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TraSe: Real-time two-dimensional ball tracking and control system

M Mednis[1,2], S Vilums[1,2] and E Stalidzans[1,3]

Abstract

A low-cost real-time two-dimensional PC-based ball tracking and control laboratory system is developed to teach real-time control system development with a real physical system instead of computer simulation. The system can be used for a single-student or a two-student competition for the best control algorithm. Training can be given on pattern recognition, modelling, stepper motor control, control strategies and other aspects.

Keywords

Real-time, modelling, pattern recognition, control

Introduction

Real-time computing is an enabling technology for many important application areas, including process control, nuclear power plants, agile manufacturing, intelligent vehicle highway systems, avionics, air-traffic control, telecommunications, multimedia, real-time simulation, virtual reality, medical applications (e.g. telemedicine and intensive-care monitoring) and defence applications (e.g. command, control and communications).[1]

Education of various aspects of real-time computing with real, physical system experience is a valuable approach[2–5] connected usually with limitations to have

[1]Biosystems Group, Faculty of Information Technology, Latvia University of Agriculture, Jelgava, Latvia
[2]Computer Control Systems Group, Faculty of Information Technology, Latvia University of Agriculture, Jelgava, Latvia
[3]SIA TIBIT, Ozolnieki, Ozolnieku novads, Latvia

Corresponding author:
S Vilums, Faculty of Information Technology, Latvia University of Agriculture, Liela iela 2, Jelgava, LV 3001, Latvia.
Email: sandis.vilums@gmail.com

access to real-life systems during studies because of safety issues and expenses. Therefore, usually computer simulations and modelling replace real environment during education. Advantages of virtual (simulated) application cases in education are low costs, instant availability, no wear-out, no limitations regarding the complexity of processes to be analysed and are described in literature.[6–8] Disadvantages of this approach are lost sense of reality and limited creativity in generation of realistic system's perturbations (real process simulators).

An alternative to get impression of computer applications in real-time applications are laboratory systems with real physical processes. This approach has following advantages: (1) gives impression of consequences in case of control failure, (2) demonstrates process fragility and low repeatability and (3) allows separation of the controlled process and computer-driven control process. Disadvantages of this kind of laboratory systems are higher development costs (compared to computer simulations), maintenance costs and sensitivity to damages. These kinds of laboratory systems[9] are not widely described in the literature.

This paper concentrates on two-dimensional real-time ball tracking laboratory system for educational purposes in the fields of information technology and control engineering. This class of tasks is related to wide range of practical and educational applications.

Two-dimensional real-time tracking is applied in video analysing of the traffic,[10–12] robot control[13–16] and other fields. Real-time ball tracking in three dimensions is applied in medical applications to follow a spherical marker of a tumor[17,18] as well as to follow lung cancer[19] within radiotherapy. Three-dimensional ball tracking is applied also in case of several sports as soccer,[20–24] tennis[25,26] and table tennis.[27]

A two-dimensional ball tracking laboratory system, TraSe, is built for educational purposes to teach the development of object recognition and trajectory forecast real-time software. The laboratory system consists of a flat horizontal table with two horizontally rotating stopper mechanisms that release the balls that roll on the flat surface and captured by a web cam that is located above. Different trajectory recognition and forecast tasks can be performed by a computer that controls all the mentioned components.

TraSe can be used in the educational process to demonstrate the complexity of a real-time control task that include image processing, pattern recognition, modelling, simulation and communication with executing devices under time pressure determined by the speed of a rolling ball. The task has to be performed taking into account imperfections of real-life systems (table is not completely flat and smooth, the ball is not exactly round, and its gravity centre is not always in the middle). Insufficient time for calculations and control actions force the students to apply different mathematical and programming tricks to fulfil the task within limited time and with limited calculation resources. A typical PC is used as a control system. The control system communicates with the web cam via USB port. The rotation and release of stopper mechanism is performed via parallel port.

