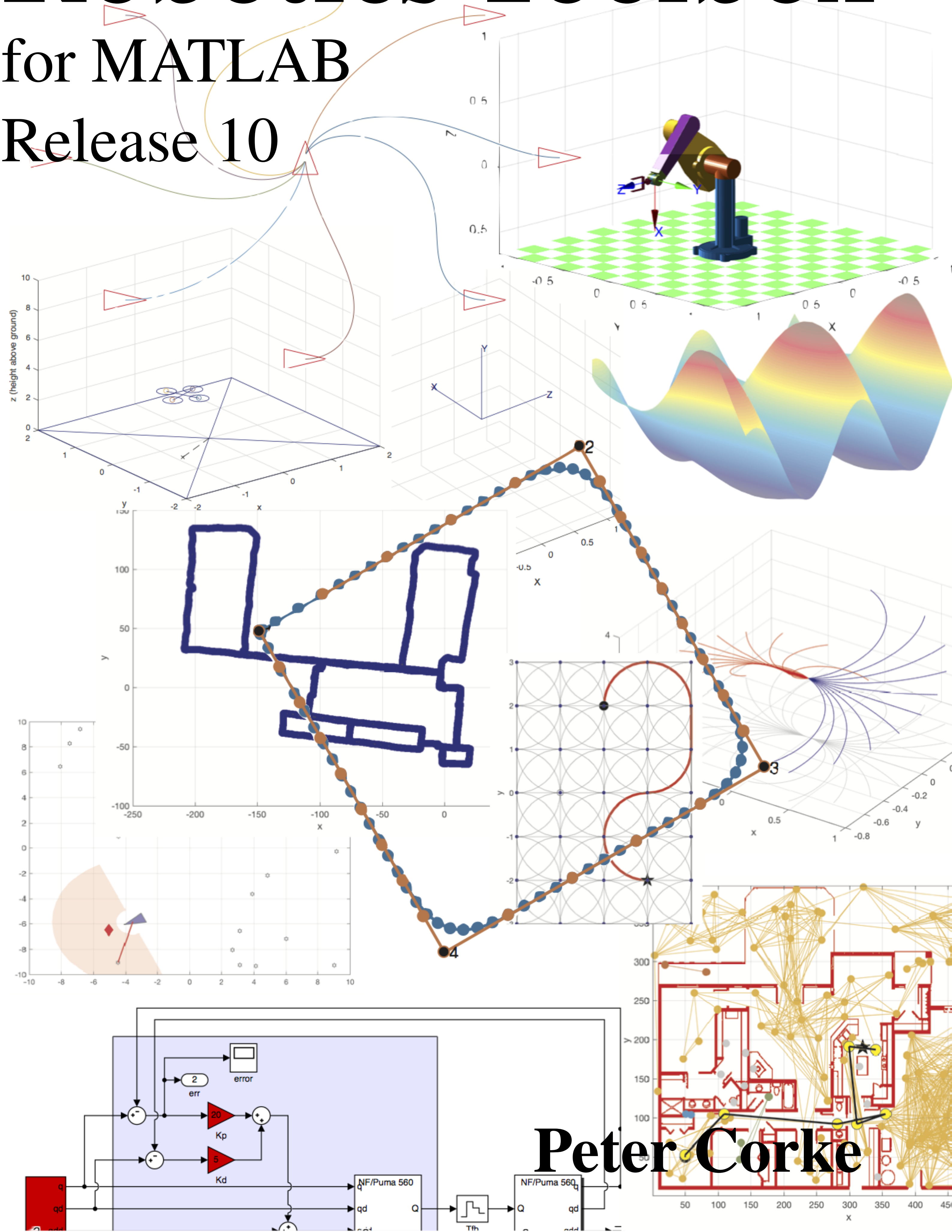
Robotics Toolbox

for MATLAB

Release 10



Peter Corke

Release	10.1
Release date	March 2017
Licence	LGPL
Toolbox home page	http://www.petercorke.com/robot
Discussion group	http://groups.google.com.au/group/robotics-tool-box

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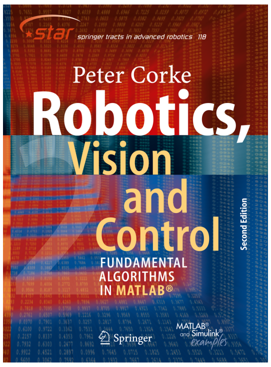
Preface



This, the tenth major release of the Toolbox, representing over twenty five years of continuous development and a substantial level of maturity. This version corresponds to the **second edition** of the book "*Robotics, Vision & Control, second edition*" published in June 2017 – RVC2.

