TMRobot Series Toolbox: Interfacing Collaborative Robots with MATLAB

João Lobato Pereira[1,2][a], Mauro Queirós[1,2][b], Nuno M. C. da Costa[2][c], S. Marcelino[6], José Meireles[3][d], Jaime C. Fonseca[2][e], António H. J. Moreira[4,5][f] and João Borges[2,5][g]

[1]University of Minho, Guimarães, Portugal
[2]Algoritmi Center, University of Minho Guimarães, Portugal
[3]MEtRICs Research Center, University of Minho, Guimarães, Portugal
[4]2Ai – School of Technology, IPCA, Barcelos, Portugal
[5]Polytechnic Institute of Cávado and Ave, Barcelos, Portugal
[6]DIB4T, Marinha Grande, Portugal

Keywords: TMRobot, TM5_700, MATLAB, Individual Function, Class_TMRobot, Modbus TCP, Socket TCP/IP.

Abstract: As collaborative robots rise in popularity in industrial and domestic environments, TECHMAN Robot developed the TMRobot series, a wide variety of smart, safe, and straightforward collaborative robots. This paper presents the TMRobot Series Toolbox, which contains functions and methods to interface with the TMRobot series cobots from an external device using MATLAB. By using these, the users have access to connection, kinematic, point motion, set, get, and simulation functionalities which run on a remote computer connected to the TMRobot controller via TCP/IP protocols. The toolbox is then validated with some application examples.

1 INTRODUCTION

1.1 Motivation and Related Work

One of the significant changes that accompany the implementation of the new concept of Industry 4.0 is the use of collaborative robots (Poor & Basl, n.d.). The most common industrial robots are large, heavy, strong, and robust devices that work on very specific tasks. Sensors, signals, and safety nets are installed for safety reasons. According to relatively complex programs, they are used to complete human tasks while operating in a restricted area (Poór et al., 2019). A collaborative robot or cobot is also an industrial robot designed to cooperate with the human operator to create value. These robots can perform different tasks, such as picking up and inserting objects, delivering parts to the operator, among others (Broum & Šimon, n.d.).

In order to control a TM5_700 (TMRobot series), one needs to have an external toolkit for communication and control. TMRobot, unlike Kuka (Safeea & Neto, 2019), Puma (Gil et al., 2015), and Universal Robotics (Vivas & Sabater, 2021), does not have one. As such, our motivation for this project was to create ways to command and monitor this robot.

To support this project development Peter Corke's Robotics Toolbox is used, one of the most popular MATLAB toolboxes in the field of robotics. Peter Corke's Toolbox includes functionalities for robotic manipulators, such as homogeneous transformations, direct and inverse kinematics, direct and inverse dynamics, and trajectory generation (Corke, 2017). Also, it is essential to mention the Kuka Sunrise Toolbox (KST) project, where the

[a] https://orcid.org/0000-0002-1053-7405
[b] https://orcid.org/0000-0001-5896-7423
[c] https://orcid.org/0000-0002-8425-3501
[d] https://orcid.org/0000-0003-0881-2348
[e] https://orcid.org/0000-0001-6703-3278
[f] https://orcid.org/0000-0002-2148-9146
[g] https://orcid.org/0000-0002-5880-033X

Pereira, J., Queirós, M., C. da Costa, N., Marcelino, S., Meireles, J., Fonseca, J., Moreira, A. and Borges, J.
TMRobot Series Toolbox: Interfacing Collaborative Robots with MATLAB.
DOI: 10.5220/0011526000003329
In *Proceedings of the 3rd International Conference on Innovative Intelligent Industrial Production and Logistics (IN4PL 2022)*, pages 46-55
ISBN: 978-989-758-612-5; ISSN: 2184-9285

authors, similarly to this project, developed more than 50 functions divided into six categories to interface with the KUKA LBR iiwa manipulators—creating the first Toolbox to interface with the KUKA Sunrise.OS with functionalities like networking, real-time control, point-to-point motion, setters, getters, and physical interaction (Safeea & Neto, 2019).

1.1 Project Goals

The main goal of this project is to develop an easy-to-use toolkit capable of interfacing with the TM5_700 collaborative robot. Since this specific robot shares the same software and communication protocols with the rest of the TM series cobots, the methods developed can be used for every TMRobot, which is already a significant advantage of the TMRobot Series Toolbox. Other advantages are:

1) It takes the user away from having to learn a new software associated with this robot's controller TMFlow;
2) Easy and fast interaction between the robot and an external computer;
3) External sensors/devices are integrated into the computer, and data are transmitted to/from the robot via TCP/IP;
4) Complex applications can be included in the external device allowing for more advanced robot manipulation (i.e. machine learning, vision);
5) Supplementing the robot's system functionalities with simulation capabilities.

The functions and methods within the package, much like the KST toolbox, are divided into different categories depending on their role: connection, setters, getters, point motion, simulation, and gripper. A deep study of the TMRobot manuals was required to define which types of communication with external devices were most suitable for the different functions (*Software Manual TMflow_ Software Version: 1.68_Document Version: 1.01 i Software Manual TMflow Original Instruction Software Version: 1.68*, n.d.). With that, for the acquisition and manipulation of robot parameters like joint values, end-effector position, IO connectors, and others, the Modbus TCP protocol was picked since, by extensive testing, it turned out to be simpler and provide more information. For the motion control of the robotic arm, the socket TCP/IP transport protocol was used alongside the robot's external script protocol, which defines the specific command exchange format (*Expression Editor and Listen Node Software Version: 1.80 Expression Editor and Listen Node*, n.d.).

