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(54) **LATENCY REDUCTION IN CAMERA-PROJECTION SYSTEMS**

(71) Applicant: **Microsoft Corporation**, Redmond, WA (US)

(72) Inventors: **Jarrod Knibbe**, Bristol (GB); **Hrvoje Benko**, Seattle, WA (US); **Andrew Wilson**, Seattle, WA (US)

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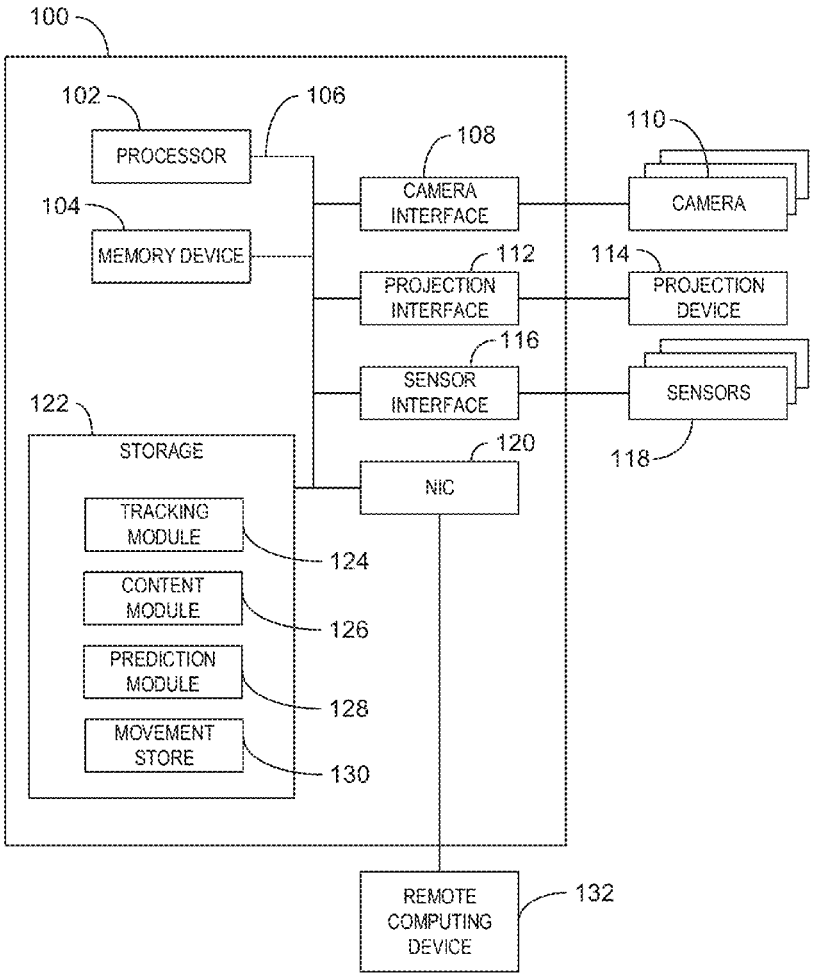
(57) **ABSTRACT**

Various methods and systems for reducing the effects of latency in a camera-projection system are described herein. A method includes recording, via a camera, a plurality of frames of one or more moving objects, wherein at least one of the moving objects is a target object to have an image projected thereupon. The method can include analyzing the recorded frames of the one or more moving objects to determine a predicted path of the target object. Additionally, the method can include projecting, via a projection device, an image onto the target object using the predicted path of the target object to compensate for a predetermined system latency. The method can include recording a plurality of frames of the target object and the image. The method can include adjusting the predicted path of the target object until an offset between the target object and the image is below a predetermined threshold.



