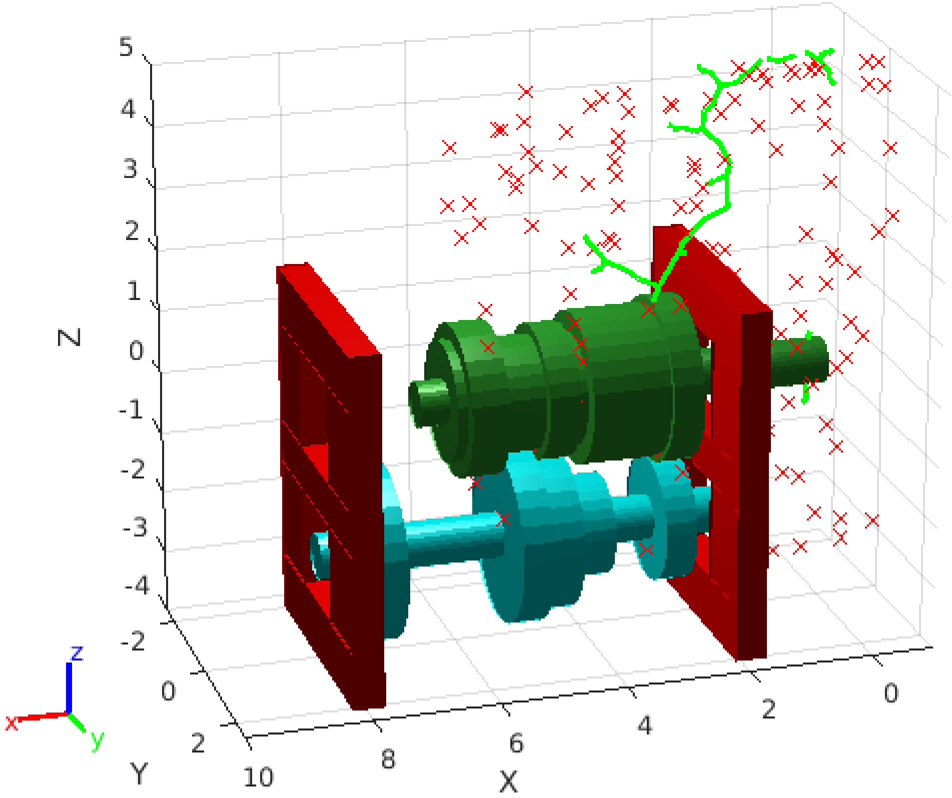
```
clear

figure
shaft = create_primary_shaft();
show(shaft, 'Collisions',"on",'Visuals',"off");
hold on;
draw_walls();
draw_fixed_shaft();

xlim([-1 10])
ylim([-2.5 2.5])
zlim([-4 5])
view([162.62 20.75])

start_pose = [0 0 0 0 0 0];
goal_pose = [2 0 3 0 0 0];

path = rrt(start_pose, goal_pose)
```

```
collision_count = 157
path = 1×35 struct
```

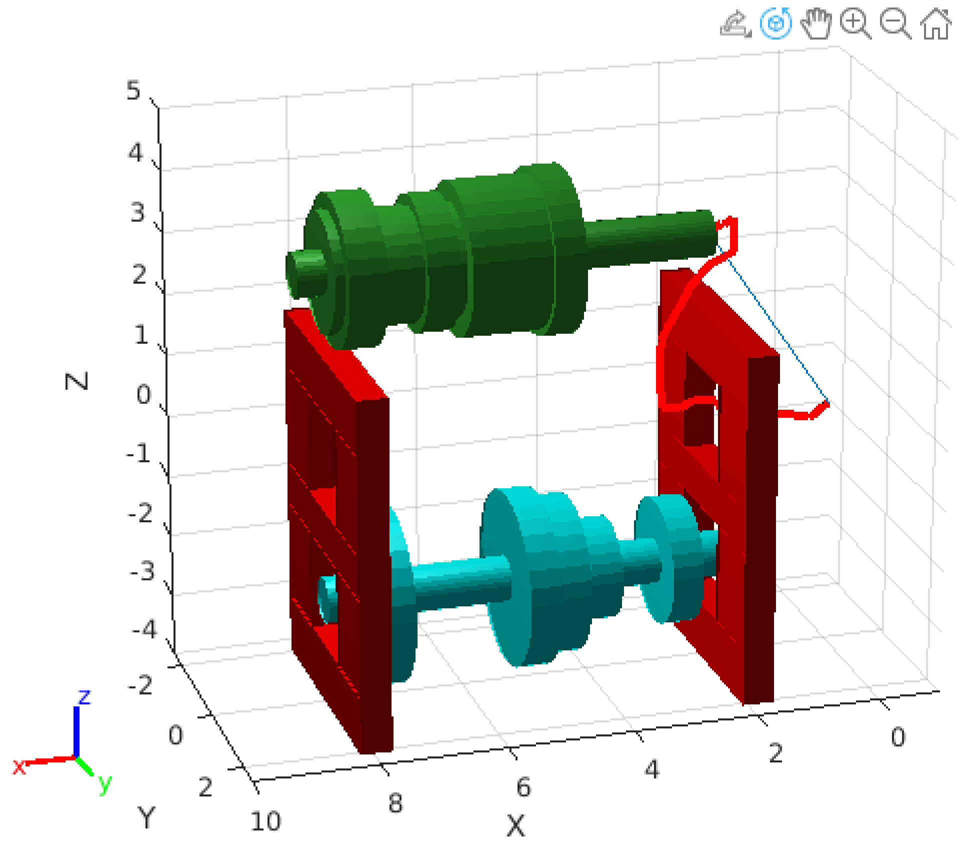
| Fields | pose | parent |
|---|---|---|
| 1 | [0,0,0,0... | -1 |
| 2 | [0.3009,... | 1×1 struct |
| 3 | [0.3270,... | 1×1 struct |
| 4 | [0.8782,... | 1×1 struct |
| 5 | [1.0156,... | 1×1 struct |
| 6 | [1.4675,... | 1×1 struct |
| 7 | [1.7774,... | 1×1 struct |
| 8 | [2.1619,... | 1×1 struct |
| 9 | [2.4180,... | 1×1 struct |
| 10 | [2.7044,... | 1×1 struct |
| 11 | [2.6854,... | 1×1 struct |
| 12 | [2.7684,... | 1×1 struct |
| 13 | [2.7747,... | 1×1 struct |
| 14 | [2.6972,... | 1×1 struct |

⋮

```
hold off;
```



```
% Now we draw the generated path!
figure
goal_shaft = pose_shaft(goal_pose);
show(goal_shaft, 'Collisions',"on",'Visuals',"off");
xlim([-1 10])
ylim([-2.5 2.5])
zlim([-4 5])
view([162.62 20.75])
hold on;
draw_walls();
draw_fixed_shaft();
draw_path(path);
hold off;
```