2 SYSTEM ARCHITECTURE

This project is composed of two main subsystems: the operational subsystem, which incorporates the TMRobot and its controller; and the control and monitoring subsystem defined by the external device and its properties. Figure 1 shows how these two components interact. After deliberation and research on projects with similar goals, we choose MATLAB as the software to associate with the external device. This is a tool that is in constant improvement. It is flexible, versatile, and supports a variety of communication protocols which represent an essential requirement for this development. MATLAB has been commonly used on a big scale in the academic environment, so its high-level programming structure is well-known, allowing users with minimal experience to easily understand and utilize this work.

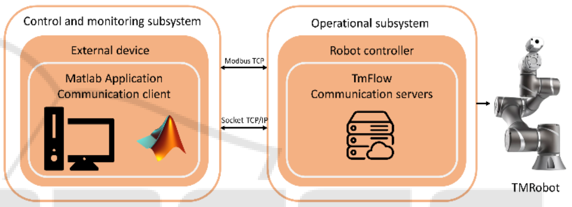


Figure 1: System architecture and communication scheme.

2.1 Operational Subsystem: Robot Controller

This subsystem is mainly responsible for interpreting the commands and requests coming from the external device, following the instructions on those communication messages, moving the robotic arm to the requested poses, sharing and setting different parameters in the controller, and even confirming connections and states of movements. For this to be possible, some steps must be performed on the side of the robot's software TMFlow. As the scheme in Figure 1 shows, to control the real robot to the extent required, both Modbus TCP and SocketTCPListenner servers need to be set up. To start the Modbus TCP server, the user only needs to login into the TMFlow software, open the settings menu, go to connection, open the Modbus slave tab, select the communication type, TCP, and enable the service.

To run the Socket server, it is required to create a new project in the project tab and place the Listen Node after the start block. Ensure the timeouts are set to zero in the node properties and run that project. Figure 2 shows this simple setup.

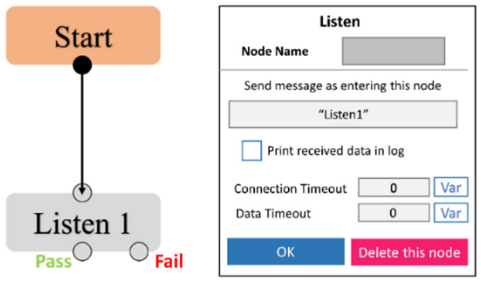


Figure 2: Setting SocketTCPListenner server.

2.2 Control and Monitoring Subsystem: External Device

This subsystem is where the user executes all the developed functions according to his tasks needs or desired actions. The commands and requests developed inside these functions were coded according to the specific protocol format of the TMRobot so that the user could control not only the TM5_700 collaborative robot but also other TM series robots. To create both Modbus TCP and Socket clients, specific MATLAB toolboxes are required (*Modbus Communication - MATLAB & Simulink*, n.d.), (*TCP/IP Communication - MATLAB & Simulink*, n.d.). Moreover, users must add to their software the Industrial communication, the Instrument control, the Optimization, and Peter Corke's Robotics toolboxes (*Access MATLAB Add-On Toolboxes - MATLAB & Simulink*, n.d.).

This way it is possible to make the TMRobots more accessible to a wide variety of people from different backgrounds and open the door of collaborative robotics for academic and educational applications. This toolbox was made publicly available (*GitHub - Joaolobatopereira117/TMRobot-Series-Toolbox*, n.d.).

3 TOOLBOX FUNCTIONS

This section is divided into two parts that represent different levels of the TMRobot Series Toolbox usage. The individual function library is more suitable for quick and simple tasks requiring a single robot to accomplish the end goal. In contrast, the Class_TMRobot, with its aggregated structure, allows for a more complex task design with the integration of several TMRobots controlled from the same platform, which will be represented as different class objects, each one with its organized properties and methods. This structured approach is where this toolbox differentiates from the KST toolbox.

3.1 Individual Function Library

In this section, implementation examples of some functions are given so that the user can follow and understand their functionalities better. For clearer understanding, the functions are divided into eight different categories:

1) Connection - Connection with the robot controller;
2) Setters – Set parameters in the robot controller (digital output, referential base);
3) Getters – Get parameters from the robot controller (end-effector position and orientation, joint angles, digital input and output);
4) Point Motion – Point to point motion in joint and cartesian space;
5) Gripper – Gripper control;
6) Kinematics – Forward and inverse kinematics;
7) Simulation – Manipulation and visualization of the virtual model;
8) Test arm configuration – Test specific robot poses in joint and cartesian space;

Table 1 aggregates all the individual functions within each category and represents all the work done in the first part of this section.

Connection:

In order to start controlling the robot, both the external device and the controller must be physically connected with the RJ45 ethernet cable in their specific ports and the IP addresses in the same network frame. With these conditions assured, the user is ready to establish the connection using the function

connect2controller(ip,socketport,modbusport),

where *ip* is a string with the IP address of the robot and *ports* are the socket and Modbus communication port, that by default are 502 and 5890, respectively. The example below illustrates a connection.

```
>>ip="192.168.0.111";

>>socketport=5890;

>>modbusport=502;

>>[socketclient,modbusclient]=connect2c
ontroller(ip,socketport,modbusport);
```

This function returns both Modbus and socket clients, which are meant to be used in the rest of the library functions.

Table 1: List of all functions in the individual function library in TMRobot Series Toolbox.

