pyNLControl

`pyNLCOntrol` is a package to solve general estimation and control problem (including non-linear problem). Further, it also provides different method for analysis of dynamic system. This package is based on `CasADi` for python (https://web.casadi.org/). This means problem should be formulated in `CasADi`.

Requirements

- python >= 3.6 (might work on older version of python3, not tested)
- casadi>=3.5.5 and jinja2>=3.0.2 `pip install casadi jinja2`

Installations

```
pip install pyNLControl
```

Supported control and estimator

- Estimators: Kalman filter, Extended Kalman Filter, Unscented Kalman Filter and simple Moving Horizon Estimators. Partical filter, advanced moving horizon estimator, etc will be added soon.
- Control: LQR and simple Model Predictive Control. Other controllers will be added soon
- Misc: Nonlinear observability analysis, Noise covariance identification will be added soon

Module pynlcontrol.BasicUtils

Functions

`Gen_Code(func, filename, dir='/', mex=False, printhelp=False, optim=False)` : Function to generate c code (casadi generated as well as interface) for casadi function.

```
Generates c and h file (from CasADi) as well as interface code. Using interface
code, the generated
codes can be integrated with other platform such as Simulink, PSIM, etc.

Parameters
----------
func : casadi.Function
    CasADi function for which code needs to be generated. This function maps input
to output.
filename : str
    File name of the generated code. Note: Filename should not contain "_Call" in
it.
dir : str, optional
    Directory where codes need to be generated. Defaults to current directory.
mex : bool, optional
    Option if mex is required. Defaults to False.
printhelp : bool, optional
    Option if information about input/output and its size are to be printed . If
```

```
mex is False, sfunction help is also printed. Defaults to False.
optim : bool, optional
    Whether code is being generated for CasADi optimization problem. Defaults to
False.

See Also
--------
Gen_Test: Generates main function code which can be compiled and debugged.

Example
--------
>>> import casadi as ca
>>> import numpy
>>> x = ca.SX.sym('x')
>>> y = ca.SX.sym('y', 2)
>>> f1 = x + y[0]
>>> f2 = x + y[1]**2
>>> Func = ca.Function(
    'Func',
    [x, y],
    [f1, f2],
    ['x', 'y'],
    ['f1', 'f2'],
    )
>>> BasicUtils.Gen_Code(Func, 'GenCodeTest', dir='./', mex=False, printhelp=True)
x(1, 1), y(2, 1) -> f1(1, 1), f2(1, 1)
GenCodeTest.c
GenCodeTest_Call.c
#include "GenCodeTest.h"
#include "GenCodeTest_Call.h"
GenCodeTest_Call_Func(x, y, f1, f2);


Above code creates `GenCodeTest.c`, `GenCodeTest_Call.c`, `GenCodeTest.h` and
`GenCodeTest_Call.h` that evaluates `f1` and `f2` from value of `x` and `y`. `x`
and `y` in the above example should be declared as pointer.
```

`Gen_Test(headers, varsIn, sizeIn, varsOut, sizeOut, callFuncName, filename, dir='/')` : Generates C code with main function. This code along with code generated by `Gen_Code` function can be compiled to executable to check computation time or debug. It can also be used as example to compile on other target.

```
Parameters
----------
headers : list[str]
    List of header files name along with extension `.h`. These files will be added
in main file as #include "header".
varsIn : list[str]
    List of name of input variables.
sizeIn : list[int]
    List of size of input variables.
varsOut : list(str)
    List of name of output variables.
sizeOut : list[int]
    List of size of output variables.
```

```
callFuncName : list(str)
    Name of the C function that needs to be called.
filename : str
    Name of the generated C file (along with extension .c).
dir : str, optional
    Directory where code needs to be generated. Defaults to current directory.

Example
_______
>>> from pynlcontrol import BasicUtils
>>> import casadi as ca
>>> x = ca.SX.sym('x')
>>> y = ca.SX.sym('y', 2)
>>> f1 = x + y[0]
>>> f2 = x + y[1]**2
>>> Func = ca.Function(
    'Func',
    [x, y],
    [f1, f2],
    ['x', 'y'],
    ['f1', 'f2'],
    )
>>> BasicUtils.Gen_Code(Func, 'GenCodeTest', dir='./', mex=False, printhelp=False)
>>> BasicUtils.Gen_Test(
    headers=['GenCodeTest.h', 'GenCodeTest_Call.h'],
    varsIn=['x', 'y'],
    sizeIn=[1, 2],
    varsOut=['f1', 'f2'],
    sizeOut=[1, 1],
    callFuncName='GenCodeTest_Call_Func',
    filename='MainTest.c',
    dir='./',
    )


All the line except last one is same as from `Gen_Code()` function. The last line
generates filename with `MainTest.c` which can be used to test and debug the
generated code.
```

