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Basketball Practice Mechatronic Assistant (BPMA)

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***Abstract*:** *The Basketball Practice Mechatronic Assistant (BPMA) is a relatively small, agile, mobile, mechatronic device which assists an aspiring basketball player, with efficiently improving his or her shooting skills, by choosing an optimized observation location, prior to the shot, observing and anticipating the path of the thrown basketball, intercepting/catching or retrieving it, and rapidly returning it to the shooter, facilitating the rapid completion of a relatively large number of practice shots in minimum time. The robot will be small enough to easily accompany the shooter to different practice locations/courts, by being able to follow the owner/practice shooter to a standard road vehicle, and will be able to be loaded in the vehicle for transportation, or offloaded from the vehicle, by a single person. The robot will be designed to function on flat surfaces, as may be expected on a parking lot, interior floor or court surface, so it will have no extraordinary "off-road" or "steep terrain" capabilities. The default mode of returning the ball to the shooter will be to roll the basketball across the floor, in the direction of the shooter. It is envisioned that in future development, the capability to throw the ball back to the shooter, or throw the ball to "lead" the shooter will be added, but the initial capability of rolling the ball back to the shooter has been chosen with safety in mind. This robot will appeal to a broad population of young athletes, and will be as fun to watch (and "play with") as the family pet dog that retrieves tennis balls for a child.*

Keywords: *Basketball, robot, retrieve, practice, intercept.*

1. Introduction

One of the most important aspects of this mechatronic device, besides performing a specified task, is the appeal of it, on a subjective level, to prospective owners. This mechatronic device needs to be effective at accomplishing it's job, which may be judged with the standard laboratory metrics, but it also needs to convey the qualitative attributes of "fun," "convenience," and hopefully, an anthropometric "personality," which encourages a sense of bonding with the owner/operator. Convenience is also manifested in some of the supporting behaviors of the mechatronic device. These conveniences are the result of the limitations of weight and size. The limitations of weight and size are implied by the scenario that is envisioned. In one scenario, the majority of prospective owners would drive (or be driven,) to the basketball practice court, and would then need to deploy the mechatronic device from a car. This scenario proves the need for limitations to size and weight for the robot, because this mechatronic device must be light enough for the operator to remove from the trunk or back seat of a car. This should be a simple operation, after which, the mechatronic device follows the operator to the basketball court, under it's own power. Also the weight should be limited, so that youthful athletes may use the device. This revisits the classic conflict between energy storage and weight. In this case, we feel that a target weight of approximately 20 kg should not be exceeded, and that a lower weight is extremely desirable. The physical dimensions are also defined by this scenario. This is an important decision, for which market research can provide a more reasoned specification. At this point, we feel that there are a number of children's' toy products which give us a sense of a "convenient" size for the mechatronic device. As examples, there are baby scooters, which parents repeatedly transport by car, and then there are electrically powered children's' "cars," which are popular, but are rarely transported away from the home, due to size and weight. This paper presents the idea of a basketball practice mechatronic assistant and includes the components, features, concerns, the commands and controls, and the tasks of this machine.

2. System Description

2.1 Base Locomotion

The mechatronic device will have a base structure, which will be able to drive on a variety of relatively flat surfaces, accelerating quickly, stopping, and turning. The base must be able to avoid "no-go" areas, and maneuver around persons and other (possibly moving) obstacles. The end effector(s) and sensing apparatus, computing, and control circuitry will be mounted to the mobile base. The mobile base must place the end effector(s) in a position to catch or chase the basketball. The power supply and propulsion apparatus are also parts of the mobile base. The energy storage and propulsion systems are anticipated to be electrical. To attain the desired performance, the base should be wireless. Ideally, the robot would be able to be plugged into any convenient electrical receptacle and quickly recharge.

2.2 Basketball End-Effector(s)

The end effector(s) must do three different jobs, which are to catch the ball, or capture the ball, and propel the ball back to the operator. The difference between catching and capturing the ball is that catching the ball is accomplished by moving the robot to a position where the ball falls directly onto the robot, intercepting the ball in the optimum orientation selected by the robot. Capturing the ball is required when the robot cannot move quickly enough to the intercept the ball, and must chase it, to retrieve it. The challenge with catching the ball is twofold. The trajectory of the ball must be observed, the path to intercept point calculated and driven, while avoiding obstacles, and the end effector oriented to make the catch. Then, since a falling basketball can arrive with considerable kinetic energy, the next concern is dissipating that energy, while making the catch, so the ball does not simply bounce off the robot, or break the robot. In both cases, the subsequent operation is to return the ball to the player. We anticipate developing a default return mode of rolling the ball across the floor, to the player. This will be the default mode, because we would like the robot to initiate play in the safest mode possible. Subsequent play with the experienced operator will include the operator option of changing modes to one of two more advanced techniques. The "Throw" technique will cause the robot to launch the ball toward the operator, on a trajectory to arrive at the operator's position, at chest height. The "Lead" technique will launch the ball toward a position between the operator and the basket, to simulate receiving a pass, in an actual game. Both of these advanced techniques can be activated through an app on your phone. This app will require the owner to enter a unique code that comes with the mechatronic device. This code will ensure that the app will only control the robot that is linked to that unique code. The end-effector for catching the ball can be relatively passive, and can actually harness the kinetic energy of the ball to assist in it's function. The end-effector(s) for capturing a rolling ball, and then rolling or launching the ball would ideally all be accomplished by the same mechanism, instead of three different ones. This is one of our most interesting design challenges.

