrix} u \\ v \end{pmatrix}$$ = [6.371827204924591e+02;7.305192428489443e+02]

METHOD 2

m-file name – findPixelCoordinates_check.m

```
clear all; clc

% Define camera parameters without lens distortion or skew.
% Specify the focal length and principal point in pixels.
f = 30; % focal length in mm.
focalLength    = [1000/24 * f, 1000/24 * f]; % in pixels
principalPoint = [500, 500];
imageSize      = [1000, 1000];

% Create a camera intrinsics object.
intrinsics =
cameraIntrinsics(focalLength,principalPoint,imageSize);

theta = 12*pi/180; % in radians

% Create the Rotation Matrix and intialize the Translation
Vector
rotationMatrix = [cos(theta) -sin(theta) 0;
                  sin(theta)  cos(theta) 0;
                  0              0      1];
translationVector = [0.1; 0.2; 1];

% Coordinates of Point in World Frame
Xw = 0.05; % in meters
Yw = 0.03; % in meters
Zw = 0.3; % in meters
worldPoints = [Xw; Yw; Zw];

% Final pixel coordinates (a 1x2 row vector)
```

```
projectedPoints =
worldToImage(intrinsics,rotationMatrix,translationVector,worldPoints');
```

Result:

$p = \begin{pmatrix} u \\ v \end{pmatrix}$ = [6.491776257319452e+02,7.105277341164675e+02]

This result is slightly different from the one obtained with method 1; however, I couldn’t discover why.

REFERENCES

https://mars.nasa.gov/mars2020/spacecraft/rover/wheels/

https://en.wikipedia.org/wiki/Perseverance_(rover)#:~:text=Perseverance%2C%20nicknamed%20Percy%2C%20is%20a,%2C%20at%2011%3A50%20UTC.

https://robots.ieee.org/robots/perseverance/?gallery=photo4

https://www.foxnews.com/science/perseverance-mars-rover-accomplishments

https://scitechdaily.com/nasa-perseverance-rovers-first-major-successes-on-mars-an-update-from-mission-scientists/

https://www.scientificamerican.com/article/success-perseverance-mars-rover-finally-collects-its-first-rock-core/

https://motivss.com/designing-for-the-challenges-of-opertions-on-mars-motiv-on-wdun/

https://www.mathworks.com/help/vision/ref/worldtoimage.html

https://www.mathworks.com/help/vision/ref/cameraintrinsics.html