`Integrate(odefun, method, Ts, x0, u0, *args)` : Function to integrate continuous-time ODE. It discretize the provided ODE function and gives value of state variables at next discrete time.

```
Parameters
----------
odefun : function
    Python function with states as first and control input as second argument.
Remaining argument could be anything required by state equations.
method : str
    Method to integrate ODE. Supported methods are: 'FEuler', 'rk2', 'rk3',
'ssprk3', 'rk4', 'dormandprince'.
Ts : float
    Step time to solve ODE
x0 : float or casadi.SX or numpy.1darray
    Current states of the system
u0 : float or casadi.SX or numpy.1darray
```

```
        Current control input to the system

    Returns
    -------
    float or casadi.SX or numpy.1darray
        Next states of the system.

    Example
    -------
    >>> import numpy as np
    >>> import matplotlib.pyplot as plt
    >>> def Fc(x, u):
        x1 = x[0]
        x2 = x[1]
        return np.array([(1-x2**2)*x1 - x2 + u, x1])
    >>> T = 10
    >>> Ts = 0.1
    >>> t = np.arange(0, T+Ts, Ts)
    >>> x = np.zeros((2, t.shape[0]))
    >>> for k in range(t.shape[0]-1):
        u = 0 if t[k] < 1 else 1.0
        x[:,k+1] = Integrate(Fc, 'rk4', Ts, x[:,k], u)
    >>> plt.plot(t, x[0,:])
    >>> plt.plot(t, x[1,:])
    >>> plt.xlabel('time (s)')
    >>> plt.ylabel('$x_1$ and $x_2$')
    >>> plt.show()

    The above code integrates the ODE defined by function Fc from 0 to 10 s with step-
    time of 0.1 s using RK4 method.
```

`casadi2List(x)` : Converts casadi vector to list.

```
    Parameters
    ----------
    x : casadi.SX.sym
        Input casadi symbolic vector.

    Returns
    -------
    list
        List that contains element of vector x.
```

`directSum(A)` : Direct sum of matrices in the list A.

```
    Parameters
    ----------
    A : list
        List of matrices.

    Returns
    -------
    casadi.SX.sym
```

```
    Direct sum of all matrices in list A.

Example
-------
>>> import casadi as ca
>>> from pynlcontrol import BasicUtils
>>> import casadi as ca
>>> from pynlcontrol import BasicUtils
>>> A1 = ca.SX.sym('A1', 2, 2)
>>> A2 = ca.SX.sym('A2', 3, 3)
>>> A = [A1, A2]
>>> BasicUtils.directSum(A)
SX(@1=0,
[[A1_0, A1_2, @1, @1, @1],
 [A1_1, A1_3, @1, @1, @1],
 [@1, @1, A2_0, A2_3, A2_6],
 [@1, @1, A2_1, A2_4, A2_7],
 [@1, @1, A2_2, A2_5, A2_8]])

Above code puts matrices `A1` and `A2` in the diagonal and fills zero elsewhere.
```

