IEEE Catalog Number: 06EX1499C
ISBN: 1-4244-0571-8
Library of Congress: 2006930783

# Proceedings of ROBIO 2006



## IEEE International Conference on

# ROBOTICS & BIOMIMETICS

## Kunming, China, December 17-20, 2006

Co-Sponsors:
IEEE Robotics and Automation Society
Robotics Society of Japan
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Proceedings of the 2006 IEEE
International Conference on Robotics and Biomimetics
December 17 - 20, 2006, Kunming, China

# Throwing Objects – A bio-inspired Approach for the Transportation of Parts*

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**Abstract – In this paper a new way of transporting parts in production systems is described. Based on the fact that in nature the highest speeds are reached at flight, a bio-inspired technical approach for the fast transportation of objects is derived. Objects shall be thrown by a throwing device and are caught again by a catching device. Such a transport approach requires besides proper working throwing and catching devices a high precision object detection mechanism. For object detection a 3D Photonic Mixer Device (PMD) sensor is proposed. By assembling of this sensor on the catching device, it can detect the flying objects on their trajectories like a raptor which is hunting a prey. The technical feasibility of this concept is investigated and possible applications are described.**

***Index Terms: Biomimetics, Transportation, Objects, Throwing, Robot Vision***

## I. Introduction

The permanently existing competitive pressure requires a more and more extensive improvement of their systems from the manufacturers of machines and facilities. An important functional area in this connection is the material flow for the transportation of objects like material, single parts, tools, containers, packages etc. The most important innovation potentials are the acceleration of these actions, the improvement of the environmental compatibility as well as the cost reduction for the realization of such systems.

In current production different conveyors and vehicles are used for transporting parts from one station to the other. Fig. 1 shows as an example the transportation of parts within a current flexible manufacturing system (FMS) [1], [2]. A rail-guided vehicle enables the transportation between the machines in all possible processing sequences. If the working-times of the parts are short, the transportation has to be done on pallets in units of several parts. Such systems have the following problems:

- The material flow within the manufacturing system is discontinuous.
- The in-process inventory is high and the throughput time of a single part through the system is long.
- High investments are required for the transportation system (rail-guided vehicle, different pallets for different parts and loading/unloading stations at the machines).

In this paper a novel bio-inspired approach for the transportation of parts is described.

## II. Biomimetic Considerations

In nature the fastest land animals are the cheetah and the fastest fishes are the sail fish. Both can reach speeds up to 100 km/h. Birds reach even much higher speeds. In a horizontal flight a swift can reach up to 200 km/h and in a dive the peregrine can be up to 300 km/h [3]. Obviously flying animals reach the fastest speeds.

As well human beings have realized very early in their history, that they can improve their hunting success tremendously by using fast flying objects like shafts or catapults. To further

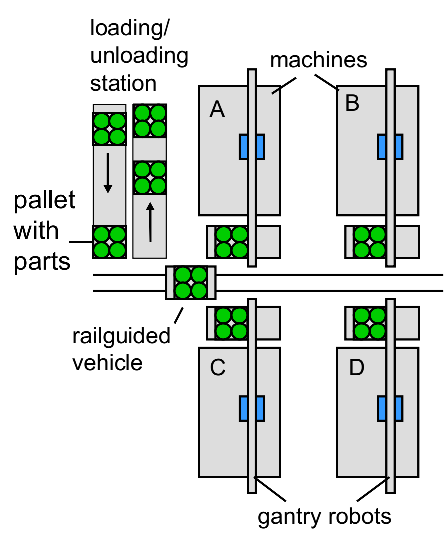



Fig. 1: Traditional Part Flow in FMS

* This work is partially supported by the company of ifm-electronic, Essen and the Foundation for the promotion of the Reinhold Würth-University of the University Heilbronn in Künzelsau.

increase the speed, men later invented arrow and arch (Fig. 2) as well as fire arms.

As a conclusion of these observations in nature it can be reasoned, that the fastest and most efficient movement type for objects is flying by throwing or shooting. The term biomimetics means to learn from nature as stimulation for an independent technological design [5].

