Usermanual

Version: 1.0.2

Symbolic-OCPbasic

June 25, 2025

Author:
Andreas Huber*

*info@ocpbasic.com, www: http://www.ocpbasic.com

Contents

1 Installing Symbolic-OCPbasic

Unlike OCPBASIC and IPBASIC, Symbolic-OCPBASIC is licensed under the GNU General Public License (GPL) Version 3. This is due to its use of GPL-licensed dependencies such as GiNaC and CLN, in addition to Qt Charts. As a result, distribution under GPL v3 is the only legally permitted option.

1.1 Fast Installing Procedure

If you do not like to build Symbolic-OCPBASIC, OCPBASIC and IPBASIC yourself you can get precompiled packages for Ubuntu 24.04.

1.1.1 Installing via apt-get on Ubuntu 24.04

This section will install Symbolic-OCPBASIC, OCPBASIC, IPBASIC and LAPACK_WRAPPER using an apt-repository and the packages libblas-dev, liblapack-dev, qttools5-dev, libqt5charts5, libqt5charts5-dev and ginac-tools using the ubuntu repository.
First download and activate the ocpbasic gpg key and install it to your system.

Comment 1.1 *Only add software repositories from sources that you trust! Third-party software repositories are not checked for security or reliability and may contain software which is harmful to your computer. The use of these repositorys is at your own risk!*

```
$ wget https://archive.ocpbasic.com/dists/noble/ocpbasic.gpg
$ sudo install -o root -g root -m 644 ocpbasic.gpg \
  /etc/apt/trusted.gpg.d/
$ rm ocpbasic.gpg
```

After that you can activate the ocpbasic apt-repository with the command:

```
$ sudo add-apt-repository \
'deb [arch=amd64] http://archive.ocpbasic.com/dists/noble /'
```

If the apt-repository is installed correctly you can install Symbolic-OCPBASIC with the command:

```
$ sudo apt-get install symbolic-ocpbasic
```

The software packages libblas-dev, liblapack-dev, qttools5-dev, libqt5charts5, libqt5charts5-dev, ginac-tools, LAPACK_WRAPPER, IPBASIC and OCPBASIC will then also be installed by apt.
Supported Ubuntu Versions:

Ubuntu version:	**apt-repository**
Ubuntu 24.04	'deb [arch=amd64] http://archive.ocpbasic.com/dists/noble /'
Ubuntu 22.04	'deb [arch=amd64] http://archive.ocpbasic.com/dists/jammy /'

Table 1: Supported Ubuntu Versions

Comment 1.2 *The maintainer may remove or delete these apt-repositorys any time!*

2 Using Symbolic-OCPbasic

Symbolic-OCPBASIC is a graphical front-end for OCPBASIC, tailored to help you prototype and solve optimal control problems (OCPs) without writing a single line of C++ by hand. In addition to providing a fully visual workflow, Symbolic-OCPBASIC also automatically generates all required symbolic derivatives using the GiNaC library. The workflow divides naturally into three stages:

1. **Problem definition** (*Symbolic OCP* tab): enter the symbolic dynamics, constraints, boundary conditions, cost functional and bounds.

2. **Optimisation** (*Optimize* tab): call OCPBASIC's interior-point solver, monitor convergence and inspect residuals.

3. **Visualisation** (*Plots* tab): plot states, controls or path-dependent quantities against time—or against each other.

A toolbar allows you to *save* a problem as XML, *open* an existing XML file, or *export* a self-contained C++ project that links directly against OCPBASIC.

2.1 Optimal Control Problems in Symbolic-OCPbasic

The class of optimal-control problems accepted by OCPBASIC (and therefore by Symbolic-OCPBASIC) is summarised below.