This MATLAB® Toolbox has a rich collection of functions that are useful for the study and simulation of robots: arm-type robot manipulators and mobile robots. For robot manipulators, functions include kinematics, trajectory generation, dynamics and control. For mobile robots, functions include path planning, kinodynamic planning, localization, map building and simultaneous localization and mapping (SLAM).

The Toolbox makes strong use of classes to represent robots and such things as sensors and maps. It includes Simulink® models to describe the evolution of arm or mobile robot state over time for a number of classical control strategies. The Toolbox also provides functions for manipulating and converting between datatypes such as vectors, rotation matrices, unit-quaternions, quaternions, homogeneous transformations and twists which are necessary to represent position and orientation in 2- and 3-dimensions.

The code is written in a straightforward manner which allows for easy understanding, perhaps at the expense of computational efficiency. If you feel strongly about computational efficiency then you can always rewrite the function to be more efficient, compile the M-file using the MATLAB compiler, or create a MEX version.

The bulk of this manual is auto-generated from the comments in the MATLAB code itself. For elaboration on the underlying principles, extensive illustrations and worked examples please consult "*Robotics, Vision & Control, second edition*" which provides a detailed discussion (720 pages, nearly 500 figures and over 1000 code examples) of how to use the Toolbox functions to solve many types of problems in robotics.

Functions by category

Contents

Chapter 1

Introduction

1.1 Changes in RTB 10

RTB 10 is largely backward compatible with RTB 9.

1.1.1 Incompatible changes

- The class `Vehicle` no longer represents an Ackerman/bicycle vehicle model. `Vehicle` is now an abstract superclass of `Bicycle` and `Unicycle` which represent car-like and differentially-steered vehicles respectively.
- The class `LandmarkMap` replaces `PointMap`.
- Robot-arm forward kinematics now returns an `SE3` object rather than a 4×4 matrix.
- The `Quaternion` class used to represent both unit and non-unit quaternions which was untidy and confusing. They are now represented by two classes `UnitQuaternion` and `Quaternion`.
- The method to compute the arm-robot Jacobian in the end-effector frame has been renamed from `jacobn` to `jacobe`.
- The path planners, subclasses of `Navigation`, the method to find a path has been renamed from `path` to `query`.
- The Jacobian methods for the `RangeBearingSensor` class have been renamed to `Hx`, `Hp`, `Hw`, `Gx`,`Gz`.
- The function `se2` has been replaced with the class `SE2`. On some platforms (Mac) this is the same file. Broadly similar in function, the former returns a 3×3 matrix, the latter returns an object.
- The function `se3` has been replaced with the class `SE3`. On some platforms (Mac) this is the same file. Broadly similar in function, the former returns a 4×4 matrix, the latter returns an object.

RTB 9	RTB 10
Vehicle	Bicycle
Map	LandmarkMap
jacobn	jacobe
path	query
H_x	Hx
H_xf	Hp
H_w	Hw
G_x	Gx
G_z	Gz

Table 1.1: Function and method name changes

These changes are summarized in Table **??**.