`nlp2GGN(z, J, g, lbg, ubg, p)` : Converts provided nonlinear programming into quadratic form using generalized Gauss-Newton method.

```
Parameters
----------
z : casadi.SX
    Vector of unknown variables of optimization problem
J : casadi.SX
    Object function of the optimization problem
g : casadi.SX
    Vector of constraints function
lbg : casadi.SX
    Vector of lower limits on constraint function
ubg : casadi.SX
    Vector of upper limits on constraint function
p : casadi.SX
    Vector of input to the optimization problem

Returns
-------
dict
    Dictionary of optimization problem.
    keywords
        x: Vector of decision variables
        f: New quadratic cost function
        g: New constraint function
        lbg: Lower limits on constraint function
        ubg: Upper limits on constraint function
```

`qrSym(A)` : Performs QR decomposition of matrix A using householder reflection.

```
Args:
    A (ca.SX.sym): Matrix A in casadi symbolics

Returns:
    Q: Q matrix of decomposition
    R: R matrix of decomposition
```

Module pynlcontrol.Estimator

Functions

`EKF(nX, nU, nY, F, H, Qw, Rv, Ts, Integrator='rk4')` : Function to implement Extended Kalman filter (EKF).

```
Parameters
----------
nX: (int)
    Number of state variables
nU: (int)
    Number of control inputs
ny: (int)
    Number of measurement outputs
F: (function)
    Function that returns right-hand side of state differential equation. Input
arguments to F should be states and inputs respectively.
H: (function)
    Function that retuns measurement variable from state and input variables. nput
arguments to H should be states and inputs respectively.
Qw: (numpy.2darray or casadi.SX array)
    Process noise covariance matrix
Rv: (numpy.2darray or casadi.SX array)
    Measurement noise covariance matrix
Ts: (float)
    Sample time of the Kalman filter.
Integrator: (str, optional)
    Integration method. Defaults to 'rk4'. For list of supported integrator, please
see documentation of function `Integrate()`.

Returns
-------
tuple:
    Tuple of Input, Output, Input name and Output name. Inputs are u, y, xp, Pp and
output are xhat and Phat. Input and output are casadi symbolics (`casadi.SX`).
        u: Current input to the system
        y: Current measurement of the system
        xp: State estimate from previous discrete time
        Pp: Covariance estimate from previous discrete time (reshaped to column
matrix)
        xhat: State estimate at current discrete time
        Phat: Covariance estimate at current discrete time (reshaped to column
matrix)

        These inputs are and outputs can be mapped using `casadi.Function` which
can further be code generated.
```

`KF(A, B, C, D, Qw, Rv, Ts, Integrator='rk4')` : Function to implement Kalman filter (KF).

```
Parameters
----------
A: (numpy.2darray or casadi.SX array)
    Continuous-time state matrix of the system
B: (numpy.2darray or casadi.SX array)
    Continuous-time input matrix of the system
C: (numpy.2darray or casadi.SX array)
    Continuous-time measurement matrix of the system
D: (numpy.2darray or casadi.SX array)
    Continuous time output matrix coefficient of input
Qw: (numpy.2darray or casadi.SX array)
    Process noise covariance matrix
Rv: (numpy.2darray or casadi.SX array)
    Measurement noise covariance matrix
Ts: (float)
    Sample time of KF
Integrator: (str, optional)
    Integrator to be used for discretization. Defaults to 'rk4'.

Returns
-------
tuple
    Tuple of Input, Output, Input name and Output name. Inputs are u, y, xp, Pp and
output are xhat and Phat. Input and output are casadi symbolics (`casadi.SX`).
        u: Current input to the system
        y: Current measurement of the system
        xp: State estimate from previous discrete time
        Pp: Covariance estimate from previous discrete time (reshaped to column
matrix)
        xhat: State estimate at current discrete time
        Phat: Covariance estimate at current discrete time (reshaped to column
matrix)

        These inputs are and outputs can be mapped using `casadi.Function` which
can further be code generated.

Example
-------
>>> from pynlcontrol import Estimator, BasicUtils
>>> import casadi as ca
>>> Q11 = ca.SX.sym('Q11')
>>> Q22 = ca.SX.sym('Q22')
>>> Q33 = ca.SX.sym('Q33')
>>> Q = BasicUtils.directSum([Q11, Q22, Q33])
>>> R11 = ca.SX.sym('R11')
>>> R22 = ca.SX.sym('R22')
>>> R = BasicUtils.directSum([R11, R22])
>>> A = ca.SX([[-0.4,0.1,-2],[0,-0.3,4],[1,0,0]])
>>> B = ca.SX([[1,1],[0,1],[1,0]])
>>> C = ca.SX([[1, 0, 0], [0, 1, 0]])
>>> D = ca.SX([[0, 0], [0, 0]])
>>> In, Out, InName, OutName = Estimator.KF(A, B, C, D, Q, R, 0.1)
>>> KF_func = ca.Function('KF_func', In + [Q11, Q22, Q33, R11, R22], Out, InName +
```

```
['Q11', 'Q22', 'Q33', 'R11', 'R22'], OutName)
>>> BasicUtils.Gen_Code(KF_func, 'KF_code', printhelp=True)
u(2, 1), y(2, 1), xhatp(3, 1), Pkp(9, 1), Q11(1, 1), Q22(1, 1), Q33(1, 1), R11(1,
1), R22(1, 1) -> xhat(3, 1), Phat(9, 1)
KF_code.c
KF_code_Call.c
#include "KF_code.h"
#include "KF_code_Call.h"
KF_code_Call_Func(u, y, xhatp, Pkp, Q11, Q22, Q33, R11, R22, xhat, Phat);


Running above code generates C-codes for KF implementation. Implementation using
Simulink can be found in example folder.
```