Category	Function m-Modbus client object; clinet-TCP socket client objec	Description
Connection	`connect2controller()`	Returns two client objects (Modbus and Socket) connected to the Robot Servers;
Setters	`setBase(newbase)`	Sets the referential base of the Robot to newbase;
	`setHeadlight(state)`	Turns ON and OFF camera light: state=1-ON, state=0-OFF;
	`setDO(n, value)`	Sets digital state of the Robot Controller DO's: n-number of DO, value=1-HIGH, value=0-LOW;
Getters	`getRealpos()`	Returns the position and orientation of the end-effector according to Robot's base;
	`getBase()`	Returns current Robot referential base;
	`getRealJoints()`	Returns all 6 joints current positions in degrees;
	`RunTimProj()`	Returns and displays the days, hours, minutes and seconds that the project has been running for;
	`getProjspeed()`	Returns the percentage (as multiple of 5) of the max speed defined in Robot security settings;
	`getDI()`	Returns the state of the n digital input of the controller where 1 is HIGH and 0 is LOW;
	`getDO()`	Returns the state of the n digital output of the controller where 1 is HIGH and 0 is LOW;
Point Motion	`LineMove2pos(pose, velperc)`	Moves the end-effector to specified cartesian position with the speed percentage defined in velperc thru a Line trajectory;
	`PTPMove2pos(pose, velperc)`	Moves the end-effector to specified cartesian position with the speed percentage defined in velperc thru a PTP trajectory;
	`Move2joint(pose, velperc)`	Moves the robot joints to specified joint space position with the speed percentage defined in velperc thru PTP trajectory;
	`circleMove(Endpose, Passpose, arcAng, velperc)`	Moves the end-effector to a specified Endpose pathing near Passpose with the speed percentage defined in velperc in a circle trajectory with the angle defined in arcAng;
	`MoveJ1(value, velperc)`	Increments or decrements joint 1 position by value degrees;
	`MoveJ2(value, velperc)`	Increments or decrements joint 2 position by value degrees;
	`MoveJ3(value, velperc)`	Increments or decrements joint 3 position by value degrees;
	`MoveJ4(value, velperc)`	Increments or decrements joint 4 position by value degrees;
	`MoveJ5(value, velperc)`	Increments or decrements joint 5 position by value degrees;
	`MoveJ6(value, velperc)`	Increments or decrements joint 6 position by value degrees;
	`MoveX(value, config, velperc)`	Moves the end-effector position only in the X accel by value mm, using Line or PTP trajectory as defined in the config parameter;
	`MoveY(value, config, velperc)`	Moves the end-effector position only in the Y accel by value mm, using Line or PTP trajectory as defined in the config parameter;
	`MoveZ(value, config, velperc)`	Moves the end-effector position only in the Z accel by value mm, using Line or PTP trajectory as defined in the config parameter;
	`MoveRx(value, config, velperc)`	Moves the end-effector orientation only in the Rx accel by value mm, using Line or PTP trajectory as defined in the config parameter;
	`MoveRy(value, config, velperc)`	Moves the end-effector orientation only in the Ry accel by value mm, using Line or PTP trajectory as defined in the config parameter;
	`MoveRz(value, config, velperc)`	Moves the end-effector orientation only in the Rz accel by value mm, using Line or PTP trajectory as defined in the config parameter;
Gripper	`opengripper()`	Opens the gripper fingers;
	`closegripper()`	Closes the gripper fingers;
Kinematics	`F_Kinematics(q)`	Returns the cartesian pose and orientation according to specified joint configuration q;
	`I_Kinematics(Pose)`	Returns the joint configuration for the cartesian pose specified;
Simulation	`symControl()`	Allows user to manipulate the robot simulation by moving each joint;
	`symJoint(Pose)`	Simulates a specific joint pose configuration;
	`getSymjoints()`	Returns the joint value of the current simulation;
	`getSympos()`	Returns the postion and orientation of the current simulation;
Test arm config	`isposReach(pos)`	Checks if pos is a reachable position for the robotic arm;
	`isjointReach(q)`	Checks if q is inside the robot's joint limitations;

Setters:

This category includes functions to set different referential bases for the Robot base and to control LED and digital output states. For example, to set a new base:

```
>>newbase=[300 300 300 180 0 90];
>>setBase(socketclient,newbase);
```

To set the digital output five to a HIGH state:

```
>>setDO(modbusclient,5,1);
```

Getters:

These functions will allow users to monitor all kinds of robot parameters, from the input-output (IO) states to joint and cartesian positions. To illustrate the acquisition of the current base and end-effector position according to this new base:

```
>>getBase(modbusclient);
ans
    300 300 300 180 0 90
>>getRealpos(modbusclient);
```

Both these functions return a 1x6 cell array with the [X Y Z Rx Ry Rz] values.

To get the state of digital input 2:

```
>>getDI(modbusclient,2);
ans
    0
```

Point Motion:

This category allows users to move the robotic arm from the current configuration/position to a final pose through different types of trajectories (PTP, line, and circle) with the desired speed percentage. In addition to this, the user can move the end-effector through a single axis or even actuate over one specific joint.

