A Sufficient Condition for Force-Closure Grasps Synthesis of 3D Objects

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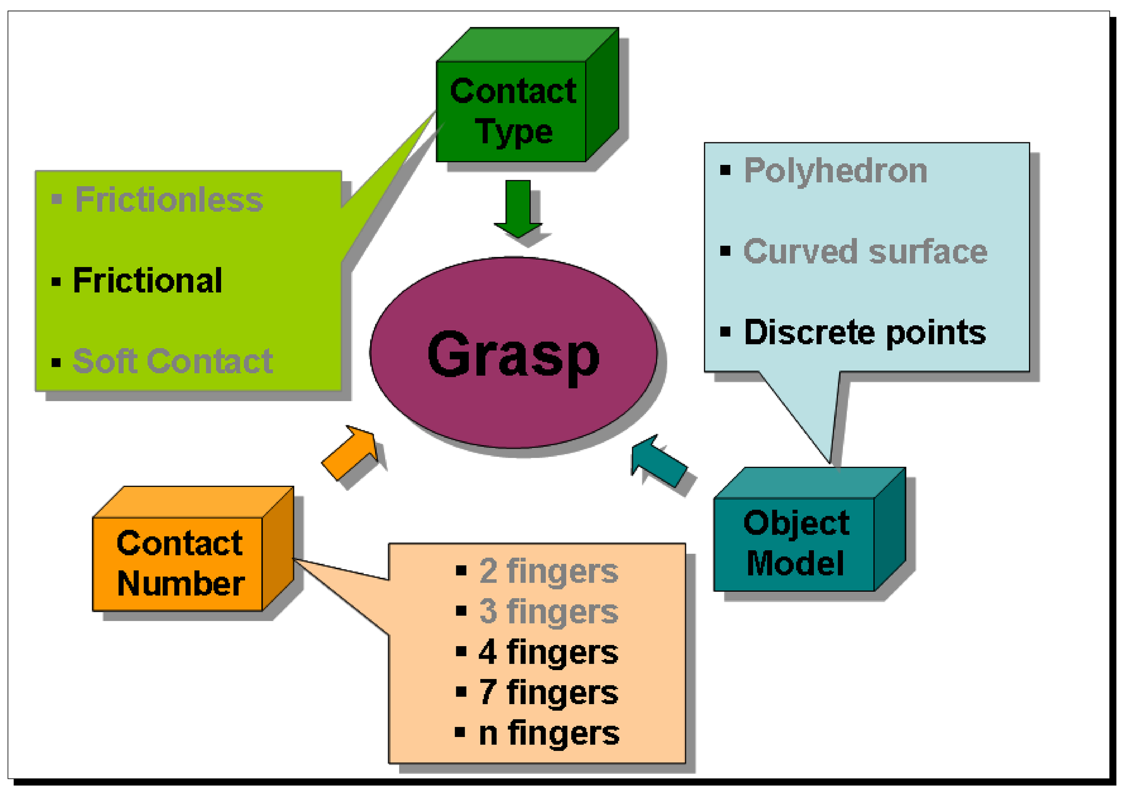
Problem Statement

GENERATING a grasp requires information about :

- Contact Type
- Contact Number
- Local Object Surface



GIVEN a set of N points along with their normals,

compute, as fast as possible,

n-finger ($n \geq 4$) force-closure grasps assuming hard-finger frictional contacts.

Proposed Approach

WHEN DOES A GRASP HAVE FORCE-CLOSURE ?

