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Design and Experimental Testing of a Robotic System for High Speed Recording

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Abstract

The high-speed filming industry sets tasks demanding complex camera movement, such as shooting along a nonlinear trajectory relative to a freely falling body. Such sophisticated requirements can be completed only by means of a mechatronic or robotic system. To solve these problems we have created a robotic system consisting of a 6-DOF industrial robot with a high-speed camera fixed on the flange. In order to ensure precise timing and repeatability of the shooting we have developed a synchronization device and a number of custom automatic dispensers. The prototype was tested with a high-speed camera on a number of real-world tasks with different types of movement.

Keywords: robot; high speed; camera; filming; motion control

1. Introduction

High-speed shooting is an important tool for research in various fields of knowledge. This is used both in science to study fast processes elusive to the human eye, as well as in the entertainment industry for unusual, fascinating shots. However, generally, filming is static, i.e. the camera is not moved during the shooting. The demand for dynamic shooting is mainly experienced by television and the film industry, where there is a specific need to provide the camera motion relative to a moving object. Considering the requirements of repeatability for different takes, for such tasks like combining with computer graphics, shooting along a path with moving camera controlled

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manually is an almost impossible task even at the standard frame rate of 25-30 fps. High-speed shooting with such requirements is possible only by means of mechatronic or robotic systems. The progress in the production of compact high-speed high-resolution cameras in recent years makes this task practically feasible. Robotic systems which include cameras mounted on the flange of the manipulator are used for a number of different tasks such as object tracking [1] or calibration [2]. In the film industry robots have already been used to move cameras in the shooting process for quite some time as well. There are both specialized robots, such as MILO [3] of the MRMC, which have proved themselves on sets all over the world, and specialized robotic systems based on industrial manipulators. In the field of high-speed shooting best known are robotic systems such as SPIKE [4], from The Marmalade, and BOLT [5] from the MRMC, both based on the Staubli industrial robot. These systems allow you to move a high-speed camera during shooting at speeds up to 10 m/s, in the work area with a radius of more than one and a half meters [6]. They are used when computer graphics cannot achieve the required level of authenticity. The main objective of such systems is to provide, complex movements with high precision, synchronized with the movement of the object being filmed. Industrial manipulators are well suited to move the high-speed camera, as they have a high dynamic repeatability and speed. And for difficult tasks such as shooting along a nonlinear path relative to a freely falling body, robots are simply irreplaceable. Our goal was to develop a robotic system capable of working with different models of ABB industrial robots to solve the tasks described above.

2. Design

The robotics system consists of an industrial robot with six degrees of freedom with a high-speed camera fixed on the flange, a multichannel synchronization device and different kind of peripheral equipment, allowing the filmed object to move in sync with the movement of the robot. A structural diagram of the robotic system is shown in Figure 1.

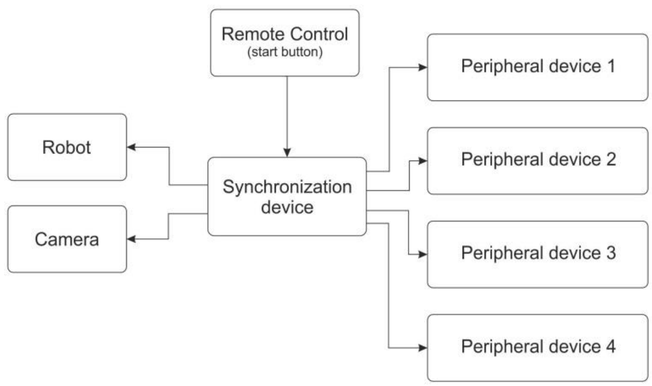

Fig. 1. Structural diagram of the robotic system.

2.1. Synchronization

During the implementation of such shootings arises a problem of synchronous motion of the camera and the object being filmed. Repeatability of the process must also be ensured. To solve these problems, we have developed a multichannel synchronization device (see. fig. 2c) based on an ATmega328p processor with a frequency of 16 MHz. The synchronization device supports up to five independent processes (including the robot with the camera). The control system allows you to set the delay independently for each process, with accuracy up to 1 ms. The device runs specialized peripheral equipment, allowing dropping the object synchronously with the movement of the robot (see. fig. 2 a,b). Delays can be changed promptly using a built-in keypad and are displayed on an integrated screen.

2.2. Peripheral equipment

The system includes three types of additional automatic dispensers for filming. To drop various objects a special gripper with two degrees of freedom is used (see. fig. 2a). Pouring of small objects at different angles is provided by one servo motor controlling a shutter in a dispenser (see. fig. 2b). The third device operates with different liquids and is based on a compact pump.