`UKF(nX, nU, nY, F, H, Qw, Rv, Ts, PCoeff=None, Wm=None, Wc=None, alpha=0.001, beta=2.0, kappa=0.0, Integrator='rk4')` : Function to implement Unscented Kalman filter (UKF).

```
If either of PCoeff or Wm or Wc is None, it calculates those values with alpha=1e-
3, Beta=2 and kappa=0. To use manual weights, specify PCOeff, Wm and Wc. Otherwise,
use alpha, beta and kappa parameters to set those values.

Parameters
----------
nX: (int)
    Number of state variables
nU: (int)
    Number of control inputs
nY: (int)
    Number of measurement outputs
F: (function)
    Function that returns right-hand side of state differential equation. Input
arguments to F should be states and inputs respectively.
H: (function)
    Function that retuns measurement variable from state and input variables. nput
arguments to H should be states and inputs respectively.
Qw: (numpy.2darray or casadi.SX array)
    Process noise covariance matrix
Rv: (numpy.2darray or casadi.SX array)
    Measurement noise covariance matrix
Ts: (float)
    Sample time of the Kalman filter.
PCoeff: (float)
    Coefficient of covariance matrix (inside square root term) when calculating
sigma points. Defaults to None
Wm: (list, optional)
    List of weights for mean calculation. Defaults to None.
Wc: (list, optional)
    List of weights for covariance calculation. Defaults to None.
alpha: (float, optional)
    Value of alpha parameter. Defaults to 1.0e-3.
beta: (float, optional)
    Value of beta parameter. Defaults to 2.0.
kappa: (float, optional)
    Value of kappa parameter. Defaults to 0.0.
Integrator: (str, optional)
```

```
        Integration method. Defaults to 'rk4'. For list of supported integrator, please
    see documentation of function `Integrate`.

    Returns
    -------
    tuple:
        Tuple of Input, Output, Input name and Output name. Inputs are u, y, xp, Pp and
    output are xhat and Phat. Input and output are casadi symbolics (`casadi.SX`).
            u: Current input to the system
            y: Current measurement of the system
            xp: State estimate from previous discrete time
            Pp: Covariance estimate from previous discrete time (reshaped to column
    matrix)
            xhat: State estimate at current discrete time
            Phat: Covariance estimate at current discrete time (reshaped to column
    matrix)

            These inputs are and outputs can be mapped using `casadi.Function` which
    can further be code generated.
```