In nature there exist different methods for throwing or shooting objects. Examples are:

- Dehiscent fruits use the gravitation to move on in a trajectory.
- Catapult plants use pre-stressed carpels to eject their seeds up to 5 m.
- Archerfishes can shoot insects, which are out of the water, with a water jet over a distance of up to 1 m. With their palate and their tongue they therefore make a kind of blowgun.
- Jellyfishes can discharge nematocysts with a hydraulic pressure of up to 150 bar and accelerate them to speeds up to 250 km/h.

Versatile technical solutions for throwing or shooting objects already exist. It can be assumed that this sub-function is also applicable for the transportation of objects in a material flow.

## III. Problem Analysis

Based on the demand of accelerating the speed of the production flow we propose a reduction of the transport time by throwing parts. Fig. 3 shows the new realization approach for the transportation of parts within a flexible manufacturing system. By throwing the parts directly between the machines all possible processing sequences can be enabled also. With that a continuous material flow with few in-process inventory and short throughput times can be achieved at low investments.

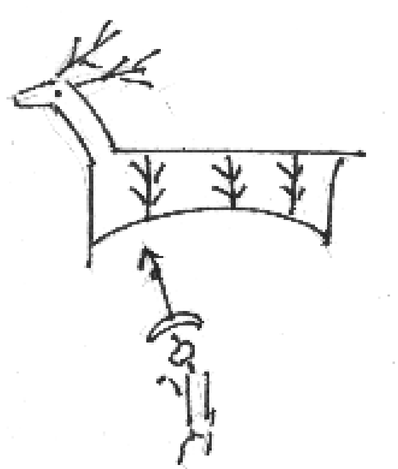


Fig. 2: Prehistoric rock painting [4]

The challenges of the new systems are:

- It is a completely new approach for the transportation of parts. No experiences are existing up to now.
- Challenges which should be solvable short-term:
    - throwing of the parts,
    - detecting the parts on their trajectory,
    - tracking of the catching device.
- Challenges which need some more research-work:
    - detecting the orientation of the objects just before catching,
    - catching the parts within a very short time (few milliseconds).

The basic flow of that transportation approach can be subdivided according Fig. 4 into four sub-functions:

- Throwing or shooting of an object,
- Detecting the object on its trajectory,
- Tracking of the catching-device and
- Catching of the object.

### A. *Detecting of Objects on their Trajectory*

When throwing objects, which are unsymmetrical and not absolute identical, their trajectories are depending on some very sensitive influences, so that they cannot be exactly predicted. Examples are different conditions during the acceleration, the influence of the gravitation and the aerodynamic resistance. For catching the objects, the trajectory of the objects therefore must be observed online during the flight.

Up to now two different principles have been taken over from nature to techniques for this sub-function. At first the vision is

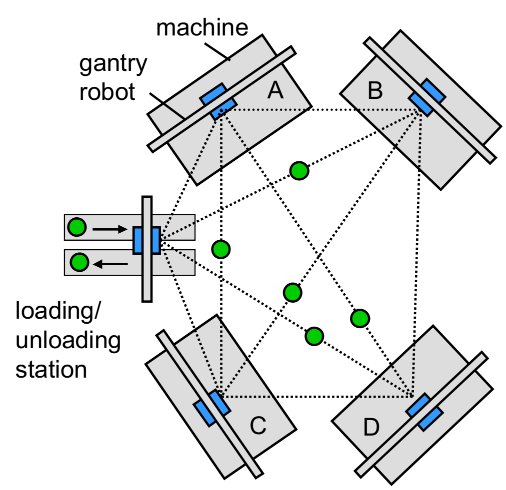



Fig. 3: New Approach for the transportation of parts within a FMS by throwing

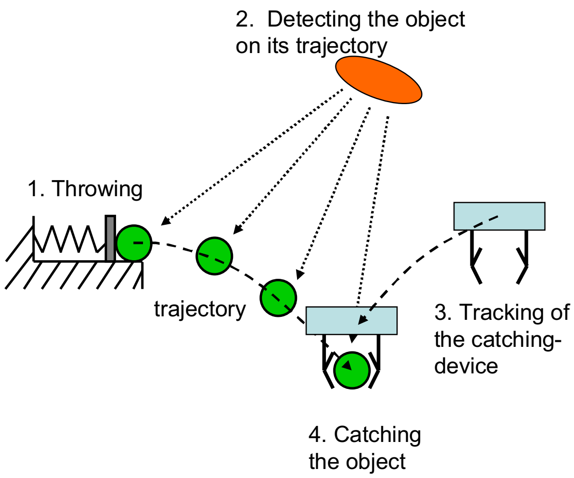



Fig. 4: Functional areas for the transportation of parts by throwing

replaced by cameras. By using dual vision cameras and the method of triangulation a spatial vision can be realized [6]. Second the echolation of whales and bats has been technically realized by the run-time of ultrasonic- or laser-signals.