```
animate_path(path)
```

```
path = 1×35 struct
```

| Fields | pose | parent |
|---|---|---|
| 1 | [0,0,0,0... | -1 |
| 2 | [0.3009,... | 1×1 struct |
| 3 | [0.3270,... | 1×1 struct |
| 4 | [0.8782,... | 1×1 struct |
| 5 | [1.0156,... | 1×1 struct |
| 6 | [1.4675,... | 1×1 struct |
| 7 | [1.7774,... | 1×1 struct |
| 8 | [2.1619,... | 1×1 struct |
| 9 | [2.4180,... | 1×1 struct |
| 10 | [2.7044,... | 1×1 struct |
| 11 | [2.6854,... | 1×1 struct |
| 12 | [2.7684,... | 1×1 struct |
| 13 | [2.7747,... | 1×1 struct |
| 14 | [2.6972,... | 1×1 struct |

⋮

## Functions

```
function path = rrt(start, goal)
    start_node = node_from_pose(start);
    goal_node = node_from_pose(goal);
    walls = get_walls();
    fixed_shaft = get_fixed_shaft();

    nodes = [start_node];
    max_nodes = 2000;
    incremental_step = 0.1;

    collision_count = 0;

    for i=1:max_nodes
        % Chance of a random pose or a goal pose
        if mod(i,10)==0
            random_pose=goal;
        else
            random_pose = get_random_pose();
        end
        random_node = node_from_pose(random_pose);

        % Draw the node in 3d space
        draw_pose = random_pose(1,1:3);
        plot3(draw_pose(1), draw_pose(2), draw_pose(3), ...
