US 20030066050A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2003/0066050 A1

Wang et al. (43) Pub. Date: Apr. 3, 2003

(54) METHOD AND SYSTEM FOR PROGRAMMING DEVICES USING FINITE STATE MACHINE DESCRIPTIONS

(76) Inventors: **Douglas W. Wang**, Lake Forest, CA (US); **Sudhir Dattacam Kadkade**, Lake Oswego, OR (US); **Clifton Alton Lyons JR.**, Lake Oswego, OR (US)

Correspondence Address:
ROSENBERG, KLEIN & LEE
3458 ELLICOTT CENTER DRIVE-SUITE 101
ELLICOTT CITY, MD 21043 (US)

(21) Appl. No.: **09/962,232**

(22) Filed: **Sep. 26, 2001**

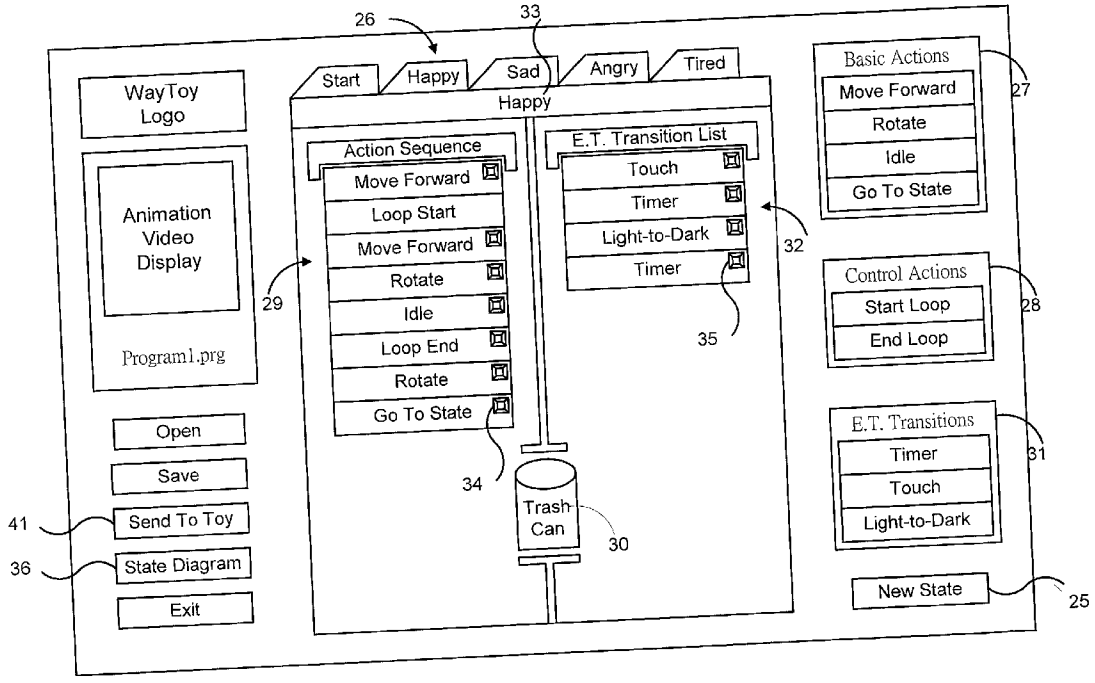
Publication Classification

(51) **Int. Cl.**[7] **G06F 9/44**

(52) **U.S. Cl.** **717/105**

(57) **ABSTRACT**

A method and system for capturing a Finite State Machine (FSM) description of the desired behavior of a device, and converting that description into a program that is executable by the device. In the preferred embodiment, the device is a programmable robot toy. The user enters an FSM description of the desired behavior of the robot toy using a graphical user interface running on a personal computer. When requested, the preferred embodiment compiles the FSM description into a program executable by a virtual machine running on a micro-controller inside the robot toy. This program is sent to the toy via an infrared transmitter and infrared receiver, and stored in the toy's memory. Then, when the robot toy is used, the virtual machine executes the stored program so that the toy behaves as specified by the FSM description.



