Set-Based Design of Automobile Independent Suspension Linkages

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The independent suspension allows each wheel of an automobile to move vertically relative to the vehicle body without affecting the motion of the other wheels. It consists primarily of a linkage connecting the wheel carrier to the vehicle body, a spring element, and a damper element. The linkage is responsible for guiding the wheel along the desired trajectory, providing the vertical degree-of-freedom upon which the spring and damper can act to support the vehicle body and isolate it from road irregularities [1, Ch. 4]. Nowadays, independent suspensions are designed whenever an existing vehicle is in need of improved performance or when a new vehicle is being developed. From vehicle-level ride-and-handling requirements, experienced designers select a suspension architecture (linkage type) which is potentially suitable. Next, designers create a draft linkage geometry which fits inside the allotted space for the linkage, and iterate its dimensions until it guides the wheel satisfactorily. The spring and damper themselves are then located and their properties selected. Vehicle-level testing and tuning completes the suspension's development, including the addition of mounts and bushings to improve suspension performance.

This approach to suspension design is classified as point-based design, in that it is characterized by choosing a solution and then iterating until a better solution is found. Architecture selection and geometry selection are portions of suspension design particularly suited to a different approach, namely set-based design. There exists the obvious possibility of a designer selecting an architecture which will never meet the desired wheel trajectory. Moreover, the geometric design process is tedious, requiring even an experienced designer to run simulations dozens of times [2]. Fortunately, kinematicians have long worked on methods to systematically enumerate linkage types and solve directly for link dimensions based on the kinematic requirements [3, 4]. Rather than choosing one suspension architecture based on experience, a set of candidate architectures can be enumerated [5]. Rather than choosing one geometry and iterating it, a family of geometries that achieve the desired motion can be found [6, 7, 8]. In this way, a large number of possible suspension linkages can be produced, some of which can then be eliminated by subsequent concerns, leaving only the viable design solutions, thus following a set-based design process.

In pursuing the set-based design approach, a mathematically-complete description of spatial wheel motion is needed which is compatible with the kinematic characteristics used by suspension designers. For example, *roll center height* is a characteristic associated with body roll during cornering; its definition includes the velocity vector of the tire contact point. It should be possible to define a curve in $SE(3)$, the group of spatial rigid body motions, in terms of application-specific characteristics like roll center height. Previous attempts at achieving desired roll center height behavior relied on architecture-specific rules [9], unsuitable for set-based design, where we do not wish to assume a particular architecture. To this end, a rigid body motion parameterization is presented which is mathematically-complete, yet compatible with the kinematic characteristics valued by suspension designers. This framework makes clear what compromises are inherent in specifying wheel motion in the abstract, since there are often more characteristics designers care about than are independent. Next, methodologies are presented to efficiently synthesize suspension linkages that accurately guide the wheel, including the use of polynomial continuation software [10] when the link design equations are polynomial. Polynomial continuation allows a large number of link geometry solutions to be found simultaneously, so it is well-suited to this design problem. In contrast to the general linkage synthesis problem, suspensions are required to satisfy prohibitive space requirements; included are problem-specific methods for fitting a given linkage "inside the box".

Examples are provided which demonstrate the efficacy of the design methods. Fig. 1 presents the results of the design process employing spherical-spherical links. Considering a 600 mm cube, 226,981 solutions were identified (using a 10 mm grid spacing). In Fig. 1, 5,712 spherical-spherical link solutions are shown that are contained completely inside the 600 mm cube for a given motion specification. Further filtering based on fitting the outer spherical joint within a hypothetical rim gives 196 solutions. Finally, in the rightmost image of Fig. 1, an example five-link independent suspension is assembled from the solutions. This five-link suspension guides the wheel through four specified positions.

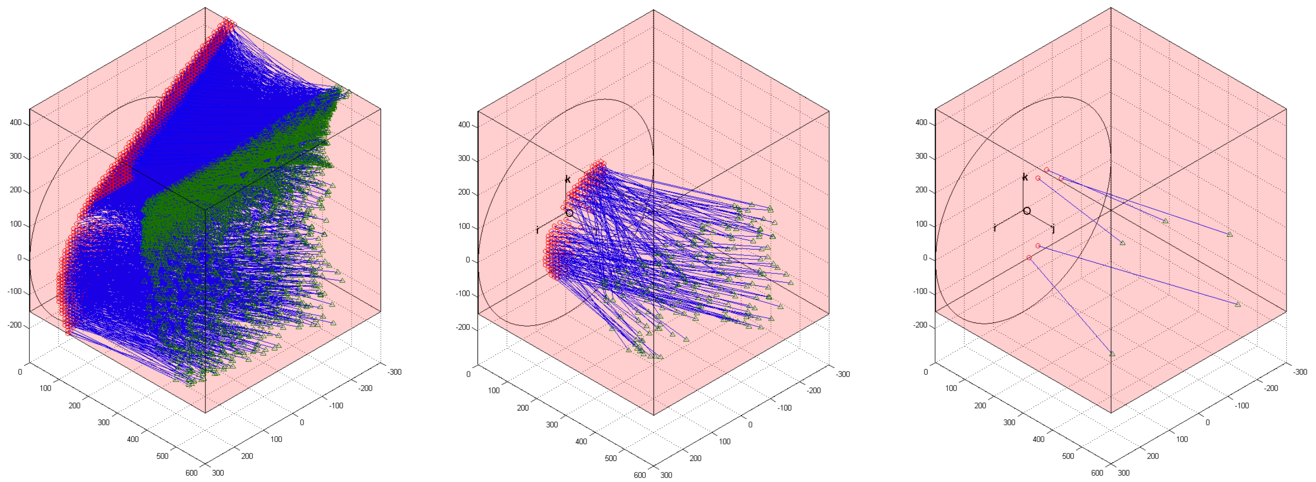

Fig. 1: Left: Solutions which fit inside alloted space. Middle: Solutions which package the outer spherical joint inside a wheel. Right: A five-link independent suspension assembled from the solutions.

References

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