3. Sensors

3.1 Computer Vision System

The core sensing system of this robot will probably be a pair of digital video cameras, and stereo vision, 3-dimensional computing hardware. All objects, both static and moving will be observed and mapped, using the data from this vision system. The data will be used initially to develop a baseline environmental map of the play space, and then will be used to track the ball, stationary and moving obstacles, and will be used for navigation and location determination.

The challenge of designing a low-cost mechatronic device that can track an airborne, bouncing and/or rolling basketball, demands an analysis of the computer vision task, and optimization analysis of cost versus performance, among the available technologies. As in other computer vision problems, the first consideration is the required field-of-view. If the mechatronic device can be expected to be in any position, on the floor, between the basketball shooter and the hoop, behind the shooter, or behind the backboard, then the mechatronic device will require a view of the entire volume of space, above the playing floor. This entire hemispheric volume may be observed with a single camera, oriented vertically, with a 180 degree fish-eye lens. This is usually NOT the preferred arrangement for tracking random objects in the field-of-view, because it is difficult to extract necessary distance information, to an object, in the field-of-view, from such a single camera.

Our device provides a unique opportunity to use such a simple system, however, due to pre-programmed knowledge of the target object. The dimensions of the basketball are known in advance. The color of the basketball is known in advance of play. (There may a slight difference between college, and professional basketball dimensions, but that can be easily calibrated for, by the owner of the system and basketball.) This is a rare opportunity for a single camera system to track azimuth, elevation and range of a target. The range can be computed, with a very simple algorithm, from the pixel coverage of the ball.

We intend to also investigate the use and integration of alternative/supporting sensors, for both tracking the ball, and avoiding obstacles. While the single sensor camera arrangement may offer an advantage with regard to tracking the ball, avoiding obstacles such as people of different height, in the field of play, or avoiding crashing into a visually featureless wall may require the use of a stereo vision system, possible supplemented with an array of low-cost, acoustic distance sensors.

It will be of great interest to explore the pre-positioning options for the robot (prior to the ball being thrown,) based on the possible sensing apparatus.

3.2 Gyroscope/accelerometers

This type of sensor assists in determining the initial pose and the dynamic stability of the mechatronic device. Motion will not be allowed to commence unless the surface played on is “level” within a specified tolerance. It is also used to anticipate and prevent tip-over, as a result of a high G turn.

3.3 Sonic distance measurement

An acoustic array is used to confirm the location of “hard” obstacles in the vicinity of the mechatronic device, to provide redundancy for safety, and to assist in capture and retrieval of roll-away basketballs.

3.4 Feeler Sensors

The retention of the basketball will also be confirmed by simple on/off switches, which are built into the articulating mechanism of the end effectors.

3.5 Microphone

An audio microphone will be employed to detect voice commands from the operator, which will be interpreted by the computing system.

3.6 Weight

When a basketball is caught or captured, as opposed to bouncing off the machine, its retention will be confirmed by a weight sensor and feeler sensors.

3.7 Voltage/battery

When the energy in the battery is too low, an LED warning light will turn on. The device will shut itself down when the battery voltage becomes too low to reliably operate the computer(s). The low voltage warning will be initiated long enough in advance, that sufficient time is available for the operator to lead the robot to an electrical receptacle, or back to the vehicle used to transport it to the play area.

4. Computing

Due to the demands of a complex 3-dimensional vision and tracking system, combined with a high performance motion control and collision avoidance system, the computing demands will require state-of-the-art, but off-the-shelf computing hardware.

A complete description of the interaction between all the subordinate software modules is beyond the scope of this paper, but the overall goals of those modules are described qualitatively herein.

The first task of the computers is navigation-related. Sensor inputs are used to build a map of the environment that the mechatronic device will be "playing" in. This map will be synthesized from 3-D video information and sonic array information.

Next, the key objects in the environment must be perceived and mapped. These include the human operator, the basketball backboard and hoop, the post which holds up the backboard, the walls and ceiling surrounding the court, in addition to benches and fences. (We look forward to the challenge of discerning the chain-link fences surrounding many outdoor courts.) Last but not least, the basketball itself must be identified and tracked.