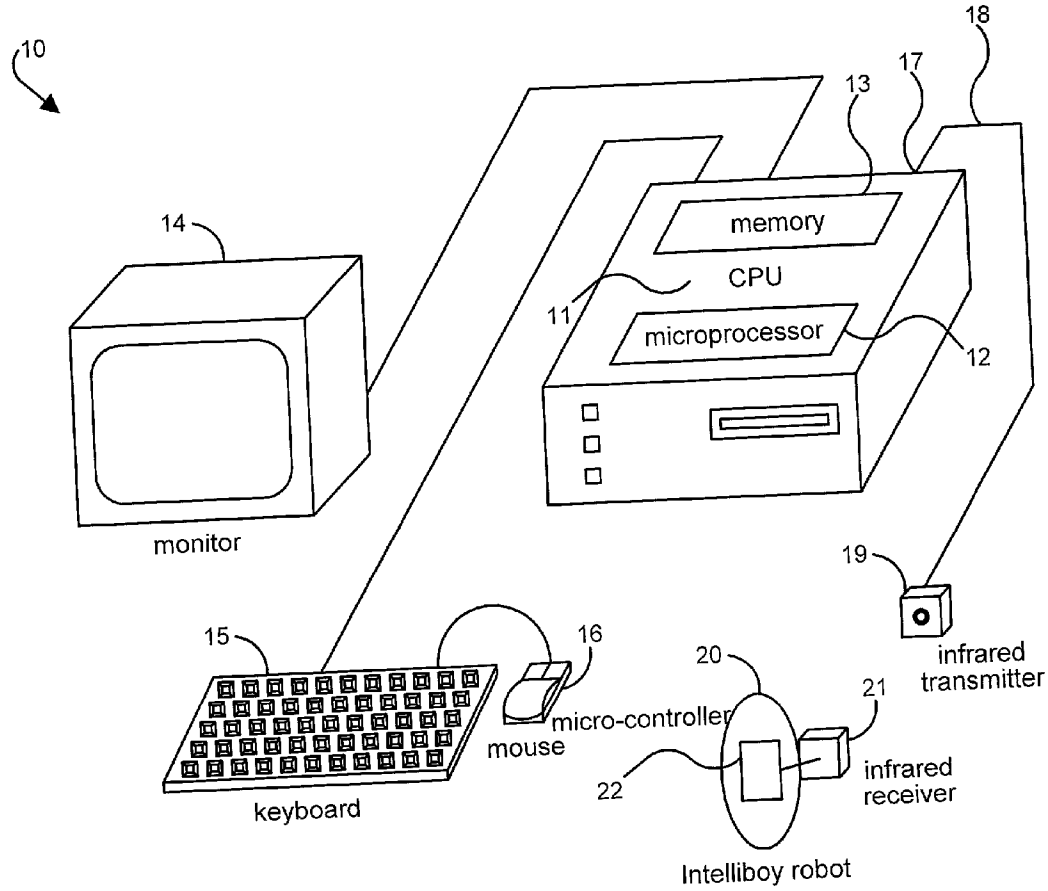

10
18
17
13
14
memory
CPU
11
microprocessor
12
monitor
19
infrared
transmitter
15
16
20
21
micro-controller
mouse
infrared
receiver
22
keyboard
Intelliboy robot