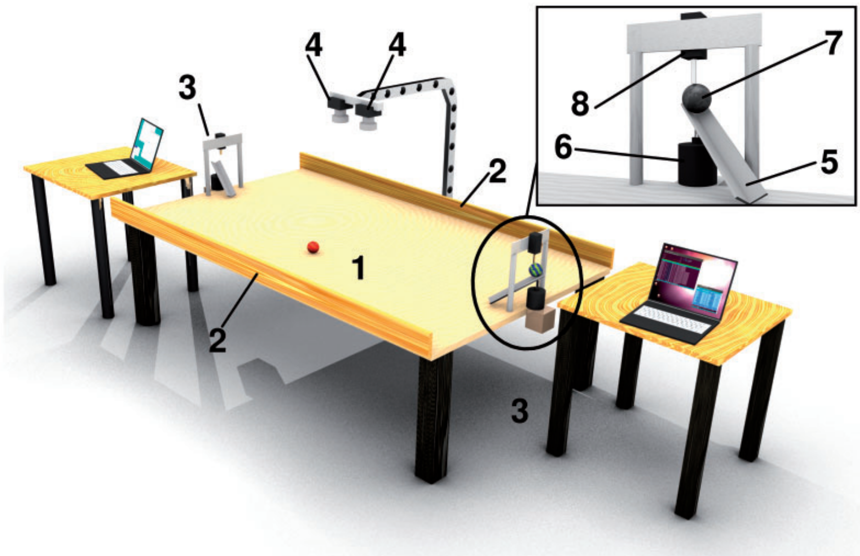

Figure 1. Training set TraSe. (1) table, (2) two side guards on the long sides of the table, (3) two starter mechanisms, (4) web cam, (5) trough, (6) stepper motor, (7) ball, (8) stopper mechanism.

The laboratory system TraSe is a relatively simple real-world complexity trainer that uses the physics of a rolling ball to teach complex real-time control development process using experiments with duration of several seconds. TraSe enables also competitions of students that makes the educational process much more attractive and in this aspect can be compared with robot fight.[28–30]

Construction of laboratory system TraSe

The developed laboratory system TraSe uses the feature of a rolling ball to keep the direction on a horizontal surface. That feature is used for instance in the well-known table games ‘snooker’ and ‘billiards’.

Several features of rolling balls and predictable outcomes of their collision can be applied in teaching computer control tasks: (1) the process is slow enough to be well observed by students and quick enough to make several exercises during 5 min, (2) this is a low-cost system as it can be set up at any table in a short time using a moderate performance desktop computer.

TraSe (Figure 1) consists of table (1) with two side guards on the long sides of the table (2), two computer-controlled ball starter mechanisms (3) one on each short side of the table. The table surface is observed by a web cam (4) that is located above the table and the pictures are available to the computers of both starter mechanisms.

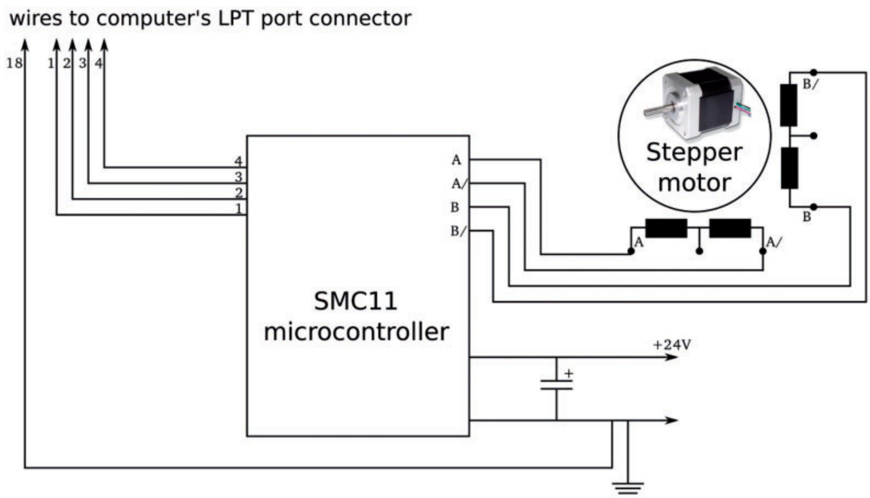

Figure 2. Stepper motor and controller connection scheme via parallel port (LPT). LPT: line print terminal.