Based on the location of the hoop and the shooter, the algorithm must choose an optimized position from which the field-of-view is maximized, while pre-positioning to intercept and catch a ball is also optimized. This location is likely to vary with the individual operator.

Once a shot has been made, there are two phases to the mechatronic device's behavior. It must observe and track the ball, on it's way to the hoop, but must not move toward the end of that parabolic trajectory. It must wait for the path to be altered by the ball bouncing off the backboard or hoop (unless it is discerned that the ball will miss both!)

Once the ball achieves the dynamic state of having no chance to go through the hoop, the mechatronic device must make multiple observations of the ball's position, calculate the rebound trajectory, calculate the best lead pursuit path to intercept the ball, and then move (while avoiding obstacles,) to that intercept position, at maximum speed.

In the final phase, the program controls the capture and confirms the retention of the ball, and then rolls it back toward the shooter. The mechatronic device then moves back to it's optimal observation position.

5. Operation

The mechatronic device will not attempt to intercept or retrieve to ball, if it is anticipated to land in, or roll through, the operator's personal space (no-go area). This will be a circle of approximately 1 meter radius, surrounding the operator, where it is assumed that the operator will simply catch the ball, or pick it up. A subtle programming challenge emerges here, as the robot must anticipate whether a ball is going to roll through, or land in the operator's personal space, and if so, cancel it's primary catch/retrieval operation. In this case it should immediately return to it's optimal observation position. If the ball rolls or bounces through the "no-go area" then the mechatronic device will move to retrieve it.

Other obstacles in the play area have different attributes than the primary operator. They fall into two categories: Fixed structural obstacles and “high-liability obstacles,” that can move, such as other humans, or a pet dog running around the court. The mechatronic device will sense fixed obstacles with it's vision system, backed-up by it's acoustic array. It will avoid those obstacles, but it is not possible to set a fixed radius of avoidance, as is the case with the primary operator, because the robot may need, at times, to press the ball right up against the wall, to capture it. Other soft targets, like people and pets, will have to have an avoidance perimeter calculated for safe operation.

6. Command and Control

It is anticipated that primary power control will be facilitated with an on/off switch. The switch will be guarded, to prevent inadvertent switching from being struck by a basketball.

After power is turned on, the robot will boot and run it's self diagnostics. There will be no immediate motion initiated by any actuator or motor on the robot, although processing of sensor data relating to position sensing will initiate immediately. The robot will signal successful self testing with a green LED light. Ideally, once turned on, the mechatronic device can be operated by voice command. Since it's a wireless machine, it defeats the purpose to add a cabled control module. There should be some control mode and testing functionality facilitated through on-board switchology, but those switches will obviously not be accessible while the mobile robot is moving. For this reason, the robot operator will enable motion of the robot through a “kill-switch” key fob, approximately the size of a car key fob, which can be hung from the operator's belt loop. Movement of the mechatronic device and it's actuators will not be allowed without positive confirmation of wireless connectivity with the key fob. Depressing the main switch button on the key fob will command the robot to immediately decelerate to a safe stop. Voice commands will be used to command the mechatronic device to start playing and to stop playing. Additional voice commands will be used to change between robot behavior modes. For example, the experienced operator may desire the mechatronic device to throw the ball back to him/her, through the air, instead of rolling the ball across the ground in the default “safe” mode. If the voice command system is defeated by ambient noise, then other buttons on the key-fob will be used to maintain desired operation of the robot.

7. Math

The Average Time Between Free throw Shots Taken:

The average time between free throw shots taken of a high school student and middle student may be different therefore, the mechatronic device should be able to the average time between free throw shots. To calculate the average time between free throw shots, divide the time by the number of free throw shots taken during that time period. Equation (1) is t, which defines time, divided by n, which defines the number of free throw shots taken, equals a, which defines the average time between free throw shots.

$a= t/n$

Feedback of this performance metric will guide future development of the device, and define successful operation as a skill-development assistant.

The computer will also be running a constant series of kinematic calculations, position estimations, and mapping functions.

8. Summary

In order to be effective and efficient, for assisting the owner/operator to improve his/her shooting technique, the mechatronic device must be fast. Every effort will be made to maximize the device's physical speed and decision-making abilities. Along with that, the developers must constantly remind themselves that the increased rewards of enhanced performance come hand-in-hand with increased severity of potential injury to operators. More power comes with more weight. More weight comes with more potential for injurious collision. We believe that these concerns can be addressed through smart planning, rigorous testing, and redundant systems. Any suggestions regarding safe development are welcome and solicited.

9. Important Information

No substantial portion of this paper has been published or is under consideration for publication elsewhere and its submission for publication has been approved by all of the authors and by the institution where the work was carried out. It is further understood that any person cited as a source of personal communications has approved such citation.

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