FIG. 1

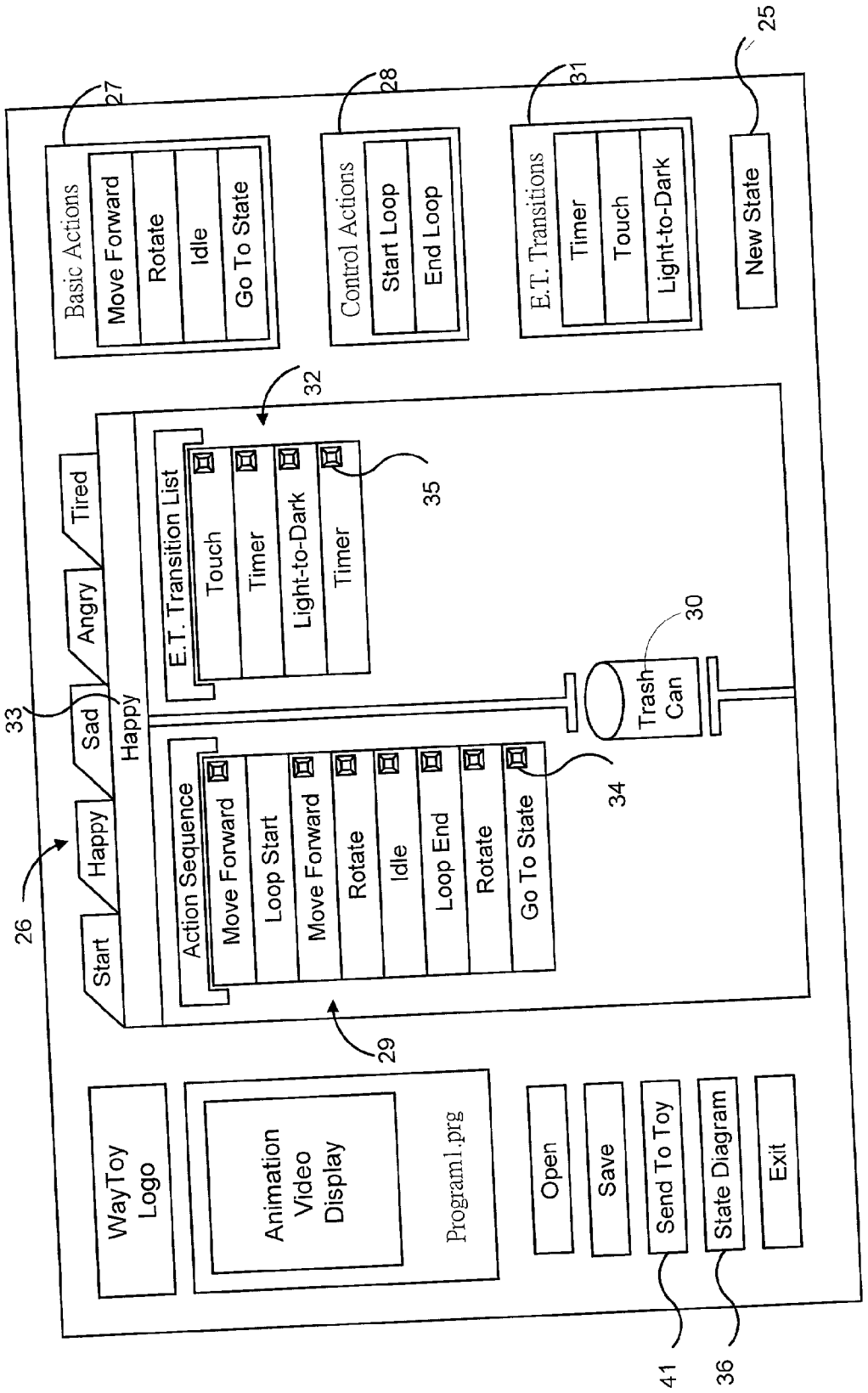

Basic Actions
Move Forward
Rotate
Idle
Go To State
Control Actions
Start Loop
End Loop
E.T. Transitions
Timer
Touch
Light-to-Dark
New State
E.T. Transition List
Touch
Timer
Light-to-Dark
Timer
Action Sequence
Move Forward
Loop Start
Move Forward
Rotate
Idle
Loop End
Rotate
Go To State
Start
Happy
Sad
Angry
Tired
Happy
Trash Can
WayToy Logo
Animation Video Display
Program1.prg
Open
Save
Send To Toy
State Diagram
Exit
25
26
27
28
29
30
31
32
33
34
35
36
41

