Geodetic Concepts for Collision Avoidance Along Industrial Transport and Assembly Lines

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SUMMARY

Complex and time-critical process chains in industrial production of premium automobiles demand a sophisticated supply chain management and logistics as well as safe and reliable transport systems. Inside a vast factory individual parts (e.g. engines) cover large distances by using electric monorail suspension conveyers. In such an environment, the avoidance of any collision of units with the surrounding area or flexible tools becomes a must. Last minute changes in the product's design demand a simulation tool to compute dynamic interference checking and to visualize risk zones where problems might occur.

This paper gives an overwiev over common interference detection techniques of moving objects among solids and surfaces and finally introduces the self-developed Software KoSimu (Kollisionsprüfungs-Simulator) – a collision check simulator that enables the designer to simulate the movement of a prototype along a known trajectory through the facility and detect collision spots.

To acquire the surrounding, conventional methods are usually disturbing the manufacturing process. Therefore, in this research project Terrestrial Laser Scanning (TLS) is applied and the surrounding can be represented by a point cloud. In addition, the input for KoSimu are geometric models of the prototype and the mounting device on the suspension conveyers. In a first step, these two models have to be linked using specific connecting points. Afterwards, the new model is approximated by adequate cubes of selectable size and reduced to its characteristic envelope. Under the assumption of homogeneous mass distribution (centre of mass equals the geometric centre) physical effects (centrifugal and reset forces, oscillating movements) can be considered as well. The geometric and and the physical model are jointly used to create a space of impact along the track which is tested against the point clouds of obstacles to reveal and succesively prevent any possible collisions

An outlook on further applications (inspection of clearance cross sections) concludes the report.

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1. INTRODUCTION

Collision avoidance has become a major issue in navigation and in industrial automation. It is the latter field on which we focus here. Starting with the broad employment of ever faster acting industrial robots in the late Seventies of the past century, the problem of preventing any collision of moving robot arms and effectors with infrastructure or treated objects arose. Parallel to sensor-based and visual control procedures, analytical approaches evolved. Their power increased with growing computational capacities and, obviously, simulations to detect possible collisions virtually in advance were preferred to in-situ collision avoidance attempts.

Before 1980 collision tests were developped which made use of dilatation (a geometric method which reduces the size of an object by a constant amount and enlarges the environment to the same extent) to simplify intersections (Udupa 1977) or of contact proofs of corner points and edges with polyhedron surfaces (Boyse 1979). Then methods followed which aimed at substituting complex objects by simple solids like ashlers (Ozaki et al. 1984) or cubes (Uchiki et al. 1987) to to keep the computation load in limits. A different approach tried to wrap the objects (Gilbert et al. 1988, 1989) by means of quadrics like cylinders or spheres to make mutual spacing control easier. At the turn of the century clear claims have been set up for analytical collision avoidance methods: simple, accurate and efficient (prompt). In the same treatise (Bao 2000) two simple but capable tools were suggested as to:

- wrap objects by cubes and test both three co-ordinate intervals for common content
- inscribe and circumscribe spheres to allow rotation-invariant distance calculations.

Our investigations are based on these tools, increasing the level of detail by using an appropriate segmentation of complex objects into a large number of equal cubes.

The quoted advances came from the robotics and CAD/CAM community as well as from computational geometry; engineering surveyors at that time rather dealt with robot calibration processes. It was the appearence of Terrestrial Laser Scanning that now involved geodesy in the field. Current interest focusses on simulations of transport missions in large, laser surveyed environments within vast production facilities. The challenge is represented by combining the geometrical model with a physical one to account for the resulting effects of centrifugal and gravitational forces along curved parts of the transport line. There, the trajectories have to be used for building up a space of impact, changing with the velocity of the transport platform. The space of impact can then serve for a static test of collision at suspected bottlenecks and obstacles.