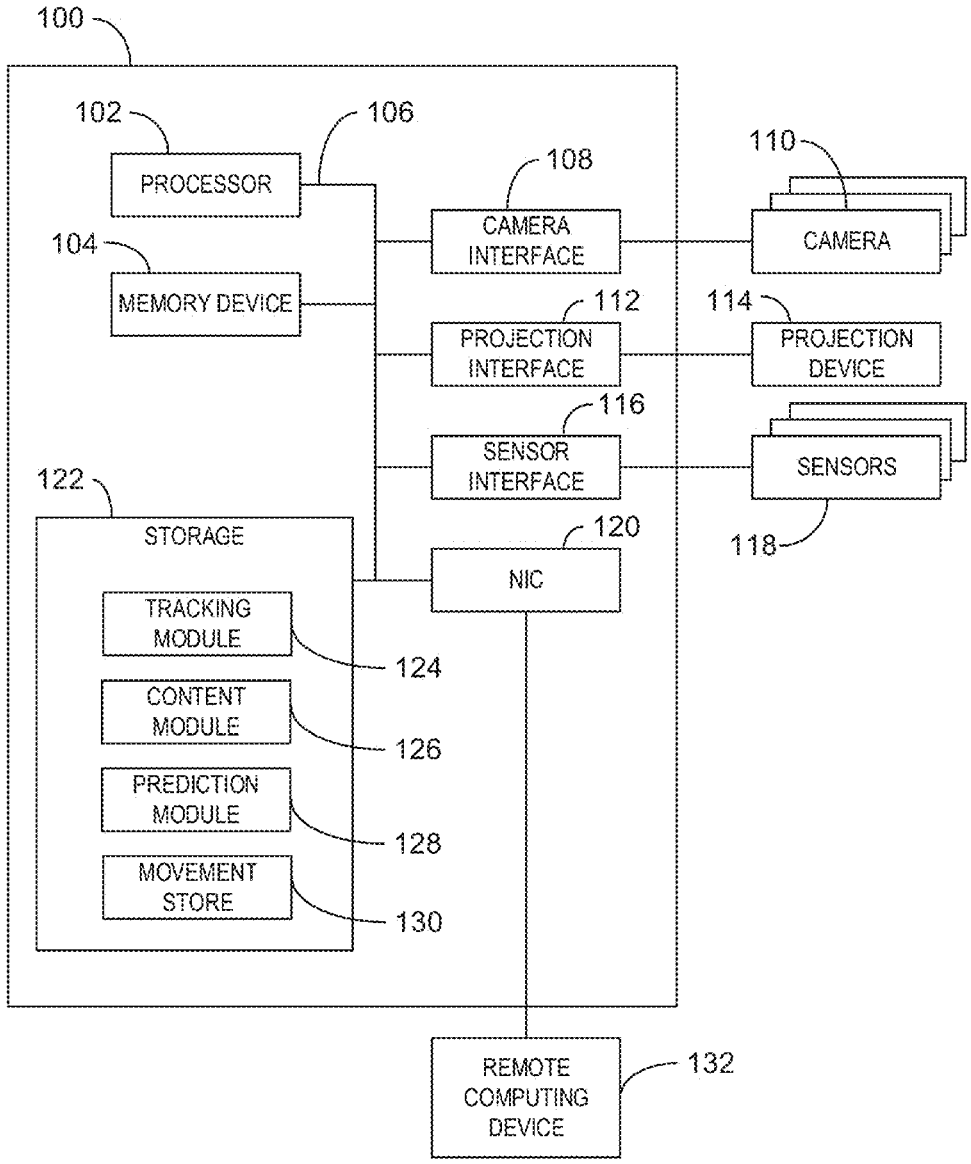
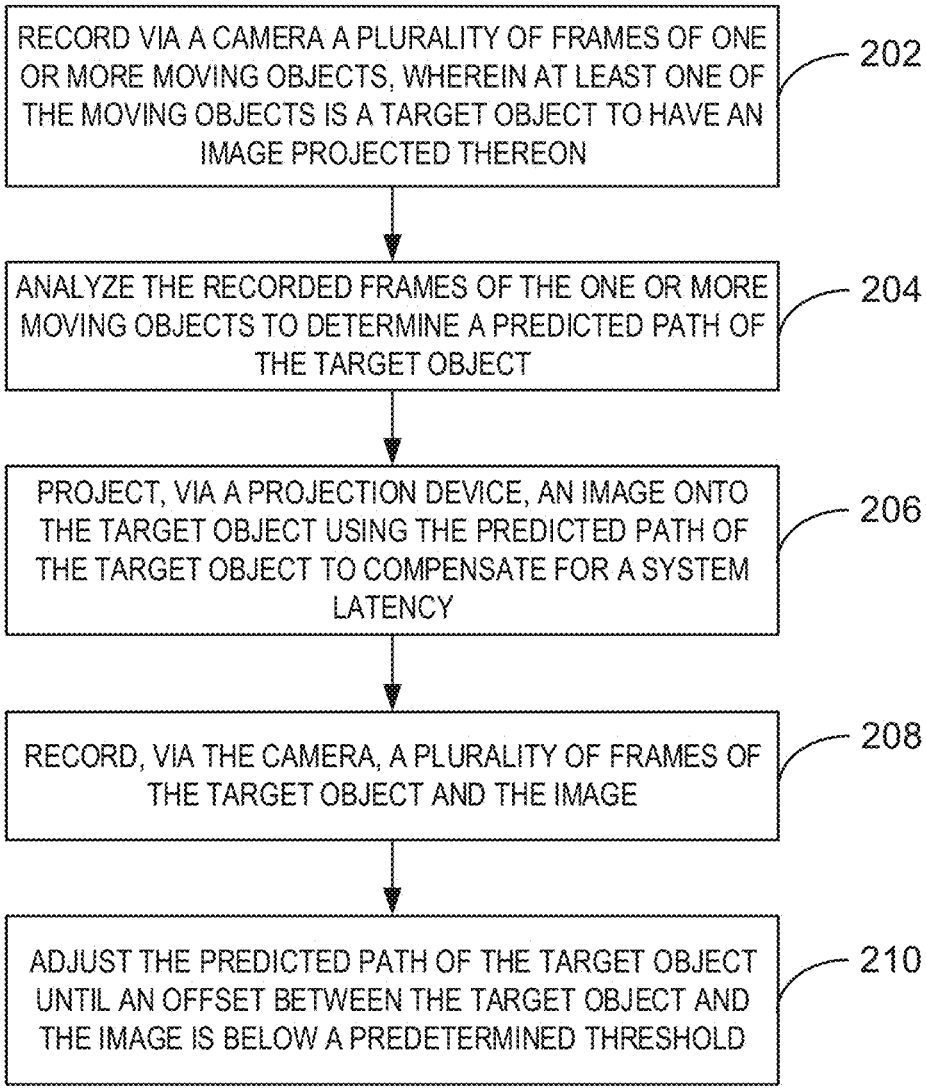
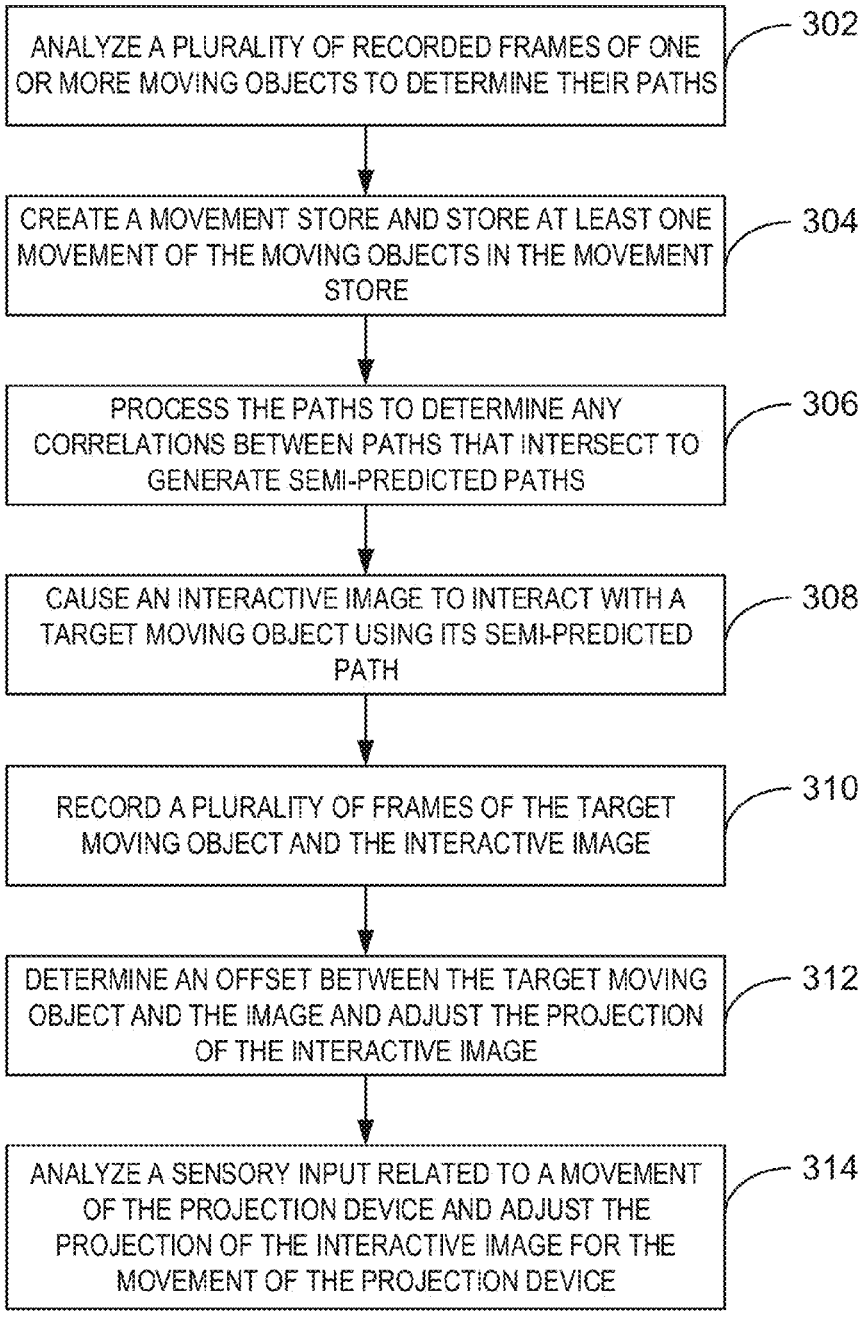

100
102
PROCESSOR
106
104
MEMORY DEVICE
108
CAMERA INTERFACE
110
CAMERA
112
PROJECTION INTERFACE
114
PROJECTION DEVICE
116
SENSOR INTERFACE
SENSORS
118
120
NIC
122
STORAGE
TRACKING MODULE
124
CONTENT MODULE
126
PREDICTION MODULE
128
MOVEMENT STORE
130
REMOTE COMPUTING DEVICE
132