Problem 2.1 (Optimal Control Problem (OCP))
Find the states $y : [t_0, t_f] \to \mathbb{R}^{n_y}$, *the parameter vector* $p \in \mathbb{R}^{n_p}$ *and the controls* $u : [t_0, t_f] \to \mathbb{R}^{n_u}$, *such that*

$$\varphi(y(t_0), y(t_f), p)$$

is minimal, subject to the nonlinear constraints

$$\begin{aligned} y'(t) &= F(t, y(t), u(t), p) \\ \psi_{\min} &\leq \psi(y(t_0), y(t_f), p) \leq \psi_{\max} \\ v_{\min} &\leq v(t, y(t), u(t), p) \leq v_{\max} && t \in [t_0, t_f] \end{aligned}$$

and the box conditions

$$\begin{aligned} y_{\min} &\leq y(t) \leq y_{\max} && t \in [t_0, t_f] \\ u_{\min} &\leq u(t) \leq u_{\max} && t \in [t_0, t_f] \\ p_{\min} &\leq p \leq p_{\max}. \end{aligned}$$

Herein, the functions

$$
\begin{aligned}
\varphi &: \mathbb{R}^{n_y} \times \mathbb{R}^{n_y} \times \mathbb{R}^{n_p} \to \mathbb{R} \\
F &: [t_0, t_f] \times \mathbb{R}^{n_y} \times \mathbb{R}^{n_u} \times \mathbb{R}^{n_p} \to \mathbb{R}^{n_y} \\
\psi &: \mathbb{R}^{n_y} \times \mathbb{R}^{n_y} \times \mathbb{R}^{n_p} \to \mathbb{R}^{n_\psi} \\
v &: [t_0, t_f] \times \mathbb{R}^{n_y} \times \mathbb{R}^{n_u} \times \mathbb{R}^{n_p} \to \mathbb{R}^{n_v}.
\end{aligned}
$$

are user-defined functions.

For details on the interior-point method in IPBASIC and the direct collocation strategy employed by OCPBASIC, see [1, 2].

2.2 The Symbolic-OCPbasic GUI in Detail

This section walks through every element of the interface using the screenshots bundled with the manual.

2.2.1 Tab *Symbolic OCP*

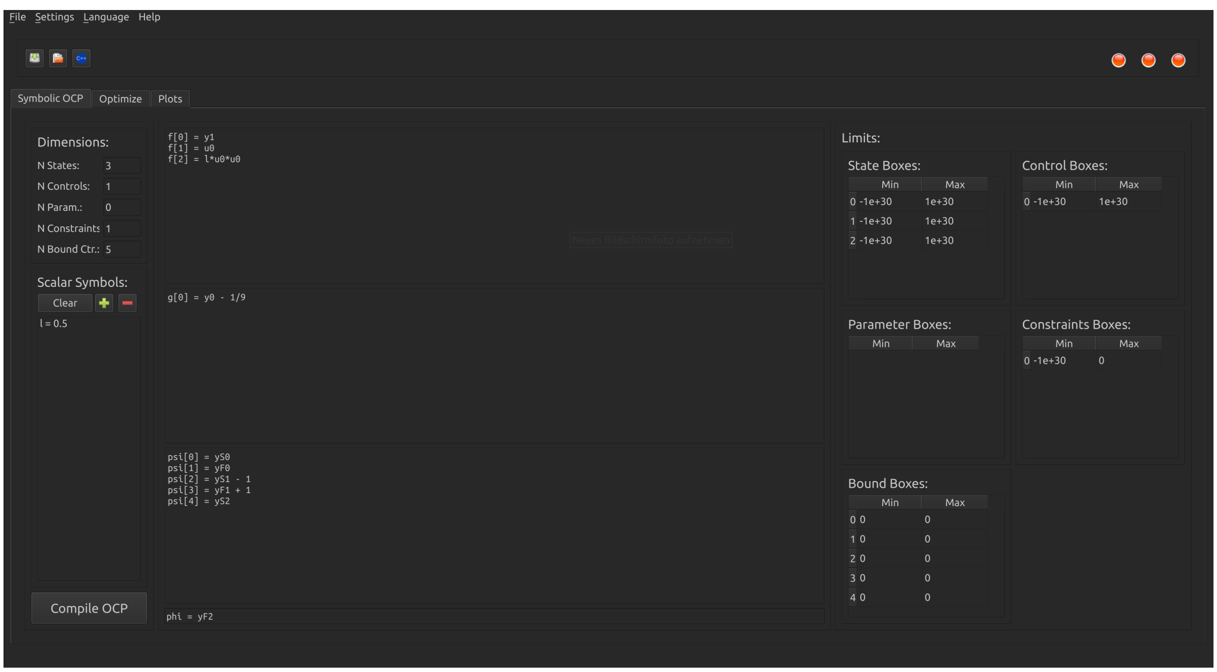

Figure 1: The *Symbolic OCP* tab.