Starter mechanisms are fixed on the table and consist of a trough (5) that is fixed on the shaft of a computer-controlled motor (6). The trough is inclined towards the table to allow the ball (7) roll on the table under gravity with highly repeatable speed. Rolling of the ball is started after release of stopper mechanism (8). Motor allows change the horizontal start angle of the ball within $\pm 90^{\circ}$. Starter mechanisms are fully controlled by a computer (start angle and start time). The ball has to be put manually on the trough.

The stepper motor *Nanotec ST4209M1206-B* in the circuit has been wired in bipolar serial connection via controller *Nanotec SMC11* (see http://de.nanotec.com/). The stopper mechanism consists of two DC resistances, one transistor, one diode and one linear D-Frame solenoid. The control of stepper motor and stopper mechanism is performed via parallel port (Figures 2 and 3)

For the computational purposes the ordinary desktop computer was chosen. The very first TraSe software version (also mentioned on YouTube video (https://youtu.be/l0bjPSnOj7M) capable of successful defense in 5 of 10 cases was running on the computer with the following key parameters: 2.0 GHz single core processor, 1 GB of RAM. The software was developed on Ubuntu and written in GNU C++.

The criteria for camera selection were: easily connected to the computer and well supported by v4l (video for Linux) or later version. The Z-Star Microelectronics ZC0305 Webcam was used.

Educational game

TraSe is developed as a game for two players who compete implementing different control algorithms for their control program in the programming language of their

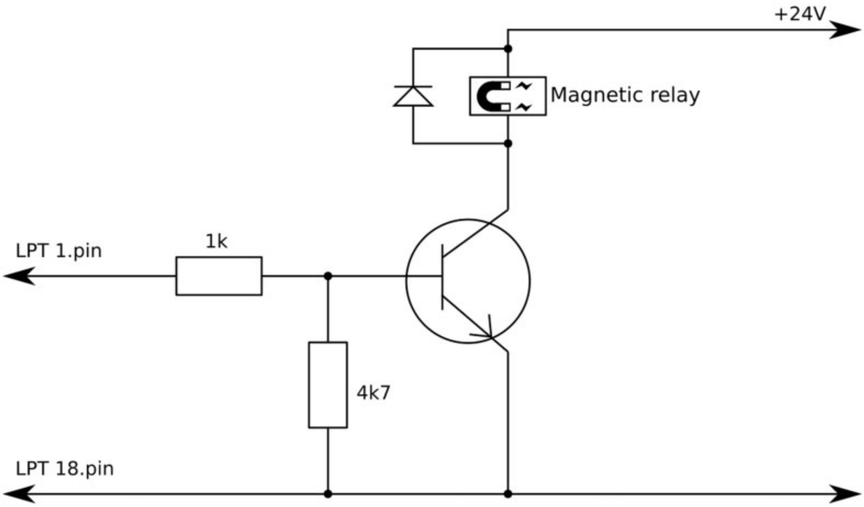

Figure 3. Electrical scheme for the amplification of signal for starter mechanism (magnetic relay) and connection to LPT.
LPT: line print terminal.

choice. The computer and starter mechanisms have to act without help of players during the game.

One of players is called *Initiator*. His task is during his the attack session get as many balls as possible out of 10 to fall over the opposite short side of the table that is defended by *Defender's* starter mechanism. *Initiator* can choose direction of rolling ball by controlling the stepper motor of stopper device and the start moment by giving 'release' signal to the stopper mechanism. *Initiator* algorithm can use signal from Webcam to adjust its strategy to avoid his ball being hit by *Defender's* ball.

Defender should forecast the trajectory of rolling *Initiator's* ball using signal from web cam and plan trajectory of his own ball so that balls hit each other and *Initiator's* ball would not fall over the *Defender's* short side of the table (Figure 4(a)). To realise the collision of balls, the *Defender* has to forecast trajectories of both balls, execute turning of his start mechanism and release of stopper mechanism in the right time moment. Otherwise the *Initiator's* ball will not be hit and will reach its goal – opposite short side of the table.

After some number of *Initiator's* attacks the players change their tasks and former *Initiator* becomes *Defender* and vice versa.