FIG. 1


RECORD VIA A CAMERA A PLURALITY OF FRAMES OF ONE OR MORE MOVING OBJECTS, WHEREIN AT LEAST ONE OF THE MOVING OBJECTS IS A TARGET OBJECT TO HAVE AN IMAGE PROJECTED THEREON
202
ANALYZE THE RECORDED FRAMES OF THE ONE OR MORE MOVING OBJECTS TO DETERMINE A PREDICTED PATH OF THE TARGET OBJECT
204
PROJECT, VIA A PROJECTION DEVICE, AN IMAGE ONTO THE TARGET OBJECT USING THE PREDICTED PATH OF THE TARGET OBJECT TO COMPENSATE FOR A SYSTEM LATENCY
206
RECORD, VIA THE CAMERA, A PLURALITY OF FRAMES OF THE TARGET OBJECT AND THE IMAGE
208
ADJUST THE PREDICTED PATH OF THE TARGET OBJECT UNTIL AN OFFSET BETWEEN THE TARGET OBJECT AND THE IMAGE IS BELOW A PREDETERMINED THRESHOLD
210

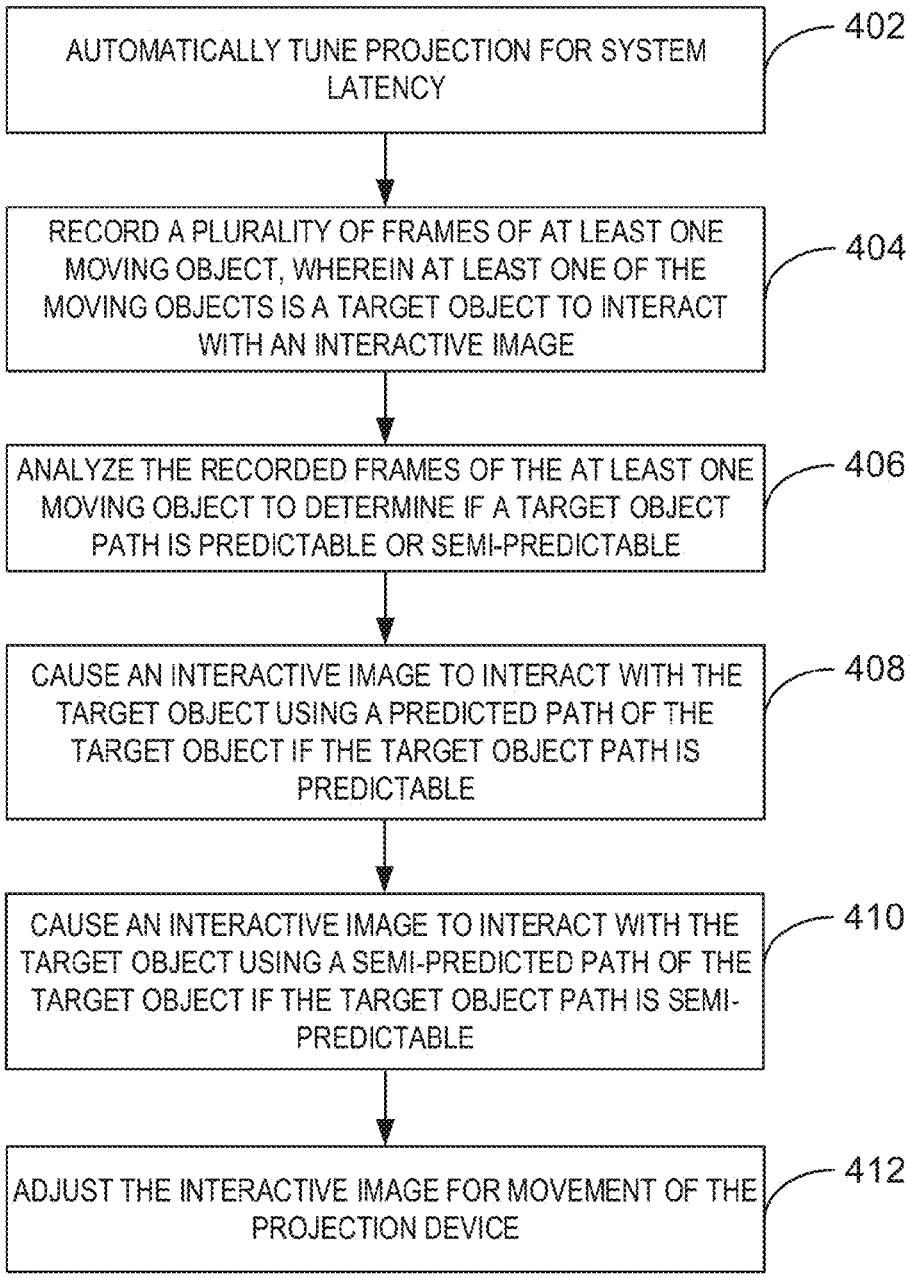
200

FIG. 2


ANALYZE A PLURALITY OF RECORDED FRAMES OF ONE OR MORE MOVING OBJECTS TO DETERMINE THEIR PATHS
302
CREATE A MOVEMENT STORE AND STORE AT LEAST ONE MOVEMENT OF THE MOVING OBJECTS IN THE MOVEMENT STORE
304
PROCESS THE PATHS TO DETERMINE ANY CORRELATIONS BETWEEN PATHS THAT INTERSECT TO GENERATE SEMI-PREDICTED PATHS
306
CAUSE AN INTERACTIVE IMAGE TO INTERACT WITH A TARGET MOVING OBJECT USING ITS SEMI-PREDICTED PATH
308
RECORD A PLURALITY OF FRAMES OF THE TARGET MOVING OBJECT AND THE INTERACTIVE IMAGE
310
DETERMINE AN OFFSET BETWEEN THE TARGET MOVING OBJECT AND THE IMAGE AND ADJUST THE PROJECTION OF THE INTERACTIVE IMAGE
312
ANALYZE A SENSORY INPUT RELATED TO A MOVEMENT OF THE PROJECTION DEVICE AND ADJUST THE PROJECTION OF THE INTERACTIVE IMAGE FOR THE MOVEMENT OF THE PROJECTION DEVICE
314

300

FIG. 3


AUTOMATICALLY TUNE PROJECTION FOR SYSTEM LATENCY
402
RECORD A PLURALITY OF FRAMES OF AT LEAST ONE MOVING OBJECT, WHEREIN AT LEAST ONE OF THE MOVING OBJECTS IS A TARGET OBJECT TO INTERACT WITH AN INTERACTIVE IMAGE
404
ANALYZE THE RECORDED FRAMES OF THE AT LEAST ONE MOVING OBJECT TO DETERMINE IF A TARGET OBJECT PATH IS PREDICTABLE OR SEMI-PREDICTABLE
406
CAUSE AN INTERACTIVE IMAGE TO INTERACT WITH THE TARGET OBJECT USING A PREDICTED PATH OF THE TARGET OBJECT IF THE TARGET OBJECT PATH IS PREDICTABLE
408
CAUSE AN INTERACTIVE IMAGE TO INTERACT WITH THE TARGET OBJECT USING A SEMI-PREDICTED PATH OF THE TARGET OBJECT IF THE TARGET OBJECT PATH IS SEMI-PREDICTABLE
410
ADJUST THE INTERACTIVE IMAGE FOR MOVEMENT OF THE PROJECTION DEVICE
412