            'x', 'Color', 'red');

        % Grab the nearest node to our random point
        % to branch from
        nearest_node = get_closest_node(random_node, nodes);

        % Move the transmission a controlled step in
        % that direction
        new_node = step(nearest_node, random_node, incremental_step);

        % Ensure that the 3d pose generated is possible
        % and does not create collisions
        tmp_shaft = pose_shaft(new_node.pose);
        collides = check_collisions(tmp_shaft, fixed_shaft, walls);
        if collides == 1
            collision_count = collision_count+ 1;
            continue
        end

        draw_pose_a = nearest_node.pose(1,1:3);
        draw_pose_b = new_node.pose(1,1:3);
        line(...
            [draw_pose_a(1), draw_pose_b(1)], ...
            [draw_pose_a(2), draw_pose_b(2)], ...
            [draw_pose_a(3), draw_pose_b(3)], ...
            'Color', 'green', 'LineWidth', 2);
        drawnow;

        % Append to our nodelist and move on!
        nodes(end+1) = new_node;

        % If our new node is the goal, we can break!
        if distance_between(new_node, goal_node) < 0.1
            goal_node.parent = new_node;
            break;
        end

    end

    collision_count

    if ~isstruct(goal_node.parent)
        path = [];
        return
    end

    path(1) = goal_node;
    parent = goal_node.parent;
    while isstruct(parent)
        path(end+1) = parent;
        parent = parent.parent;
    end
    path = flip(path);
    return
end
```

```
function new_node = step(start, towards, incremental_step)
    distance = distance_between(start, towards);
    new_node = struct("pose", [0 0 0], "parent", start);

    if distance <= 0.1
        new_node = towards;
        new_node.parent = start;
    else
        towards_diff = towards.pose - start.pose;
        new_node.pose(1) = start.pose(1) + (towards_diff(1)*incremental_step);
        new_node.pose(2) = start.pose(2) + (towards_diff(2)*incremental_step);
        new_node.pose(3) = start.pose(3) + (towards_diff(3)*incremental_step);
        new_node.pose(4) = start.pose(4) + (towards_diff(4)*incremental_step);
        new_node.pose(5) = start.pose(5) + (towards_diff(5)*incremental_step);
        new_node.pose(6) = start.pose(6) + (towards_diff(6)*incremental_step);
    end
end
```

```matlab
function shaft = pose_shaft(pose)
    shaft = create_primary_shaft();
    new_tree = rigidBodyTree("DataFormat", "column");
    rigid_body = rigidBody("new_base");
    transform = trvec2tform([pose(1), pose(2), pose(3)]) * ...
        axang2tform([1 0 0 pose(4)]) * axang2tform([0 1 0 pose(5)]) * ...
        axang2tform([0 0 1 pose(6)]);
    rigid_body.Joint.setFixedTransform(transform);
    new_tree.addBody(rigid_body, 'base');
    tmp_tree = removeBody(shaft, "cylinder_1");
    new_tree.addSubtree('new_base', tmp_tree);

    shaft = new_tree;
end
```

```matlab
function node = node_from_pose(pose)
    node = struct("pose", pose, "parent", -1);
end
```

```matlab
function value = random(min, max)
    value = min + (max-min)*rand(1);
end
```

```matlab
function random_pose = get_random_pose()
    x_min = -2;
    x_max = 6;
    y_min = -1;
    y_max = 1;
    z_min = -3;
    z_max = 8;
    roll_min = 0;
    roll_max = 0;
    pitch_min = -pi/2;
    pitch_max = 3*pi/4;
    yaw_min = 0;
    yaw_max = 0;

   random_pose = [random(x_min, x_max), ...
       random(y_min, y_max), random(z_min, z_max), ...
       random(roll_min, roll_max), random(pitch_min, pitch_max), ...
       random(yaw_min, yaw_max)];
end
```

```matlab
function closest_node = get_closest_node(node, node_list)
    distances = [];
    for i = 1:1:length(node_list)
        considered_node = node_list(i);
        distance = distance_between(node, considered_node);
        distances = [distances distance];
    end
    [distance, index] = min(distances);
    closest_node = node_list(index);
end
```

```matlab
function distance = distance_between(node_a, node_b)
    distance = sqrt( ...