1.1.2 New features

- `SerialLinkplot3d()` renders realistic looking 3D models of robots. STL models from the package ARTE by Arturo Gil (`https://arvc.umh.es/arte`) are now included with RTB, by kind permission.
- `ETS2` and `ETS3` packages provide a gentle (non Denavit-Hartenberg) introduction to robot arm kinematics, see Chapter 7 for details.
- Distribution as an `.mltbx` format file.
- A comprehensive set of functions to handle rotations and transformations in 2D, these functions end with the suffix 2, eg. `transl2`, `rot2`, `trot2` etc.
- Matrix exponentials are handled by `trexp`, `trlog`, `trexp2` and `trlog2`.
- The class `Twist` represents a twist in 3D or 2D. Respectively, it is a 6-vector representation of the Lie algebra $se(3)$, or a 3-vector representation of $se(2)$.
- The method `SerialLink.jointdynamics` returns a vector of `tf` objects representing the dynamics of the joint actuators.
- The class `Lattice` is a kino-dynamic lattice path planner.
- The class `PoseGraph` solves graph relaxation problems and can be used for bundle adjustment and pose graph SLAM.
- The class `Plucker` represents a line using Plücker coordinates.
- The folder `RST` contains Live Scripts that demonstrate some capabilities of the MATLAB Robotics System Toolbox™.
- The folder `symbolic` contains Live Scripts that demonstrate use of the MATLAB Symbolic Math Toolbox™ for deriving Jacobians used in EKF SLAM (vehicle and sensor), inverse kinematics for a 2-joint planar arm and solving for roll-pitch-yaw angles given a rotation matrix.
- All the robot models, prefixed by `mdl_`, now reside in the folder `models`.

- New robot models include Universal Robotics UR3, UR5 and UR10; and Kuka light weight robot arm.
- A new folder `data` now holds various data files as used by examples in RVC2: STL models, occupancy grids, Hershey font, Toro and G2O data files.

Since its inception RTB has used matrices[1] to represent rotations and transformations in 2D and 3D. A trajectory, or sequence, was represented by a 3-dimensional matrix, eg. $4 \times 4 \times N$. In RTB10 a set of classes have been introduced to represent orientation and pose in 2D and 3D: `SO2`, `SE2`, `SO3`, `SE3` and `UnitQuaternion`. These classes are fairly polymorphic, that is, they share many methods and operators[2]. All have a number of static methods that serve as constructors from particular representations. A trajectory is represented by a vector of these objects which makes code easier to read and understand. Overloaded operators are used so the classes behave in a similar way to native matrices[3]. The relationship between the classical Toolbox functions and the new classes are shown in Fig **??**.

You can continue to use the classical functions. The new classes have methods with the names of classical functions to provide similar functionality. For instance

```
>> T = transl(1,2,3);  % create a 4x4 matrix
>> trprint(T)  % invoke the function trprint
>> T = SE3(1,2,3);  % create an SE3 object
>> trprint(T)  % invoke the method trprint
>> T.T   % the equivalent 4x4 matrix
>> double(T) % the equivalent 4x4 matrix
```

```
>> T = SE3(1,2,3);  % create a pure translation SE3 object
>> T2 = T*T;  % the result is an SE3 object
>> T3 = trinterp(T, 5); % create a vector of five SE3 objects
>> T3(1)  % the first element of the vector
>> T3*T  % each element of T3 multiplies T, giving a vector of five SE3 objects
```

1.1.3 Enhancements

- Dependencies on the Machine Vision Toolbox for MATLAB (MVTB) have been removed. The fast dilation function used for path planning is now searched for in MVTB and the MATLAB Image Processing Toolbox (IPT) and defaults to a provided M-function.
- A major pass over all code and method/function/class documentation.
- Reworking and refactoring all the manipulator graphics, work in progress.
- An “app" is included: `tripleangle` which allows graphical experimentation with Euler and roll-pitch-yaw angles.
- A tidyup of all Simulink models. Red blocks now represent user settable parameters, and shaded boxes are used to group parts of the models.

[1] Early versions of RTB, before 1999, used vectors to represent quaternions but that changed to an object once objects were added to the language.

[2] For example, you could substitute objects of class `SO3` and `UnitQuaternion` with minimal code change.

[3] The capability is extended so that we can element-wise multiple two vectors of transforms, multiply one transform over a vector of transforms or a set of points.