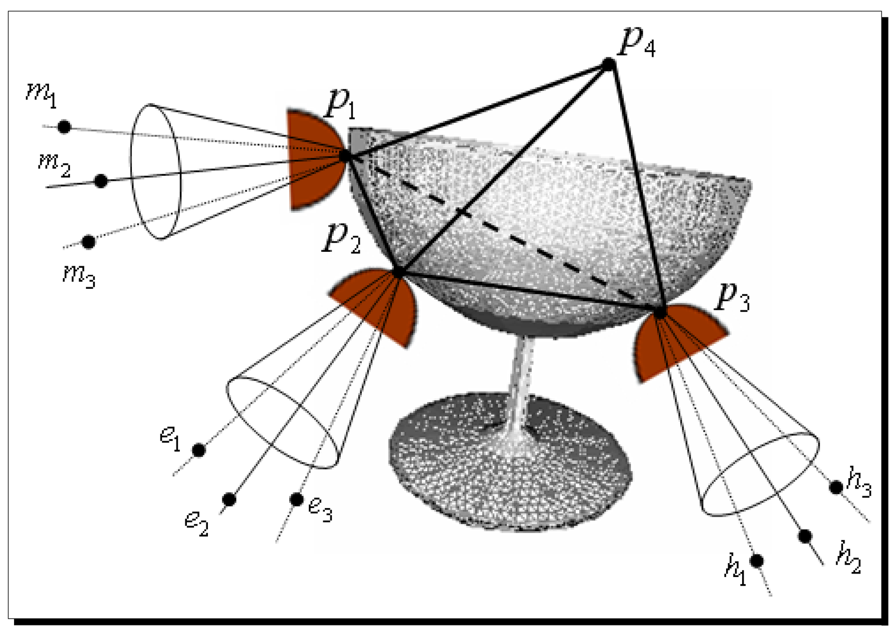
According to the definition of Salisbury and Roth, a grasp has **force-closure** if and only if any external wrench can be balanced by the wrenches at the fingertips $\Rightarrow$ when the primitive contact wrenches resulted by contact forces at the contact points positively span the entire 6-dimensional wrench space.

CAN 6D CONTACT WRENCHES BE REPRESENTED IN A 3D SPACE ?

- A primitive contact wrench is defined by : $w = (f; p \times f)$.
- Using Pl$\ddot{u}$cker coordinates, w can also be seen as a representation of the line of action L_f of the force f applied at the point p.

KEY IDEAS

- All lines through one point are of rank 3.
- When all lines meet one line, they are of rank 5.
- Wrenches associated to 3 non-aligned contact points are of rank 6 and thus form a basis of the 6D wrench space.



THE SUFFICIENT CONDITION

ASSUME that :

- the grasp of $n-1$ non-aligned fingers is not force-closure.
- $\{b_i\}_{i=1..6}$ is a 6-dimensional basis associated to their corresponding contact wrenches.

SUFFICIENT condition for a n-finger force-closure grasp is that there exists a contact wrench γ such that :

- γ is inside the linearized friction cone of the nth finger
- $\gamma = \sum_{i=1}^{k} \beta_i b_i,\ \beta_i < 0 \Rightarrow \gamma = B\beta \Rightarrow \beta = B^{-1}\gamma$

where :
$B = [b_1, b_2, ..., b_6]$ is a 6×6 matrix.
$\beta = [\beta_1, \beta_2, ..., \beta_6]^T$ is a 6×1 strictly negative vector.

SIMPLE multiplication by B^{-1} permits to test if a contact wrench γ, and consequently the location of the nth contact point, ensures a force-closure grasp.

Results and Conclusions

TESTS are accomplished on a sphere model, represented by its 762 vertices and its respective normal directions. Two experiments are performed :

COMPLETENESS test :
- Depends on the quality of the first $n-1$ generated fingers locations. Their quality should be above a threshold.
- In the worst case, when the $n-1$ fingers are generated randomly, our method finds 18.7% of the force-closure grasps.

RAPIDITY test :
- Depends on the quality of the first $n-1$ generated fingers locations.
- In the worst case, our force-closure computation time is four times faster than the convex-hull one.

TAB. 1 – Completeness results for different thresholds $0 = Th0 < Th1 < Th2 < Th3 < Th4$.

	Number of Solutions (s)		
$threshold$	classic	new	n/c
Th0	315	59	18.73%
Th1	349	82	23.5 %
Th2	366	96	26.23 %
Th3	392	118	30.1 %
Th4	419	149	35.56 %

TAB. 2 – Force-Closure grasp computation time

	Time (ms)		
$threshold$	classic	new	n/c
Th0	3.74	0.93	24.87 %
Th1	3.60	0.76	21.11 %
Th2	3.43	0.68	19.83 %
Th3	3.20	0.53	16.56 %
Th4	2.84	0.45	15.90 %

OUR aim is to compute as fast as possible n-finger force-closure grasps for a given 3D object.

THE proposed force-closure sufficient condition is not necessary. Our method sacrifices completeness in favor of fast computation.

FAST computation is due to reducing the force-closure test to an inverse matrix calculation.

IN the worst case, our approach is four times faster than the convex-hull method.

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