        (node_a.pose(1)-node_b.pose(1))^2+...
        (node_a.pose(2)-node_b.pose(2))^2+...
        (node_a.pose(3)-node_b.pose(3))^2 ...
        );
end
```

```matlab
function fixed_shaft = get_fixed_shaft()
    cylinders ={
        struct("length", 0.76, "radius", 0.36, "translation", [.38+1.6; 0; -2.31;]),
        struct("length", 0.5, "radius", 1, "translation", [1.01+1.6; 0; -2.31;]),
        struct("length", 0.76, "radius", 0.36, "translation", [1.64+1.6; 0; -2.31;]),
        struct("length", 0.5, "radius", 0.8, "translation", [2.27+1.6; 0; -2.31;]),
        struct("length", 0.16, "radius", 0.36, "translation", [2.6+1.6; 0; -2.31;]),
        struct("length", 0.5, "radius", 1.235, "translation", [2.91+1.6; 0; -2.31;]),
        struct("length", 0.5, "radius", 1.395, "translation", [3.43+1.6; 0; -2.31;]),
        struct("length", 1.82, "radius", 0.36, "translation", [4.59+1.6; 0; -2.31;]),
        struct("length", 0.5, "radius", 1.40, "translation", [5.75+1.6; 0; -2.31]),
        struct("length", 0.6, "radius", 0.36, "translation", [6.3+1.6; 0; -2.31;]),
    };

    fixed_shaft = {};

    for i=1:length(cylinders)
        part = cylinders{i};

        len = part.length;
        radius = part.radius;

        cylinder = collisionCylinder(radius, len);
        axis = [0 1 0 pi/2];
        transformation = axang2tform(axis);
        transformation(1:3, 4) = part.translation;
        cylinder.Pose = transformation;
        fixed_shaft{end+1} = cylinder;
    end
end
```

```
function walls = get_walls()
    right_wall = {
        struct("x", .5, "y", 4.2, "z", 1.7, "origin", [.25+1.6; 0; -3.95]),
        struct("x", .5, "y", 1.3, "z", 1.6, "origin", [.25+1.6; 1.45; -2.3]),
        struct("x", .5, "y", 1.3, "z", 1.6, "origin", [.25+1.6; -1.45; -2.3]),
        struct("x", .5, "y", 4.2, "z", 0.7, "origin", [.25+1.6; 0; -1.15]),
        struct("x", .5, "y", 1.3, "z", 1.6, "origin", [.25+1.6; 1.45; 0]),
        struct("x", .5, "y", 1.3, "z", 1.6, "origin", [.25+1.6; -1.45; 0]),
        struct("x", .5, "y", 4.2, "z", 0.9, "origin", [.25+1.6; 0; 1.25]),
    };
    left_wall = {
        struct("x", .5, "y", 4.2, "z", 1.7, "origin", [6.35+1.6; 0; -3.9]),
        struct("x", .5, "y", 1.3, "z", 1.6, "origin", [6.35+1.6; 1.45; -2.3]),
        struct("x", .5, "y", 1.3, "z", 1.6, "origin", [6.35+1.6; -1.45; -2.3]),
        struct("x", .5, "y", 4.2, "z", 0.7, "origin", [6.35+1.6; 0; -1.15]),
        struct("x", .5, "y", 1.3, "z", 1.6, "origin", [6.35+1.6; 1.45; 0]),
        struct("x", .5, "y", 1.3, "z", 1.6, "origin", [6.35+1.6; -1.45; 0]),
        struct("x", .5, "y", 4.2, "z", 0.9, "origin", [6.35+1.6; 0; 1.25]),
    };
    boxes = [left_wall; right_wall;];

    walls = {};

    for i=1:length(boxes)
        wall = boxes{i};
        box = collisionBox(wall.x, wall.y, wall.z);
        transformation = [eye(3) wall.origin; 0 0 0 1];
        box.Pose = transformation;
        walls{end+1} = box;
    end
end
```

```
function draw_shaft(shaft, color)
    for i=1:length(shaft)
        cylinder = shaft{i};
        [~, patch_object] = show(cylinder);
        patch_object.FaceColor = color;
        patch_object.EdgeColor = 'none';
    end
end
```

```
function draw_fixed_shaft()
    shaft = get_fixed_shaft();
    draw_shaft(shaft, [0 1 1]);
end
```

```
function draw_walls()