Interesting in this context is a new 3D video range camera, which combines both the optical detection and the echolation (see Fig. 5) [7], [8]. It is comprised of a high-speed 3D-camera based on a 64 x 48 pixel Photonic Mixer Device (PMD) sensor array, and enables 3D distance measurements to be made with 50 frames per second. Distance data is acquired using the "time-of flight" principle with invisible Near-Infra-Red (NIR) light. The resolution of measured distances is about 6 mm.
Each pixel simultaneously delivers distance information, distance resolution and greyscale information.
One of the key features of the camera is the active suppression of background illumination for each pixel. These PMD-Opto-ICs "see" only their own active illumination, and are not affected by ambient light, including sunlight.
For the online-detection of flying objects in a 3D-space it has the following advantages:

- For the detection of the position of an object only one camera is required.
- It is robust regarding the illumination.
- The distance-information can be acquired over a wide range without optical adjustments.
- The 3D-camera has a competitive price.

### *B. Tracking the Catching-Device*

The tracking of objects can be watched in nature for example with birds of prey [9]. The view of the hunting bird is thereby always targeted directly to the prey. At evasive movements the bird of prey realigns its movement direction permanently.

Fig. 5: 3D video range camera

A technical realization of this behaviour will be described and investigated in chapter IV.

### *C .Catching the Objects*

For grasping of objects in nature there also exist various solutions. Examples are the suckers of the great diving beetle, the tentacles of sarcophagous plants and the claws of birds of prey.

One of the most flexible grasping-tool in nature is the human hand. Already young children practice their abilities with their hands when catching subjects. During a TV-show a very well trained adult was able to catch tennis-balls at a speed of 100 km/h. Today there already exist various realizations of artificial hands which can e.g. close their fingers within 0.1s [10].

## IV. REALIZATION APPROACH

### *A. Basic Concept*

Based on the biomimetical considerations in the previous chapter, the described subsystems can be combined to a concept for a material flow system. In Fig. 6 such a concept for the transportation of objects by throwing is described.

The objects to be transported are thrown in the x-direction. So the "prey-objects" always fly, in contrast to nature, towards the catching device. Since the catching device has to follow the object only relatively, just two motion-axes (in y- and z-direction) are required for its movement.

For the detection of the objects on their trajectories, the already described 3D video range camera shall be arranged on the top of the catching device. So it will follow the flying

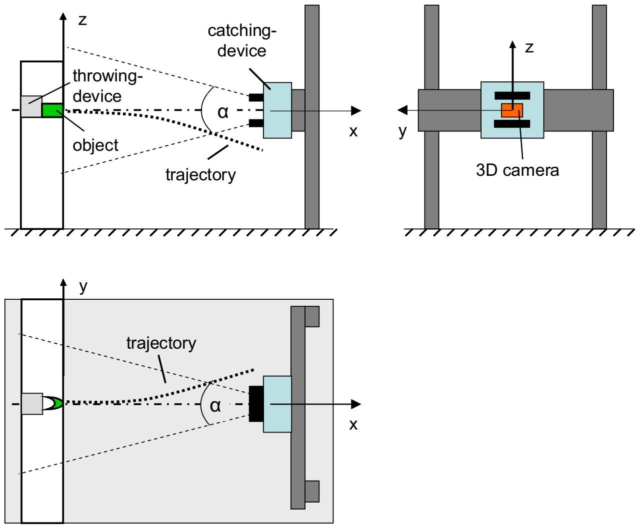



Fig. 6: Configuration for throwing objects (example)

objects together with the catching device. The relative movement between the catching device and the object corresponds to the movements of a bird of prey when hunting a prey (see Fig. 7). A special advantage of this arrangement is, while the catching device and the object are approaching, that the object can be detected like in nature with an increasing precision.