`arrivalCost(nX, nU, nY, nP, Fc, Hc, Ts, method='QR', Integrator='rk4')` : Method to implement arrival cost for moving horizon estimator.

```
    The general form of arrival cost term is:

        J_{arrival} = ||P_L(x_L-xLb, p-pLb)||^2

    Parameters
    ----------
    nX : int
        Number of state variables
    nU : int
        Number of input variables
    nY : int
        Number of measurement variables
    nP : int
        Number of parameter to be estimated
    Fc : python function
        Function that returns right hand side of continuous time state equations
    Hc : python function
        Function that returns measurement variable. This function takes x and p as
    input arguments. When nP=0, the function only takes x as input argument.
    Ts : float
        Sample time for MHE
    method : str, optional
        Method to implement arrival cost. Currently, only QR factorization based
    approach is supported. Possible values are 'QR'.
        'QR': Method as given on "A real-time algorithm for moving horizon state and
    parameter estimation., Peter K{"u}hl and Moritz Diehl and Tom Kraus and Johannes P.
    Schl{"o}der and Hans Georg Bock"
    Integrator : str, optional
        Integrator method to discretize state equations., by default 'rk4'

    Returns
    -------
```

```
tuple
    In: Input symbolics to the arrival cost function
        xLo: Estimates of states at end of horizon window estimated at previous
discrete time
        pLo: Estimates of parameters estimated at previous discrete time
        xLb: Value of $\bar{x}_L$ to be used for arrival cost update
        pLb: Value of $\bar{p}_L$ to be used for arrival cost update
        PL: Weight for arrival cost from previous discrete time
        u: Control input at the end of horizon window
        yL: Measurement at the end of horizon window
        VL: Weight for measurement term
        WL: Weight for process term
        Wp: Weight for parameter term
    InName: Corresponding name of above input

    Out: Output symbolics returned by arrival cost function
        xLbn: New value of $\bar{x}_L$ to be used for arrival cost update
        pLbn: New value of $\bar{x}_L$ to be used for arrival cost update
        PLn: New value of $\bar{x}_L$ to be used for arrival cost update
    OutName: Corresponding name of above output

Above In, Out, InName and OutName can be unsed to create casadi Function which can
be code generated.

Note: When nP=0, Input/Output corresponding to parameters are not returned.
```

`simpleMHE(nX, nU, nY, nP, Fc, Hc, N, Ts, pLow, pUpp, arrival=False, GGN=False, Integrator='rk4', Options=None)` : Function to generate simple MHE code using `qrqp` solver. For use with other advanced solver, see `MHE` class.

```
Parameters
----------
nX: (int)
    Number of state variables.
nU: (int)
    number of control variables.
nY: (int)
    Number of measurement variables.
nP: (int)
    Number of parameter to be estimated. nP=0 while performing state estimation
only.
Fc: (function)
    Function that returns right hand side of state equation.
Hc: (function)
    Function that returns right hand side of measurement equation.
Wp: (float or casadi.SX array or numpy.2darray)
    Weight for process noise term. It is $Q_w^{-1/2}$ where $Q_w$ is process noise
covariance.
Wm: (float or casadi.SX array or numpy.2darray)
    Weight for measurement noise term. It is $R_v^{-1/2}$ where $R_v$ is
measurement noise covariance.
N: (int)
    Horizon length.
Ts: (float): Sample time for MHE
pLow: (list, optional)
```

```
    List of lower limits of unknown parameters. Defaults to [].
pUpp: (list, optional)
    List of upper limits of unknown parameters. Defaults to [].
arrival: (bool, optional
     Whether to include arrival cost. Defaults to False.
GGN: (bool, optional)
    Whether to use GGN. Use this option only when optimization problem is
nonlinear. Defaults to False.
Integrator: (str, optional)
    Integration method. See `BasicUtils.Integrate()` function. Defaults to 'rk4'.
Options: (dict, optional)
    Option for `qrqp` solver. Defaults to None.

Returns
-------
tuple:
    Tuple of Input, Output, Input name and Output name. Input and output are list
of casadi symbolics (`casadi.SX`).
        Input should be control input and measurement data of past horizon length
        Output are all value of decision variable, estimations of parameter,
estimates of states and cost function.
```