This next example moves the robot to the user defined *finalpos* with 75% of the speed defined for the project.

```
>>finalpos=[400 50 350 180 0 90];
>>vel_percent=75;
>>LineMove2pos(socketclient,finalpos,ve
l_percent);
```

To individually move the first joint plus 10 degrees with 100% speed, use the *moveJ1* function with the following parameters:

```
>>MoveJ1(socketclientmodbusclient,10,10
0)
```

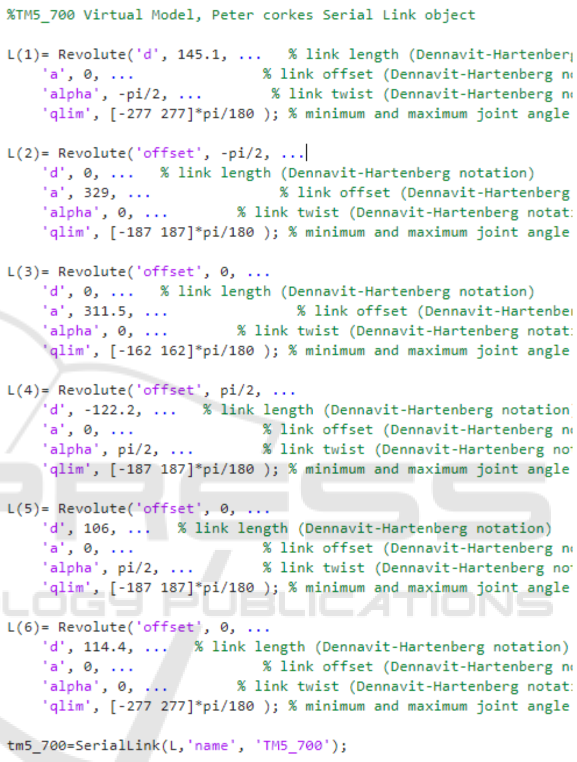
Gripper:

The functions developed in this category are specific to the 2FG7 Omron gripper, and some additional blocks have to be added to the project in the TMFlow. If the user has the same gripper properly installed, the complete project folder is also available on the Github page with the name *ToolboxProj,* so it is required to download it, import it to the robot operational system and run it. After that, the system is ready to interpret both open and close actions:

```
>>opengripper(modbusclient,socketclient
);
>>closegripper(modbusclient,socketclien
t);
```

Kinematics:

By relying on the Peter Corke robotic toolbox for all the virtual model related work, kinematic functions are already defined and associated with the serial link object, created with the portion of code bellow, *sym_model* - virtual representation of the TMRobot to control according to its Denavit Hartenberg parameters Figure 3. So, it was just a matter of shaping their inputs and outputs to the format that suited this work.



```
%TM5_700 Virtual Model, Peter corkes Serial Link object

L(1)= Revolute('d', 145.1, ...   % link length (Dennavit-Hartenber
    'a', 0, ...                  % link offset (Dennavit-Hartenberg n
    'alpha', -pi/2, ...          % link twist (Dennavit-Hartenberg n
    'qlim', [-277 277]*pi/180 ); % minimum and maximum joint angle

L(2)= Revolute('offset', -pi/2, ...
    'd', 0, ...   % link length (Dennavit-Hartenberg notation)
    'a', 329, ...                  % link offset (Dennavit-Hartenberg
    'alpha', 0, ...          % link twist (Dennavit-Hartenberg notat
    'qlim', [-187 187]*pi/180 ); % minimum and maximum joint angle

L(3)= Revolute('offset', 0, ...
    'd', 0, ...   % link length (Dennavit-Hartenberg notation)
    'a', 311.5, ...                  % link offset (Dennavit-Hartenbe
    'alpha', 0, ...          % link twist (Dennavit-Hartenberg notat
    'qlim', [-162 162]*pi/180 ); % minimum and maximum joint angle

L(4)= Revolute('offset', pi/2, ...
    'd', -122.2, ...   % link length (Dennavit-Hartenberg notation
    'a', 0, ...                  % link offset (Dennavit-Hartenberg n
    'alpha', pi/2, ...           % link twist (Dennavit-Hartenberg no
    'qlim', [-187 187]*pi/180 ); % minimum and maximum joint angle

L(5)= Revolute('offset', 0, ...
    'd', 106, ...   % link length (Dennavit-Hartenberg notation)
    'a', 0, ...                  % link offset (Dennavit-Hartenberg n
    'alpha', pi/2, ...           % link twist (Dennavit-Hartenberg no
    'qlim', [-187 187]*pi/180 ); % minimum and maximum joint angle

L(6)= Revolute('offset', 0, ...
    'd', 114.4, ...   % link length (Dennavit-Hartenberg notation)
    'a', 0, ...                  % link offset (Dennavit-Hartenberg n
    'alpha', 0, ...          % link twist (Dennavit-Hartenberg notat
    'qlim', [-277 277]*pi/180 ); % minimum and maximum joint angle

tm5_700=SerialLink(L,'name', 'TM5_700');
```

Links	*Θº*	*αº*	*a mm*	*d mm*	*Offset*
1	Θ_1	-90º	0	145.1	0º
2	Θ_2	0º	329	0	-90º
3	Θ_3	0º	311.5	0	0º
4	Θ_4	90º	0	-122.2	90º
5	Θ_5	90º	0	106	0º
6	Θ_6	0º	0	114.4	0º

Figure 3: TM5_700 Denavit Hartenberg parameters.

Users are free to use these functions, however their purpose is to support other functions to test specific pose configurations and to allow switching between joint and Cartesian space, and vice-versa.

In the forward kinematic function, the user defines a set of 6 joint values in degrees as a 1x6 array cell and will be answered with the position and orientation of the end-effector, [X Y Z Rx Ry Rz] in mm and degrees. For the inverse kinematic, it is the exact opposite:

```
>>F_Kinematics(sym_model,[0 0 0 0 0 0]);
```

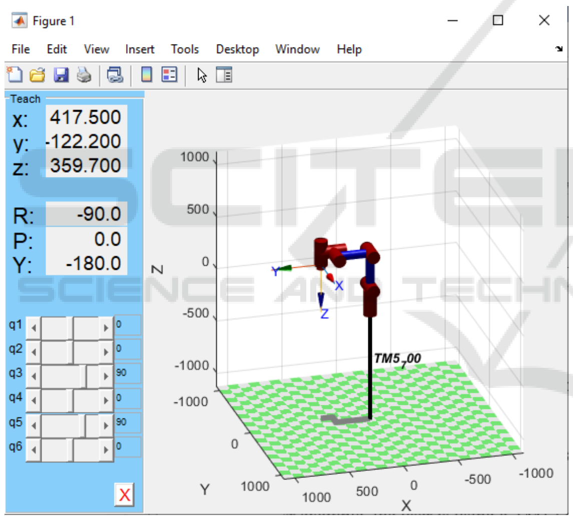
```
>>I_Kinematics(sym_model,[0       -236.6
891.6 90 0 0]);
```

Simulation:

The functions in this category are meant to help users visualize specific robot pose configurations, before sending any definitive commands to the real robot.

