Comparison of HINFSTRUCT Matlab Robust Control Toolbox R2010b and HIFOO 3.0 with HANSO 2.0

1 The test bench

The testing considered here is an update of previous software versions and compares

- HINFSTRUCT from the Matlab Robust Control Toolbox R2010b [4, 1] and
- HIFOO 3.0 with HANSO 2.0 [2].

We consider 228 tests cases extracted from the *COMPl$_e$ib* benchmark library [3] . Both codes are run in default mode with 3 randomized restarts in each case and HIFOO 3.0 runs the gradient sampling phase to enhance accuracy.

Results in terms of achieved H_∞ objectives and running times are displayed in tables 2-4. The acronyms AC1 – TL and so on in the left column of the tables allow to identify the model in [3]. Repetition of the same acronym means that the same open-loop model has been used to synthesize controllers of different orders. Column 2 of the tables labeled $P/K/dimx$ gives the plant order, the controller order and the number of decision variables. Columns 3 and 4 give the cpu times that were achieved on a PC with Windows XP 32, Intel Core 2, 2Ghz and 4Gb memory for HIFOO and HINFSTRUCT, respectively. Columns 5 and 6 display the lowest H_∞ norm achieved by HIFOO and HINFSTRUCT, respectively.

2 Results and comments

Failure occurrences for the test set and for each technique are reported in table 1. Note some failure cases may correspond to infeasible problems except when either one of the technique is successful. Note failures are flagged by "NaN" and "Inf" in tables 2-4.

Table 1: number of failures for each test set

	HIFOO	HINFSTRUCT
TEST	14	3

A comparative graphical view of the achieved objective values as well as execution times for both techniques are given in figures 1 and 2. Note these plots do not account for failure occurrences. The left plot in figure 1 shows the x-axis bar diagram of H_∞-norm ratios:

$$\log_{10}(H_\infty\text{-norm }\texttt{HINFSTRUCT}/H_\infty\text{-norm }\texttt{HIFOO})\,.$$

The right diagram is a magnification of the central region for H_∞-norm ratios. Test cases are indexed along the y axis.

Similarly, the left diagram of figure 2 displays cpu time ratios:

$$\log_{10}(\text{cpu time }\texttt{HINFSTRUCT}/\text{cpu time }\texttt{HIFOO})\,.$$

The right diagram in figure 2 shows $\log_{10}$ of cpu time ratios for problems where HINFSTRUCT and HIFOO agree within 3% in the objective.

Note a left-half plane bar indicates advantage of HINFSTRUCT over HIFOO and conversely for right-half plane bars. A bar of unit length materializes improvement by a factor 10, a bar of length 2 a factor of 100, etc.

3 Conclusion

HINFSTRUCT has been compared to HIFOO version 3.0. Numerical testing demonstrates that HINFSTRUCT is both fast and accurate on a variety of problems. It reveals therefore as an attractive practical tool for solving difficult synthesis problems.