2. TASK

Complex and time-critical process chains in industrial production of premium automobiles demand a sophisticated supply chain management and logistics as well as safe and reliable transport systems. Inside a vast factory individual parts (e.g. engines) cover large distances by using electric monorail suspension conveyers. In such an environment, the avoidance of any collision of units with the surrounding area or flexible tools becomes a must. Last minute changes in the product's design demand a simulation tool to compute dynamic interference checking and to visualize risk zones where problems might occur.

In particular, financial losses have to be prevented which would occur either by the partial damage of a high-tech engine or, much more expensive, by provoking a standstill of transport line and whole production units.

3. SOLUTION

The solution for the specific task splits up into four main parts:

- obtain a CAD-model of the transport object itself and of the bearing conveyor unit or scan them; get physical properties (weight, centre of mass, velocity, motions allowed)
- obtain a CAD-model of the guiding rail of the transport line or scan it
- scan the present environment (and manipulator positions) along the transport line
- develop a simulation program to virtually move conveyor with object along the rail through the scanned environment and search for collision zones.

This report will only deal with the fourth, most demanding item.

3.1 Simulation Strategy

We start with preparing a point cloud of the transport object and a conveyor, either by precise scanning or by converting present VRML-models, which can be realized by a scene export from the professional programme 3ds Max. Then the two point clouds are combined, using a defined matching point and defined orientations (specific bearing cone of the conveyor). Next, the couple is attached to the guiding rail by a transformation to the common system of rail and environment. Now the approximation of the point cloud is achieved by segmentation into numerous cubes of equal size (5 to 10 cm length of edge) as a basis for a volume model. From these cubes only those remain for subsequent use which contain points of the object's skin. This reduction by means of the min-max test (Bao 2000) proves very efficient to lessen the computational workload of the following alogorithms and is also applied to the obstacles.

In course of the motion simulation a space of impact is created by shifting the transport object with the suspending conveyor along the guiding rail by small increments (e.g. 3 cm) and investigating intersections of the volume model of the object skin and the surroundings. For each incremental position the cases of no collision, pseudocollision or certain collision are discriminated by judging distances between cube centres.

3.2 Collision Investigation

Using the rotation-invariant spherical substitutes (Bao 2000) mentioned in the introduction, we can easily set up criteria to discriminate. It is sufficient to compare the actual distance S of two neighbouring cubes centres with certain maximum and minimum values. The maximum Smax is represented by the spacing of the cube centres if the circumscribed spheres are in contact, the minimum one Smin if the spheres inscribed behave the same way. The numerical values equal the sum of the corresponding radii. Now the decision can be taken:

- no collision, if S > Smax
- possible collision (pseudocollision), if Smin ≤ S ≤ Smax
- certain collision, if S > Smin.

Figure 1 gives a plane representation of the three cases.

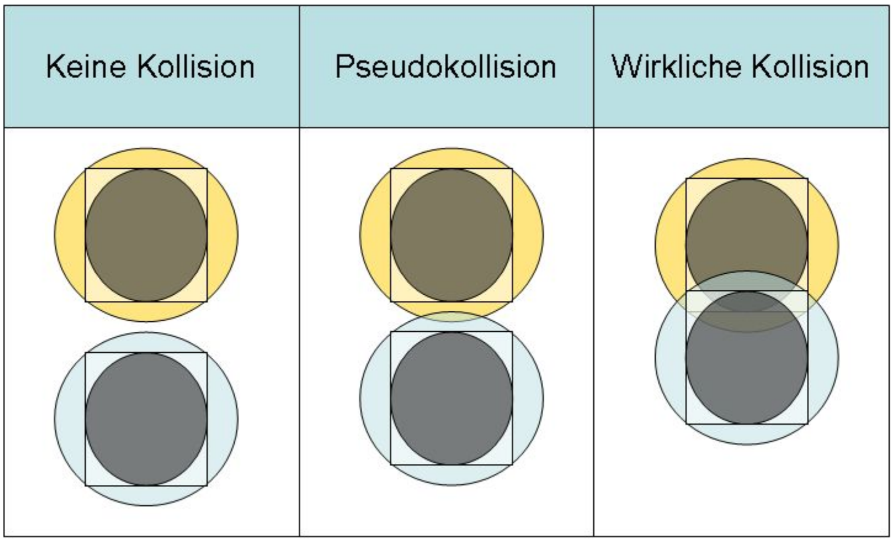

Fig.1: Test of centre spacings to discriminate between the 3 different collision cases