400

FIG. 4

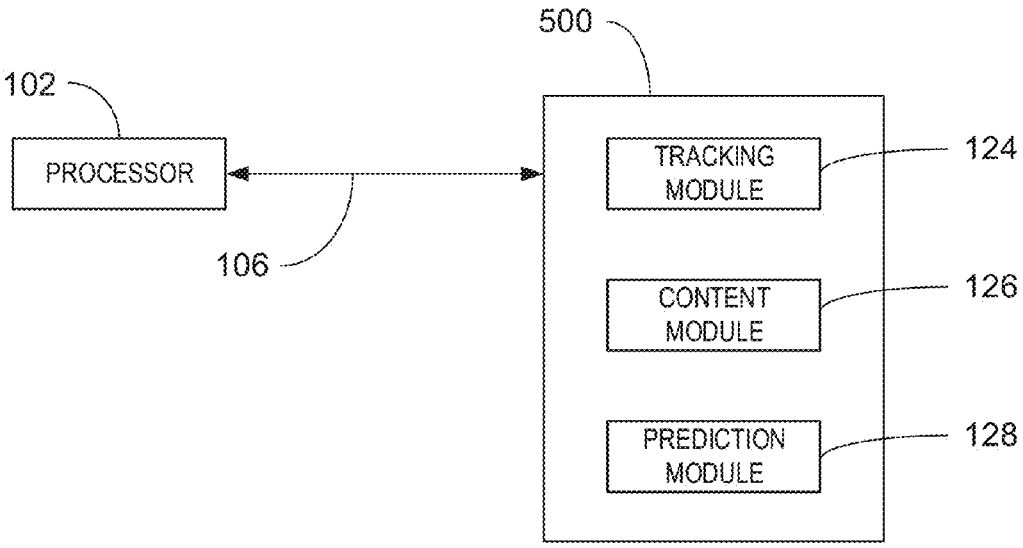
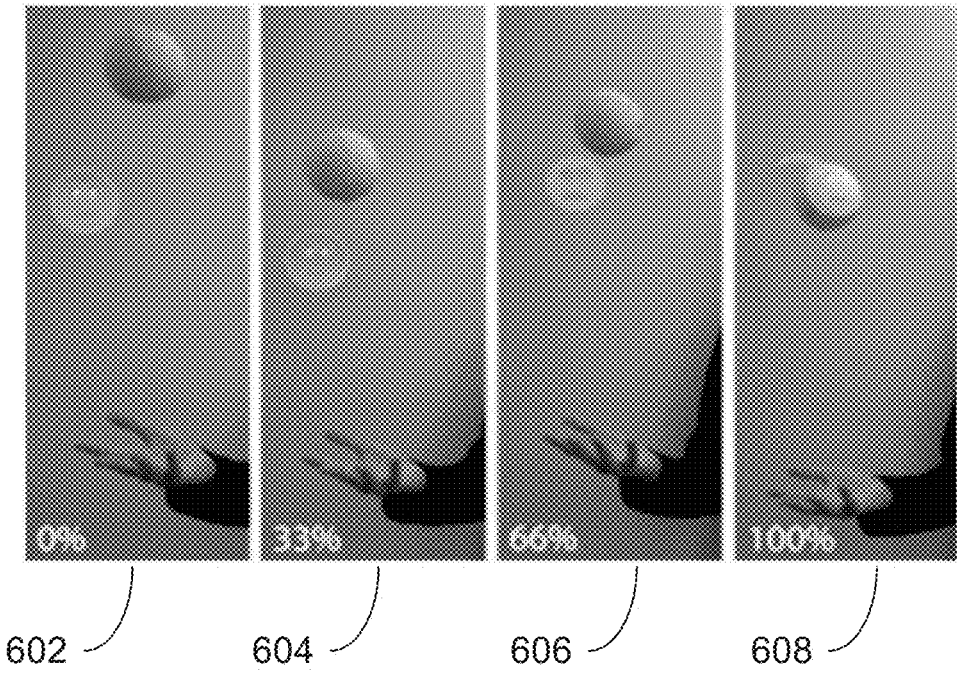

500
102
PROCESSOR
106
TRACKING MODULE
124
CONTENT MODULE
126
PREDICTION MODULE
128

FIG. 5



600

FIG. 6

LATENCY REDUCTION IN CAMERA-PROJECTION SYSTEMS

BACKGROUND

[0001] Camera-projection systems can overlay images onto objects as perceived by a person or allow a person to interact with a virtual reality. For example, a projection device may overlay a pattern onto an object so that the object appears to have the pattern on its surface. In some examples, these objects may be moving along a predictable or semi-predictable path. In some examples, the objects may be persons interacting with a virtual world.

SUMMARY

[0002] The following presents a simplified summary in order to provide a basic understanding of some aspects described herein. This summary is not an extensive overview of the claimed subject matter. This summary is not intended to identify key or critical elements of the claimed subject matter nor delineate the scope of the claimed subject matter. This summary's sole purpose is to present some concepts of the claimed subject matter in a simplified form as a prelude to the more detailed description that is presented later.

[0003] An embodiment provides a method for reducing the effects of system latency in camera-projection systems. The method includes recording, via a camera, a plurality of frames of one or more moving objects, one of which may be a target object. The recorded frames of the one or more moving objects are analyzed to determine a predicted path of the target object. An image is projected via a projection device onto the target object using the predicted path of the target object to compensate for a system latency. A plurality of frames target object and the image are recorded via the camera. The predicted path of the target object is adjusted until an offset between the target object and the image is below a predetermined threshold. The predicted path of the at least one moving object is stored in a movement store.

[0004] Another embodiment provides for one or more computer-readable storage media comprising a plurality of instructions that, when executed by a processor, cause the processor to analyze a plurality of recorded frames of one or more moving objects to determine their paths. The instructions direct the processor to create a movement store and store at least one movement of the moving objects in the movement store. The instructions direct the processor to perform a lookup in the movement store to generate a semi-predicted path for a target moving object. The instructions direct the processor to cause an interactive image to interact with a target moving object using the semi-predicted path of the target moving object. The instructions direct the processor to record a plurality of frames of the target moving object and the interactive image. The instructions direct the processor to determine an offset between the paths of the target moving object and the image and adjust the projection of the interactive image for the offset.

[0005] Another embodiment provides a system for reducing the effect of hardware latency in camera-projection systems. The system includes a processor to execute processor executable code, a camera, a projection device; and, a storage device that stores processor executable code. The processor executable code, when executed by the processor, causes the processor to analyze a plurality of recorded frames of a moving object to determine a predicted path, wherein the moving object is a target object to have an image projected thereupon. The processor executable code, when executed by the processor, causes the processor to project, via the projection device, the image onto the target object based on the predicted path of the target object. The processor executable code, when executed by the processor, causes the processor to record, via the camera, a plurality of frames of the target object and the image. The processor executable code, when executed by the processor, causes the processor to adjust the predicted path for the target object based on an offset. The processor executable code, when executed by the processor, causes the processor to project the image onto the target object based on the adjusted predicted path.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The following detailed description may be better understood by referencing the accompanying drawings, which contain specific examples of numerous features of the disclosed subject matter.