Orientation		Pose	
Classic	New	Classic	New
rot2	SO2	trot2	SE2
		transl2	SE2
trplot2	.plot	trplot2	.plot
rotx, roty, rotz	SO3.Rx, SO3.Ry, SO3.Rz	trotx, troty, trotz	SE3.Rx, SE3.Ry, SE3.Rz
		T = transl(v)	SE3(v)
eul2r, rpy2r	SO3.eul, SO3.rpy	eul2tr, rpy2tr	SE3.eul, SE3.rpy
angvec2r	SO3.angvec	angvec2tr	SE3.angvec
oa2r	SO3.oa	oa2tr	SE3.oa
		v = transl(T)	.t, .transl
tr2eul, tr2rpy	.toeul, .torpy	tr2eul, tr2rpy	.toeul, .torpy
tr2angvec	.toangvec	tr2angvec	.toangvec
trexp	SO3.exp	trexp	SE3.exp
trlog	.log	trlog	.log
trplot	.plot	trplot	.plot

Functions starting with dot are methods on the new objects. You can use them in functional form `toeul(R)` or in dot form `R.toeul()` or `R.toeul`. It's a personal preference. The trailing parentheses are not required if no arguments are passed, but it is a useful convention and reminder that you that you are invoking a method not reading a property. The old function `transl` appears twice since it maps a vector to a matrix as well as the inverse.

	Output type										
Input type	t	Euler	RPY	θ, v	R	T	Twist vector	Twist	Unit-Quaternion	SO3	SE3
t (3-vector)						transl		Twist('T')			SE3()
Euler (3-vector)					eul2r	eul2tr			UnitQuaternion.eul()	SO3.eul()	SE3.eul()
RPY (3-vector)					rpy2r	rpy2tr			UnitQuaternion.rpy()	SO3.rpy()	SE3.rpy()
θ, v (scalar + 3-vector)					angvec2r	angvec2tr			UnitQuaternion.angvec()	SO3.angvec()	SE3.angvec()
R (3×3 matrix)		tr2eul	tr2rpy	tr2angvec		r2t	trlog		UnitQuaternion()	SO3()	SE3()
T (4×4 matrix)	transl	tr2eul	tr2rpy	tr2angvec	t2r		trlog	Twist()	UnitQuaternion()	SO3()	SE3()
Twist vector (3- or 6-vector)					trexp	trexp		Twist()		SO3.exp()	SE3.exp()
Twist						.T	.S				.SE
Unit-Quaternion		.toeul	.torpy	.toangvec	.R	.T				.SO3	.SE3
SO3		.toeul	.torpy	.toangvec	.R	.T	.log		.UnitQuaternion		.SE3
SE3	.t	.toeul	.torpy	.toangvec	.R	.T	.log	.Twist	.UnitQuaternion	.SO3	

Dark grey boxes are not possible conversions. Light grey boxes are possible conversions but the Toolbox has no direct conversion, you need to convert via an intermediate type. Red text indicates classical Robotics Toolbox functions that work with native MATLAB® vectors and matrices. Class.type() indicates a static factory method that constructs a Class object from input of that type. Functions shown starting with a dot are a method on the class corresponding to that row.

Figure 1.1: (top) new and classic methods for representing orientation and pose, (bottom) functions and methods to convert between representations. Reproduced from "*Robotics, Vision & Control, second edition, 2017*"

- RangeBearingSensor animation
- All the java code that supports the `DHFactor` functionality now lives in the folder `java`. The `Makefile` in there can be used to recompile the code. There are java version issues and the shipped class files are built to java 1.7 which allows operation

1.2 Changes in RTB 10.2

This release has a relatively small number of bug fixes compared to 10.1:

- Fixed bugs in `jacobe` and `coriolis` when using symbolic arguments.
- New robot models: UR3, UR5, UR10, LWR.
- Fixed bug for `interp` method of `SE3` object.
- Fixed bug with detecting Optimisation Toolbox for `ikcon` and `ikunc`.
- Fixed bug in `ikine_sym`.
- Fixed various bugs related to plotting robots with prismatic joints.

1.3 How to obtain the Toolbox

The Robotics Toolbox is freely available from the Toolbox home page at

http://www.petercorke.com

The file is available in MATLABtoolbox format (`.mltbx`) or zip format (`.zip`).

1.3.1 From .mltbx file

Since MATLAB R2014b toolboxes can be packaged as, and installed from, files with the extension `.mltbx`. Download the most recent version of `robot.mltbx` or `vision.mltbx` to your computer. Using MATLAB navigate to the folder where you downloaded the file and double-click it (or right-click then select Install). The Toolbox will be installed within the local MATLAB file structure, and the paths will be appropriately configured for this, and future MATLAB sessions.