This intellectual control game sets a task for *Defender* to use in a rational way his resources (time and technical means with given limitations of stepper motor and stopper mechanism). Several strategies can be applied: good prediction of trajectory of the *Initiator's* ball is precondition for later collision of balls. Unfortunately, good prediction takes time for processing of video signal and calculations causing lack of time to turn the starter mechanism to the calculated start angle and release

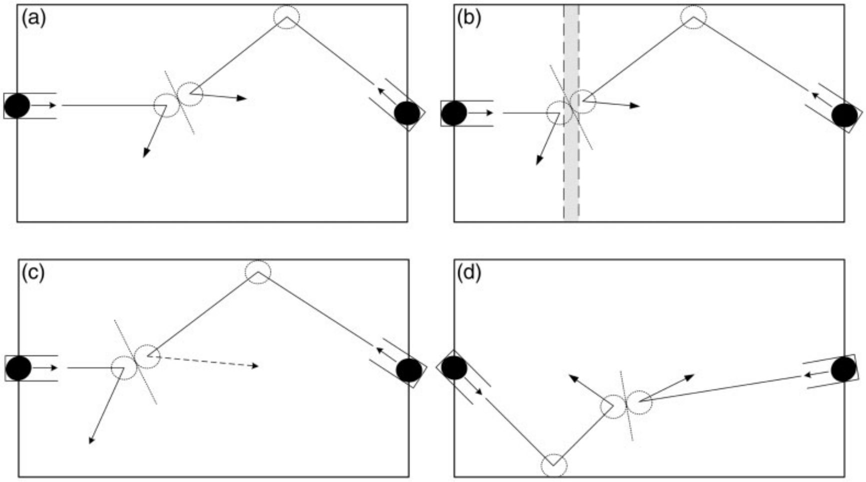

Figure 4. Tasks with increased complexity for two players (Defender is on the left side and Initiator is on the right side): (a) hit the Initiator's ball, (b) predefined collision line, (c) planed trajectory (dashed line) of the Initiator's ball, (d) hit after Defender's ball recoils off the wall.

the ball. A compromise has to be found by reactor to reach the goal: prevent the Initiators ball to cross defended short side of the table.

Complexity of TraSe soccer can be increased in case of two players: (1) hit the ball within predefined zone (Figure 4(b)), (2) predefined direction of the Initiators ball after the collision (Figure 4(c)), (3) hit after *Defender's* ball has touched the wall (Figure 4(d)) and so on.

Individual tasks on TraSe

Single-player tasks can be generated on TraSe. The *Initiator* can be replaced by special function or a random number generator of the start angle of the ball. This mode can be used as a separate task or as a training phase for the soccer game. To increase the complexity of the trajectory forecast tasks, there are several possible variations of TraSe (Figure 5) that can be applied in different combinations: (1) changes of trough angle influencing the speed of the ball, (2) slightly damaged ball (Figure 5(a)), (3) table under angle (Figure 5(b)), (4) Camera-visible obstacles (Figure 5(c)) and (5) Camera-invisible (transparent) obstacles (Figure 5(d)).

That allows creation of interesting tasks even for a single player: (1) determination of trough angle, (2) forecast of the trajectory by speed and direction, (3) determination of the table angle by the trajectory of the ball, (4) avoiding visible obstacles on the way of the ball and (5) scanning of invisible obstacles by registering changes of the ball trajectory.

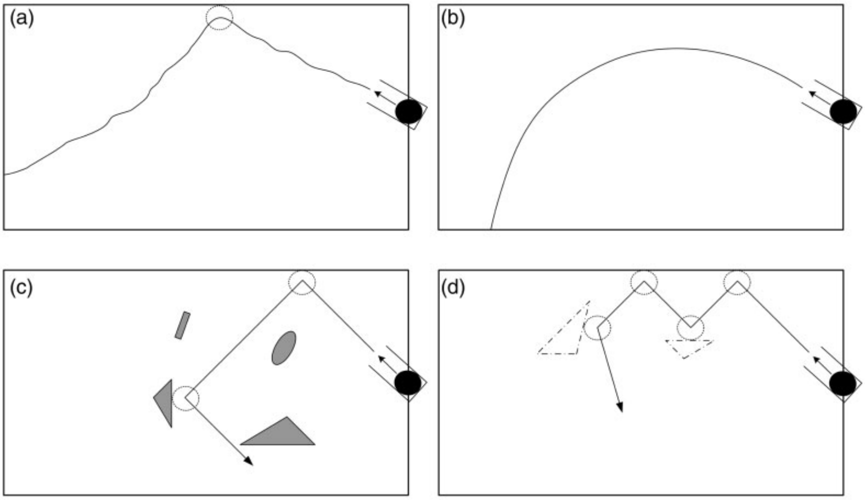

Figure 5. Different tasks that can be performed on TraSe: (a) damaged ball (b) table under angle, (c) camera-visible obstacles, (d) camera-invisible obstacles.