*B. Investigation of the Technical Feasibility*

The technical feasibility of the described basic concept was exemplified by throwing an electrical terminal block. This object was thrown several times by a throwing device. The trajectories were recorded by a high speed camera. In Fig. 8 the two most deviating trajectories are shown. For a flight in the x-direction over a distance of 3000 mm the flight time was about 300 ms. At its destination a deviation in the z-axis of $\Delta z \approx 120$ mm was measured.

The technical specifications of the 3D video range camera are as follows [8]:

- Resolution in the yz-plane: 64 x 48 pixels
- Field of view: 40° at f = 12 mm
- Measuring distances in x-direction: 20 … 3000 mm
- Resolution in x-direction: 6 mm
- Frame rate: 50 fps

With a flight time of 300 ms 15 positions can be collected with this camera. So the position of the terminal block can be detected on its trajectory in distance-intervals of $\Delta s \approx 200$ mm.

For the analysis of the accuracy the trajectory can be idealized as a straight line on the x-axis (Fig. 9).
The 3D video range camera can detect the flying object within its field of observation in intervals of $\Delta t = 20$ ms respectively

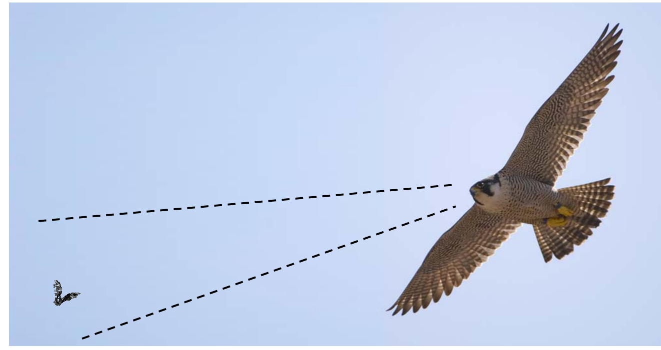
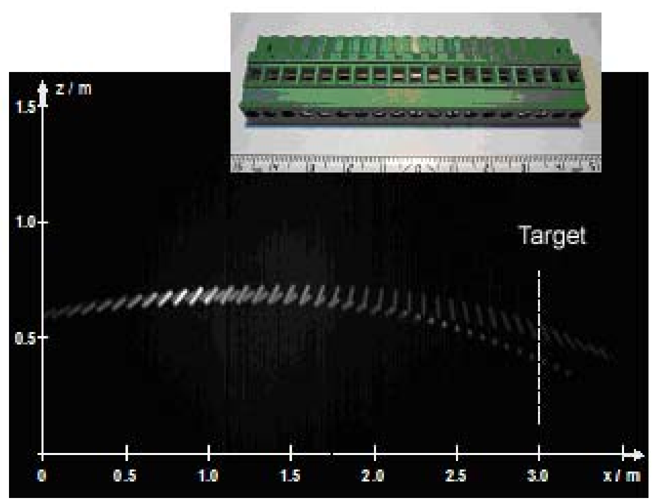


Fig. 7: Peregrine in flight

$\Delta x \approx 200$ mm. The accuracies of measurement which can be achieved depend on the distance of the object to the camera (a). In table 1 the side lengths of the field of observation $\Delta y$ and $\Delta z$ as well as of one single pixel ($\Delta p$) are listed in dependence of this distance a. With these values the achievable accuracies of measurement are shown in Fig. 10 for the example of a ball-shaped object with a diameter of 70 mm (i.e. a tennis ball) at four different distances.

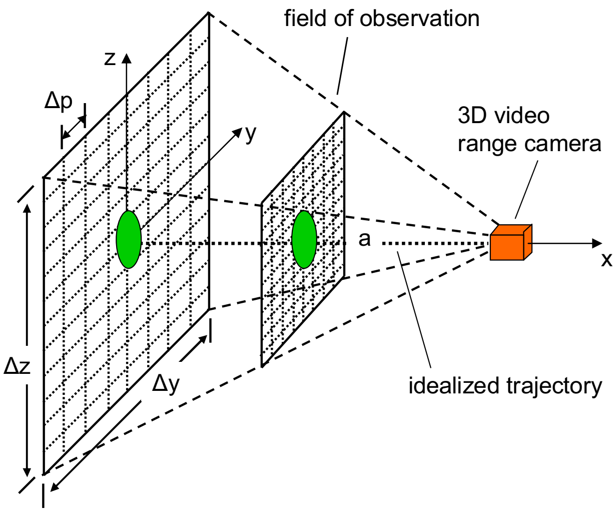
It shows that such an object can be detected at the starting position in a distance of 3000 mm with only four pixels. When the object approaches to the camera it can be detected with an increasing number of pixels. So the position can be measured with an increasing accuracy.