Module pynlcontrol.Controller

Functions

`LQR(A, B, C, D, Q, R, Qt, Ts, horizon=inf, reftrack=False, NMAX=1000, tol=1e-05, Integrator='rk4')` : Function to implement discrete-time linear quadratic regulator (LQR).

```
Parameters
----------
A : numpy.2darray or casadi.SX.array
    Continuous time state matrix
B : numpy.2darray or casadi.SX.array
    Continuous time input matrix
C : numpy.2darray or casadi.SX.array
    Continuous time output matrix
D : numpy.2darray or casadi.SX.array
    Continuous time output matrix coefficient of input
Q : numpy.2darray or casadi.SX.array
    Weight to penalize control error
R : numpy.2darray or casadi.SX.array
    Weight to penalize control effort
Qt : numpy.2darray or casadi.SX.array
    Weight of terminal cost to penalize control error
Ts : float
    Sample time of controller
horizon : int, optional
    Horizon length of LQR. Defaults to inf for infinite horizon LQR problem.
reftrack : bool, optional
    Whether problem is reference tracking. Defaults to False.
NMAX : int, optional
    Maximum iteration for solving matrix Ricatti equation. Defaults to 1000.
tol : float, optional
```

```
    Tolerance for solution of matrix Ricatti equation. Defaults to 1e-5.
Integrator : str, optional
    Integrator to be used for discretization. Defaults to 'rk4'.

Returns
-------
tuple
    Tuple of Input, Output, Input name and Output name. Inputs are x or [x, r]
(depending upon the problem is reference tracking or not) and output are u and K.
        Input and output are casadi symbolics (`casadi.SX`).
        These inputs are and outputs can be mapped using `casadi.Function` which
can further be code generated.

Example
-------
>>> from pynlcontrol import Controller, BasicUtils
>>> import casadi as ca
>>> Q11 = ca.SX.sym('Q11')
>>> Q22 = ca.SX.sym('Q22')
>>> Q33 = ca.SX.sym('Q33')
>>> Q = BasicUtils.directSum([Q11, Q22, Q33])
>>> R11 = ca.SX.sym('R11')
>>> R22 = ca.SX.sym('R22')
>>> R = BasicUtils.directSum([R11, R22])
>>> A = ca.SX([[-0.4,0.1,-2],[0,-0.3,4],[1,0,0]])
>>> B = ca.SX([[1,1],[0,1],[1,0]])
>>> C = ca.SX([[1, 0, 0], [0, 1, 0]])
>>> D = ca.SX([[0, 0], [0, 0]])
>>> In, Out, InName, OutName = Controller.LQR(A=A, B=B, C=C, D=D, Q=Q, R=R, Qt=Q,
Ts=0.1, horizon=10, reftrack=True)
>>> lqr_func = ca.Function('lqr_func', In + [Q11, Q22, Q33, R11, R22], Out, InName
+ ['Q11', 'Q22', 'Q33', 'R11', 'R22'], OutName)
>>> BasicUtils.Gen_Code(lqr_func, 'lqr_code', printhelp=True)
x(3, 1), ref(2, 1), Q11(1, 1), Q22(1, 1), Q33(1, 1), R11(1, 1), R22(1, 1) -> u(2,
1), K(6, 1)
lqr_code.c
lqr_code_Call.c
#include "lqr_code.h"
#include "lqr_code_Call.h"
lqr_code_Call_Func(x, ref, Q11, Q22, Q33, R11, R22, u, K);


Running above code generates C-codes for LQR implementation. Implementation using
Simulink can be found in example folder.
```

