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Harmonic Motion-based Simulator Design for Multipurpose Sports Simulation

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Abstract

This study proposes a sports simulation device with various harmonics generation. The proposed system is composed of 6 degrees of freedom simulator devices and three types of sports simulation such as walking, snowboard, and jet-ski. In this research, every joint movement is designed with a crank-and-slider mechanism, which is efficient for generating continuous curvature smoothly. Contrary to the conventional spatial simulator with linear actuators, harmonics generation and its spatial combinations become the crucial issue in this research. The harmonic pattern in each joint is modelled for generating smooth curvatures that are also superposed for achieving overall motions. In addition, the targeted motions of sports simulations have different physical factors of periodic gait motion, frictionless surface, and buoyant effects, which are respectively designed by integrating three dimensional graphics information.

Keywords: *Harmonic motion, Sports simulation, Vestibular sensation, Dynamics simulation*

1. INTRODUCTION

In recent years, the development of robotic technology has led to virtual simulation and thus to sports simulator in our home. For example, driving a car or an aircraft is popular product that merges visual information with human vestibular sensation that is the sensory system about the sense of balance and spatial orientation.

From the viewpoint of vestibular sensation, human is more sensitive to angular velocity and linear acceleration. [1] Considering that simulating environment is limited, these small amounts of momentum changes are preferable for simulator designs. Therefore, more than two degrees- of-freedom (DOF) is used for rendering spatial movements such as tilt and roll angles.

However, the lack of understanding human sensation often leads that human feels uncomfortable when simulated movements are displayed inharmoniously or their continuities are improperly concatenated. In the past, most simulators are designed with linear actuators [2] and the generated motions are inappropriate for generating smooth trajectories. In recent years, the parallel type of three manipulators, a delta robot, becomes popular because the synthesized motions become closer to continuous trajectories [3,4].

One shortcoming is that the simulator is designed for universal purposes and thus is not optimized to generate specific motions: walking simulation needs vertical movements of mass center periodically and moving on water are affected by wave pattern and buoyancy.

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In the reason, harmonics-based actuations are proposed. The harmonic motion in mechanical engineering is defined as the continuous curvature generation through kinematic combinations of a rotating source. A crank-and-slider mechanism that is approximately simple harmonic transforms a circular motion into a linear.

In this paper, the harmonics generating actuators are used for generating six DOF spatial motions and its combination and control scheme are proposed. Also, the case studies with three sports simulation are introduced by integrating virtual three dimensional environments.

2. HARMONICS-BASED SIMULATOR DESIGN

For generating six DOF movement, seven actuaors are used and each of them are desgined for harmonics generation in the previous research [5, 6]. As mentioned above, a crank-and-slider generates simple harmonic motion and the mechanism is desgined for the targeted simulation environments.

For a horse riding simulatior as depicted in Fig. 1, the second joints requires the highest torque for a simulator to overcome human's weight. The rotating crank stores inertia to lift a human rider. Also, instead of a conventional crank-and-slider mechanism, the radius of a crank can be varied by using an active sliding mechanism. Therefore, the second and third joints behaves as a varying cam mechanism the motion of which can generated arbitrary curvature with regarding to the angle of a rotating crank. The inertia of a crank is favorable for gravity compensation. However, it also has a side effect that the cancellation of machine inertia is not easy for human to feel the motion of targeted simulation.

On the top of a simulator, two crank-and-sliders are used for generating two DOF yawing motion. The front and the back actuators generate sliding motions respectively. Compared to the yawing control at the bottome of a simulator that generates bigger rotation, these two sliding mechanims generate coupled small translation and yawing rotation to transfer balanced walking feelings.