Figure 1 shows the main editing view. The left sidebar summarises the *Dimensions* (numbers of states, controls, parameters, . . .) and provides quick access to global *scalar symbols*. The central editor is free text: each line follows the grammar

```
ODE     :  f[i] = <expression in y*,u*,p*,t>
CSTR    :  g[i] = <expression in y*,u*,p*,t>
BOUND   :  psi[i] = <expression using yS*, yF*>
OBJ     :  phi = <expression using yS*, yF*, p*>
```

where $*$ is the index of the variable. The variable $y*$ refers to the states, $u*$ refers to the controls, $p*$ refers to the parameters and $yS*$ and $yF*$ refer to start and final values, respectively. The right-hand panels let you enter lower/upper limits for states, controls, parameters, path constraints and boundary expressions.
Press ***Compile OCP*** to parse the symbolic input. A green light appears in the title bar if compilation succeeds, unlocking the *Optimize* tab.

2.2.2 Tab *Optimize*

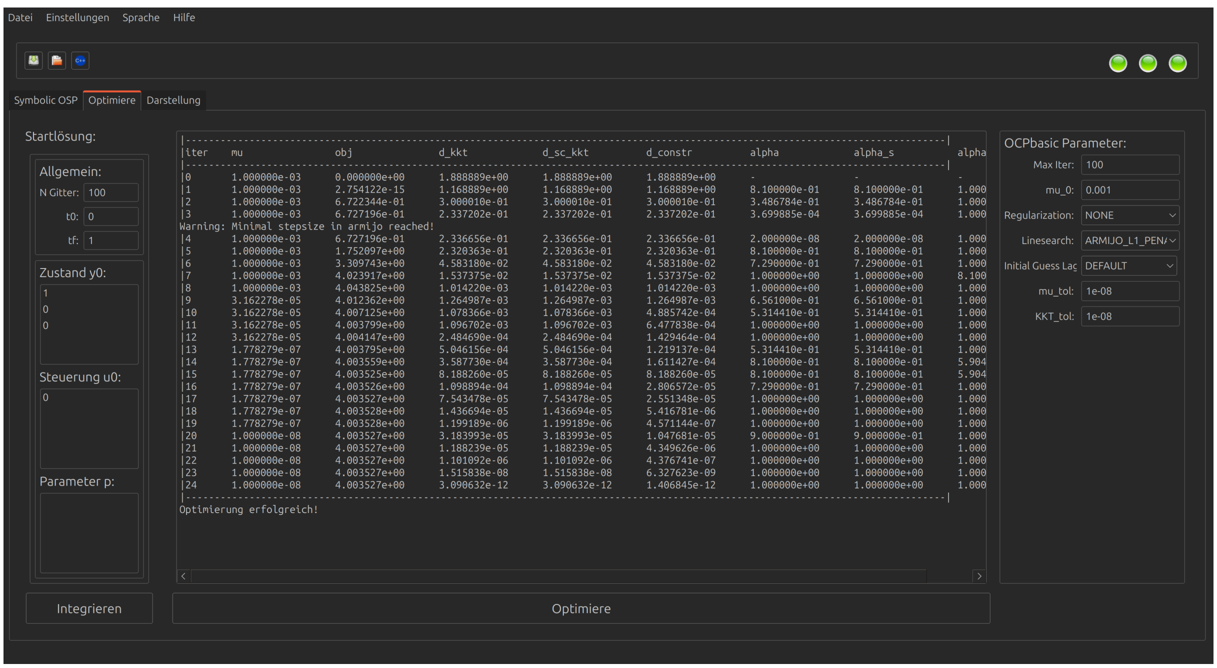

Figure 2: The *Optimize* tab during an interior-point run.