The *symControl(sym_model,q)* function, based on a method from the serial link class, allows for direct manipulation of the virtual model. Moreover, when users run this method, an interactive plot opens, where they can change joint values and watch the robot motion, as shown in Figure 4:

```
>>symControl(sym_model,[0 0 90 0 90 0]);
```



X: 417.500
Y: -122.200
Z: 359.700
R: -90.0
P: 0.0
Y: -180.0
q1 0
q2 0
q3 90
q4 0
q5 90
q6 0

Figure 4: Interactive plot.

The user can then call *getSympos()* to obtain the coordinates and orientation of the pose defined in the plot:

```
>>getSympos(sym_model);
```

Test Arm Config:

Much like the kinematic methods, the two functions in this category will support other functions, ensuring the robot does not receive invalid joint target poses and unreachable cartesian positions.

The *isjointReach(sym_model,q)* returns logical value 1 if the joint values on the input *q* are inside the joint limits defined on the model. The same happens if the input position on *isposReach(sym_model,pos)* obtains a successful output from the inverse kinematics function used inside this method.

```
>>isjointReach(sym_model,[0  0  90  0  90
0]);
```

```
>>isposReach(sym_model,[300  10  50  0  0
0]);
```

3.2 Class_TMRobot

As mentioned before, this class originates not only from the need to integrate both real and virtual systems but also from the fact that many of the functions developed before needed access to common data. So, to optimize the TMRobot Series Toolbox, we aggregate these functions into an organized structure where their common inputs become its properties, and all these functions are rearranged into its methods.

Merging the system communication attributes with the simulation model of the robot into the Class_TMRobot creates advantages in integrating different categories like Kinematics and Test arm config with Point Motion methods. Access to all this new information makes for improvements in some of the old functions, mainly those responsible for arm movement. Also, it enables access to functions that allow the user to test the capacity of the robot to reach certain arm positions, making sure the user cannot send wrong target coordinates or joint poses to the controller. Figure 5 demonstrates the composition and organization of the whole class relating the method categories with the type of property they require for processing.

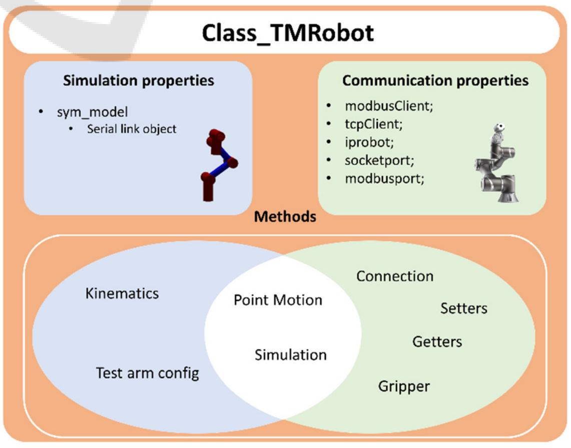


Figure 5: Class_TMRobot.

Class Properties:

As illustrated above, these are divided into two types:

1) Simulation properties – *sym_model*, object from serial link class;
2) Communication properties – *modbusClient* and *tcpClient* are private properties that are only set in the connect and disconnect methods, so users cannot access them. The rest of the properties are public and meant to be defined by users for their specific robot, *iprobot*, *socketport,* and *modbusport*.

Class Methods:

In this topic, implementation examples of the constructor will be demonstrated since the rest of the methods in the class come from the functions developed before and are similar in usage and achieve the same action within the physical world.

Constructor:

Before using all these methods, the user must be able to represent his own robot as an object of this class. For that, the object constructor *Class_TMRobot(varargin)* is used. This function can be called in many different ways:

```
>>TM5_700=Class_TMRobot();
```

In this example, the object created, *TM5_700* has its properties defined by default, where the sym*_model* property is a serial link object created based on the Denavit Hartenberg parameters of a TM5_700 cobot. The *iprobot*, *modbusport,* and *socketport* are defined as “192.168.0.111”, 502, and 5890, respectively.

```
>>TM5_700=Class_TMRobot(‘iprobot’,’192.
168.0.1’);
```

In this case, the object is created with the IP “192.168.0.1,” and the rest of the properties remain defined by default. It is advised to use this constructor if the user is trying to control a TM5_700 because the virtual model is already set. If, for example, the user is using a TM12 or other type of TMRobot, just create a serial link object with the correct DH parameters and specify all the properties within the constructor:

```
>>TM5_700=Class_TMRobot(‘sym_model’,TM1
2Model,’iprobot’,’192.168.0.2’,’modbusp
ort’,503,’socketport’,5891);
```

Table 2 aggregates all the class methods within each of their respective categories.

Table 2: List of all CLASS_TMROBOT Methods.