1.3.2 From .zip file

Download the most recent version of robot.zip or vision.zip to your computer. Use your favourite unarchiving tool to unzip the files that you downloaded. To add the Toolboxes to your MATLAB path execute the command

```
>> addpath RVCDIR ;
>> startup_rvc
```

where `RVCDIR` is the full pathname of the folder where the folder `rvctools` was created when you unzipped the Toolbox files. The script `startup_rvc` adds various subfolders to your path and displays the version of the Toolboxes. After installation the files for both Toolboxes reside in a top-level folder called `rvctools` and beneath this are a number of folders:

`robot`	The Robotics Toolbox
`vision`	The Machine Vision Toolbox
`common`	Utility functions common to the Robotics and Machine Vision Toolboxes
`simulink`	Simulink blocks for robotics and vision, as well as examples
`contrib`	Code written by third-parties

If you already have the Machine Vision Toolbox installed then download the zip file to the folder above the existing `rvctools` directory, and then unzip it. The files from this zip archive will properly interleave with the Machine Vision Toolbox files.

You need to setup the path every time you start MATLAB but you can automate this by setting up environment variables, editing your `startup.m` script, using `pathtool` and saving the path, or by pressing the “Update Toolbox Path Cache" button under MATLAB General preferences. You can check the path using the command `path` or `pathtool`.

A menu-driven demonstration can be invoked by

```
>> rtbdemo
```

1.3.3 MATLAB Online™

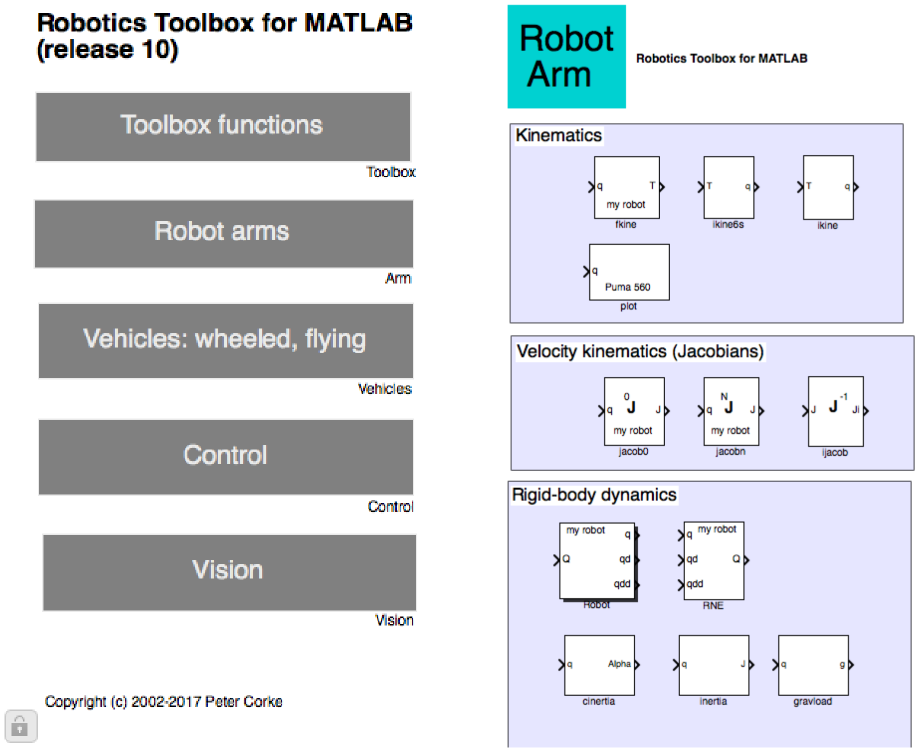
The Toolbox works well with MATLAB Online™ which lets you access a MATLAB session from a web browser, tablet or even a phone. The key is to get the RTB files into the filesystem associated with your Online account. The easiest way to do this is to install MATLAB Drive™ from MATLAB File Exchange or using the Get Add-Ons option from the MATLAB GUI. This functions just like Google Drive or Dropbox, a local filesystem on your computer is synchronized with your MATLAB Online account. Copy the RTB files into the local MATLAB Drive cache and they will soon be synchronized, invoke `startup_rvc` to setup the paths and you are ready to simulate robots on your mobile device or in a web browser.