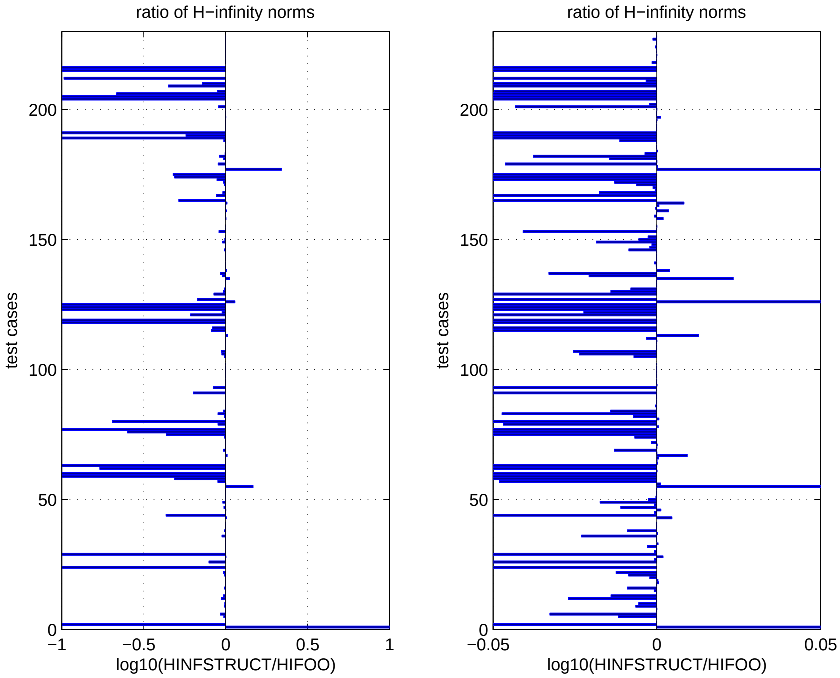

Figure 1: gradient sampling in HIFOO

left: $\log_{10}$ of H_∞-norm ratios
right: $\log_{10}$ of H_∞-norm ratios - magnification of central region

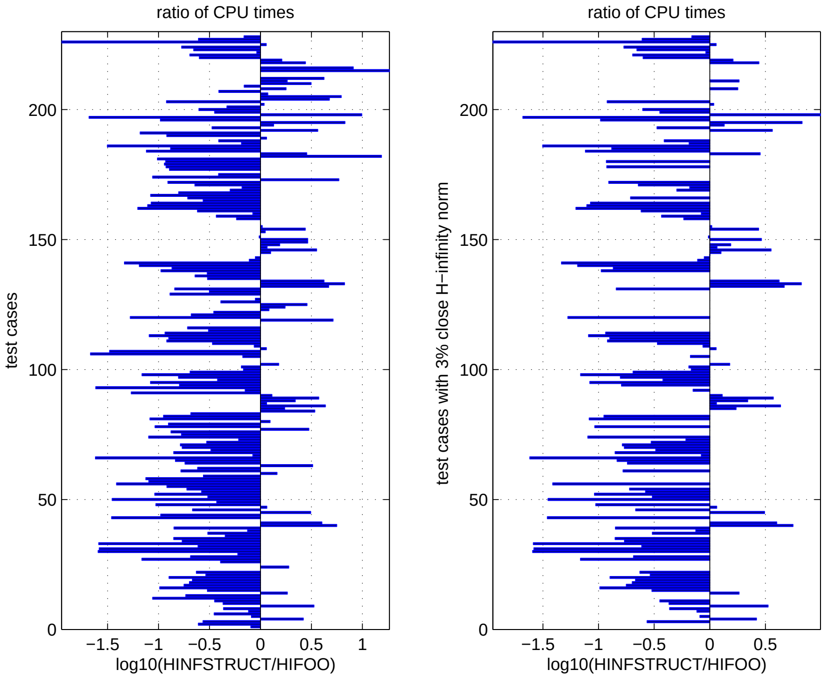

Figure 2: gradient sampling in `HIFOO`

left: $\log_{10}$ of cpu time ratios
right: $\log_{10}$ of cpu time ratios for problems where `HINFSTRUCT` and `HIFOO` agree within 3% in the H_∞ norm.