FIG. 2

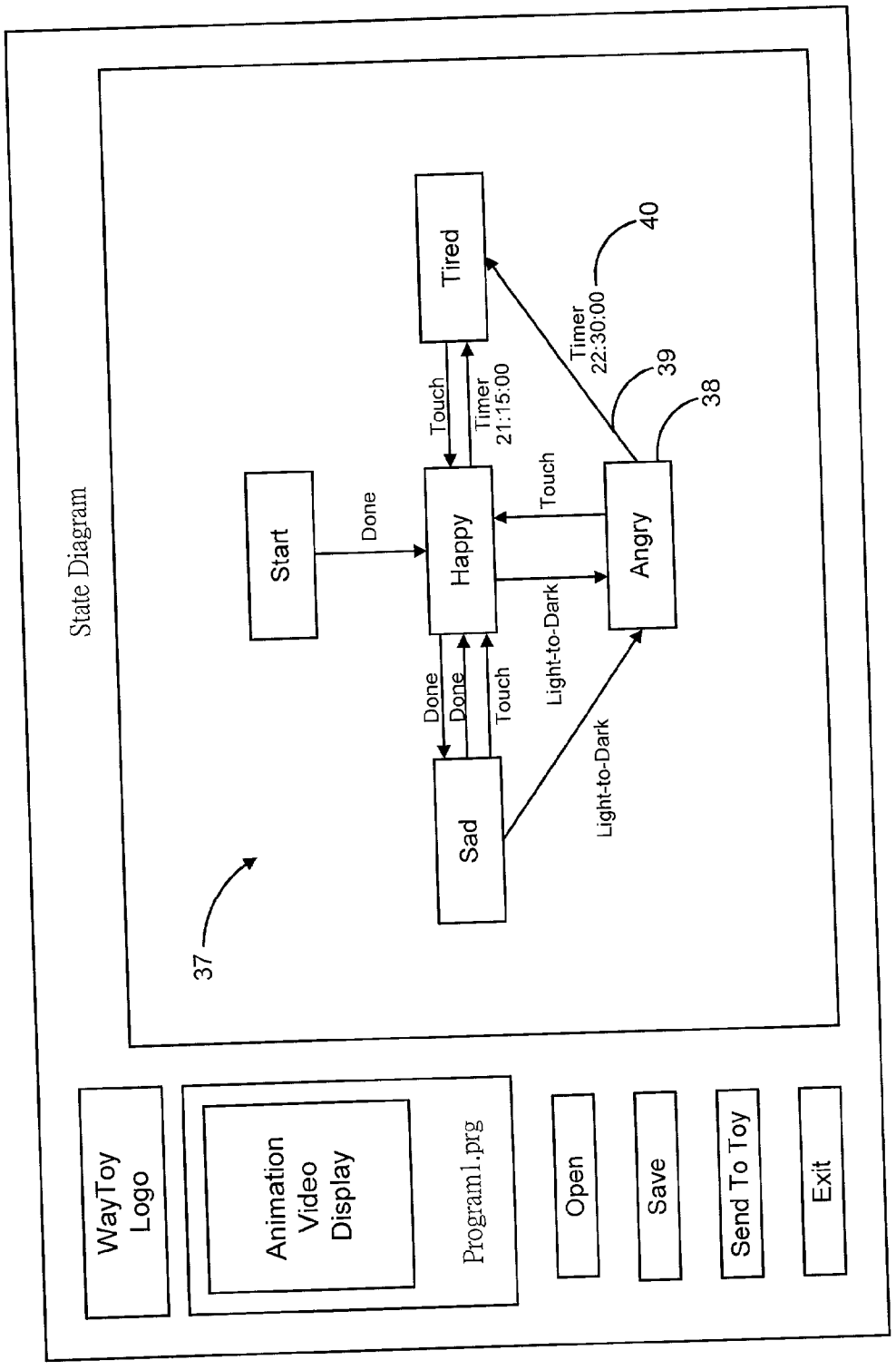

State Diagram
Start
Done
Happy
Touch
Timer
21:15:00
Tired
Timer
22:30:00
40
39
38
Touch
Angry
Light-to-Dark
Done
Done
Touch
Sad
Light-to-Dark
37
WayToy
Logo
Animation
Video
Display
Program1.prg