1.3.4 Simulink®

Simulink® is the block-diagram-based simulation environment for MATLAB. It provides a very convenient way to create and visualize complex dynamic systems, and is particularly applicable to robotics. RTB includes a library of blocks for use in constructing robot kinematic and dynamic models. The block library is opened by

```
>> roblocks
```

and a window like that shown in Figure **??**(a) will be displayed. Double click a particular category and it will expand into a palette of blocks, like Figure **??**(b), that can be dragged into your model.



(a) (b)

Figure 1.2: The Robotics Toolbox blockset.

Users with no previous Simulink experience are advised to read the relevant Mathworks manuals and experiment with the examples supplied. Experienced Simulink users should find the use of the Robotics blocks quite straightforward. Generally there is a one-to-one correspondence between Simulink blocks and Toolbox functions. Several demonstrations have been included with the Toolbox in order to illustrate common topics in robot control and demonstrate Toolbox Simulink usage. These could be considered as starting points for your own work, just select the model closest to what you want and start changing it. Details of the blocks can be found using the File/ShowBrowser option on the block library window.

Arm robots	
`Robot`	represents a robot, with generalized joint force input and joint coordinates, velocities and accelerations as outputs. The parameters are the robot object to be simulated and the initial joint angles. It is similar to the `fdyn()` function and represents the forward dynamics of the robot.
`rne`	computes the inverse dynamics using the recursive Newton-Euler algorithm (function `rne`). Inputs are joint coordinates, velocities and accelerations and the output is the generalized joint force. The robot object is a parameter.

`cinertia`	computes the manipulator Cartesian inertia matrix. The parameters are the robot object to be simulated and the initial joint angles.
`inertia`	computes the manipulator joint-space inertia matrix. The parameters are the robot object to be simulated and the initial joint angles.
`inertia`	computes the gravity load. The parameters are the robot object to be simulated and the initial joint angles.
`jacob0`	outputs a manipulator Jacobian matrix, with respect to the world frame, based on the input joint coordinate vector. outputs the Jacobian matrix. The robot object is a parameter.
`jacobn`	outputs a manipulator Jacobian matrix, with respect to the end-effector frame, based on the input joint coordinate vector. outputs the Jacobian matrix. The robot object is a parameter.
`ijacob`	inverts a Jacobian matrix. Currently limited to square Jacobians only, ie. for 6-axis robots.
`fkine`	outputs a homogeneous transformation for the pose of the end-effector corresponding to the input joint coordinates. The robot object is a parameter.
`plot`	creates a graphical animation of the robot in a new window. The robot object is a parameter.
Mobile robots	
`Bicycle`	is the kinematic model of a mobile robot that uses the bicycle model. The inputs are speed and steer angle and the outputs are position and orientation.
`Unicycle`	is the kinematic model of a mobile robot that uses the unicycle, or differential steering, model. The inputs are speed and turn raate and the outputs are position and orientation.
`Quadrotor`	is the dynamic model of a quadrotor. The inputs are rotor speeds and the output is translational and angular position and velocity. Parameter is a quadrotor structure.
`N-rotor`	is the dynamic model of a N-rotor flyer. The inputs are rotor speeds and the output is translational and angular position and velocity. Parameter is a quadrotor structure.
`ControlMixer`	accepts thrust and torque commands and outputs rotor speeds for a quadrotor.
`Quadrotor plot`	creates a graphical animation of the quadrotor in a new window. Parameter is a quadrotor structure.
Trajectory	
`jtraj`	outputs coordinates of a point following a quintic polynomial as a function of time, as well as its derivatives. Initial and final velocity are assumed to be zero. The parameters include the initial and final points as well as the overall motion time.
`lspb`	outputs coordinates of a point following an LSPB trajectory as a function of time. The parameters include the initial and final points as well as the overall motion time.
`circle`	outputs the xy-coordinates of a point around a circle. Parameters are the centre, radius and angular frequency.

