Table 5 The detailed coordinates of the disks for instance 2.2

表 5 QPAS 在算例 2.2 上的布局坐标

序号	x	y	r	序号	x	y	r
1	80.1351323284289380	−174.2023068567893600	23.72	7	8.4862674099740953	−166.9895225393457300	48.26
2	−190.9252746029229700	17.7190075114753010	23.72	8	−148.8655241280515600	76.1366994473319070	48.26
3	−126.1192497662789800	144.4281879554832200	23.72	9	140.3744397256365100	90.852731256598460	48.26
4	188.1446426120991200	37.0091421663224690	23.72	10	−5.8696703055848909	115.3207713477796400	100.00
5	−62.0317319779710490	−181.4379769711466100	23.72	11	102.8055527267827500	−52.5771020719231150	100.00
6	110.8164212362197800	156.4843261553089900	23.72	12	−96.9358824217438840	−62.7436692651842520	100.00

Table 6 The detailed coordinates of the disks for instance 2.3

表 6 QPAS 在算例 2.3 上的布局坐标

序号	x	y	r	序号	x	y	r
1	−34.4285028640997980	15.3599224650793880	1	9	29.5978182608661910	4.8850041441504137	9
2	33.7982848157157110	15.0514234115894800	2	10	19.8145470847353020	21.1726560649652740	10
3	−21.6524602536760750	28.4376011278335700	3	11	24.0525861758465070	−14.3308851436723210	11
4	12.0850842044562640	32.8455050566270970	4	12	−3.0581017131112964	26.7483741738768860	12
5	−14.3018406622605100	−30.8437570028816100	5	13	2.9847288377083285	−25.8263358602666740	13
6	−25.3871342260474290	20.2490597241375770	6	14	5.2082358848268644	2.0974581114548387	14
7	−30.5954319015216850	8.3379877604766062	7	15	−21.0677897267708370	−11.4918895611060560	15
8	−15.0382783779291960	10.7043541958554160	8				

对于第 3 组算例,表 7 给出了 QPAS 与 PA[5]和 SATS[4]的计算结果的比较.在这 3 种算法中,QPAS 的计算结果很接近于典型的圆形 Packing 问题的最好结果.由于带平衡约束的圆形 Packing 问题比典型的圆形 Packing 问题多了一项平衡约束,后者的最优解一定好于等于前者的最优解.因此 QPAS 计算结果略弱于典型圆形 Packing 问题的解是可以理解的.另外,QPAS 在算例 3.1 找到了更小的外包络圆半径.QPAS 在第 3 组算例取得的布局如图 6 和图 7 所示.

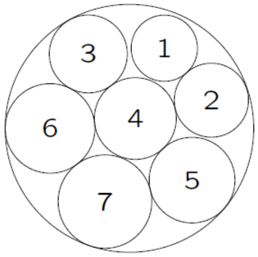

Fig.3 Packing layout of instance 1.4

图 3 算例 1.4 的布局图

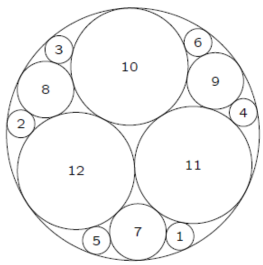

Fig.4 Packing layout of instance 2.2

图 4 算例 2.2 的布局图

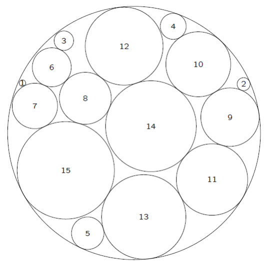

Fig.5 Packing layout of instance 2.3

图 5 算例 2.3 的布局图

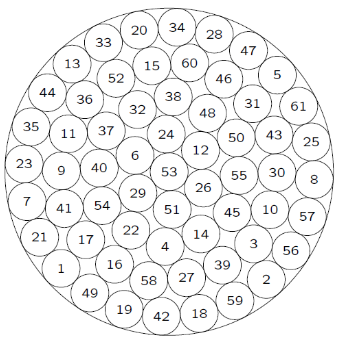

Fig.6 Packing layout of instance 3.1

图 6 算例 3.1 的布局图

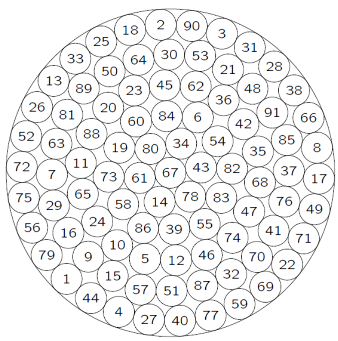

Fig.7 Packing layout of instance 3.2

图 7 算例 3.2 的布局图

Table 7 Computing results on the third set of instances

表 7 第 3 组算例计算结果比较

算例	n	PA		SATS		QPAS		
		R_0	$T(s)$	R_0	$T(s)$	R_0	J	$T(s)$
算例 3.1	61	173,226	0.32	173.226	0.52	**173.225 951 5**	2.40×10^{-8}	345.423
算例 3.2	91	–	–	211.334	4.85	211.335 449 2	3.53×10^{-8}	453.229

5 结 论

对于带平衡约束的圆形Packing问题,基于弹力模型和拉力模型,把拟物下降方法与若干拟人策略相结合以提高连续优化的效率.当拟物过程遇到局部陷阱需要跳坑时,由于外包络圆中的剩余空间都是不规则的,很难通过精确计算从中选出最空闲的空间以作为跳坑的位置.本文通过化圆为方,将外包络圆和待置入圆饼近似看做矩形,并借鉴求解矩形Packing问题的拟人算法中动作空间的概念,把不规则的剩余空间转化为易计算和比较的矩形空间,从而较快且较准确地找到最空闲空间.对国际上公开的 13 个代表性算例的计算结果表明,所提的拟物求解算法是快速且有效的.在今后的工作中,拟进一步提高基于动作空间的跳坑方法的有效性,并将其应用到一般的圆形 Packing 问题的求解中去.

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何琨(1972－),女,北京人,博士,教授,CCF 高级会员,主要研究领域为 NP 难度问题现实求解,算法设计与分析.

杨辰凯(1988－),男,硕士生,主要研究领域为 NP 难度问题现实求解,算法设计与分析.

黄梦龙(1988－),男,硕士生,主要研究领域为 NP 难度问题现实求解,算法设计与分析.

黄文奇(1938－2013),男,教授,博士生导师,主要研究领域为 NP 难度问题现实求解,算法设计与分析.