Figure 2 depicts the optimisation dashboard. On the left you specify an initial grid, time horizon and initial guesses for y, u and p. On the right you can tweak OCPbasic parameters such as μ_0, the maximum iteration count or regularisation settings. Press **Optimize** to launch the interior-point solver; progress is streamed live in the centre window. When convergence is reached the third green lamp lights up and the *Plots* tab becomes available.

2.2.3 Tab Plots

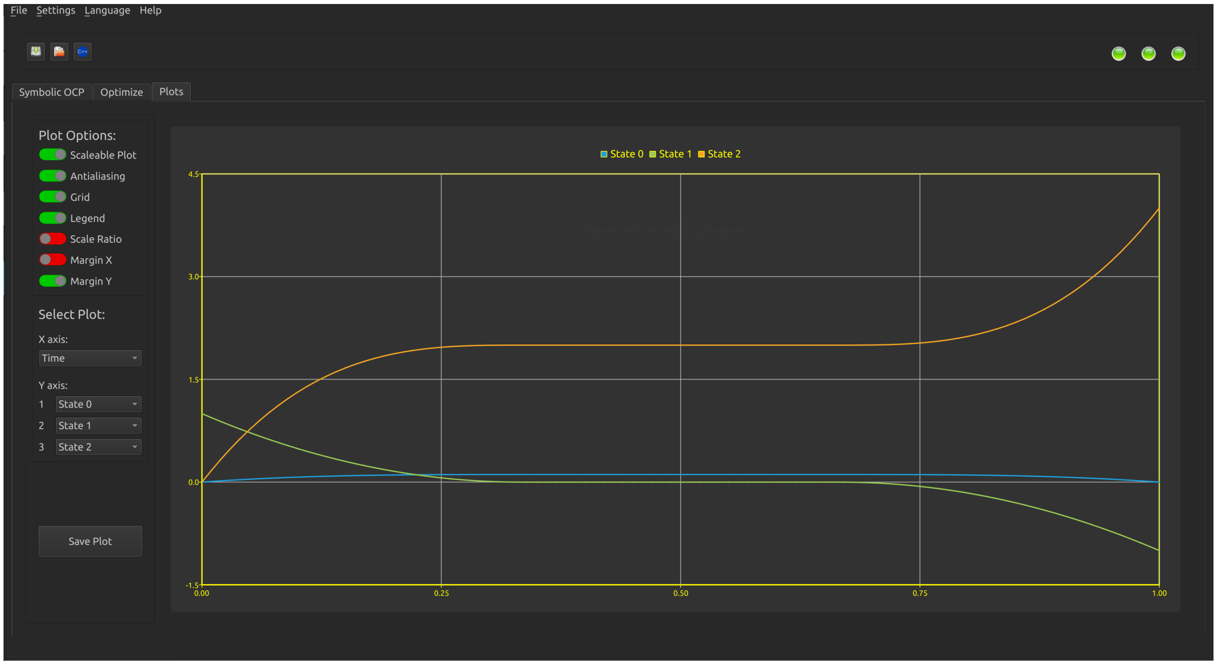

Figure 3: Plotting three states versus physical time.

The plotting module (Figure 3) offers immediate visualisation of states, controls, parameters or constraint functions. Choose one quantity for the x-axis and up to three for the y-axis. Toggling *Scaleable Plot*, *Grid*, *Legend*, etc. controls the appearance; *Margin X/Y* adds padding around the axis ranges, *Scale Ratio* enforces equal aspect ratio.
If the problem contains a free final time $t_f = p_0$ you can select *Time * p0* on the horizontal axis—effectively mapping the solution to a *scaled* time interval of unit length.
Right-click inside the chart to pan or zoom. The **Save Plot** button exports the current view as PNG.

2.2.4 Toolbar functions

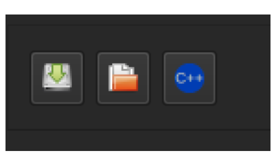

Figure 4: Toolbar: save, open and C++ export.

The following icons are always accessible in the main window (see Figure 4):

Save Export the current problem to an XML file (see Section 2.4).

Open Load an existing Symbolic-OCPBASIC XML description.