Open
Save
Send To Toy
Exit

FIG. 3

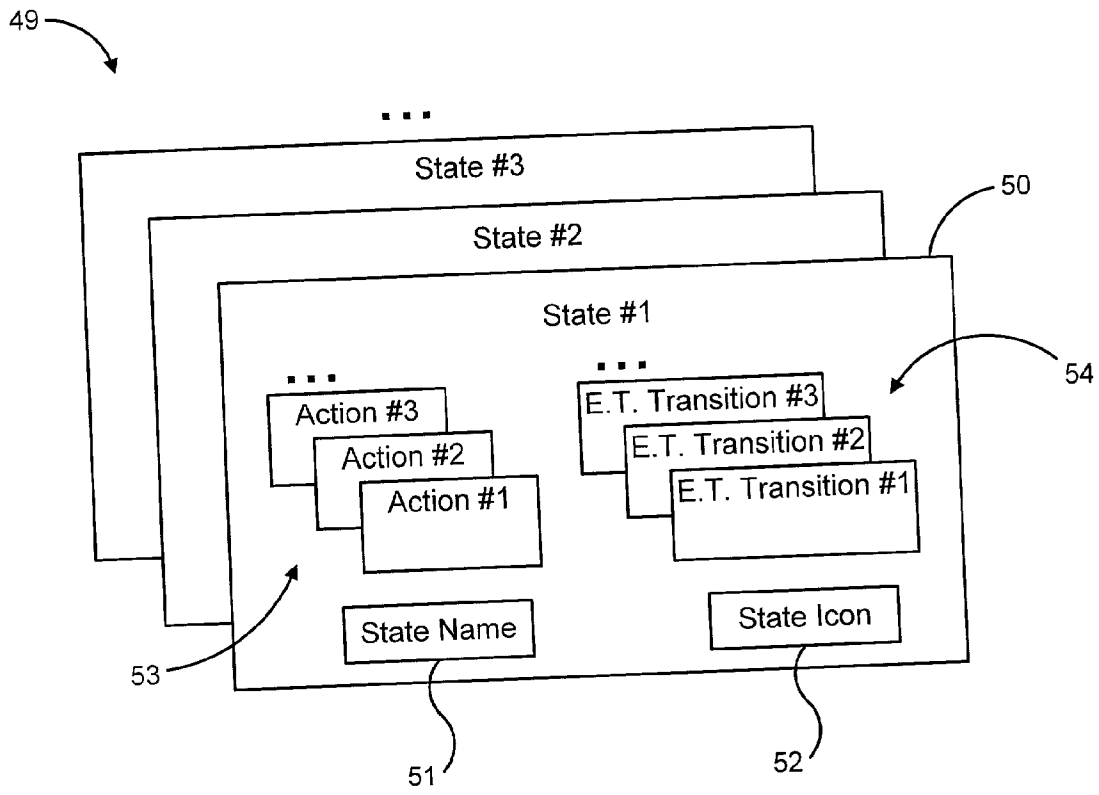

49
State #3
State #2
State #1
50
54
Action #3
Action #2
Action #1
E.T. Transition #3
E.T. Transition #2
E.T. Transition #1
State Name
State Icon
53
51
52