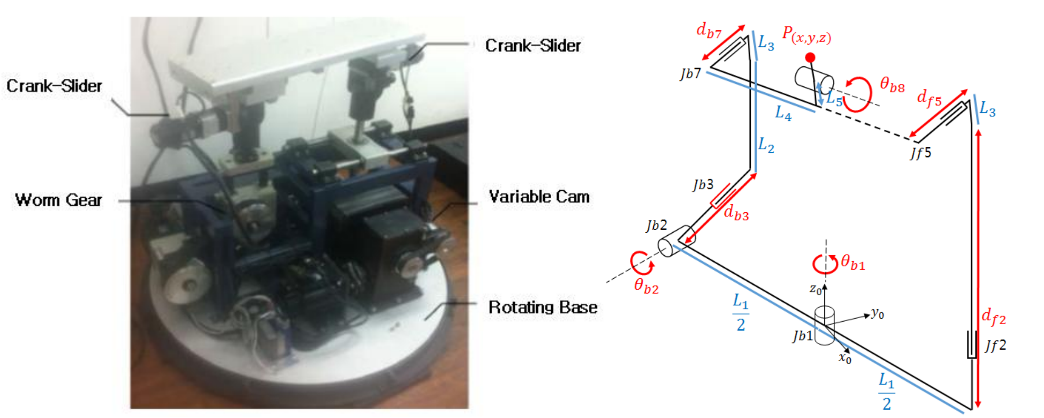


Fig. 1. Horse riding simulator with crank mechanism and its kinematic structure

3. SIMULATOR SYSTEM DESIGN

A. Controller Design

In the proposed system, to control the individual joint movement, the conventional proportional-integral-derivative feedback controller is used. Also, to control the harmonic motion in six parts, virtual harmonic motions are defined: two crank-and-slider mechanism for coupled translation and small yawing, one variable crank-and-slider for sustaining human's weight, a virtual crank-and-slider for controlling nose angle, one crank-and-slider for rolling, and a virtual cycloid motion at the bottom for controlling overall yawing angle.

In the case of two crank-and-slider mechanisms at the top, each joint movement is designed with a given frequency. According to the phase difference between two joints can generated pure translation or coupled translation and yawing motion.

The variable crank-and-slider is designed with a passive controller to compensate human and machine weight. The kinematic structure and its Jacobian matrix is as following:

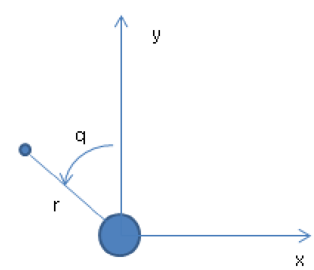


Fig. 2. Kinematics structure of a variable crank-and-slider

$$J = \frac{\partial(x, y)}{\partial(\mathrm{r}, \theta)} = \begin{bmatrix} -\sin q & -L\sin q - (r + Lq)\cos q \\ \cos q & L\cos q - (r + Lq)\sin q \end{bmatrix}$$

$$Det(J) = r + Lq.$$

where L is the kinematic limitation of a sliding mechanism. The kinematic limitation is helpful to avoid singularity at a center.

By adjusting designed passive trajectories, human feeling of gravitational force can be controlled. To generate smooth trajectories, the changes of amplitudes are modelled based on infinite impulse response (IIR) filter. During the simulation, the changes of amplitude and frequency lead that the phase of the previous motion has the difference with the current inputs. To keep the continuity, the phase difference in any input changes are added for calculating the current harmonics.

The nose angle is controlled by a linear movement structure based on worm gear. Since the motion is controlled by a virtual crank-and-slider mechanism, the change of a nose angle is not smoothly generated. However, in the proposed simulation the nose movement is marginally slow and thus the proposed virtual movement does not generate jerk to a human rider.

Finally, the bottom joint has the highest inertia to rotate a simulator and a human. Its movement engages a human to feel the orientation feeling. The proposed cycloid motion works poor because of its limited instantaneous torque output.

B. Controller Architecture

This control system is designed to lift and down a human rider to feed the proper dynamics. The overall motor power is up to three thousands watt and thus the very fast torque control is the minimum condition.

For industrial purposes, alternating current (AC) motors that generate higher power are preferable and the network based fast responses are required. EtherCAT [7] is a new communication technology and it also provides real time performance.

In this system, EtherCAT based communication is used where each actuator is regarded as a slave and a PC is used as a master device. On a Linux system, a software-based master code is developed and its maximum speed is about 1600 samplings in a second. It is sufficient to control the seven actuators by considering the amount of dynamics computation. The detailed view of overall system architecture is described in Fig. 3.