Export C++ Generate a stand-alone C++ project that reproduces the problem setup and calls OCPBASIC.

2.3 Example Optimal Control Problems

Symbolic-OCPBASIC ships with several ready-to-run example problems, each of which is presented in the subsections below. The examples are provided in XML format, which is described in Section 2.4.

2.3.1 Minimum-Energy Problem.

The goal is to bring a point mass back to its start position in a fixed horizon $t \in (0, 1)$ while reversing its velocity, minimising the total energy accumulated in the auxiliary state x_3. The position is additionally limited by a path-state inequality $x_1(t) \leq \frac{1}{9}$ (like a safety barrier).

Problem 2.2 (Minimum-Energy)
Minimize the objective

$$x_3(1)$$

subject to the constraints

$$\begin{aligned} x_1'(t) &= x_2(t) \\ x_2'(t) &= u(t) \\ x_3'(t) &= \frac{1}{2}u(t)^2 \\ x_1(t) &\leq \frac{1}{9} \end{aligned}$$

and the boundary conditions

$$\begin{aligned} x_1(0) &= 0, & x_1(1) &= 0, \\ x_2(0) &= 1, & x_2(1) &= -1, \\ x_3(0) &= 0, . \end{aligned}$$

2.3.2 Simple Kinematic Car.

A car with wheel-base l must drive around half a circle ostracle ($x^2 + y^2 = r^2$) from $(-1, 0)$ to $(1, 0)$ in minimum travel time and modest steering effort. The free-final-time parameter p_0 scales the horizon and enters the objective $p_0 + c_s \int_0^{t_f} \delta(t)^2 dt$.

Problem 2.3 (Kinematic Car)
Minimize the objective

$$p_0 + c_s \eta(t)$$

subject to the constraints

$$\begin{aligned}
x'(t) &= v(t)\cos(\psi(t)) \\
y'(t) &= v(t)\sin(\psi(t)) \\
\psi'(t) &= \frac{v(t)}{\ell}\tan(\delta(t)) \\
\eta'(t) &= \delta(t)^2 \\
r^2 &\le x(t)^2 + y(t)^2 \\
y(t) &\ge -0{,}01
\end{aligned}$$

and the boundary conditions

$$\begin{aligned}
x(0) &= -1, & x(t_f) &= 1, \\
y(0) &= 0, & y(t_f) &= 0, \\
\psi(0) &= 0, & \psi(t_f) &= 0.
\end{aligned}$$

2.3.3 Two-Link Robot Arm.

A planar two-link arm of length-one segments must swing from its rest pose $(\theta_1, \theta_2) = (1, 0)$ to the target $\left(\frac{\pi}{2}, \frac{\pi}{4}\right)$. A free-final-time parameter p_0 allows the optimiser to trade speed (small p_0) against control effort (accumulated squared torques in the energy state E). Torque magnitude is limited by a quadratic constraint.

Problem 2.4 (Two-Link Arm)
Minimise

$$c_0\, p_0 + c_1\, E(1)$$

subject to the constraints

$$
\begin{aligned}
\theta_1'(t) &= p_0\, \theta_1'(t), \\
\theta_2'(t) &= p_0\, \theta_2'(t), \\
\theta_1''(t) &= p_0\left(\tau_1(t) - 0.1\, \theta_1'(t)\right), \\
\theta_2''(t) &= p_0\left(\tau_2(t) - 0.1\, \theta_2'(t)\right), \\
E'(t) &= \frac{p_0}{2}\left(\tau_1^2(t) + \tau_2^2(t)\right), \\
\tau_1^2(t) + \tau_2^2(t) \le&\ u_{\max}^2,
\end{aligned}
$$

with boundary conditions

$$
\begin{array}{llll}
\theta_1(0) = 1, & \theta_2(0) = 0, & \theta_1'(0) = \theta_2'(0) = 0, & E(0) = 0, \\
\theta_1(1) = \frac{\pi}{2}, & \theta_2(1) = \frac{\pi}{4}, & \theta_1'(1) = \theta_2'(1) = 0. &
\end{array}
$$

2.3.4 Mass–Spring–Damper Oscillator.

A unit mass attached to a spring–damper system shall be brought from an initial displacement x_0 to rest at the origin as fast as possible while limiting the actuator force u and penalising the cumulative control energy.