Vision	
`camera`	input is a camera pose and the output is the coordinates of points projected on the image plane. Parameters are the camera object and the point positions.
`camera2`	input is a camera pose and point coordinate frame pose, and the output is the coordinates of points projected on the image plane. Parameters are the camera object and the point positions relative to the point frame.
`image Jacobian`	input is image points and output is the point feature Jacobian. Parameter is the camera object.
`image Jacobian sphere`	input is image points in spherical coordinates and output is the point feature Jacobian. Parameter is a spherical camera object. computes camera pose from image points. Parameter is the camera object.
`Pose estimation`	computes camera pose from image points. Parameter is the camera object.
Miscellaneous	
`Inverse`	outputs the inverse of the input matrix.
`Pre multiply`	outputs the input homogeneous transform pre-multiplied by the constant parameter.
`Post multiply`	outputs the input homogeneous transform post-multiplied by the constant parameter.
`inv Jac`	inputs are a square Jacobian $\mathbf{J}$ and a spatial velocity ν and outputs are $\mathbf{J}^{-1}$ and the condition number of $\mathbf{J}$.
`pinv Jac`	inputs are a Jacobian J and a spatial velocity and outputs are J+ and the condition number of J.
`tr2diff`	outputs the difference between two homogeneous transformations as a 6-vector comprising the translational and rotational difference.
`xyz2T`	converts a translational vector to a homogeneous transformation matrix.
`rpy2T`	converts a vector of roll-pitch-yaw angles to a homogeneous transformation matrix.
`eul2T`	converts a vector of Euler angles to a homogeneous transformation matrix.
`T2xyz`	converts a homogeneous transformation matrix to a translational vector.
`T2rpy`	converts a homogeneous transformation matrix to a vector of roll-pitch-yaw angles.
`T2eul`	converts a homogeneous transformation matrix to a vector of Euler angles.
`angdiff`	computes the difference between two input angles modulo 2π.

A number of models are also provided:

Robot manipulator arms	
sl_rrmc	Resolved-rate motion control
sl_rrmc2	Resolved-rate motion control (relative)
sl_ztorque	Robot collapsing under gravity
sl_jspace	Joint space control
sl_ctorque	Computed torque control
sl_fforward	Torque feedforward control
sl_opspace	Operational space control
sl_sea	Series-elastic actuator
vloop_test	Puma 560 velocity loop
ploop_test	Puma 560 position loop
Mobile ground robot	
sl_braitenberg	Braitenberg vehicle moving to a source
sl_lanechange	Lane changing control
sl_drivepoint	Drive to a point
sl_driveline	Drive to a line
sl_drivepose	Drive to a pose
sl_pursuit	Drive along a path
Flying robot	
sl_quadrotor	Quadrotor control
sl_quadrotor_vs	Control visual servoing to a target

1.3.5 Notes on implementation and versions

The Simulink blocks are implemented in Simulink itself with calls to MATLAB code, or as Level-1 S-functions (a proscribed coding format which MATLAB functions to interface with the Simulink simulation engine).

Simulink allows signals to have matrix values but not (yet) object values. Transformations must be represented as matrices, as per the classic functions, not classes. Very old versions of Simulink (prior to version 4) could only handle scalar signals which limited its usefulness for robotics.

1.3.6 Documentation

This document `robot.pdf` is a comprehensive manual that describes all functions in the Toolbox. It is auto-generated from the comments in the MATLAB code and is fully hyperlinked: to external web sites, the table of content to functions, and the “See also” functions to each other.

1.4 Compatible MATLAB versions

The Toolbox has been tested under R2016b and R2017bPRE. Compatibility problems are increasingly likely the older your version of MATLAB is.

1.5 Use in teaching

This is definitely encouraged! You are free to put the PDF manual (`robot.pdf` or the web-based documentation `html/*.html` on a server for class use. If you plan to distribute paper copies of the PDF manual then every copy must include the first two pages (cover and licence).

Link to other resources such as MOOCs or the Robot Academy can be found at www.petercorke.com/moocs.