[0007] FIG. **1** is a block diagram of an example of a computing system that can reduce the effects of camera-projection latency;

[0008] FIG. **2** is a process flow diagram of an example method for reducing camera-projection system latency effects for objects with predictable paths;

[0009] FIG. **3** is a process flow diagram of an example method for reducing camera-projection system latency effects for objects with semi-predictable paths;

[0010] FIG. **4** is a process flow diagram of an example method for reducing camera-projection system latency effects for objects having both predictable and semi-predictable paths;

[0011] FIG. **5** is a block diagram showing an example computer-readable storage media that may be used to reduce the effects of latency in projection systems; and,

[0012] FIG. **6** is a set of four drawings showing an example of camera-projection system latency reduction of varying levels.

DETAILED DESCRIPTION

[0013] Camera-projection systems are often used to project images onto the surfaces of objects or used in conjunction with virtual reality systems to track user movement and integrate the user movement within a virtual experience. In hardware based solutions, an overall latency within the hardware system introduces a lag effect wherein the system tracking the object to have an overlayed image or virtual presence has a delayed response in projecting an image or moving a virtual object in connection with a physical moving object. Embodiments described herein provide a method and system for reducing the latency present in camera-projection ("procam") systems.

[0014] As a preliminary matter, some of the figures describe concepts in the context of one or more structural components, referred to as functionalities, modules, features, elements, etc. The various components shown in the figures can be implemented in any manner, for example, by software, hardware (e.g., discrete logic components, etc.), firmware, and so on, or any combination of these implementations. In one embodiment, the various components may reflect the use of corresponding components in an actual implementation. In other embodiments, any single component illustrated in the figures may be implemented by a number of actual compo-

nents. The depiction of any two or more separate components in the figures may reflect different functions performed by a single actual component. FIG. **1**, discussed below, provides details regarding one system that may be used to implement the functions shown in the figures.

[0015] Other figures describe the concepts in flowchart form. In this form, certain operations are described as constituting distinct blocks performed in a certain order. Such implementations are exemplary and non-limiting. Certain blocks described herein can be grouped together and performed in a single operation, certain blocks can be broken apart into plural component blocks, and certain blocks can be performed in an order that differs from that which is illustrated herein, including a parallel manner of performing the blocks. The blocks shown in the flowcharts can be implemented by software, hardware, firmware, manual processing, and the like, or any combination of these implementations. As used herein, hardware may include computer systems, discrete logic components, such as application specific integrated circuits (ASICs), and the like, as well as any combinations thereof.

[0016] As for terminology, the phrase "configured to" encompasses any way that any kind of structural component can be constructed to perform an identified operation. The structural component can be configured to perform an operation using software, hardware, firmware and the like, or any combinations thereof.

[0017] The term "logic" encompasses any functionality for performing a task. For instance, each operation illustrated in the flowcharts corresponds to logic for performing that operation. An operation can be performed using software, hardware, firmware, etc., or any combinations thereof.

[0018] As utilized herein, terms "component," "system," "client" and the like are intended to refer to a computer-related entity, either hardware, software (e.g., in execution), and/or firmware, or a combination thereof. For example, a component can be a process running on a processor, an object, an executable, a program, a function, a library, a subroutine, and/or a computer or a combination of software and hardware. By way of illustration, both an application running on a server and the server can be a component. One or more components can reside within a process and a component can be localized on one computer and/or distributed between two or more computers.

[0019] As utilized herein, terms "projection" or "projecting" are intended to include the projection of an image onto a physical surface using light as well as the collocation of an image with other images within an augmented reality device.

[0020] Furthermore, the claimed subject matter may be implemented as a method, apparatus, or article of manufacture using standard programming and/or engineering techniques to produce software, firmware, hardware, or any combination thereof to control a computer to implement the disclosed subject matter. The term "article of manufacture" as used herein is intended to encompass a computer program accessible from any computer-readable device, or media.

[0021] Computer-readable storage media can include but are not limited to magnetic storage devices (e.g., hard disk, floppy disk, and magnetic strips, among others), optical disks (e.g., compact disk (CD), and digital versatile disk (DVD), among others), smart cards, and flash memory devices (e.g., card, stick, and key drive, among others). In contrast, computer-readable media generally (i.e., not storage media) may additionally include communication media such as transmission media for wireless signals and the like.

[0022] FIG. **1** is a block diagram of an example of a computing system that can reduce the effects of camera-projection latency. The computing system **100** may be, for example, a virtual reality device, a mobile phone, laptop computer, desktop computer, or tablet computer, gaming system, or camera-projection system, among others. A camera-projection system can include an augmented reality device and any suitable type of computing device that supports an augmented reality device, such as a mobile device, desktop computer, gaming system, etc. The computing system **100** may include a processor **102** that is adapted to execute stored instructions, as well as a memory device **104** that stores instructions that are executable by the processor **102**. The processor **102** can be a single core processor, a multi-core processor, a computing cluster, or any number of other configurations. The memory device **104** can include random access memory, read only memory, flash memory, or any other suitable memory systems. The instructions that are executed by the processor **102** may be used to reduce the effects of latency caused by the various hardware components within the system.

[0023] The processor **102** may be connected through a system bus **106** (e.g., PCI®, PCI-Express®, HyperTransport®, NuBus, etc.) to a camera device interface **108** adapted to connect the computing system **100** to one or more camera devices **110**. The camera device **110** may be, for example, a webcam, a gesture recognition input device, a digital single lens reflex camera, or a digital point-and-shoot camera, among others. The camera devices **110** may be built-in components of the computing system **100**, or may be devices that are externally connected to the computing system **100**.

[0024] The processor **102** may also be linked through the system bus **106** to a projection interface **112** adapted to connect the computing system **100** to a projection device **114**. The projection device **114** may include a semi-transparent display screen or projector that is a built-in component of the computing system **100**. The projection device **114** may also be a virtual reality headset, a pair of digital glasses or goggles, among other devices with semi-transparent screens that are externally connected to the computing system **100**. In some examples, the projection device **114** may be a projector connected to the projection interface **112**. In some examples, the projection device **114** may be part of an augmented reality device.

[0025] The processor **102** may also be linked through the system bus **106** to one or more sensors through sensor interface **116**. In some examples, the sensors may be integrated into the projection device. In some examples, the sensors may be external to the projection device. In some examples, the sensors may include input devices, such as a keyboard, mouse, game pad, or the like. A network interface card (NIC) **120** may also be adapted to connect the computing system **100** through the system bus **106** to a network (not depicted). In some examples, the camera-projection system **100** may be connected to another camera-projection system **100** through the network.

[0026] The storage **122** can include a hard drive, an optical drive, a USB flash drive, an array of drives, or any combinations thereof. The storage **122** may include a tracking module **124**, a content module **126**, a prediction module **128**, and a movement store **130**. In some embodiments, the tracking module **124** may track the movements of at least one moving object. For example, the tracking module may analyze a set of

recorded frames from a camera **110** and determine a location, velocity and acceleration of an object within the frames. In some examples, the tracking module **124** may track the paths of multiple objects at the same time. In some examples, the tracking module **124** may track movements of the objects. In some examples, the movements may be repeated segments of the path of an object. In some examples, these movements may include repeated interactions between objects. For example, a ball may be hit by a racket. In some examples, these movements may include repeated interactions between objects and the images. For example, an image of a ball may be hit by a racket. In some embodiments, tracking module **124** may track the movements of projection device **114**. For example, tracking module **124** may track the movement of projection device **114** through a movement sensor **118** built into a projection interface **112**. For example, the movement sensor input may be information from a gyroscope, accelerometer or compass, or the like, built into the projection device.

