Using Geometry Sketchers & CAD Tools for Mechanism Synthesis
Synthesis into the design process

**Design process**

- **Synthesis:**
  - Structural and dimensional
- **Iterative**
  - Process
- **Sketchers**
  - Could possibly cover structural & dimensional synthesis
- **CAD tools**
  - Represent the product in a more detailed form
- This paper focuses on **dimensional synthesis**
- **Comparison**
  - Sketchers vs. CAD

**Tools & Software**

- **Sketchers**
- **CAD, CAE, Optimisation**
- **Mind maps**

**Design tasks**

1. Customer specification
   1'. Functional requirements
2. Structural definition
   2'. Structural synthesis
3. Dimensioning
   3'. Dimensional synthesis
4. Detailed design
5. Manufacturing

**Applications**

- **IGS**
- **CAD**
- **Design proc.**

**Conclusion**
Existing software for mechanism design

Geometric tools for synthesis

- Con constructive Solid Geometry (CSG)
- Boundary representation (B-Rep)
- Parametrized models
- Variational models (constraint based)

Examples of CAD software for SMEs
Solidworks www.solidworks.fr
SolidEdge www.plmautomation.siemens.com
Think3 www.think3.eu

Examples of CAD software for big groups
Catia www.3ds.com/fr/produits-et-services/catia
Creo www.ptc.com/product/creo
Inventor www.autodesk.fr/products/inventor
NX www.plm.automation.siemens.com/fr_fr/products/nx

Tools for design
- Design proc.
- CAD
- IGS

Synthesis

Applications

Conclusion

Inventor 2016 Commercial

Catia V6 Commercial
Existing software for machine design

Geometric tools for synthesis

Special software for machine design

SAM (Synthesis and Analysis of Mechanisms) V7.0
www.artas.nl
Commercial
- Linkages
- Transmissions
- Analysis
- Optimisation

GPK gearbox package
www.kissoft.ch
Commercial
- Sizing, optimization and rating of gearboxes
- Dimensioning of elements: gears, shafts, bearings, springs, belts

Tools for design
- Design proc.
- CAD
- IGS

Synthesis

Applications

Conclusion
Existing software for machine design

Multibody simulation
- Rigid bodies, Joints
- Kinematics & dynamics
- Iterative solving of dynamics differential equation
- Parametrizing, Optimization
- Flexible bodies → Extension to FEM

Examples of multibody software

Adams www.mscsoftware.com/fr/product/adams
LMS Virtual Lab Motion
Simpack www.simpack.com
Open Dynamic Engine www.ode.org
Gazebo http://gazebosim.org

MSC Adams 2015
Commercial

Tools for design
- Design proc.
- CAD
- IGS

Synthesis

Applications

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Existing software for mechanism design

Interative Geometry Software (IGS)

2 representative solutions:
- Java implementation
- Linux / MacOS / Windows

Cinderella V2.8
www.cinderella.de
Free, since 1998
- Euclidean, spherical & hyperbolic geometry
- Physics simulation
- Scripting & algorithms

GeoGebra V5.0.166
www.geogebra.org
Free, since 2001
- 2D / 3D geometry
- Algebraic expressions
- Symbolic calculation
- Spreadsheet
- Parametrization / scenarios
Interactive Geometry Software (IGS)

**Main functions**
- Sketching in 2D/3D as with a ruler and compass
- Parametrization
- Simple constraints (point on curve) but not really variational

**IGS vs. Paper work**
- Precision
- Parametrization for *a posteriori* modification
- Sequential process that can be replayed

**Geometric tools for synthesis**

**Main functions**

- Sketching in 2D/3D as with a ruler and compass
- Parametrization
- Simple constraints (point on curve) but not really variational

**Designing with mechanism skeletons**

- **Mechanism skeleton**: simplified product representation for synthesis at a higher lever of abstraction
- **Skeleton in CAD**: group of reference geometrical entities (points, lines, planes) required to reconstruct a shape by a self-coherent process
- Using a skeleton **minimizes reconstruction problems** due to referencing features that do not exist any more within the current set of parameters.