Educational applications of TraSe control development

The main educational value of TraSe is the possibility to demonstrate the process of real-time control development for a simple real physically occurring process. Different tasks can be performed separately and simultaneously.

Pattern recognition

Recognition of a rolling ball by a web cam under limitations of computational power and time, forces to choose the best performing algorithm to be implemented in the program and analyse computational costs of any action performed by the program.TraSe programmers can use a vast array of available image pattern recognition algorithms.[31] However, the authors have implemented and tested a method of continuous subtraction of two consecutive images from the camera. The chosen method gives almost monochromatic image where it is easy to locate the brightest and darkest spot indicating two positions of the rolling ball – the present and past. This approach avoids the use of computationally expensive pattern recognition algorithms.

Modelling of ball trajectory

The mathematical background of ball trajectory model is based on ball trajectory and speed analysis from image analysis. We propose to base the forecasts on two consecutive images (capture moments have to be known) taken as early as possible when the ball has reached the table surface (trough caused acceleration process is over and speed will stay relatively constant). The distance of ball location on images divided by difference in time between image capturing gives the initial speed of the ball. The trajectory is a line through ball locations on images. In case the trajectory is hitting the side guard, the reflection angle has to be assessed.

The above described procedure would be relatively simple task if the ball is round and table is ideally flat. Usually that is not the case and it has to be taken into account assessing the accuracy of the forecasted trajectory. Several strategies can be performed: mathematical modelling trying to assess the effect of imperfections of the system or collecting of trajectories in the database to search the most similar scenario when the ball is recognized. Instead of complex calculations, we suggest to implement experimentally developed function of reflection angle dependence on start angle. Artificial intelligence methods can be applied as well in case of sufficient computational power.

In case if the ball hits the side guard, even more uncertainty comes into play as the collision of the side guard gives a horizontal rotation impulse. Thus, the reflection angle is influenced by several physical interactions between the ball, table and side guard.

Calculation of the collision point and time

Forecast of the trajectory of rolling ball of the Initiator is a prerequisite for calculation of the collision point where the Defender's ball should hit the Initiator's ball. This real-time task has to take into account the models of rolling balls both of the Initiator and the Defender. Time for turning of the starter mechanism also has to be taken into account to be able to start Defender's ball in time.

Different strategic decisions can be made depending on the trajectory of the Initiator's ball. Hitting the ball before the collision point of Initiator's ball with the side guard is good approach as the reflection angle calculation becomes unnecessary.

It is easy to hit the ball while it moves towards the starter mechanism of Defender. In this case the release angle is constant, there is more time for calculations, and late release of Defender's ball becomes good strategy. If it is predicted that Initiator's ball will roll towards starter mechanism after collision with side guard, a late release of Defender's ball is a good strategy as well.

Turning of the starter mechanism

Different strategies may be used to turn the starter mechanism: it can be turned once when the collision point and time is calculated or it can be turned after processing of each recalculation of the time point assuring that each iterative step is smaller. Thus, time can be saved by turning the starter mechanism in parallel to calculations of the next iterations. Other strategies can be developed using parallel calculations and actions.

Conclusion

A low-cost real-time two-dimensional PC-based ball tracking and control laboratory system TraSe is developed to teach real-time control system development operating with real physical systems instead of computer simulation in fields of information technology and control engineering.

The main educational value of TraSe is the possibility to demonstrate the process of real-time control development for a simple real-life physical process. The system can be used for educational purposes to demonstrate the complexity of a real-time control task including image processing, pattern recognition, modelling, simulation and communication with executing devices under time pressure determined by the speed of a rolling ball. Educational process can be performed for a single student as well as a competition of two students at different levels of complexity adding additional features or perturbations to the system.

Declaration of Conflicting Interests

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