If the transport line only consisted of a straight track, programming could start right off. In reality, there will exist also curved sections to enable direction changes. A conveyor entering such a section will experience a gradual radial deviation outwards according to its velocity until a constant value is reached and a gradual return to the nominal attitude after leaving the bend. Usually, circular right angle turns of small radius link straight sections of the transport line. The sudden change of curvature without transition results in oscillating lateral motions which have to be carefully modelled to find out the angular deviations along time stamped increments of the virtual trajectory. The radial motions follow a differential equation describing the instantaneous state of balance between the driving centrifugal force and the backdriving effect of gravity.

3.2.1 Modelling lateral deviation along a circular curved path

Although the behaviour of the joint transport unit could be explored by kinematic monitoring with a tracking servo-tacheometre, we decided to set up a theoretical model of the angular deviation caused by the effects of centrifugal force in course of the travel along a circular section. The angular values subsequently can be used to find the metric lateral deviations for the expanded derivation of the space of impact.

As a matter of fact, a differential equation has to be set up. To keep things simple, we chose the conventional wire pendulum model from physics and assumed all masses being concentrated at the common centre of mass of conveyor and transport object. The angular velocity is estimated for each increment of the simulated motion. The differential equation (Auer 2005) to be solved reads:

$$\frac{d^2\varphi}{dt^2} = \omega^2 * \cos(\varphi) * \left(\frac{r}{l} + \sin(\varphi)\right) - \frac{g}{l} * \sin(\varphi) - \gamma * \frac{d\varphi}{dt}$$

The rail radius r, the distance suspension – centre of mass l and the local gravity g are constant values, whereas ω has to be adapted to each interval of the bend passage. The parameter γ has to be set according to friction of the conveyor joints. The motion is regularly incremented and the solution delivers the angle φ for each step based on the former one, starting with the φ = 0 for the transition from the straight path to the curved. Figure 2 shows the sudden changes of φ at the beginning and the end of the bend as well as the following damped oscillations. The model of the angular deviation turns out very realistic.