Problem 2.5 (Mass–Spring–Damper)
Minimise

$$p_0 + c_u\, E(1)$$

subject to the constraints

$$
\begin{aligned}
x'(t) &= p_0\, v(t), \\
v'(t) &= p_0\left(\frac{1}{M}u(t) - \frac{K}{M}x(t) - \frac{B}{M}v(t)\right), \\
E'(t) &= \frac{p_0}{2}\, u^2(t), \\
u^2(t) &\le u_{\max}^2(t),
\end{aligned}
$$

and the boundary conditions

$$
\begin{array}{lll}
x(0) = x_0, & v(0) = 0, & E(0) = 0, \\
x(1) = 0, & v(1) = 0. &
\end{array}
$$

2.3.5 Brachistochrone (Time-Optimal Slide).

Determine the curve along which a bead under gravity slides from $(0, 2)$ to $(2, 0)$ in minimum time. Time scaling p_0 equals the final time, and the control $u(t)$ is the instantaneous slope angle of the path.

Problem 2.6 (Brachistochrone)
Minimise

$$p_0$$

subject to the constraints

$$\begin{aligned} x' &= p_0\, v(t) \sin\left(u(t)\right), \\ y' &= -p_0\, v(t) \cos\left(u(t)\right), \\ v' &= p_0\, g \cos\left(u(t)\right), \end{aligned}$$

with boundary conditions

$$\begin{aligned} &x(0) = 0, \qquad && y(0) = 2, \qquad && v(0) = 0, \\ &x(1) = 2, && y(1) = 0. \end{aligned}$$

2.3.6 Car Lane Change

This example models a car performing a dynamic lane change maneuver. The objective is to move laterally from one lane to another while adhering to velocity and control constraints. The system minimises the final time, which is defined by the time scaling factor p_0.

Problem 2.7 (Car Lane Change)
Minimise

$$p_0$$

subject to the constraints

$$\begin{aligned} x'(t) &= p_0 v(t) \cos(\psi(t)), \\ y'(t) &= p_0 v(t) \sin(\psi(t)), \\ \psi'(t) &= p_0 u_0(t), \\ v'(t) &= p_0 u_1(t), \\ u_0^2(t) &\le u_{0,\max}^2, \\ u_1^2(t) &\le u_{1,\max}^2, \\ 0 \le v(t) &\le 10, \end{aligned}$$

and the boundary conditions

$$
\begin{aligned}
x(0) &= 0, & v(0) &= 0, \\
y(0) &= 0, & y(1) &= 3.5, \\
\psi(0) &= 0, & \psi(1) &= 0.
\end{aligned}
$$

2.3.7 Pendulum

The objective is to swing up and stabilise a pendulum in the upright position using torque input $u(t)$. The total energy of the force usage is penalised, while the trajectory must obey physical limits.

Problem 2.8 (Inverted Pendulum)
Minimise the objective

$$p_0 + y_2(t_f)$$

subject to the system dynamics

$$
\begin{aligned}
y_0'(t) &= p_0 \cdot y_1(t), \\
y_1'(t) &= p_0 \cdot \left(u(t) - \frac{g}{L} \sin(y_0(t)) \right), \\
y_2'(t) &= \frac{p_0}{2} \cdot u^2(t), \\
u^2(t) &\le u_{\max}^2.
\end{aligned}
$$

with boundary conditions

$$
\begin{aligned}
y_0(0) &= -1, & y_0(1) &= \pi, \\
y_1(0) &= 0, & y_1(1) &= 0, \\
y_2(0) &= 0.
\end{aligned}
$$