1.6 Use in research

If the Toolbox helps you in your endeavours then I'd appreciate you citing the Toolbox when you publish. The details are:

```
@book{Corke17a,
    Author = {Peter I. Corke},
    Note = {ISBN 978-3-319-54413-7},
    Edition = {Second},
    Publisher = {Springer},
    Title = {Robotics, Vision \& Control: Fundamental Algorithms in {MATLA
    Year = {2017}}
```

or

> P.I. Corke, Robotics, Vision & Control: Fundamental Algorithms in MATLAB. Second edition. Springer, 2017. ISBN 978-3-319-54413-7.

which is also given in electronic form in the CITATION file.

1.7 Support

There is no support! This software is made freely available in the hope that you find it useful in solving whatever problems you have to hand. I am happy to correspond with people who have found genuine bugs or deficiencies but my response time can be long and I can't guarantee that I respond to your email.

I can guarantee that I will not respond to any requests for help with assignments or homework, no matter how urgent or important they might be to you. That's what your teachers, tutors, lecturers and professors are paid to do.

You might instead like to communicate with other users via the Google Group called "Robotics and Machine Vision Toolbox"

> http://tiny.cc/rvcforum

which is a forum for discussion. You need to signup in order to post, and the signup process is moderated by me so allow a few days for this to happen. I need you to write a few words about why you want to join the list so I can distinguish you from a spammer or a web-bot.

1.8 Related software

1.8.1 Robotics System Toolbox™

The Robotics System Toolbox™ (RST) from MathWorks is an official and supported product. System toolboxes (see also the Computer Vision System Toolbox) are aimed at developers of systems. RST has a growing set of functions for mobile robots, arm robots, ROS integration and pose representations but its design (classes and functions) and syntax is quite different to RTB. A number of examples illustrating the use of RST are given in the folder `RST` as Live Scripts (extension `.mlx`), but you need to have the Robotics System Toolbox™ installed in order to use it.

1.8.2 Octave

GNU Octave (www.octave.org) is an impressive piece of free software that implements a language that is close to, but not the same as, MATLAB. The Toolboxes will not work well with Octave, though with Octave 4 the incompatibilities are greatly reduced. An old version of the arm-robot functions described in Chap. 7–9 have been ported to Octave and this code is distributed in `RVCDIR/robot/octave`.

Many Toolbox functions work just fine under Octave. Three important classes (Quaternion, Link and SerialLink) will not work so modified versions of these classes is provided in the subdirectory called `Octave`. Copy all the directories from `Octave` to the main Robotics Toolbox directory. The Octave port is now quite dated and not recently tested – it is offered in the hope that you might find it useful.

1.8.3 Machine Vision toolbox

Machine Vision toolbox (MVTB) for MATLAB. This was described in an article

```
@article{Corke05d,
        Author = {P.I. Corke},
        Journal = {IEEE Robotics and Automation Magazine},
        Month = nov,
        Number = {4},
        Pages = {16-25},
        Title = {Machine Vision Toolbox},
        Volume = {12},
        Year = {2005}}
```

and provides a very wide range of useful computer vision functions and is used to illustrate principals in the Robotics, Vision & Control book. You can obtain this from http://www.petercorke.com/vision. More recent products such as MATLABImage Processing Toolbox and MATLABComputer Vision System Toolbox provide functionality that overlaps with MVTB.

1.9 Contributing to the Toolboxes

I am very happy to accept contributions for inclusion in future versions of the toolbox. You will, of course, be suitably acknowledged (see below).

1.10 Acknowledgements

I have corresponded with a great many people via email since the first release of this Toolbox. Some have identified bugs and shortcomings in the documentation, and even better, some have provided bug fixes and even new modules, thankyou. See the file `CONTRIB` for details.

Giorgio Grisetti and Gian Diego Tipaldi for the core of the pose graph solver. Arturo Gil for allowing me to ship the STL robot models from ARTE. Jörn Malzahn has donated a considerable amount of code, his Robot Symbolic Toolbox for MATLAB. Bryan Moutrie has contributed parts of his open-source package phiWARE to RTB, the remainder of that package can be found online. Other mentions to Gautam Sinha, Wynand Smart for models of industrial robot arm, Paul Pounds for the quadrotor and related models, Paul Newman for inspiring the mobile robot code, and Giorgio Grissetti for inspiring the pose graph code.

Chapter 2

Functions and classes