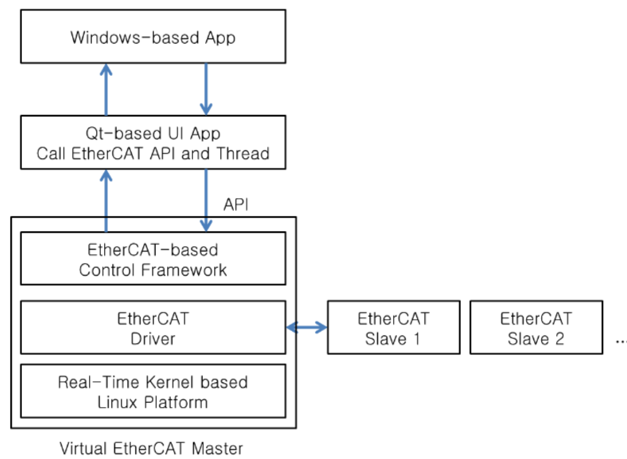


Fig. 3. Software-based EtherCAT master module

C. System Architecture

The overall system architecture is designed as shown in Fig. 4. In general, a simulator is the emerging technology that integrates robotics technology and multi modal information.

For a human to feel dynamics and vestibular sensation from a virtual environment, a simulator has the ability of tracking given six DOF trajectories. Considering the complexity of spatial motions, the trajectory generation should be easily achieved. In the paper, each joint motion is modeled with several harmonics generation. It leads to synthesize other harmonic motions easily, which is one of the major advantages of the proposed system architecture. With the help of database, the frequent usages of harmonic motions are stored and its simple superposition is achieved in harmonics motion cueing process.

Also, considering that a human rides the proposed simulator, the fail safe function is the important factor. As a human user controls a simulator by using a position joystick and a force sensed seat, the contact force between a human and a simulator indicates the current human balance on a simulator. The force-based recognition module is the minimum condition for a simulator to stop to avoid unpredictable accident.

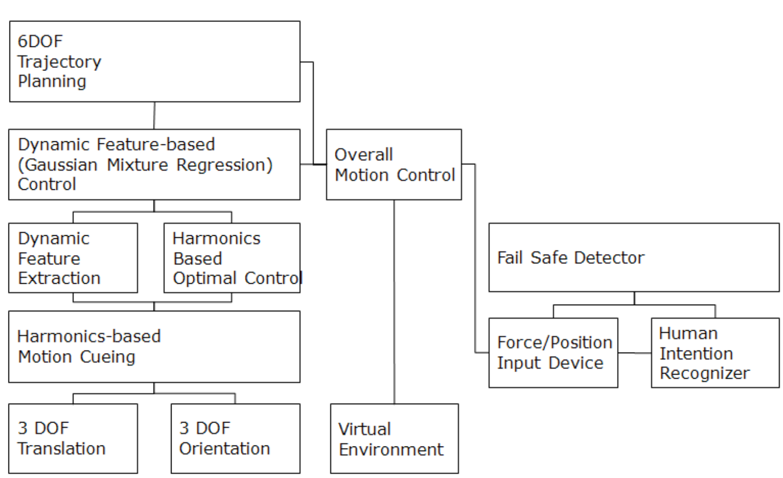


Fig. 4. Overall system architecture

D. Dynamics Simulation

For the test of three targeted movements, the generated motions of a simulator is testified through forward dynamics simulation. The proposed simulator has closed loop on its kinematic structure: a variable crank-and-slider and a worm gear are connected to a seat at the top. In this reason, the forward dynamics of the proposed structure becomes complex, which is even compact than a delta robot.

For a forward dynamics, Open Dynamics Engine [8] is applied to approximate the dynamic movements of the proposed simulator. The purposes of a dynamic simulation is not to estimate an actual simulator but to verify the dynamic movement and controller scheme, as shown in Fig. 5.

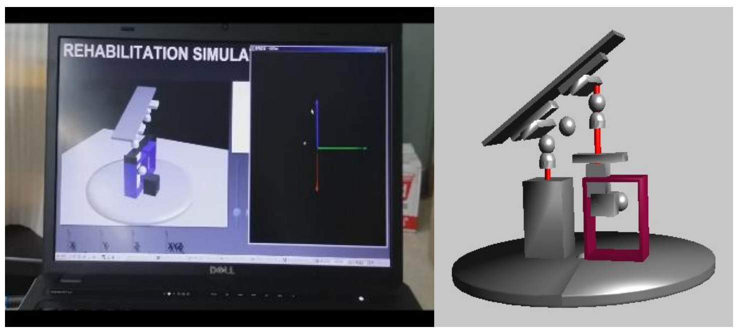


Fig. 4. Dynamic simulation of a virtual simulator.