2.4 XML file format

Listing 1: Excerpt from `MinEnergy.xml`

```xml
<?xml version="1.0" encoding="UTF-8"?>
<SymbolicOCP>
    <Dimensions>
```

```
        <NState>3</NState>
        <NControl>1</NControl>
        <NParam>0</NParam>
        <NConstraints>1</NConstraints>
        <NBound>5</NBound>
    </Dimensions>
    <SymbolicInput>
        <ODE id="0">f[0] = y1</ODE>
        <ODE id="1">f[1] = u0</ODE>
        <ODE id="2">f[2] = l*u0*u0</ODE>
        <CSTR id="0">g[0] = y0 - 1/9</CSTR>
        <BOUND id="0">psi[0] = yS0</BOUND>
        <BOUND id="1">psi[1] = yF0</BOUND>
        <BOUND id="2">psi[2] = yS1 - 1</BOUND>
        <BOUND id="3">psi[3] = yF1 + 1</BOUND>
        <BOUND id="4">psi[4] = yS2</BOUND>
        <OBJ>phi = yF2</OBJ>
    </SymbolicInput>
    <ScalarSymbols>
        <Scalar>l = 0.5</Scalar>
    </ScalarSymbols>
    <Boxes>
        <BoxStatesMin id="0">-1e+30</BoxStatesMin>
        <BoxStatesMax id="0">1e+30</BoxStatesMax>
        <BoxStatesMin id="1">-1e+30</BoxStatesMin>
        <BoxStatesMax id="1">1e+30</BoxStatesMax>
        <BoxStatesMin id="2">-1e+30</BoxStatesMin>
        <BoxStatesMax id="2">1e+30</BoxStatesMax>
        <BoxControlsMin id="0">-1e+30</BoxControlsMin>
        <BoxControlsMax id="0">1e+30</BoxControlsMax>
        <BoxConstraintsMin id="0">-1e+30</BoxConstraintsMin>
        <BoxConstraintsMax id="0">0</BoxConstraintsMax>
        <BoxBoundsMin id="0">0</BoxBoundsMin>
        <BoxBoundsMax id="0">0</BoxBoundsMax>
        <BoxBoundsMin id="1">0</BoxBoundsMin>
        <BoxBoundsMax id="1">0</BoxBoundsMax>
        <BoxBoundsMin id="2">0</BoxBoundsMin>
        <BoxBoundsMax id="2">0</BoxBoundsMax>
```

```xml
        <BoxBoundsMin id="3">0</BoxBoundsMin>
        <BoxBoundsMax id="3">0</BoxBoundsMax>
        <BoxBoundsMin id="4">0</BoxBoundsMin>
        <BoxBoundsMax id="4">0</BoxBoundsMax>
    </Boxes>
    <StartSolution>
        <NGrid>100</NGrid>
        <t0>0</t0>
        <tf>1</tf>
        <y0Start id="0">1</y0Start>
        <y0Start id="1">0</y0Start>
        <y0Start id="2">0</y0Start>
        <u0Start id="0">0</u0Start>
    </StartSolution>
    <OCPbasicParams>
        <maxIter>100</maxIter>
        <mu0>0.001</mu0>
        <Regularization>REGULARIZE_NONE</Regularization>
        <mu_tol>1e-8</mu_tol>
        <KKT_tol>1e-8</KKT_tol>
    </OCPbasicParams>
</SymbolicOCP>
```

Every GUI action ultimately translates into a plain-text XML file. The schema is straightforward—Listing 1 shows the minimal-energy example bundled with this manual.

Key sections

- **Dimensions** – scalar counts used by the GUI.
- **SymbolicInput** – one line per ODE, per constraint, per boundary and the objective (see Section 2.2.1).
- **ScalarSymbols** – compile-time constants that can be referenced in expressions.
- **Boxes** – lower and upper bounds on states, controls, parameters, bounds and constraints.
- **StartSolution** – number grid points, time horizon and initial guesses.
- **OCPbasicParams** – solver-level parameters such as the initial barrier μ_0 or the KKT tolerance.

Editing the XML files by hand is not recommended.

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References

[1] A. Huber, M. Gerdts, and E. Bertolazzi. Structure exploitation in an interior-point method for fully discretized, state constrained optimal control problems. *Vietnam Journal of Mathematics*, Oct 2018.

[2] A. K.-P. Huber. *Methoden zur Berechnung optimaler Rennlinien im dynamischen Grenzbereich.* PhD thesis, Universität der Bundeswehr München, 2020.