Table 2: Aircraft and helicopter models

model	order P/K/ dim x	cpu HIFOO	cpu HINFSTRUCT	H_∞-norm HIFOO	H_∞-norm HINFSTRUCT
AC1	5/0/9	7.09	5.70	0.00	0.00
AC1	5/2/25	34.48	8.48	0.00	0.00
AC2	5/0/9	4.23	1.16	0.11	0.11
AC2	5/2/25	0.30	0.78	0.11	0.11
AC3	5/0/8	2.11	1.72	3.67	3.57
AC3	5/2/24	8.05	2.83	3.21	2.98
AC4	4/0/2	1.53	1.17	0.94	0.94
AC4	4/2/12	4.67	2.03	0.56	0.56
AC5	4/0/4	0.41	1.36	674.92	664.97
AC5	4/2/16	4.36	1.88	673.61	665.10
AC6	7/0/8	5.67	2.02	4.11	4.11
AC6	7/2/24	60.39	5.28	3.74	3.52
AC6	7/4/48	44.64	8.27	3.57	3.45
AC7	9/0/2	0.38	0.69	0.07	0.07
AC7	9/3/20	12.91	3.89	0.04	0.04
AC7	9/5/42	52.81	5.42	0.04	0.04
AC8	9/0/5	5.89	1.05	2.01	2.01
AC8	9/3/32	33.66	6.77	1.63	1.63
AC8	9/5/60	25.53	5.48	1.62	1.62
AC9	10/0/20	35.52	4.50	1.01	1.00
AC9	10/3/56	32.25	9.39	1.02	1.00
AC9	10/5/90	68.89	16.20	1.03	1.00
AC10	55/0/4	NaN	20.20	Inf	13.24
AC10	55/3/25	58.03	110.03	184.00	6.49
AC10	55/10/144	NaN	317.20	Inf	7.88
AC11	5/0/8	5.42	2.20	3.56	2.81
AC11	5/2/24	28.66	1.97	2.82	2.81
AC12	4/0/12	7.58	1.56	0.32	0.32
AC12	4/2/30	10.53	6.31	0.31	0.02
AC13	28/0/12	482.23	12.33	163.60	163.30
AC13	28/2/30	537.19	14.09	156.30	156.30
AC13	28/7/110	120.94	29.56	157.38	156.33
AC14	40/0/12	371.17	9.61	101.76	101.86
AC14	40/2/30	24.22	4.14	100.00	100.00
AC14	40/10/182	114.20	16.11	100.00	100.00
AC15	4/0/6	2.73	1.23	16.01	15.19
AC15	4/2/20	5.80	1.77	14.86	14.87
AC16	4/0/8	1.48	1.11	15.17	14.86
AC16	4/2/24	9.25	1.31	14.86	14.86
AC17	4/0/2	0.08	0.44	6.61	6.61
AC17	4/2/12	0.09	0.38	6.61	6.61
AC18	10/0/4	NaN	2.50	Inf	10.70
AC18	10/2/16	67.25	2.33	7.58	7.66
AC18	10/5/49	94.66	9.95	14.13	6.11
HE1	4/0/2	0.28	0.88	0.15	0.15
HE1	4/2/12	11.83	2.55	0.08	0.08
HE2	4/0/4	0.81	0.94	4.00	3.90
HE2	4/2/16	25.86	2.44	2.43	2.43
HE3	8/0/24	7.67	2.86	0.84	0.81
HE3	8/2/48	97.98	3.44	0.81	0.80
HE3	8/4/80	33.69	10.25	0.80	0.80
HE4	8/0/24	32.52	2.98	22.84	22.84
HE4	8/2/48	14.41	3.81	22.84	22.84
HE4	8/4/80	29.20	5.55	22.84	22.84
HE5	8/0/8	7.88	0.95	8.90	13.07
HE5	8/2/24	50.88	1.97	2.16	2.17
HE5	8/4/48	110.33	8.86	2.03	1.82
HE6	20/0/24	95.19	7.16	394.30	192.42
HE6	20/2/48	188.41	51.94	191.08	15.77
HE6	20/8/168	56.45	82.06	394.64	2.50
HE7	20/0/24	88.98	14.75	192.39	192.43
HE7	20/2/48	199.08	48.19	150.56	25.66
HE7	20/8/168	28.00	91.03	114.46	2.85
DIS1	8/0/16	7.81	1.42	4.16	4.17
DIS1	8/2/36	8.95	1.31	4.16	4.16
DIS1	8/4/64	129.31	3.11	4.16	4.17
DIS2	3/0/4	0.78	0.66	1.03	1.05
DIS2	3/2/16	10.86	1.53	0.95	0.95
DIS3	6/0/16	9.61	3.14	1.10	1.06
DIS3	6/2/36	15.20	2.59	1.05	1.05
DIS4	6/0/24	9.06	1.48	0.74	0.74
DIS4	6/2/48	7.05	2.09	0.74	0.73
DIS5	4/0/4	1.84	1.13	1035.53	1035.53
DIS5	4/2/16	33.03	2.64	678.05	667.60
JE1	30/0/15	236.72	39.83	23.45	10.16
JE1	30/2/35	404.41	53.59	16.08	4.05
JE1	30/8/143	35.92	107.31	98.05	3.94
JE2	21/0/9	152.48	14.08	183.35	183.57
JE2	21/2/25	309.44	38.72	82.04	73.65
JE2	21/8/121	77.52	96.22	258.62	52.82
JE3	24/0/18	134.69	11.09	5.10	5.10
JE3	24/2/40	304.47	34.05	2.94	2.90
JE3	24/8/154	124.98	25.95	3.22	2.89