Class methods	
Connection	connect2controller_C()
Kinematics	F_Kinematics_C(q)
	I_Kinematics_C(Pose)
Setters	setBase_C(newbase)
	setHeadlight_C(state)
	setDO_C(n, value)
Getters	getRealpos_C()
	getBase_C()
	getRealJoints_C()
	RunTimProj_C()
	getProjspeed_C()
	getDI_C()
	getDO_C()
Point Motion	LineMove2pos_C(pose, velperc)
	PTPMove2pos_C(pose, velperc)
	Move2joint_C(pose, velperc)
	circleMove_C(Endpose, Passpose, arcAng, velperc)
	MoveJ1_C(value, velperc)
	MoveJ2_C(value, velperc)
	MoveJ3_C(value, velperc)
	MoveJ4_C(value, velperc)
	MoveJ5_C(value, velperc)
	MoveJ6_C(value, velperc)
	MoveX_C(value, config, velperc)
	MoveY_C(value, config, velperc)
	MoveZ_C(value, config, velperc)
	MoveRx_C(value, config, velperc)
	MoveRy_C(value, config, velperc)
	MoveRz_C(value, config, velperc)
Simulation	symControl_C()
	symJoint_C(Pose)
	getSymjoints_C()
	getSympos_C()
Gripper	opengripper_C()
	closegripper_C()
Test arm config	isposReach_C(pos)
	isjointReach_C(q)

4 APPLICATION EXAMPLES

This section demonstrates some application examples and different uses of the TMRobot Series Toolbox to validate all the developed work.

1) Example 1: Development of a graphical user interface called ControllerInterface, making use of many setters, getters, gripper, and point motion methods;
2) Example 2: Pick and Place task using both individual function library and the Class_TMRobot;

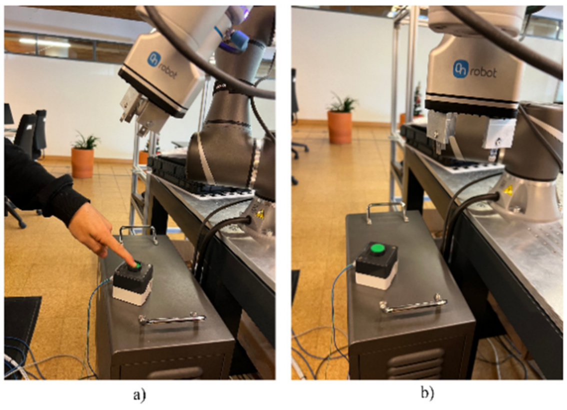
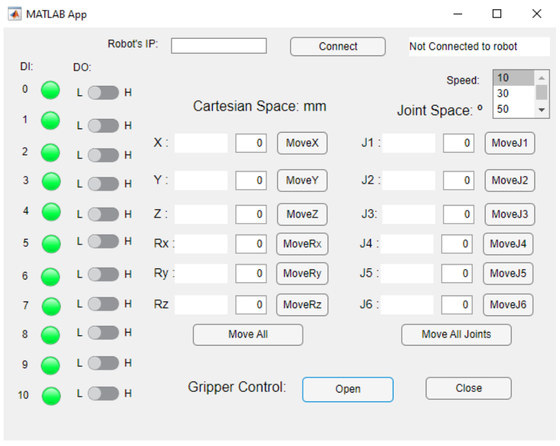


Figure 6: Different Robot states.

Figure 6 b) shows another robot state where the button is not being pressed, joint five is set to 90 degrees, and the gripper is opened. Figure 9 shows the app manipulation required to get to state b).

4.1 Example 1: Controller Interface

The goal with this example was to create a MATLAB App that would support the user in designing different tasks, in the way that he could manipulate the robot with the simple click of a button and immediately have at its disposal the positions, orientations and joint configurations to then include these points on the final motion process. Since the app required the use of many methods, it turned out to be an excellent way to validate the Class_TMRobot and its methods interacting with each other. This example is included in the TMRobot Series Toolbox repository with the name ControllerInterface as shown in Figure 7.



Not Connected to robot

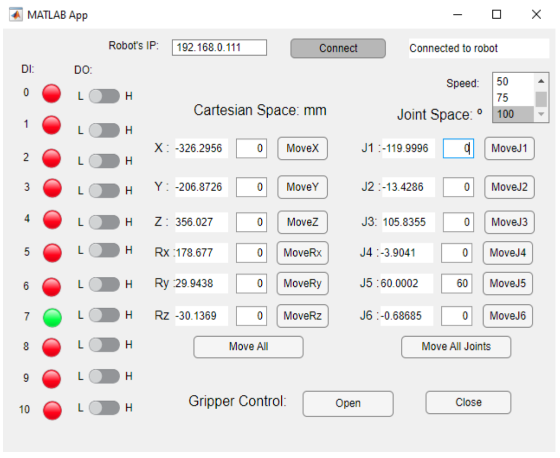
Speed: 10, 30, 50

X: 0; Y: 0; Z: 0; Rx: 0; Ry: 0; Rz: 0

J1: 0; J2: 0; J3: 0; J4: 0; J5: 0; J6: 0

Figure 7: GUI Controller Interface.

To establish a successful connection, one needs to check if the project is running in the TMFlow and proceed to define the robot's IP address and set the connect button ON. If users try to open the gripper, move the robot, and others without establishing a connection, the message "Not connected to robot" will appear (Figure 7).