[0027] In some embodiments, the content module **126** may contain interactive images to interact with an object. In some examples, the interactive image may be an image to be projected onto the surface of a moving object using projection device **114**. For example, projection device **114** may be a projector that displays an image onto a moving object. In some examples, the image may interact with an object by projecting the image onto a semi-transparent surface. For example, the semi-transparent surface may be a pair of glasses or goggles, and the like. In some examples, the semi-transparent surface may be within an augmented reality headset. In some examples, the content module **126** may adjust the appearance of the images so that the image may be accurately projected onto the surface of the target moving objects or the semi-transparent surface.

[0028] In some embodiments, the prediction module **128** may automatically calculate a system latency. For example, the prediction module **128** may cause projection device **114** to project a test image onto a moving object and camera **110** to capture a predetermined amount of frames of the test image and the moving object in order to calculate the system latency. The system latency may be calculated, for example, by projecting an image based upon a range of assumed latencies and calculating the distance error between the center of the projection and the tracked center of the moving object. For example, the latency range may be measured in milliseconds, seconds, or any other suitable measurement of time. In some examples, the prediction module **128** may calculate the system latency upon powering of the camera-projection system. In some examples, the system latency may be recalculated continuously.

[0029] In some embodiments, the prediction module **128** may calculate a predicted path for an object. This predicted path may be calculated by prediction module **128** using laws of physics. For example, projectile motion may be calculated using the acceleration of gravity and liquid motion may be calculated using laws of fluid dynamics. In some examples, the predicted path may be calculated using a Kalman filter. In some examples, the Kalman filter may be used to account for sensor noise and uncertainty in projectile movement. For example, the Kalman filter may recursively incorporate all known previous locations, velocities and accelerations of an object as recorded by tracking module **124**, and predict future locations, velocities and accelerations based upon a weighted uncertainty of observation due to noise and a weighted uncertainty of prediction due to deviation of the actual path from the laws of physics.

[0030] In some embodiments, the prediction module **128** uses a movement store **130**. This movement store **130** may contain, for example, the location, velocity and acceleration information of objects as recorded by tracking module **124**. In some examples, the movement store **130** may be used by the prediction module **128** as a lookup table to reduce effects of latency caused by large deviations in the path of an object from a predicted path. In some embodiments, the prediction module **128** may generate semi-predicted paths for target objects based on the paths of other objects that the target objects cross paths with. For example, the prediction module **128** may determine a previously recorded location in movement store **130** that corresponds to an object's current location. In some examples, the direct location comparison might be weighted by the distances between the last positions of the object and the previous positions in the movement store **130**. For example, the distances between the last three positions and the previous three positions in the movement store **130** might be calculated by the prediction module **128**. If the distances are below a predefined threshold, then this location may be used as a starting value from which to proceed through the movement store **130** to arrive at a semi-predicted location. If the distances meet a predefined threshold, then the prediction module **128** may seek another location as a starting value or wait for the tracking module to add more object movements to the movement store **130**.

[0031] In some embodiments, the prediction module **128** may use a Kalman filter to determine the semi-predicted path of an object. In some examples, the Kalman filter may be weighted for any degree of uncertainty in projectile movement. For example, the Kalman filter may be assigned a high uncertainty in acceleration based on observed deviations in acceleration.

[0032] In some embodiments, the movement store **130** is created by the tracking module **124** upon powering on the system. In some embodiments, the movement store **130** may be stored before powering the system off in order to allow for a larger history of object movements for improved performance.

[0033] It is to be understood that the block diagram of FIG. **1** is not intended to indicate that the computing system **100** is to include all of the components shown in FIG. **1**. Rather, the computing system **100** can include fewer or additional components not illustrated in FIG. **1** (e.g., additional applications, additional modules, additional memory devices, additional I/O Devices, etc.). Furthermore, any of the functionalities of the tracking module **124**, content module **126**, or prediction module **128**, may be partially, or entirely, implemented in hardware and/or in the processor **102**. For example, the functionality may be implemented with an application specific integrated circuit, in logic implemented in the processor **102**, or in any other device.

[0034] FIG. **2** is a process flow diagram of an example method for reducing camera-projection system latency effects for objects with predictable paths. The method **200** can be implemented with any suitable computing device, such as the computing device **100** of FIG. **1**.

[0035] At block **202**, the camera **110** can record a plurality of frames of one or more moving objects, wherein at least one of the moving objects is a target object to have an image projected thereupon. The moving objects may include any

physical object onto which an image can be projected that is moving according to a predictable path. In some examples, the objects may be moving in a motion according to the laws of gravity or fluid dynamics. For example, the objects may be balls, or any other suitable objects, that have been propelled into the air. In some examples, the objects may be moving according to some other laws of physics. In some examples, the objects may be following the kinematics of the human body.

[0036] At block **204**, the tracking module **124** can analyze the recorded frames of the one or more moving objects to determine a predicted path of the target object. In some examples, the predicted paths may be determined by comparing the location of the moving objects within two or more frames. For example, the center of one object may be compared to the center of the same object in another frame to determine the object's location and velocity. In some examples, the tracking module **124** may determine a relative position that may be a position relative to the camera and initial velocity of each object from the recorded frames. In some embodiments, a Kalman filter may be used to provide more accurate results. The Kalman filter may recursively update the predicted path with observed locations for increased accuracy of the predicted path. In some examples, the values for process and observation noise of the Kalman filter may be altered based on observation of the objects. In some examples, the Kalman filter's prediction value may be given a comparatively low value due to the observed predictability of an object's path. For example, the Kalman filter may be given a relatively low value for uncertainty in the x^*_t (prediction) values in the following example update equations for position, x_t, velocity v_t, and acceleration a_t at time t, observation z_t of the target object's position, prediction x^*_t of the value of x_t given x_{t-1}, and Kalman gains k_x, k_v, k_a, where "*" denotes an element-wise operation while the other operations are vector operations:

$$x_t = x_{t-1} + k_x * (z_t - x_t^*) \quad (1)$$

$$v_t = v_{t-1} + k_v * (z_t - x_t^*) \quad (2)$$

$$a_t = a_{t-1} + k_a * (z_t - x_t^*) \quad (3)$$

[0037] In some examples, the Kalman filter may be fitted with a predesigned model for a particular type of motion. For example, the Kalman filter may be fitted with a projectile motion model based on initial launch velocities and angles of release. In some examples, the movement model may be changed or combined with other models based upon observed movements according to some law of physics.

[0038] At block **206**, the content module **126** may cause the projection device **114** to project an image onto the target object using the predicted path of the target object to compensate for a predetermined system latency. In some examples, the predetermined system latency may be determined after the device is turned on but before the image is displayed. For example, the content module **126** may cause a test image to be displayed onto a moving object and record a few frames to analyze the offset of a variety of latency settings until a local minimum is reached. The system may then set the local minimum latency setting as the predetermined system latency setting.