Table 3: Miscellaneous

model	order P/K/ dim **x**	cpu HIFOO	cpu HINFSTRUCT	H_∞-norm HIFOO	H_∞-norm HINFSTRUCT
REA1	4/0/6	0.27	0.91	0.89	0.87
REA1	4/2/20	0.34	0.59	0.86	0.86
REA2	4/0/4	0.28	1.22	1.15	1.15
REA2	4/2/16	0.53	0.61	1.13	1.13
REA3	12/0/3	0.48	1.06	74.25	74.25
REA3	12/2/15	0.34	1.28	74.25	74.25
REA3	12/5/48	1.17	1.52	74.25	74.25
WEC1	10/0/12	52.70	2.84	6.39	4.05
WEC1	10/2/30	1.66	1.17	3.64	3.64
WEC1	10/4/56	107.63	2.61	4.34	3.64
WEC2	10/0/12	21.17	3.41	4.25	4.25
WEC2	10/2/30	15.38	1.28	3.60	3.60
WEC2	10/4/56	7.83	2.97	3.60	3.60
TG1	10/0/4	9.34	1.47	12.85	12.85
TG1	10/2/16	28.11	1.94	3.47	3.47
TG1	10/4/36	22.42	4.58	3.47	3.47
AGS	12/0/4	1.42	0.97	8.17	8.17
AGS	12/2/16	4.41	2.86	8.17	8.17
AGS	12/4/36	3.61	5.45	8.17	8.17
PAS	5/0/3	NaN	2.63	Inf	0.00
PAS	5/2/15	NaN	5.89	Inf	0.00
TMD	6/0/8	2.80	1.88	2.56	2.52
TMD	6/2/24	178.89	3.84	2.27	2.15
TMD	6/4/48	207.48	6.88	2.28	2.15
CM1	20/0/2	1.53	1.75	0.82	0.82
CM1	20/2/12	4.16	3.61	0.82	0.82
CM1	20/7/72	33.25	11.25	0.82	0.82
ROC1	9/1/9	12.84	1.55	1.24	1.24
ROC1	9/3/25	19.47	2.45	1.20	1.19
ROC1	9/5/49	50.64	4.11	1.16	1.19
ROC2	10/1/12	33.72	3.91	0.05	0.05
ROC2	10/3/30	18.66	5.77	0.05	0.04
ROC2	10/5/56	94.80	18.28	0.05	0.04
ROC3	11/1/25	NaN	15.41	Inf	263.73
ROC3	11/3/49	25.95	25.94	68087.54	284.01
ROC3	11/5/81	10.72	55.25	49001.69	238.01
ROC4	9/1/9	33.69	1.78	302.21	302.21
ROC4	9/3/25	23.33	4.89	254.38	155.33
ROC4	9/5/49	24.56	8.55	232.01	220.40
ROC5	7/1/24	9.64	11.69	0.00	0.00
ROC5	7/3/48	9.19	16.03	0.00	0.00
ROC5	7/5/80	12.89	36.91	0.00	0.00
IH	21/0/110	146.17	59.64	1.89	2.16
IH	21/2/156	88.48	78.91	1.94	1.31
IH	21/8/342	NaN	175.56	Inf	1.15
TF1	7/0/8	14.58	1.89	0.38	0.32
TF1	7/2/24	16.92	5.33	0.26	0.25
TF1	7/4/48	46.52	6.70	0.25	0.25
TF2	7/0/6	0.05	0.22	5200.00	5200.00
TF2	7/2/20	0.05	0.31	5200.00	5200.00
TF2	7/4/42	0.08	0.33	5200.00	5200.00
TF3	7/0/6	6.86	2.08	0.49	0.52