Robot's IP: 192.168.0.111 — Connected to robot

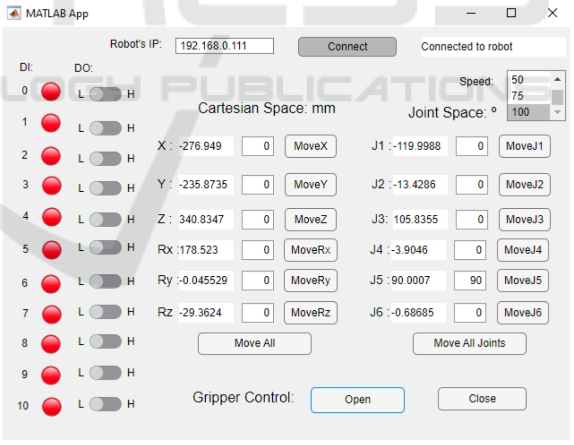
Speed: 50, 75, 100

X : -326.2956 | 0
Y : -206.8726 | 0
Z : 356.027 | 0
Rx :178.677 | 0
Ry :29.9438 | 0
Rz -30.1369 | 0

J1 :-119.9996 | 0
J2 :-13.4286 | 0
J3: 105.8355 | 0
J4 :-3.9041 | 0
J5 :60.0002 | 60
J6 :-0.68685 | 0

Figure 8: Interface connected to TM5-700.

Successfully connected to the controller in Figure 8, we have all the parameter sections, Digital Input (DI), Cartesian space, and Joint space, being updated in real-time. The DI7 is activated since the button connected to this pin is being pressed, joint five is set to 60 degrees, and the gripper is closed (Figure 6 a).



Robot's IP: 192.168.0.111 — Connected to robot

Speed: 50, 75, 100

X : -276.949 | 0
Y : -235.8735 | 0
Z : 340.8347 | 0
Rx :178.523 | 0
Ry :-0.045529 | 0
Rz -29.3624 | 0

J1 :-119.9988 | 0
J2 :-13.4286 | 0
J3: 105.8355 | 0
J4 :-3.9046 | 0
J5 :90.0007 | 90
J6 :-0.68685 | 0

Figure 9: Interface associated with Robot state b).

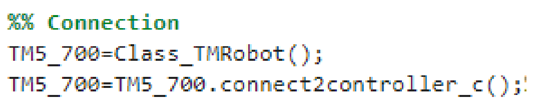
4.2 Example 2: Pick and Place Task

In this example, the goal was to build a pick and place task only using the functions and methods from this Toolbox.

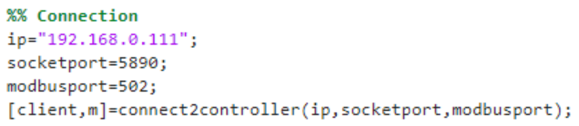
For the test conditions of this example, we have the components (pick site) on the left side of the table and the PCB board on the right side (place site). The goal is to fill the PCB with three of these components.

This simple task will be accomplished using both the individual function library and the Class_TMRobot, so the differences and similarities can be highlighted.

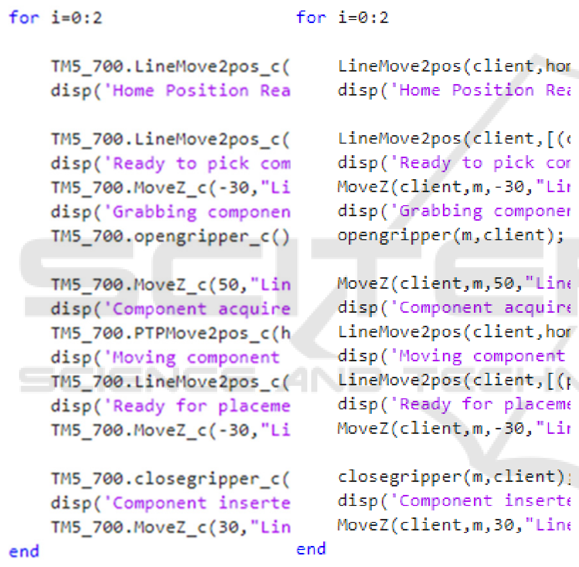
The first process of finding the pick and place positions is the same across both implementations. The following portions of code illustrate the differences between the two approaches when developing a motion sequence.



```
%% Connection
TM5_700=Class_TMRobot();
TM5_700=TM5_700.connect2controller_c();
```



```
%% Connection
ip="192.168.0.111";
socketport=5890;
modbusport=502;
[client,m]=connect2controller(ip,socketport,modbusport);
```



```
for i=0:2                          for i=0:2

    TM5_700.LineMove2pos_c(            LineMove2pos(client,hor
    disp('Home Position Rea            disp('Home Position Rea

    TM5_700.LineMove2pos_c(            LineMove2pos(client,[((
    disp('Ready to pick com            disp('Ready to pick cor
    TM5_700.MoveZ_c(-30,"Li            MoveZ(client,m,-30,"Lir
    disp('Grabbing componen            disp('Grabbing componer
    TM5_700.opengripper_c()            opengripper(m,client);

    TM5_700.MoveZ_c(50,"Lin            MoveZ(client,m,50,"Line
    disp('Component acquire            disp('Component acquire
    TM5_700.PTPMove2pos_c(h            LineMove2pos(client,hor
    disp('Moving component             disp('Moving component
    TM5_700.LineMove2pos_c(            LineMove2pos(client,[(p
    disp('Ready for placeme            disp('Ready for placeme
    TM5_700.MoveZ_c(-30,"Li            MoveZ(client,m,-30,"Lir

    TM5_700.closegripper_c(            closegripper(m,client);
    disp('Component inserte            disp('Component inserte
    TM5_700.MoveZ_c(30,"Lin            MoveZ(client,m,30,"Line
end                                end
```

Since the test performed is a simple task with only one robot, the individual function library would be suitable. However, if the goal was to control a real assembly line with many robots working simultaneously, the class becomes a more suitable approach due to its structure and organization.

Even though the way these functions and methods are implemented is different, their effect in the physical world is exactly the same, and it makes for the fact that the methods in the Class_TMRobot integrate the individual functions. To finally validate the proper behaviour of both approaches, the movements have been recorded and illustrated in Figure 10 where the PCB gets fully assembled.