    walls = get_walls();
    for i=1:length(walls)
        box = walls{i};
        [~, patch_object] = show(box);
        patch_object.FaceColor = [1 0 0];
        patch_object.EdgeColor = 'none';
    end
end
```

```
function shaft = create_primary_shaft()
    primary_shaft ={
        struct("length", 6.6, "radius", .36, "translation", [1.5; 0; 4.9]),
        struct("length", .5, "radius", 1.3, "translation", [1.01; 0; 4.9]),
        struct("length", 1.25, "radius", 1.2, "translation", [1.635; 0; 4.9]),
        struct("length", .16, "radius", .9, "translation", [2.59; 0; 4.9]),
        struct("length", .5, "radius", 1.06, "translation", [2.92; 0; 4.9]),
        struct("length", .65, "radius", .9, "translation", [3.495; 0; 4.9]),
        struct("length", .6, "radius", 1.195, "translation", [4.12; 0; 4.9]),
        struct("length", .16, "radius", .95, "translation", [4.5; 0; 4.9]),
    };

    dh_params=[0 0 0 pi/2;
               2.36 0 0 0;
               .5 0 0 0;
               1.25 0 0 0;
               .16 0 0 0;
               .5 0 0 0;
               .65 0 0 0;
               .6 0 0 0;
               .16 0 0 0];

    shaft = create_shaft(primary_shaft, dh_params);
end
```

```
function shaft = create_shaft(collision_geometries, dh_params)
    shaft = rigidBodyTree("DataFormat", "column");
    basename=shaft.BaseName;

    cylinder_1 = rigidBody('cylinder_1');
    cylinder_2 = rigidBody('cylinder_2');
    cylinder_3 = rigidBody('cylinder_3');
    cylinder_4 = rigidBody('cylinder_4');
    cylinder_5 = rigidBody('cylinder_5');
    cylinder_6 = rigidBody('cylinder_6');
    cylinder_7 = rigidBody('cylinder_7');
    cylinder_8 = rigidBody('cylinder_8');
    joint_1 = rigidBodyJoint('joint_1','revolute');
    joint_1.JointAxis=[0,1,0];
    cylinder_1.Joint=joint_1;
    setFixedTransform(joint_1,dh_params(1,:),'dh');

    joint_2 = rigidBodyJoint('joint_2','fixed');
    setFixedTransform(joint_2,dh_params(2,:),'dh');
    cylinder_2.Joint=joint_2;

    joint_3 = rigidBodyJoint('joint_3','fixed');
    setFixedTransform(joint_3,dh_params(3,:),'dh');
    cylinder_3.Joint=joint_3;

    joint_4 = rigidBodyJoint('joint_4','fixed');
    setFixedTransform(joint_4,dh_params(4,:),'dh');
    cylinder_4.Joint=joint_4;

    joint_5 = rigidBodyJoint('joint_5','fixed');
    setFixedTransform(joint_5,dh_params(5,:),'dh');
    cylinder_5.Joint=joint_5;

    joint_6 = rigidBodyJoint('joint_6','fixed');
    setFixedTransform(joint_6,dh_params(6,:),'dh');
    cylinder_6.Joint=joint_6;

    joint_7 = rigidBodyJoint('joint_7','fixed');
    setFixedTransform(joint_7,dh_params(7,:),'dh');
    cylinder_7.Joint=joint_7;

    joint_8 = rigidBodyJoint('joint_8','fixed');
    setFixedTransform(joint_8,dh_params(8,:),'dh');
    cylinder_8.Joint=joint_8;

    addBody(shaft, cylinder_1, basename);
    addBody(shaft, cylinder_2, 'cylinder_1');
    addBody(shaft, cylinder_3, 'cylinder_2');
    addBody(shaft, cylinder_4, 'cylinder_3');
    addBody(shaft, cylinder_5, 'cylinder_4');
    addBody(shaft, cylinder_6, 'cylinder_5');
    addBody(shaft, cylinder_7, 'cylinder_6');
    addBody(shaft, cylinder_8, 'cylinder_7');


    for i=1:length(collision_geometries)
        cylinder = collision_geometries{i};
        collision_cylinder = collisionCylinder(cylinder.radius, cylinder.length);
        axis = [0 1 0 pi/2];