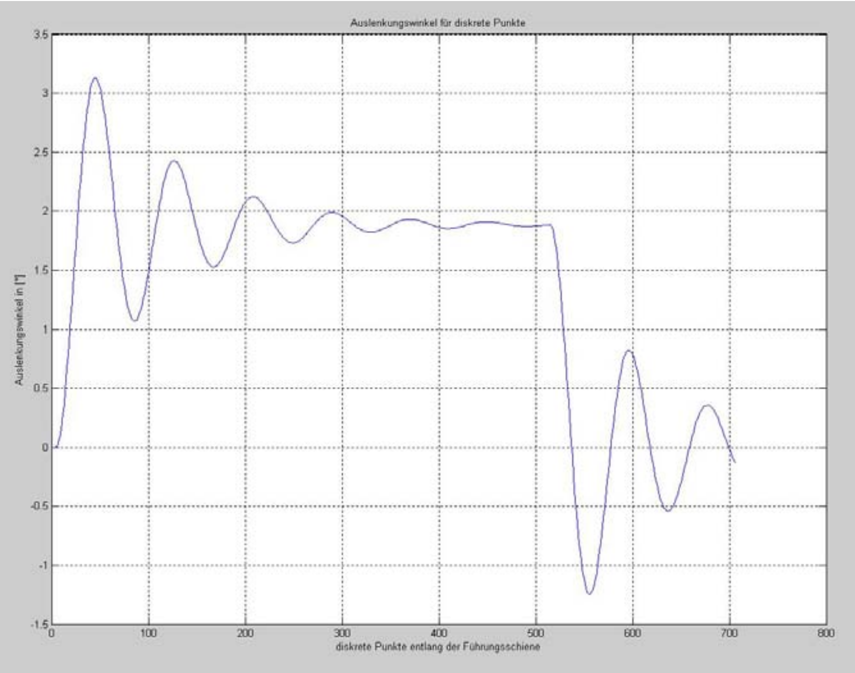

Fig.2: Development of angular deviation φ with time

4. SOFTWARE

The indicated algorithms to detect and avoid possible collisions have been thoroughly programmed and combined in a prototype software KOSIMU (Auer 2005) based on Matlab. By means of this software, which is also laid out to show interim results, numerous simulations were run. Figures 3 to 5 give an impression of important phases explained above.