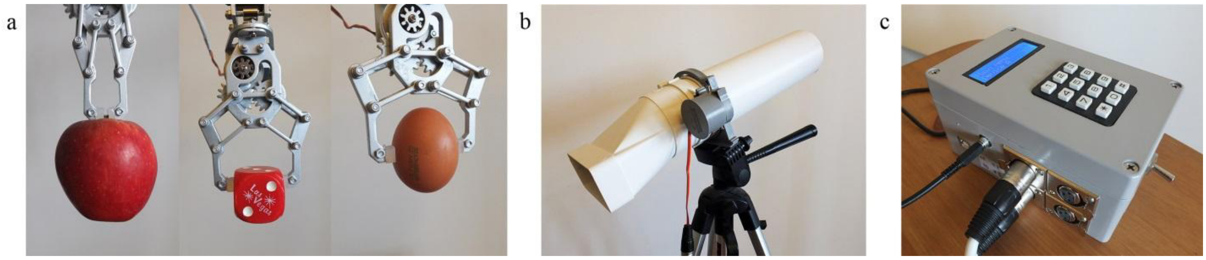

Fig. 2. (a) Special gripper; (b) Dispenser for small objects; (c) Multichannel synchronization device.

2.3. Interpolation

The main feature of the complex is the ability to move the camera with the acceleration of gravity, both along linear and parabolic trajectories. This approach provides shooting a free falling object, keeping it in the center of the frame along a significant section of the trajectory, the length of which is limited only by the maximum possible speed of the robot used (the ABB IRB 140 model was used in the prototype). The robot control program interpolates the motion of an object by key points. In case of a linear fall two points are needed - the start and the end points. In case of arbitrary parabolic motion with a non-zero initial horizontal velocity - three points are enough to define the trajectory. To ensure a complex, composite motion the system will require more key points. Once these are set, the control program calculates the intermediate points of the trajectory with a given time-discrete. An example shows the calculation of the intermediate points in case of a parabolic (ballistic) motion based on three key points - the start P_{start} (x_1, y_1, z_1), auxiliary P_{aux} (x_2, y_2, z_2) and the end point P_{end} (x_3, y_3, z_3). For the convenience of the motion programming, all the intermediate points are given as an offset from the start key point P_{start}.

Step 1. Translating the coordinates to the starting point.

$$x_1' = 0; \quad y_1' = 0; \quad z_1' = 0; \tag{1}$$

$$x_2' = x_2 - x_1; \quad y_2' = y_2 - y_1; \quad z_2' = z_2 - z_1; \tag{2}$$

$$x_3' = x_3 - x_1; \quad y_3' = y_3 - y_1; \quad z_3' = z_3 - z_1; \tag{3}$$

Step 2. Finding the rotation angle of the plane of the parabola to the XZ plane of the robot's coordinate system.

$$\varphi = arctg \frac{x_2'}{y_2'}; \tag{4}$$

Step 3. Rotation of points by an angle φ around the Z axis.

$$x_2'' = x_2' \cdot \cos\varphi - y_2' \cdot \sin\varphi; \quad y_2'' = y_2' \cdot \cos\varphi + x_2' \cdot \sin\varphi; \quad z_2'' = z_2'; \tag{5}$$

$$x_3'' = x_3' \cdot \cos\varphi - y_3' \cdot \sin\varphi; \quad y_3'' = y_3' \cdot \cos\varphi + x_3' \cdot \sin\varphi; \quad z_3'' = z_3'; \tag{6}$$

Step 4. Calculating the coefficients of the parabola $ax^2 + bx$

$$a = \frac{y_3'' - \dfrac{x_3'' \cdot y_2''}{x_2''}}{\dfrac{x_3''}{x_3'' - x_2''}}; \tag{7}$$

$$b = \frac{y_2''}{x_2''} - a \cdot x''; \tag{8}$$

Step 5. The maximum is achieved at the point in the plane XZ

$$z_{\max} = \frac{-b/2}{a}; \tag{9}$$

$$x_{\max} = a \cdot z_{\max}^2 + b \cdot z_{\max}; \tag{10}$$

Step 6. Calculating time in free flight

$$t_{rise} = \sqrt{2 \cdot \frac{z_{\max}}{g}}; \quad t_{fall} = \sqrt{2 \cdot \frac{z_{\max} - z_3''}{g}}; \tag{11}$$