[0039] At block **208**, the camera **110** may record a plurality of frames of the target object and the image. In some examples, the plurality of frames may be stored in movement store **130**.

[0040] At block **210**, the prediction module **128** may adjust the predicted path of the target object until an offset between the target object and the image is below a predetermined threshold. In some examples, the offset is an effect of latency in a projection system, which results in an image being projected at a different location than the target moving object. In some examples, this offset may be calculated by first determining a center of the target object and a center of the image. In some examples, this offset is input into a Kalman filter for further processing before determining whether the offset meets the predetermined threshold. For example, the Kalman filter may work in conjunction with a model based on physics if the object displays a predictable path.

[0041] In some examples, the prediction module **128** may determine whether a predicted path of the target object is predictable based on the plurality of recorded frames of block **208**. In some examples, the prediction module **128** may determine that a predicted path is reliable based on the feedback gained from prior recorded frames. The prediction module **128** may then adjust the uncertainty in the Kalman filter accordingly. For example, if prediction uncertainty is low, then the prediction uncertainty variable x^*_t of Equations (1), (2), and (3) may be adjusted accordingly. If the observation noise is high, then the observation uncertainty variable z_t of Equations (1), (2) and (3) may be adjusted accordingly. For example, observation uncertainty may be high if the light levels fluctuate and effect the tracking modules ability to analyze the moving objects. The corresponding uncertainty variable z_t would be adjusted for this fluctuation.

[0042] In some examples, the prediction module **128** may apply a Kalman filter to the predicted path of the target object. The content module **126** may then begin projecting the image onto the target object based upon the predicted path created by the adjusted Kalman filter.

[0043] The process flow diagram of FIG. **2** is not intended to indicate that the steps of the method **200** are to be executed in any particular order, or that all of the steps of the method **200** are to be included in every case. Further, any number of additional steps may be included within the method **200**, depending on the specific application. For example, the prediction module **128** and tracking module **124** may also generate an automatically tuned system latency to be used by content module **126** in initially projecting an image. For example, the projection device **114** may display a test image onto a moving object at a variety of latency adjustments and camera **110** may capture and send frames to tracking module **124**. The tracking module may then determine a local minimum in which the latency effect is minimized by a specific latency adjustment. This specific latency adjustment may then be used as a base latency adjustment for the system to use.

[0044] FIG. **3** is a process flow diagram of an example method for reducing camera-projection system latency effects for objects with semi-predictable paths. The method **300** can be implemented with any suitable computing device, such as the computing device **100** of FIG. **1** or using the example computer-readable storage media **500** of FIG. **5**.

[0045] At block **302**, the tracking module **124** may analyze a plurality of recorded frames of one or more moving objects to determine their paths. In some examples, analyzing the frames may involve the use of a physics model. In some examples, this may involve the use of a Kalman filter as discussed in block **204** of method **200**. In some examples, a kinematic motion model may be used with the Kalman filter.

For example, the kinematic motion model may take advantage of factors such as human joint rotation limits to improve object path prediction.

[0046] At block **304**, the tracking module **124** may create a movement store **130** and store specific movements of the moving objects in the movement store **130**. In some examples, the movements may be portions of object paths that are repeated. In some examples, the paths of the moving objects may recorded for a predetermined period of time, wherein the predetermined period of time can be any suitable number of seconds or frames per second. For example, with a juggling movement that is performed at a high frequency, the amount of time for a given movement may only be three seconds, or 90 frames at 30 frames/second. In some examples, object paths may be recorded until a certain number of movements are determined. In some examples, the object paths may be recorded continuously to maximize the available movements in the movement store.

[0047] At block **306**, the prediction module **128** may process the paths to determine any correlations between paths that intersect to generate semi-predicted paths. In some examples, a model may be created based upon the motions of a particular person and stored for later use. For example, the object may be a person swinging a bat. The person's particular swinging movement may be stored and used later to reduce effects of latency more accurately when the same person swings again. In some examples, a model may be created for the movements of a particular object and the other objects it may interact with. For example, a model for a ball may have movements recorded and stored for interactions with a bat, a tennis racket, a hand, or the like.

[0048] At block **308**, content module **126** may cause an interactive image to interact with a target moving object using its semi-predicted path. In some examples, the interactive image may be a projected image onto a surface. For example, a projector may project a smiley face onto a ball in motion. In some examples, the interactive image may be a projection on a semi-transparent surface. For example, the interactive image may be shown within an augmented reality device that may display the interactive image onto a semi-transparent screen that allows the target moving object to interact with the image seen in front of it. In some examples, the content module **126** may use an object models to create semi-predictable paths. For example, a ball's semi-predicable path may be based on a model that includes past swings of a racket attempting to hit the ball. The past swings in the model may be used to create a semi-predictable path for the ball when a racket is swung in the direction of its path.

[0049] At block **310**, the camera **110** may record a plurality of frames of the target moving object and the interactive image. In some examples the camera may be one or more external cameras connected to a camera interface. In some examples, the one or more cameras may be internally adapted to the projection device. For example, a virtual reality device may have a camera mechanism that allows the system to analyze the interaction of images that the user may be perceiving.

[0050] At block **312**, the prediction module **128** may determine an offset between the target moving object and the image and adjust the projection of the interactive image. In some examples, the offset may be measure between a determined center of the target moving object and a center of the interactive image. In some examples, the offset may be processed in a Kalman filter.

[0051] At block **314**, the prediction module **128** may analyze a sensory input related to a movement of the projection device and adjust the projection of the interactive image for the movement of the projection device. In some examples, the tracking module **124** may receive the sensory input and from a sensor **118** and send this information to the prediction module **128**. The prediction module **128** may then recalculate the semi-predicted path based on this movement information. The content module **126** may then adjust the interactive image to be displayed on the projection device **114**.

[0052] FIG. **4** is a process flow diagram of an example method for reducing camera-projection system latency effects for objects having both predictable and semi-predictable paths. The method **400** can be implemented with any suitable computing device, such as the computing device **100** of FIG. **1**.

[0053] At block **402**, the tracking module **124** and prediction module **128** may automatically tune projection for system latency. In some examples, the tuning may be done by projecting test images using different latency correction settings onto a moving object and finding a local minimum as in block **206** above. In some examples, the system latency may be the total latency of the system, including any externally attached sensors **118**, projection devices **114**, and cameras **110**.

[0054] At block **404**, the camera may record a plurality of frames of at least one moving object, wherein at least one of the moving objects is a target object to interact with an interactive image. In some examples, the moving object may be a racket, or any other object having a predictable or semi-predictable movement. For example, the target moving object may be a racket that may interact with the interactive image of a ball.

[0055] At block **406**, the prediction module **128** may analyze the recorded frames of the at least one moving object to determine if a target object path is predictable or semi-predictable. As in the above examples of **200** and **300**, the moving objects may be either moving in predictable paths or semi-predictable paths. For example, an object moving in a predictable path may be moving along a path according to some law of physics. An object moving in a semi-predictable path may be a racket that is being swung by a human arm.

[0056] At block **408**, the content module **126** may cause an interactive image to interact with the target object using a predicted path of the target object if the target object path is predictable. In some examples, the prediction module may determine which, if any, predicted path to use for a target object. For example, if the target object is moving along a predictable path according to some law of physics, then the prediction module may choose to use a predicted path for the object based upon an appropriate model of physics.