        transformation = trvec2tform([cylinder.length/2,0,0])*axang2tform(axis);
        collision_cylinder.Pose = transformation;
        addCollision(shaft.Bodies{i}, collision_cylinder);
    end

end
```

```
function collides = check_collisions(shaft, fixed_shaft, walls)
    collides = 0;
    home_config = homeConfiguration(shaft);
    collisions = checkCollision(shaft, home_config, walls);
    if collisions(2) == 1
        collides = 1;
        return
    end
    collisions = checkCollision(shaft, home_config, fixed_shaft);
    if collisions(2) == 1
        collides = 1;
        return
    end
end
```

```
function draw_path(path)
    while length(path) > 1
        start = path(1);
        next = path(2);
        path = path(2:end);

        start_xyz = start.pose(1:3);
        next_xyz = next.pose(1:3);
        line(...
            [start_xyz(1), next_xyz(1)], ...
            [start_xyz(2), next_xyz(2)], ...
            [start_xyz(3), next_xyz(3)], ...
            'Color', 'red', 'LineWidth', 3);
    end
end
```

```
function animate_path(path)
    animated=figure;
    gif('path.gif');
    for i=1:length(path)
        shaft = pose_shaft(path(i).pose);
        config = homeConfiguration(shaft);
        show(shaft,'Collisions',"on",'Visuals',"off");
        hold on;
        draw_walls();
        draw_fixed_shaft();

        xlim([-1 10])
        ylim([-2.5 2.5])
        zlim([-4 5])
        view([162.62 20.75])
        gif
        hold off;
    end
end
```

```
% gif function by Chad Greene
function gif(varargin)
% gif is the simplest way to make gifs. Simply call
%
%   gif('myfile.gif')
%
% to write the first frame, and then call
%
%   gif
%
% to write each subsequent frame. That's it.
%
%% Syntax
%
%  gif('filename.gif')
%  gif(...,'DelayTime',DelayTimeValue,...)
%  gif(...,'LoopCount',LoopCountValue,...)
%  gif(...,'frame',handle,...)
%  gif(...,'resolution',res)
%  gif(...,'nodither')
%  gif(...,'overwrite',true)
%  gif
%  gif('clear')
%
%% Description
%
% gif('filename.gif') writes the first frame of a new gif file by the name filename.gif
%
% gif(...,'DelayTime',DelayTimeValue,...) specifies a the delay time in seconds between
% frames. Default delay time is 1/15.
%
% gif(...,'LoopCount',LoopCountValue,...) specifies the number of times the gif animati
% will play. Default loop count is Inf.
%
% gif(...,'frame',handle,...) uses the frame of the given figure or set of axes. The de
% frame handle is gcf, meaning the current figure. To turn just one set of axes into a
% use 'frame',gca. This behavior changed in Jan 2021, as the default option changed fro
% gca to gcf.
%
% gif(...,'resolution',res) specifies the resolution (in dpi) of each frame. This optio
% requires export_fig (https://www.mathworks.com/matlabcentral/fileexchange/23629).
%
% gif(...,'nodither') maps each color in the original image to the closest color in the
% without dithering. Dithering is performed by default to achieve better color resoluti
% albeit at the expense of spatial resolution.
%
% gif(...,'overwrite',true) bypasses a dialoge box that would otherwise verify
% that you want to overwrite an existing file by the specified name.
%
% gif adds a frame to the current gif file.
%
% gif('clear') clears the persistent variables associated with the most recent gif.