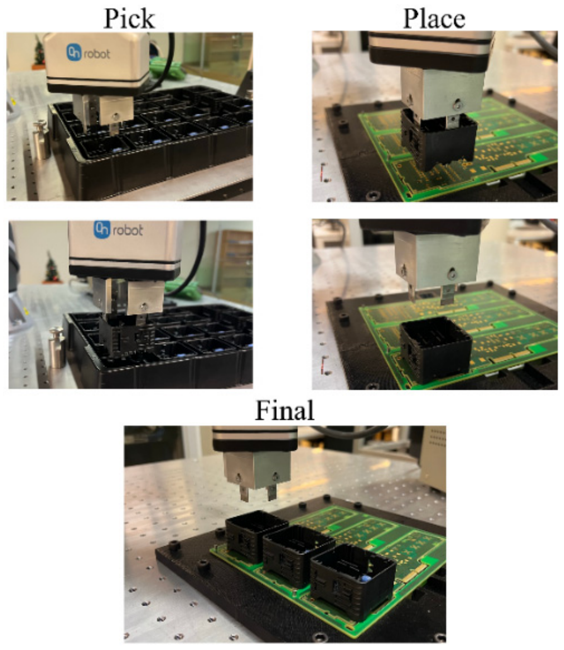


Figure 10: PCB assembling.

5 CONCLUSION

In this article, we introduced the TMRobot Series Toolbox to interface with the controller that equips the collaborative TMRobot series, which have been rising in popularity. These robots are being applied to processes in assembling notebook computers and servers and on automobile and flat panel display production lines that many thought robots would have a difficult time handling.

This Toolbox runs on an external computer connected to the TMRobot controller via TCP/IP. We presented features concerning connection, point motion, setters and getters, gripper control, and simulation functions. These features were extensively tested and demonstrated reliability, versatility, stability, and ease of use.

The TMRobot Series Toolbox is useful, not only in teaching, since it allows for students to interact with real collaborative robots through a familiar tool that is MATLAB, but also in industrial environments as it enables the integration of other hardware devices as well as other methodologies and process control techniques such as machine learning, data analysis and artificial intelligence (AI). The performance of the Toolbox was tested through two successful application examples.

The future work basically relates to the development of higher-level functions that allow for more complex control for example, the integration of machine learning methods for close loop control maintaining the highest level of precision and incorporation of the designed system into a Simulink model.

ACKNOWLEDGEMENT

This work is co-funded by the European Regional Development Fund (ERDF) through the Operational Competitiveness and Internationalization Programme (COMPETE 2020) of the Portugal 2020 Program [Project No. 45070, " FlexASComp"; Funding Reference: POCI-01-0247-FEDER-045070].

REFERENCES

Access MATLAB Add-On Toolboxes - MATLAB & Simulink. (n.d.). Retrieved March 27, 2022, from https://www.mathworks.com/help/thingspeak/matlab-toolbox-access.html

Broum, T., & Šimon, M. (n.d.). *Preparation of Collaborative Robot Implementation in the Czech Republic*.

Corke, P. (2017). Robotics, Vision and Control - Fundamental Algorithms In MATLAB® Second, Completely Revised, Extended And Updated Edition. *Annals of Mathematics and Artificial Intelligence*, *75*(1–2), 693. https://www.springer.com/gp/book/9783319544120

Expression Editor and Listen Node Software Version: 1.80 Expression Editor and Listen Node. (n.d.).

Gil, A., Reinoso, O., Marin, J. M., Paya, L., & Ruiz, J. (2015). Development and deployment of a new robotics toolbox for education. *Computer Applications in Engineering Education*, *23*(3), 443–454. https://doi.org/10.1002/CAE.21615

GitHub - joaolobatopereira117/TMRobot-Series-Toolbox. (n.d.). Retrieved April 13, 2022, from https://github.com/joaolobatopereira117/TMRobot-Series-Toolbox

Modbus Communication - MATLAB & Simulink. (n.d.). Retrieved March 24, 2022, from https://www.mathworks.com/help/icomm/modbus.html?s_tid=CRUX_lftnav

Poor, P., & Basl, J. (n.d.). *29th Daaam International Symposium On Intelligent Manufacturing And Automation Czech Republic And Processes Of Industry 4.0 Implementation*. 454–0459. https://doi.org/10.2507/29th.daaam.proceedings.067

Poór, P., Broum, T., & Basl, J. (2019). *Role of Collaborative Robots in Industry 4.0 with Target on Education in Industrial Engineering; Role of Collaborative Robots in Industry 4.0 with Target on Education in Industrial Engineering*. https://doi.org/10.1109/CRC.2019.00018

Safeea, M., & Neto, P. (2019). *KUKA Sunrise Toolbox: Interfacing Collaborative Robots With MATLAB; KUKA Sunrise Toolbox: Interfacing Collaborative Robots With MATLAB*. https://doi.org/10.1109/MRA.2018.2877776

Software Manual TMflow_ Software version: 1.68_Document version: 1.01 i Software Manual TMflow Original Instruction Software Version: 1.68. (n.d.).

TCP/IP Communication - MATLAB & Simulink. (n.d.). Retrieved March 24, 2022, from https://www.mathworks.com/help/matlab/tcpip-communication.html

Vivas, A., & Sabater, J. M. (2021). UR5 Robot Manipulation using Matlab/Simulink and ROS. *2021 IEEE International Conference on Mechatronics and Automation, ICMA 2021*, 338–343. https://doi.org/10.1109/ICMA52036.2021.9512650