[0057] At block **410**, the content module **126** may cause an interactive image to interact with the target object using a semi-predicted path of the target object if the target object path is semi-predictable. In some examples, the prediction module may determine that the path of the target object intersects with the path of another object at regular intervals or locations. In some examples, the target object may intersect paths with an interactive image. For example, an interactive image of a ball may be hit by a racket by a gamer at the same position. The prediction module may use a past swing of the racket as a model for determining the path of the interactive image of a ball after the racket is swung once again.

[0058] At block **412**, the prediction module **128** may adjust the interactive image for movement of the projection device. In some examples, the interactive image may be displayed in an augmented reality device. The sensors **118** within the device may send information to the tracking module **124** through the sensor interface **116**. For example, if a person turns their head while wearing an augmented reality device, the sensors such as a compass or gyroscope may sense the movement and send this information to the tracking module **124**. The prediction module **128** may then send this information to the content module **126** to correct the interactive image by the sensed amount of movement.

[0059] FIG. **5** is a block diagram showing an example computer-readable storage media that may be used to reduce the effects of latency in projection systems. The computer-readable storage media **500** may be accessed by a processor **102** over a computer bus **106**. Furthermore, the computer-readable storage media **500** may include code to direct the processor **102** to perform the steps of the current methods. In particular, computer-readable storage media **500** may include a tracking module **124**, a content module **126**, and a prediction module **128**. In some examples, the tracking module **124** may track the paths and movements of objects and store the movements in the movement store **130**. In some examples, the content module **126** may contain interactive images to be overlayed on an object or projected onto a semi-transparent surface. In some examples, the content module may adjust the interactive images to properly overlay the image on the object. In some examples, the prediction module **128** may calculate a system latency. In some examples, the prediction module **128** may calculate the system latency. In some examples, the prediction module **128** may create a predictable or semi-predictable path for an object based on the system latency. In some examples, the prediction model **128** may use a Kalman filter and a physics model to create a predictable or semi-predictable path for an object.

[0060] It is to be understood that any number of additional software components not shown in FIG. **5** may be included within the computer-readable storage media **500**, depending on the specific application. Although the subject matter has been described in language specific to structural features and/or methods, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific structural features or methods described above. Rather, the specific structural features and methods described above are disclosed as example forms of implementing the claims.

[0061] FIG. **6** is a set of four drawings showing an example of camera-projection system latency reduction of varying levels. In the example of FIG. **6**, a target ball is being propelled into the air by a hand. In drawing **602**, the system latency is present and the image lags behind the ball by about the diameter of the ball. In some examples, tracking module **124** may be analyzing frames recorded by camera **110**. In drawing **604**, the latency reduction system **100** is reducing the latency of projecting the image on the ball by approximately 33%. In drawing **604**, the image is now within a diameter distance of the ball. In some examples, the prediction module **128** may have determined a predicted path for the ball based on a physics model of the acceleration due to gravity. The content module **126** may partially adjust the image based on the predicted path and the 33% latency reduction setting. In drawing **606**, the system **100** is reducing the latency by approximately 66%. In some examples, the content module **126** may now adjust the image based upon the same predicted path and the 66% latency reduction setting. For example, the image is now almost displayed onto the ball, however, the image is still projected onto a wall behind the ball. In drawing **608**, the system **100** is reducing the latency by approximately 100%. In some examples, the content module **126** may adjust the image based upon the same predicted path and the 100% latency reductions setting. In the example, the image is now on the ball, with a slight portion of the image still projected onto the wall behind the ball.

1. A method for reducing the effects of system latency in camera-projection systems comprising:

recording, via a camera, a plurality of frames of one or more moving objects, wherein at least one of the moving objects is a target object to have an image projected thereupon;

analyzing the recorded frames of the one or more moving objects to determine a predicted path of the target object; and

projecting, via a projection device, an image onto the target object using the predicted path of the target object to compensate for a system latency.

2. The method of claim **1**, further comprising:

recording, via the camera, a plurality of frames of the target object and the image; and,

adjusting the predicted path of the target object until an offset between the target object and the image is below a predetermined threshold.

3. The method of claim **2**, wherein adjusting the predicted path of the target object includes using a Kalman filter.

4. The method of claim **1**, wherein analyzing the recorded frames of the one or more moving objects to determine the predicted path of the target object further comprises using a physics model.

5. The method of claim **1**, wherein the system latency may be determined by automatically tuning the system.

6. The method of claim **1**, wherein analyzing the recorded frames of the moving objects comprises calculating a relative position and a velocity of the moving objects from the plurality of frames.

7. The method of claim **1**, wherein analyzing the recorded frames of the moving objects comprises detecting movements for each moving object.

8. The method of claim **1**, further comprising storing the predicted path of the at least one moving object in a movement store.

9. One or more computer-readable storage media comprising a plurality of instructions that, when executed by a processor, cause the processor to:

analyze a plurality of recorded frames of one or more moving objects to determine their paths;

create a movement store and store at least one movement of the moving objects in the movement store;

perform a lookup in the movement store to generate a semi-predicted path for a target moving object; and,

cause an interactive image to interact with a target moving object using the semi-predicted path of the target moving object.

10. The one or more computer-readable storage media of claim **9**, wherein the instructions further cause the processor to:

record a plurality of frames of the target moving object and the interactive image; and,

determine an offset between the paths of the target moving object and the image and adjust the projection of the interactive image for the offset.

11. The one or more computer-readable storage media of claim **9**, wherein the processor may adjust the projection of the interactive image using a Kalman filter.

12. The one or more computer-readable storage media of claim **9**, wherein the interactive image is displayed within an augmented reality device.

13. The one or more computer-readable storage media of claim **9**, wherein the instructions further cause the processor to analyze a sensory input related to a movement of the projection device and adjust the projection of the interactive image for the movement of the projection device.

14. The one or more computer-readable storage media of claim **11**, wherein the Kalman filter is used with a kinematic motion model.

15. A system, comprising:

a processor to execute processor executable code;

a camera;

a projection device; and,

a storage device that stores processor executable code, wherein the processor executable code, when executed by the processor, causes the processor to:

analyze a plurality of recorded frames of a moving object to determine a predicted path, wherein the moving object is a target object to have an image projected thereupon;

project, via the projection device, the image onto the target object based on the predicted path of the target object.

record, via the camera, a plurality of frames of the target object and the image;

adjust the predicted path for the target object based on an offset; and,

project the image onto the target object based on the adjusted predicted path.

16. The system of claim **15**, wherein adjusting the predicted path for the target object based on an offset includes inputting the offset into a Kalman filter.

17. The system of claim **15**, wherein the processor executable code, when executed by the processor, causes the processor to further:

analyze a plurality of recorded frames of a plurality of moving objects, at least one of which is the target object, to determine a semi-predicted path; and,

project the image onto the target object based on the predicted path and the semi-predicted path.

18. The system of claim **17**, wherein analyzing the recorded frames of the plurality of moving objects includes creating a table.

19. The system of claim **15**, wherein the processor executable code, when executed by the processor, causes the processor to calculate a relative position and a velocity of the moving objects from the plurality of recorded frames.

20. The system of claim **15**, wherein the processor executable code, when executed by the processor, causes the processor to detect movements for each moving object.

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