`simpleMPC(nX, nU, nY, nP, Fc, Hc, N, Ts, uLow, uUpp, GGN=False, Integrator='rk4', Options=None)` : Function to generate simple MPC code using `qrqp` solver. For use with other advanced solver, see `MPC` class.

```
Parameters
----------
nX : int
    Number of state variables.
nU : int
    Number of input variables
```

```
nY : int
    Number of control output variables
nP : int
    Number of external parameters
Fc : function
    Function that returns right hand side of state equation.
Hc : function
    Function that returns right hand side of control output equation.
N : float or casadi.SX array or numpy.2darray
    Horizon length
Ts : float
    Sample time
uLow : list or float
    Lower limit on control input
uUpp : list of str
    Upper limit on control input
GGN : bool, optional
    Whether generalized Gauss Newton should be used. Use only for nonlinear
problem. by default False
Integrator : str, optional
    Integration method. See `BasicUtils.Integrate()` function. by default 'rk4'
Options : _type_, optional
    Option for `qrqp` solver. Defaults to None.

Returns
-------
tuple:
    Tuple of Input, Output, Input name and Output name. Input and output are list
of casadi symbolics (`casadi.SX`).
        Inputs are initial guess, current state, reference, corresponding weights
        Outputs value of all decision variables, calculated control signal and cost
function

Example
-------
>>> import casadi as ca
>>> from pynlcontrol import BasicUtils, Controller
>>> def Fc(x, u, p):
    A = ca.SX([[-0.4, 0.1, -2], [0, -0.3, 4], [1, 0, 0]])
    B = ca.SX([[1, 1], [0, 1], [1, 0]])
    return A @ x + B @ u
>>> def Hc(x):
    return ca.vertcat(x[0], x[1])
>>> In, Out, InName, OutName = Controller.simpleMPC(3, 2, 2, 0, Fc, Hc, 25, 0.1,
[-10, 0], [10, 3], GGN=False)
-------------------------------------------
This is casadi::QRQP
Number of variables:                             128
Number of constraints:                            78
Number of nonzeros in H:                         100
Number of nonzeros in A:                         453
Number of nonzeros in KKT:                      1112
Number of nonzeros in QR(R):                    1728
-------------------------------------------
This is casadi::Sqpmethod.
Using exact Hessian
Number of variables:                             128
Number of constraints:                            78
```

```
Number of nonzeros in constraint Jacobian:       453
Number of nonzeros in Lagrangian Hessian:        100

>>> MPC_func = ca.Function('MPC_func', In, Out, InName, OutName)
>>> BasicUtils.Gen_Code(MPC_func, 'MPC_Code', printhelp=True, optim=True)
zGuess(128, 1), x0(3, 1), xref(2, 1), Qp11(1, 1), Qp22(1, 1), Qtp11(1, 1), Qtp22(1,
1), Rp11(1, 1), Rp22(1, 1) -> zOut(128, 1), uCalc(2, 1), Cost(1, 1)
MPC_Code.c
MPC_Code_Call.c
#include "MPC_Code.h"
#include "MPC_Code_Call.h"
MPC_Code_Call_Func(zGuess, x0, xref, Qp11, Qp22, Qtp11, Qtp22, Rp11, Rp22, zOut,
uCalc, Cost);
```

Module pynlcontrol.QPInterface

Classes

`qpOASES(H, h, p=None, A=None, lbA=None, ubA=None, lbx=None, ubx=None)` : Class to create interface to qpOASES solver.

```
It can be used to generate to C/C++ code to solve given quadratic optimization
problem.

Parameters
----------
    H: (casadi.SX)
        Hessian matrix of cost function
    h: (casadi.SX)
        Linear coefficient vector of cost function
    p: (list, optional)
        List of input parameters to optimization problem. Defaults to None.
    A: (casadi.SX, optional)
        Constraint matrix. Defaults to None.
    lbA: (casadi.SX, optional)
        Lower bound on constraint matrix. Defaults to None.
    ubA: (casadi.SX, optional)
        Upper bound on constraint matrix. Defaults to None.
    lbx: (casadi.SX, optional)
        Lower bound on decision variables. Defaults to None.
    ubx: (casadi.SX, optional)
        Upper bound on decision variables. Defaults to None.
Returns
-------
None


Example
-------
Consider optimization problem:
    min (x1-a)^2 + (x2-b)^2
        s.t. 2x1+3x2 <= 3
             0 <= x1-x2 <= 10
```