This investigation shows, that the considered camera allows a fast and accurate detection of an object on its trajectory. By using a robot with dynamic NC-axes the tracking of the catching device can also be realized. This was already shown in different scientific experiments [6], [10], [11].




Duration of flight from x = 0 m to x = 3 m: $\Delta t = 336$ ms
Deviation at x = 3 m: $\Delta z \approx 120$ mm

Fig. 8: Two trajectories of a terminal block




3D video range camera:
- field of view: 40°
- resolution: y: 64 pixel
  z: 48 pixel

Fig. 9: Idealized trajectory of an object in the field of observation of a 3D video range camera

For the sub-function of catching the objects special solutions still need to be found. This applies to both the consideration of the object-orientation during catching and for the required speeds of the grippers.

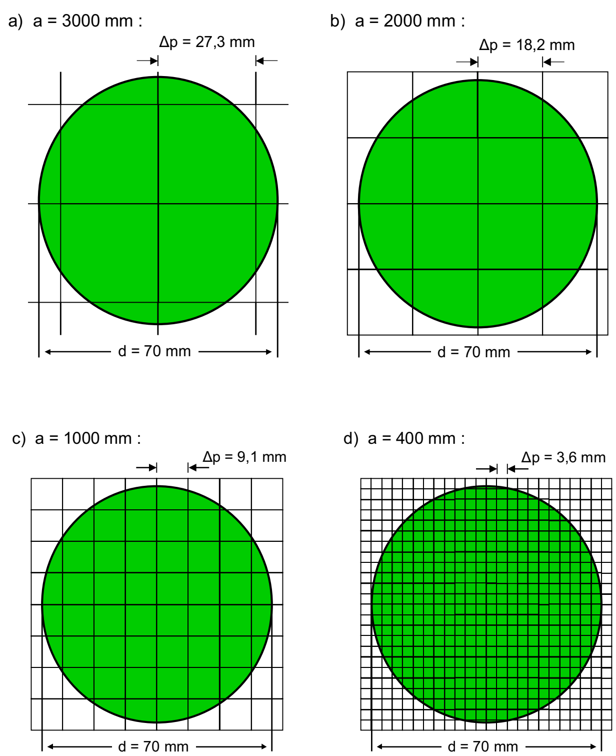



Fig. 10: Resolutions for the detection of an object with an diameter of 70 mm in different distances a to the camera

| | | | Dist. | | Field of observ. | | |
|---|---|---|---|---|---|---|---|
| No. | t | x-Pos. | a | $\Delta p$ | $\Delta y$ / mm | $\Delta z$ / mm | r |
| | [ms] | [mm] | [mm] | [mm] | [mm] | [mm] | |
| 1 | 0 | 0 | 3000 | 27,3 | 1747,1 | 1310,3 | 5,2 |
| 2 | 20 | 200 | 2800 | 25,5 | 1630,6 | 1222,9 | 5,9 |
| 3 | 40 | 400 | 2600 | 23,7 | 1514,1 | 1135,6 | 6,9 |
| 4 | 60 | 600 | 2400 | 21,8 | 1397,6 | 1048,2 | 8,1 |
| 5 | 80 | 800 | 2200 | 20,0 | 1281,2 | 960,9 | 9,6 |
| 6 | 100 | 1000 | 2000 | 18,2 | 1164,7 | 873,5 | 11,6 |
| 7 | 120 | 1200 | 1800 | 16,4 | 1048,2 | 786,2 | 14,3 |
| 8 | 140 | 1400 | 1600 | 14,6 | 931,8 | 698,8 | 18,2 |
| 9 | 160 | 1600 | 1400 | 12,7 | 815,3 | 611,5 | 23,7 |
| 10 | 180 | 1800 | 1200 | 10,9 | 698,8 | 524,1 | 32,3 |
| 11 | 200 | 2000 | 1000 | 9,1 | 582,4 | 436,8 | 46,5 |
| 12 | 220 | 2200 | 800 | 7,3 | 465,9 | 349,4 | 72,6 |
| 13 | 240 | 2400 | 600 | 5,5 | 349,4 | 262,1 | 129,1 |
| 14 | 260 | 2600 | 400 | 3,6 | 232,9 | 174,7 | 290,5 |
| 15 | 280 | 2800 | 200 | 1,8 | 116,5 | 87,4 | 1162,0 |
| 16 | 300 | 3000 | 0 | | | | |