TF3	7/2/20	25.77	5.88	0.27	0.26
TF3	7/4/42	21.92	6.59	0.27	0.25
HF2D10	5/0/6	10.94	1.16	79971.06	80700.87
HF2D10	5/2/20	13.36	1.81	79645.03	79648.46
HF2D11	5/0/6	15.17	0.98	77238.73	77198.04
HF2D11	5/2/20	36.72	1.70	76600.92	76480.80
HF2D12	5/0/8	0.56	0.44	1037666.22	1037666.22
HF2D12	5/2/24	0.58	0.52	1037666.22	1037666.22
HF2D13	5/0/8	0.34	0.34	101548.53	101548.53
HF2D13	5/2/24	0.42	0.53	101548.53	101548.53
CSE1	20/0/20	0.59	2.11	0.02	0.02
CSE1	20/2/48	2.44	2.83	0.02	0.02
CSE1	20/8/180	4.80	7.41	0.02	0.02
CSE2	60/0/60	4.31	12.55	0.02	0.02
CSE2	60/2/128	5.52	16.06	0.02	0.02
CSE2	60/10/480	61.36	59.63	0.02	0.02
NN1	3/0/2	NaN	NaN	Inf	Inf
NN1	3/2/12	1.64	1.83	14.43	13.13
NN2	2/0/1	0.25	0.69	2.22	2.22
NN2	2/2/9	0.73	0.77	1.76	1.76
NN3	4/0/1	NaN	NaN	Inf	Inf
NN3	4/2/9	NaN	2.98	Inf	20.47
NN4	4/0/6	2.17	1.27	1.36	1.37
NN4	4/2/20	5.00	1.84	1.29	1.29
NN5	7/0/2	0.78	0.66	266.54	266.54
NN5	7/2/12	7.19	1.73	239.19	241.18
NN5	7/4/30	49.14	3.08	238.74	238.55
NN6	9/0/4	20.34	1.59	5602.70	5611.29
NN6	9/2/18	84.30	7.14	264.92	270.03
NN6	9/4/40	106.98	29.30	265.48	137.39
NN7	9/0/4	4.92	0.95	74.08	74.08
NN7	9/3/28	81.05	6.78	42.54	37.48
NN7	9/5/54	85.14	13.41	38.84	37.30
NN8	3/0/4	1.58	0.80	2.89	2.89
NN8	3/3/25	2.16	1.42	2.37	2.36
NN9	5/0/6	5.91	1.34	29.21	28.80
NN9	5/3/30	48.67	6.02	14.06	13.65
NN11	16/0/15	0.23	1.38	0.10	0.09
NN11	16/2/35	133.14	11.66	0.04	0.02
NN11	16/6/99	95.08	36.94	0.03	0.01
NN12	6/0/4	NaN	NaN	Inf	Inf
NN12	6/2/16	56.45	7.23	13.37	29.28
NN13	6/0/4	19.25	2.28	14.06	14.06
NN13	6/2/16	33.94	3.88	11.65	10.47
NN14	6/0/4	10.78	1.27	17.48	17.48
NN14	6/2/16	53.36	5.20	9.79	9.47
NN15	3/0/4	0.08	1.20	0.11	0.10
NN15	3/2/16	0.39	1.11	0.10	0.10
NN16	8/0/16	25.03	1.91	0.96	0.96
NN16	8/2/36	19.50	2.56	0.96	0.96
NN16	8/4/64	153.92	4.84	0.96	0.96
NN17	3/0/2	0.72	0.47	11.22	11.22
NN17	3/2/12	3.09	1.20	5.28	5.15