**Tools for design**
- Design proc.
- CAD
- IGS

**Applications**

**Conclusion**
Synthesis 1: Three position synthesis (1/2)

Notations
- $A_0$: rot. point of the crank (frame joint)
- $B_0$: rot. point of the rocker (frame joint)
- $A$: coupling joint crank-coupler
- $B$: coupling joint coupler-rocker

Problem setting
- Given $A_0$ and $B_0$
- Given 3 poses of the coupler…
- ...Find A and B positions

Algorithm
- $A_{1,0,3} = A_0$ transferred from pose 3 to 1
- $A_{1,0,2} = A_0$ transferred from pose 2 to 1
- $A_1 = \text{intersection (}
  (\text{right_bisector} (A_{1,0,2}, A_{1,0,3}),
   (\text{right_bisector} (A_{1,0,2}, A_0))
  )$
- $B_{1,0,3} = B_0$ transferred from pose 3 to 1
- $B_{1,0,2} = B_0$ transferred from pose 2 to 1
- $B_1 = \text{intersection (}
  (\text{right_bisector} (B_{1,0,2}, B_{1,0,3}),
   (\text{right_bisector} (B_{1,0,2}, B_0))
  )$
Synthesis 1: Three position synthesis (2/2)

Transferring a point

- \( P_i \): point that has a relative position in frame \( i \) identical to the relative position of \( P \) in frame \( j \)
- Manually, can be performed with transparent paper
- With an IGS, similar to a sub-routine

Sub-Routine 1: Circle intersections

- Sub-routine 1 is less robust because the intersection of two circles gives two points → branching

Sub-Routine 2: Angle measure

Geometric tools for synthesis

Tools for design
- 3 position
- Dead Center
- Roberts-Cheb.

Synthesis

Applications

Conclusion

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The 14th IFToMM World Congress
Date: Oct. 25-30, 2015 / Venue: Taipei International Convention Center, Taiwan
Synthesis 2: Dead center position synthesis

Notations

- $A_i / A_a$: joint A in the inner / outer dead-center position
- $B_i / B_a$: joint B in the inner/outer dead-center position (dead-ends of transl. stroke)
- $k_{A0}$: circle on which $A_0$ is located, of center $M_{A0}$
- $k_{Aa}$: circle on which $A_a$ is located, of center $M_{Aa}$
- $\phi_H$: $\angle A_0 A_a A_i$, angle centered in $A_0$ and oriented from $A_a$ to $A_i$, $\phi_H = \pi - \varphi_H$
- $\psi$: $\angle B_a B_0 B_i$, swinging angle centered in $B_0$ and oriented from $B_a$ to $B_i$
- $e$: eccentricity
**Synthesis 2: Dead center position synthesis**

**Constructing circle \( k_{A0} \)**
- line \( (\Delta_{1/2}) = \text{right_bisector} (B_i, B_a) \)
- line \( (\Delta_{A0}) = \text{angular_line} (\text{angle } \bar{\varphi}_H, \text{point } B_a, \text{y-axis}) \)
- point \( M_{A0} = \text{intersection } ((\Delta_{1/2}), (\Delta_{A0})) \)
- circle \( k_{A0} = \text{circle} \) (center \( M_{A0} \), radius \( M_{A0} B_a \))

**Constructing frame axes**
- \( x\)-axis = half-line starting in \( B_a \), directed by \( B_a B_i \)
- \( y\)-axis = \( \text{angular_line} \) (90°, point \( B_a \), x-axis)

**Constructing circle \( k_{Aa} \)**
- line \( (\Delta_{1/4}) = \text{right_bisector} (B_m, B_a) \)
- line \( (\Delta_{Aa}) = \text{angular_line} (\bar{\varphi}_H/2, \text{point } B_a, \text{y-axis}) \)
- point \( M_{Aa} = \text{intersection } ((\Delta_{1/4}), (\Delta_{Aa})) \)
- circle \( k_{Aa} = \text{circle} \) (center \( M_{Aa} \), radius \( M_{Aa} B_a \))

**Applications**
- 3 position
- Dead Center
- Roberts-Cheb.

**Conclusion**
Synthesis 3: Roberts-Chebyshev substitution theorem

Notations
- $A_0B_0BA$ the reference 4-bar mechanism
- $ABK$: triangular coupler link
- Angles $\kappa = \angle BAK$, $\lambda = \angle KBA$
- Lengths $k = AK$, $l = BK$