t: flight-time of an object
x-Pos.: x-Position of the object on an idealized trajectory according to fig. 6
a: distance between the object and the 3D-camera
$\Delta p$: side-length of the field of observation for one pixel at x-Pos.
$\Delta y$: y-side-length of the field of observation at x-Pos.
$\Delta p$: z-side-length of the field of observation at x-Pos.
r: The ratio of the area of a circle with d = 70 mm to the area of a pixel at x-Pos.

Table 1: Dimensions of the yz-plane within the field of observation and of one pixel depending on the distance 'a'

## V. FIELDS OF APPLICATIONS

### *A. Feeding and Transportation of parts to respectively between machines*

Fig. 11 shows as an example the conventional production flow of a manufacturing-line for gears. With the new approach the parts can be thrown from one machine to the other as shown in Fig.12. For this concept the gantry robots as they are already used today, must be upgraded by a 3D-camera, a catching-device and a special control software for the tracking of the catching device.

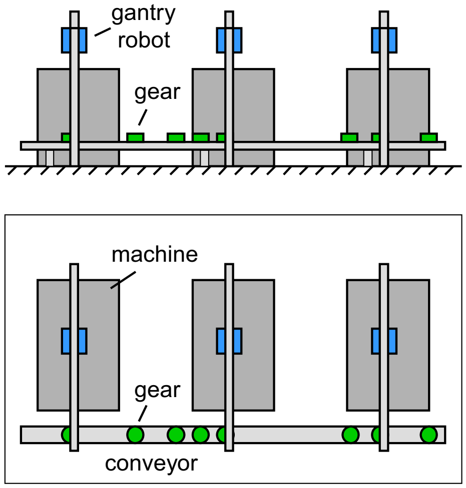



Fig. 11: Conventional transportation of the gears by a conveyor

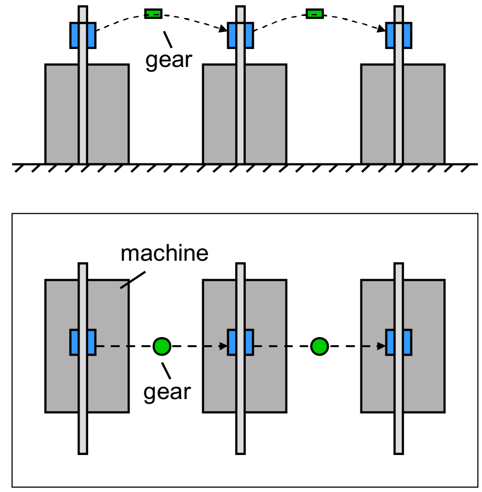



Fig. 12: Transportation of the gears by throwing

By that the following advantages can be achieved:

- A transport system between the machines like a conveyor is not needed.
- No part-specific transport containers are required.
- The transport process will be very fast.

### *B. Further Applications*

With the described realization approach further speculative applications will become possible. Examples are:

- Within a working process flying objects like a shuttle in a weaving machine can be collected.
- In storage-systems parts can be handed over to driving transport systems. So, e.g. time and energy for stopping and accelerating the transport system, can be saved.
- Random orientated objects can be grasped from moving conveyors.
- Falling objects can be collected.
- Objects can be removed from fast flowing liquids.

## VI. CONCLUSION

With the described realization approach, analogue to a wireless data communication, objects can be transported "mechanic-less". So the following general advantages can be achieved for transport processes:

- Less mechanical components are required and so fewer resources are needed.
- Less mechanical devices have to be moved and so energy can be saved.
- The transportation processes can be accelerated and so higher productivities can be reached.

It was shown, that the described realization approach can be basically realized with the technical components available in the field of automation engineering today. The Reinhold-Würth-University in Kuenzelsau, Germany, will keep on developing this realization approach in a scientific project within the next three years

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