Table 4: Miscellaneous

model	order P/K/ dim **x**	cpu HIFOO	cpu HINFSTRUCT	H_∞-norm HIFOO	H_∞-norm HINFSTRUCT
UWV	8/0/4	0.86	0.98	0.00	0.00
UWV	8/2/16	15.30	1.84	0.00	0.00
UWV	8/4/36	44.50	2.94	0.00	0.00
EB1	10/0/1	0.31	1.14	3.12	3.12
EB1	10/2/9	2.61	0.88	3.10	3.10
EB1	10/4/25	0.77	1.03	3.10	3.10
EB2	10/0/1	0.13	0.84	2.02	2.02
EB2	10/2/9	17.09	1.78	1.78	1.78
EB2	10/4/25	96.78	2.02	1.78	1.78
EB3	10/0/1	0.13	1.23	2.06	2.06
EB3	10/2/9	3.34	1.19	1.87	1.87
EB3	10/4/25	10.47	2.61	1.81	1.81
AC9	10/8/156	54.05	25.33	1.11	1.00
AC13	28/10/182	35.06	38.06	157.12	156.32
AC14	40/10/182	99.09	11.86	100.00	100.00
HE6	20/8/168	18.14	86.05	82.61	2.68
HE7	20/10/224	18.17	112.78	236.02	2.89
JE2	21/10/169	98.81	116.81	245.40	53.03
JE3	24/10/208	117.52	45.88	3.24	2.89
REA3	12/10/143	1.59	2.84	74.25	74.25
WEC1	10/9/156	9.42	6.53	8.12	3.64
IH	21/10/420	74.38	233.33	1.76	1.26
CSE2	60/10/480	26.70	48.92	0.02	0.02
JE2	21/15/324	58.91	247.63	602.68	62.18
JE3	24/20/598	NaN	224.44	Inf	2.89
IH	21/15/650	NaN	683.56	Inf	0.99
HE6	20/15/399	12.89	236.67	84.62	2.42
HE7	20/15/399	27.97	227.86	142.51	2.62
AC10	55/20/484	NaN	832.31	Inf	7.77
AC13	28/20/552	109.86	303.67	156.96	156.43
CM1	20/0/2	1.44	2.33	0.82	0.82
CM1	20/3/20	21.06	5.30	0.82	0.82
CM1	20/8/90	72.25	14.66	0.82	0.82
CM2	60/0/2	10.77	9.91	0.82	0.82
CM2	60/4/30	175.20	38.78	0.82	0.82
CM2	60/11/156	329.36	55.58	0.82	0.82
CM3	120/0/2	58.16	66.33	0.82	0.82
CM3	120/5/42	11888.70	133.03	0.82	0.82
CM3	120/14/240	1261.27	310.63	0.82	0.82
CM4	240/0/2	327.58	225.73	0.82	0.82

References

[1] P. Apkarian and D. Noll. Nonsmooth H_∞ synthesis. *IEEE Trans. Aut. Control*, 51(1):71–86, 2006.

[2] J. V. Burke, D. Henrion, A. S. Lewis, and M. L. Overton. HIFOO - a matlab package for fixed-order controller design and H_∞ optimization. In *5th IFAC Symposium on Robust Control Design*, Toulouse, France, July 2006.

[3] F. Leibfritz. COMPL_eIB, COnstraint Matrix-optimization Problem LIbrary - a collection of test examples for nonlinear semidefinite programs, control system design and related problems. Technical report, Universität Trier, 2003.

[4] MATLAB. *Robust Control Toolbox.* The MathWorks Inc., Natick, MA, 2011.