$$t_{sum} = t_{rise} + t_{fall}; \quad t_{dis} = \frac{t_{sum}}{D-1}; \tag{12}$$

where t_{rise} – rise time

t_{fall} – fall time

t_{sum} – total time in flight

g – acceleration of gravity

D – the required number of intermediate points

Step 7. Calculating the coordinates of intermediate points

$$x_i''' = (a \cdot (z_3'' / (D-1) \cdot i)^2 + b \cdot z_3'' / (D-1) \cdot i) \cdot \cos\varphi; \tag{13}$$

$$y_i''' = -z_3'' / (D-1) \cdot i; \tag{14}$$

$$z_i''' = -(a \cdot (z_3'' / (D-1) \cdot i)^2 + b \cdot z_3'' / (D-1) \cdot i) \cdot \sin\varphi; \tag{15}$$

where i – the variable indicating the ordinal number of the intermediate point between 0 and n-1.

The tool central point of the robot (TCP) is configured to be in the focal point of the high-speed camera, which is rigidly fixed on the flange. The approach allows making complex movements around the object even if it is moving, without losing focus.

2.4. Simulation

To perform a virtual test of the trajectories, the 3D-simulator ABB RobotStudio was used. This software is designed for simulation, modeling and offline programming [7]. The build-in Signal Analyzer feature allows investigating the dynamic performance of the robot at a given program of motion. The virtual testing confirms the motion interpolation based on the key points is correct.

3. Experimental testing

A prototype of the robotic system is based on an industrial robot arm ABB IRB 140 with handling capacity of 6 kg, working area radius of 0.81 meters and a maximum speed of 2.5 m/s [8]. The Phantom Miro M / LC310 camera mounted on the flange of the robot, is capable of shooting with a resolution of 1280x800 pixels with a maximum of 3260 fps [9].

The robotic system has been tested on a series of real-world tasks with different types of movement. The shooting was carried out with the highest possible resolution, at a frequency of 1500 frames per second. The figure 3 shows the filming of a falling apple. The frame 3a shows the initial phase of the object being held by the peripheral equipment. At frame 3b you can see the mid-point of the path. Finally the apple falls into a glass cup with water (see Fig. 3c).

Parabolic motion with acceleration of free fall is required, for example, when shooting objects falling with nonzero initial horizontal velocity (see. Fig. 4 a, b, c) or shooting flows of liquid. The figure 5 illustrates the advantages of the multichannel synchronization device. In the scene shown in this figure, three different processes are being filmed at once. The main object being filmed is the falling cherry. In the middle section of the route it is being hit by a stream of water (see. Fig. 5b). At the background is another process – falling small objects. Without precise timing such footage is virtually impossible to shoot, even after spending a lot of time on dozens of different takes.

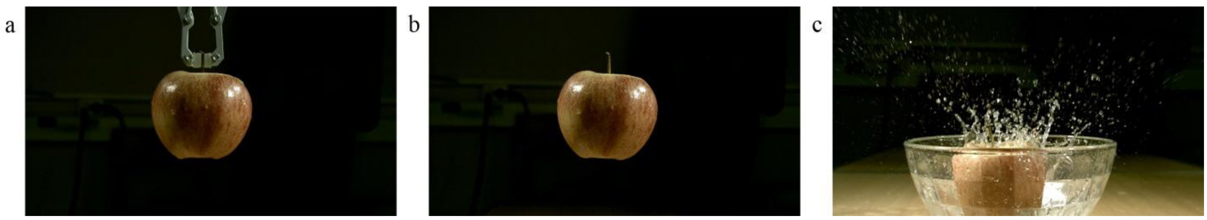

Fig. 3. (a) Linear fall, the object is being held; (b) Linear fall, middle section of the route; (c) Linear fall, end of route.

Fig. 4. (a) Parabolic motion, start; (b) Parabolic motion, mid-point; (c) Parabolic motion, end.

Fig. 5. (a) Multiple process, object is being held; (b) Multiple process, water hits object; (c) Multiple process, final frame.

4. Conclusion

A prototype of a robotic high speed filming system capable of synchronized shooting along complex paths was build. Experimental testing revealed that the prototype fully complies with the stated objectives and therefore can be used in the modern film industry with a wide range of high-speed cameras and robots.

We have designed the controlling software and the peripheral equipment in such an open way that, if necessary, industrial robots with greater working area or dynamics and payload can be used [10].

As a part of the further development, we plan to use additional servos to control the focus and the zoom of the high-speed camera using the capabilities of the industrial robot controller and as well to build a number of additional automated dispensers.

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