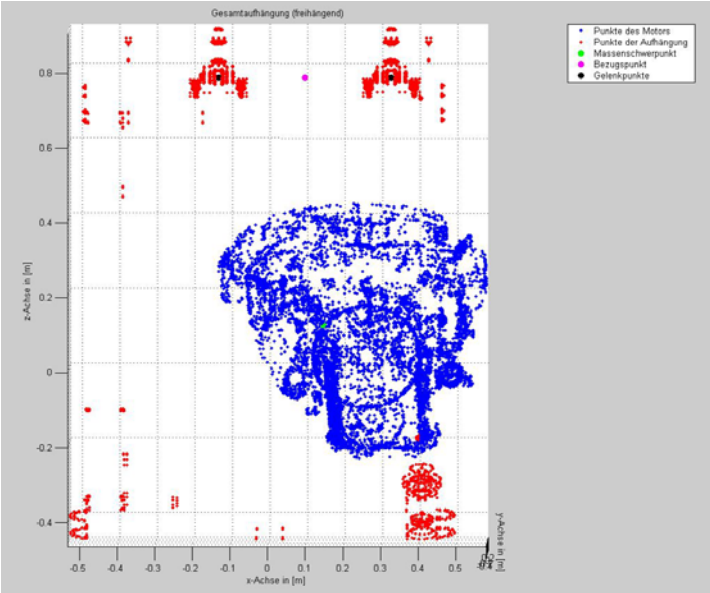

Fig.3: Point clouds of transport object and conveyor (parts) before combination

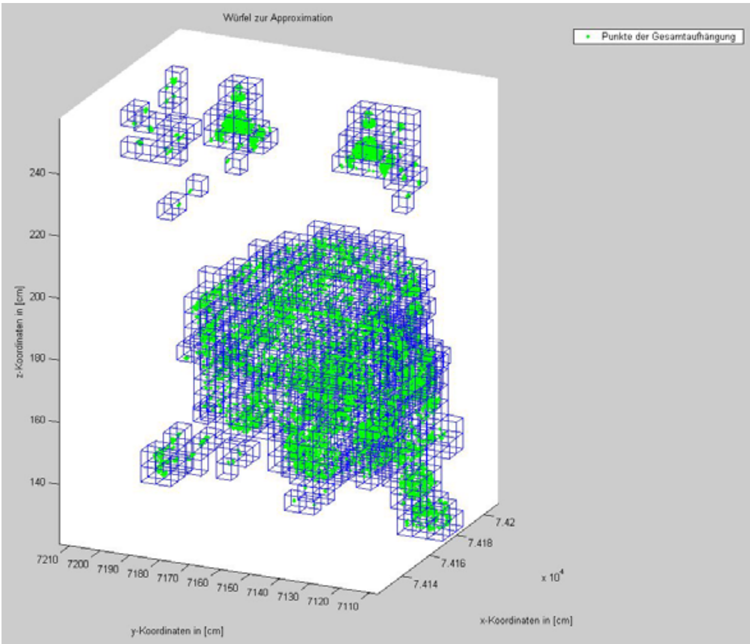

Fig.4: Cube segmentation of combined transport unit

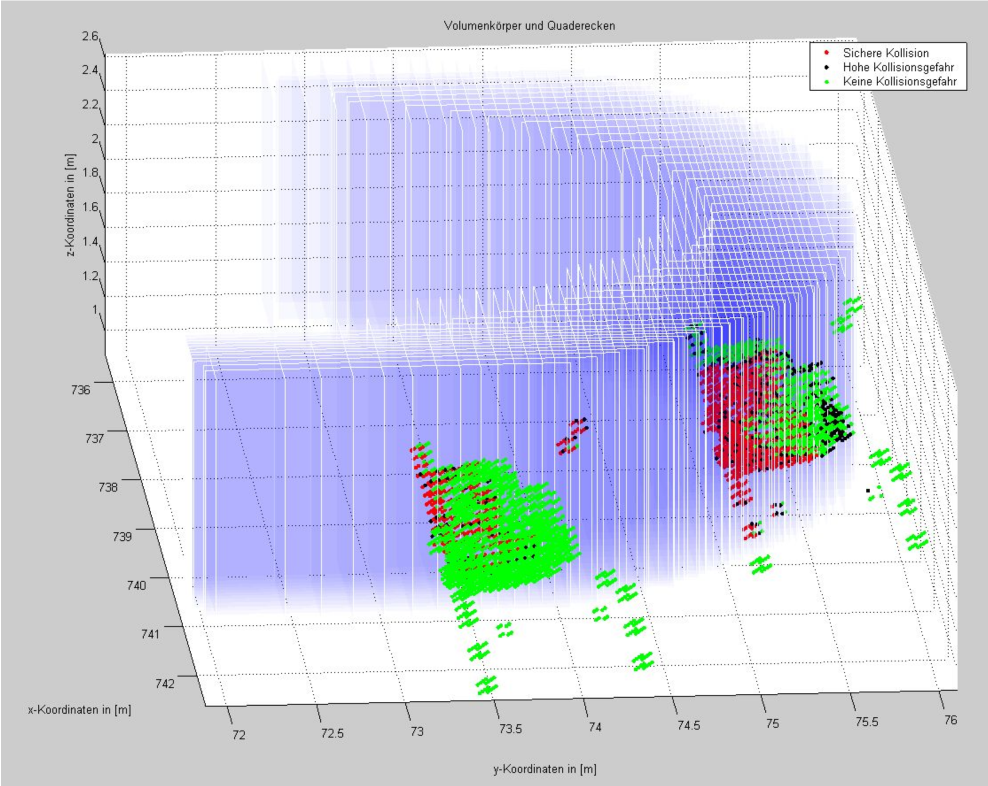

Fig.5: Space of impact along a curved section with intentional severe collisions

By using ever finer cube segmentations KOSIMU proved able to detect in advance even smallest collision or pseudocollision events so that our geodetic concept of collision avoidance is surely capable of protecting transport objects throughout their travel in the plant.

Nevertheless, KOSIMU represents a pure research product. For professional application some operating improvements would be necessary, but the runtime and storage performance has been already optimized to a high degree.

5. OUTLOOK

Future developments aim at expanding the lateral detection concept to along-track prevention of bumping. As it is common that a conveyor reduces its speed before entering a bend, also along-track oscillations will be induced. Under certain condition, e.g. when a conveyor has to stop in a curved section of the tarnsport line, this could provoke a following conveyor's load to (partly) bump into the preceding one waiting in the bend.

Apart from virtual control of industrial transport operations, the concept could also be extended and modified to be used for clearance checking in railway or road tunnels.

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BIOGRAPHICAL NOTES

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