Solver for this optimization problem can be generated as

```
>>> import casadi as ca
>>> from pynlcontrol import QPInterface
>>> x1 = ca.SX.sym('x1')
>>> x2 = ca.SX.sym('x2')
>>> a = ca.SX.sym('a')
>>> b = ca.SX.sym('b')
>>> J = (x1-a)**2 + (x2-b)**2
>>> H, h, _ = ca.quadratic_coeff(J, ca.vertcat(x1, x2))
>>> g = ca.vertcat(2*x1+3*x2, x1-x2)
>>> lbg = ca.vertcat(-ca.inf, 0)
>>> ubg = ca.vertcat(3, 10)
>>> A, c = ca.linear_coeff(g, ca.vertcat(x1, x2))
>>> lbA = lbg - c
>>> ubA = ubg - c
>>> qp = QPInterface.qpOASES(H, h, A=A, lbA=lbA, ubA=ubA, p=[a, b])
>>> qp.exportCode('test1', dir='Test1_Exported', printsfun=True, mex=False,
TestCode=False, Options={'max_iter': 5})
(xGuess[2x1], a[1x1], b[1x1])->(xOpt_VAL[2x1], Obj_VAL[1x1])
Test1_Exported/test1.c
Test1_Exported/test1_EVAL_CODE.c
Test1_Exported/test1_EVAL_CODE_Call.c
Test1_Exported/BLASReplacement.cpp
Test1_Exported/Bounds.cpp
Test1_Exported/Constraints.cpp
Test1_Exported/Flipper.cpp
Test1_Exported/Indexlist.cpp
Test1_Exported/Matrices.cpp
Test1_Exported/MessageHandling.cpp
Test1_Exported/Options.cpp
Test1_Exported/OQPinterface.cpp
Test1_Exported/QProblem.cpp
Test1_Exported/QProblemB.cpp
Test1_Exported/SolutionAnalysis.cpp
Test1_Exported/SparseSolver.cpp
Test1_Exported/SQProblem.cpp
Test1_Exported/SQProblemSchur.cpp
Test1_Exported/SubjectTo.cpp
Test1_Exported/Utils.cpp
#include "Test1_Exported/test1.h"
#include "Test1_Exported/test1_EVAL_CODE.h"
#include "Test1_Exported/test1_EVAL_CODE_Call.h"
// Try this first:
test1_Call(xGuess, a, b, xOpt_VAL, Obj_VAL);
// If previous does not work, try this:
double *xGuess_TEMP = (double *)xGuess;
double *a_TEMP = (double *)a;
double *b_TEMP = (double *)b;
test1_Call(xGuess_TEMP, a_TEMP, b_TEMP, xOpt_VAL, Obj_VAL);
```

Running above code generates C/C++ code that can be integrated into other platform. Simulink example is given. Printed output gives name and location of C/C++ files, header files and function call.

Methods

`exportCode(self, filename, dir='/', mex=False, printsfun=False, Options=None,

TestCode=False)`
:   Method of class qpOASES to export the code that solves quadratic programming.

    Parameters
    ----
        filename: (str)
            Filename for exported code.
        dir: (str, optional)
            Directory where code is to be exported. Defaults to '/'.
        mex: (bool, optional)
            Whether mex interface is required. Defaults to False.
        printsfun: (bool, optional)
            Whether MATLAB s-function interface is to be implemented. Defaults to False.
        Options: (dict, optional)
            Options for qpOASES solver. Defaults to None.
        TestCode: (bool, optional)
            Whether main function is required. Useful while testing and debugging. Defaults to False.

    Returns

    None

`exportEvalCode(self, funcname, dir='/', options=None)`
:   Method of class qpOASES to generate C code to evaluate H, h, A, lbA, ubA, lbx, ubx.

    Parameters
    ----
        funcname: (str)
            Function to be named that evaluates H, h, A, lbA, ubA, lbx and ubx.
        dir: (str, optional)
            Directory where codes are to be exported. Defaults to '/'.
        options: (dict, optional)
            Options for code generation. Same option as casadi.Function.generate() function. Defaults to None.

    Returns

    None