%
%% Example
% For examples, type
%
%   cdt gif
%
%% Author Information
% This function was written by Chad A. Greene of the University of Texas
% Institute for Geophysics (UTIG), June 2017.
%
% See also: imwrite, getframe, and rgb2ind.
% Define persistent variables:
persistent gif_filename firstframe DelayTime DitherOption LoopCount frame resolution
%% Parse Inputs
if nargin>0

   % The user may want to clear things and start over:
   if any(strcmpi(varargin,'clear'))

      % Clear persistent variables associated with this function:
      clear gif_filename firstframe DelayTime DitherOption LoopCount frame resolution
   end

   % If the first input ends in .gif, assume this is the first frame:
   if strcmpi(varargin{1}(end-3:end),'.gif')

      % This is what the user wants to call the new .gif file:
      gif_filename = varargin{1};

      % Check for an existing .gif file by the same name:
      if exist(gif_filename,'file')==2
         OverWrite = false; % By default, do NOT overwrite an existing file by the inpu
         if nargin>1
            tmp = strncmpi(varargin,'overwrite',4);
            if any(tmp)
               OverWrite = varargin{find(tmp)+1};
               assert(islogical(OverWrite),'Error: Overwrite input must be either true
            end
         end

         if ~OverWrite

            % Ask the user if (s)he wants to overwrite the existing file:
            choice = questdlg(['The file  ',gif_filename,' already exists. Overwrite it
               'The file already exists.','Overwrite','Cancel','Cancel');
            if strcmp(choice,'Overwrite')
               OverWrite = true;
            end
         end
         % Overwriting basically means deleting and starting from scratch:
         if OverWrite
            delete(gif_filename)
         else
            clear gif_filename firstframe DelayTime DitherOption LoopCount frame
            error('The giffing has been canceled.')
         end

      end

      firstframe = true;

      % Set defaults:
      DelayTime = 1/15;
      DitherOption = 'dither';
      LoopCount = Inf;
      frame = gcf;
      resolution = 0; % When 0, it's used as a boolean to say "don't use export_fig". I
   end

   tmp = strcmpi(varargin,'DelayTime');
   if any(tmp)
      DelayTime = varargin{find(tmp)+1};
      assert(isscalar(DelayTime),'Error: DelayTime must be a scalar value.')
   end

   if any(strcmpi(varargin,'nodither'))
      DitherOption = 'nodither';
   end

   tmp = strcmpi(varargin,'LoopCount');
   if any(tmp)
      LoopCount = varargin{find(tmp)+1};
      assert(isscalar(LoopCount),'Error: LoopCount must be a scalar value.')
   end

   tmp = strncmpi(varargin,'resolution',3);
   if any(tmp)
      resolution = varargin{find(tmp)+1};
      assert(isscalar(resolution),'Error: resolution must be a scalar value.')
      assert(exist('export_fig.m','file')==2,'export_fig not found. If you wish to spec
      warning off export_fig:exportgraphics
   end

   tmp = strcmpi(varargin,'frame');
   if any(tmp)
      frame = varargin{find(tmp)+1};
      assert(ishandle(frame)==1,'Error: frame must be a figure handle or axis handle.')
   end

else
   assert(isempty(gif_filename)==0,'Error: The first call of the gif function requires
end
```

```
%% Perform work:
if resolution % If resolution is >0, it means use export_fig

   if isgraphics(frame,'figure')
      f = export_fig('-nocrop',['-r',num2str(resolution)]);
   else
      % If the frame is a set of axes instead of a figure, use default cropping:
      f = export_fig(['-r',num2str(resolution)]);
   end

else
   % Get frame:
   fr = getframe(frame);
   f =  fr.cdata;
end
% Convert the frame to a colormap and corresponding indices:
[imind,cmap] = rgb2ind(f,256,DitherOption);
% Write the file:
if firstframe
   imwrite(imind,cmap,gif_filename,'gif','LoopCount',LoopCount,'DelayTime',DelayTime)
   firstframe = false;
else
   imwrite(imind,cmap,gif_filename,'gif','WriteMode','append','DelayTime',DelayTime)
end
end
```