4. EXPERIMENTS

The basic feature of a walking is that the mass center shows eight shape trajectory. When each leg steps on a ground, the position of a mass center goes down and back to the original position repetitively. Thus, the position of a mass center moves on a circular trajectory at the side view and moves eight shape at the top view. The tracking trajectory is plotted in Fig. 6. A.

For the creation of a walking trajectory, a virtual cam generate harmonic motion according to human's vertical movement. The periodic motion of a human mass center is simulated by tracking the motion capture data. The two crank-and-slider mechanisms generate the eight shape at the top view. The phase difference of 180 degree generates reversed movements on each crank-and-slider. The nose angle is used to express walking on descending or ascending slope.

In the case of a snowboard simulation, a human rider stands on the top of a simulator, wears three dimensional display on his head, and attempts to keep balance as a human rides a snowboard. His vestibular feeling becomes more important to play the virtual snowboard. To improve the actual feeling, three dimensional goggle, Oculus is used and its snow mountain view is described in Fig. 6. b. Also, snowing is implemented by particle effects.

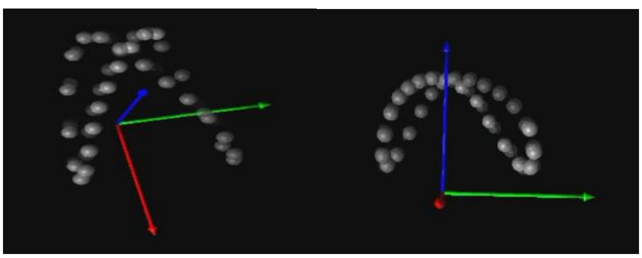
For the snowboard simulation, the feeling of a down slope is simulated by changing a nose angle. Contrary to a walking simulation, a nose angle is tracked by calculating the current slope angle. Humans' feelings about the down slope speed is simulated by changing the variable cam motion, the rotation of which is transferred to the translation.

For a walking, large translation is required but for a snowboard repetitive translation is irrelevant for a human to feel the speed by following a long track. Thus, the acceleration in the forward direction becomes dominant in a snowboard simulation. The radius of a variable cam is much smaller than a walking and the repetitive acceleration is given to a human rider.

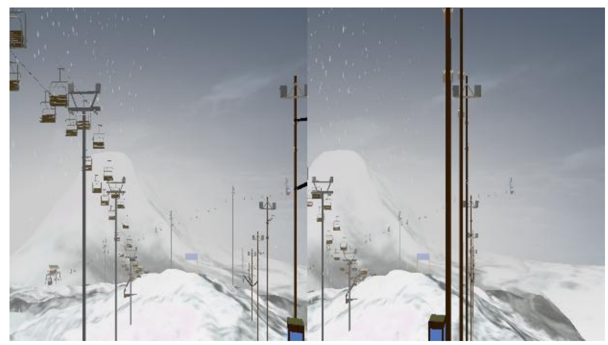
The jet-ski simulation has very different features with a walking and a snowboard: the buoyant force and the free surface wave. A jet-ski floats on water and its buoyancy varies proportional to sunken volume. As in the case of typical physics-based simulation, a bounding-box is used to calculate the sunken object. The shape of a jet-ski is complex and its volume is approximately calculated with a bounding box.

When a jet-ski is at the bottom of water wave, its buoyant force becomes larger. Also, when it is at the top of water wave, the force becomes smaller. When a jet-ski is on down slope, the buoyancy force of the head is larger than that of the tail.

For the calculation of a free surface, two hundreds of sinusoidal function are superposed and its amplitude is used to express water wave. The relative position between a jet-ski and water surface determines the buoyant force and the tilt angle. The simulation result is described in Fig. 6.c.



(a)



(b)

(c)

Fig. 6. (a) Eight shapes of a walking trajectory,
(b) Two screens for Oculus-based three dimensional environment,
(c) Two screens of a sea (Top) and a cave environment (Bottom)

5. CONCLUSION

In this research, a simulator developed for a horse riding is analyzed for simulating a walking, a snowboard, and a jet-ski. The basic features of motions are divided by harmonics generating pattern. A crank-and-slider and a varying cam are the basic components for controlling the individual joint.

Above three tests, human's actual feeling is modeled through harmonics generation respectively. A walking with eight shaped curve, small radius and fast rotation of a varying cam, and the position changes of the top seat according to water wave are designed and testified.

In future works, for the briefness of motion generation, Gaussian kernel-based harmonic feature will be expected.

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