Problem setting
The ROBERTS-CHEBYSHEV-theorem can generate two 4-bar mechanisms with the same coupler curve of a coupler point $K$ from $A_0B_0BA$
- $A_0B_0^*B^*A^*$
- $A_0^{**}B_0^{**}A^{**}$

Algorithm
- $A^*$ so that $A_0A^*KA$ is a parallelogram
- $B^*$ so that triangle $(A^*B^*K)$ is homothetic to triangle $(AKB)$
- $A_0^{**}$ so that triangle $(A_0A_0^{**}B_0)$ is homothetic to $(AKB)$
Application 1: Synthesis of a planar windscreen wiper mechanism with IGS

Problem specifications

Geometric tools for synthesis

- Tools for design
- Synthesis
- Applications
  - Planar
  - Spherical
- Conclusion

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Application 1: Synthesis of a planar windscreen wiper mechanism with IGS

Dead center position synthesis of the 4 bar mechanism for the actuation

Problem setting
- Given the inner position 1 ($\alpha_1$) & the outer position 3 ($\alpha_3$) → swinging angle $\psi$
- Given the rocker length $L_3$
- Given the time ratio forward/backward
- Given the eccentricity $e$
- Find the actuated joint $A_0$
- Find the $A_a$ joint (crank-coupler)

Solution
- Draw the stroke $x$ axis
- Construct circle $k_{A0}$
- $A_0 = \text{intersection} (k_{A0}, \parallel (x,e))$
- Construct circle $k_{Aa}$
- $A_a = \text{intersection} (k_{Aa}, [B_aA_0])$

Geometric tools for synthesis

- Tools for design
- Synthesis
- Applications
  - Planar
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3 position synthesis of the 4-bar motion-replication mechanism

- Given the three poses of the wipers
- Given joints positions $B_0$ and $C_0$
- Given a K point on the crank
- Find the coupler joint $C$

The complete movable mechanism is constructed into the same model, joint with its specifications
Application 2: Synthesis of spherical mechanisms

3 position synthesis

- Extension to 3D spherical geometry is easy

Roberts-Chebyshev substitution
Dimensional synthesis with an IGS

Geometric tools for synthesis

Geogebra vs. Cinderella

- Overall, both can do the job
- Geogebra has simpler ergonomics for
  - Parametrization
  - Angle transfer
  - Perpendicular bisector
- Other advantages of Geogebra
  - Free labeling of elements
  - Algebraic display (eq., coord.)
  - Fade out of construction elements
  - Pan-zoom

Parametrizing

Cinderella: variable = segment length (4 operations required)

Geogebra: dedicated parameter tool

Angle transfer

Cinderella: requires a construction

Geogebra: 2 dedicated tools

Applications

- Overall, both can do the job
- Geogebra has simpler ergonomics for
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- Other advantages of Geogebra
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Dimensional synthesis with a CAD software

Catia vs. Inventor

- Application 1 was reproduced both with Catia V5 and Inventor
- **Procedure** with Catia V5
  - Define a skeleton part in assembly mode
  - 3 poses = 3 reference planes
  - Each construction requires a new part
  - Publication required for using length measures in other parts
  - The designer must:
    - anticipate synthesis **steps**
    - choose what will be **published**
    - choose the correct **inter-part references**
- Overall, Catia V5 is **less intuitive** than the IGSs and less tolerant with respect to mistakes
- Inventor has advantages over Catia V5 for synthesis:
  - Creation or points/lines/planes refs in assembly mode
  - Constraint « Has the same length as »
  - No time-consuming « publishing » concept
Conclusion

Tool comparison

- Mechanism dimensional synthesis was performed with several CAD and IGS tools
- IGS tools prove to be more time efficient than CAD software
  - They help to concentrate on the skeleton only
- Geogebra requires less operations than Cinderella for the same task

<table>
<thead>
<tr>
<th>Tool</th>
<th>Parametrize</th>
<th>Transfer angles</th>
<th>Transfer lengths</th>
<th>Draw perpendicular bisectors</th>
<th>Find rotating point (position synthesis)</th>
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<td>3</td>
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</table>

Towards better tools for synthesis

- CAD software should take inspiration from IGS for dimensional synthesis
- Towards new CAD tools that integrate in the same model:
  - Specifications
  - A mechanism skeleton obtained by dimensional synthesis
  - A 3D model parametrized by the skeleton