FIG. 4

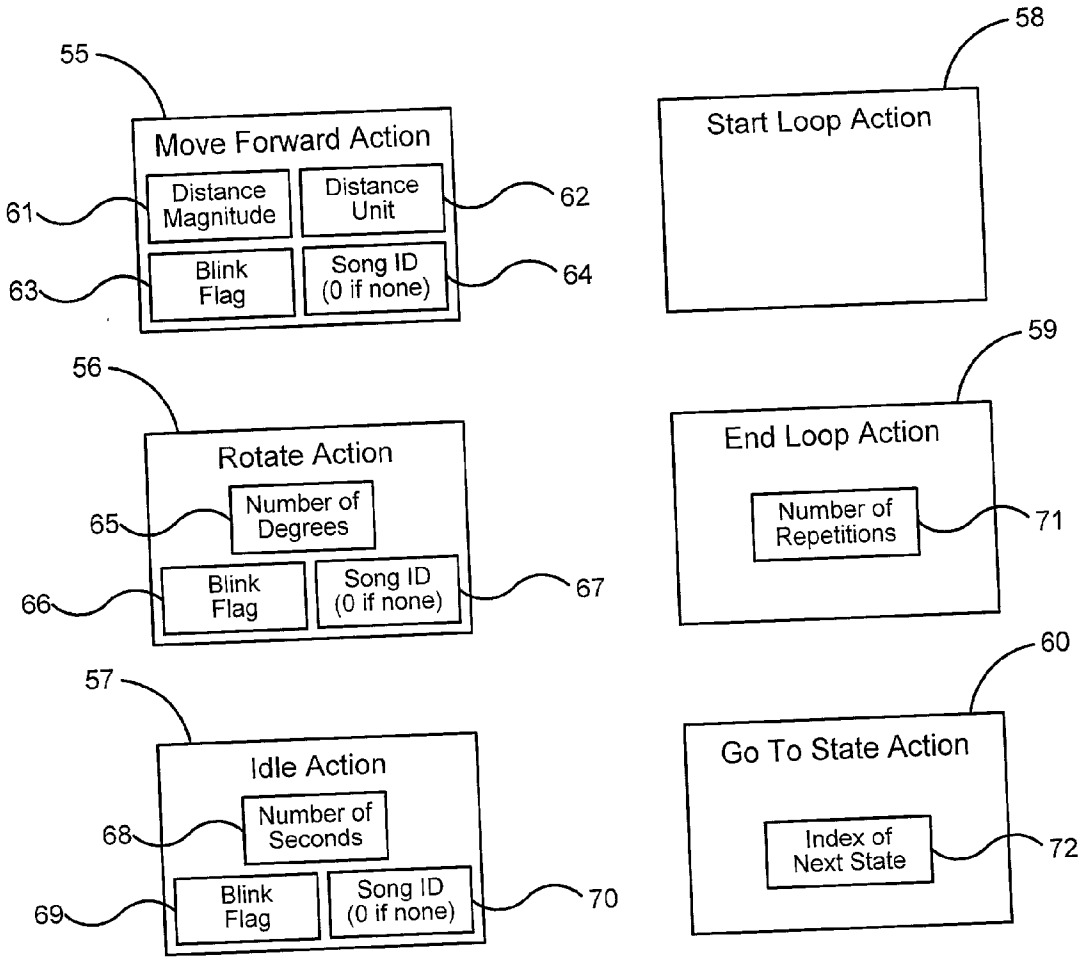

55
Move Forward Action
Distance Magnitude
Distance Unit
61
62
Blink Flag
Song ID (0 if none)
63
64
56
Rotate Action
Number of Degrees
65
Blink Flag
Song ID (0 if none)
66
67
57
Idle Action
Number of Seconds
68
Blink Flag
Song ID (0 if none)
69
70
58
Start Loop Action
59
End Loop Action
Number of Repetitions
71
60
Go To State Action
Index of Next State
72

FIG. 5

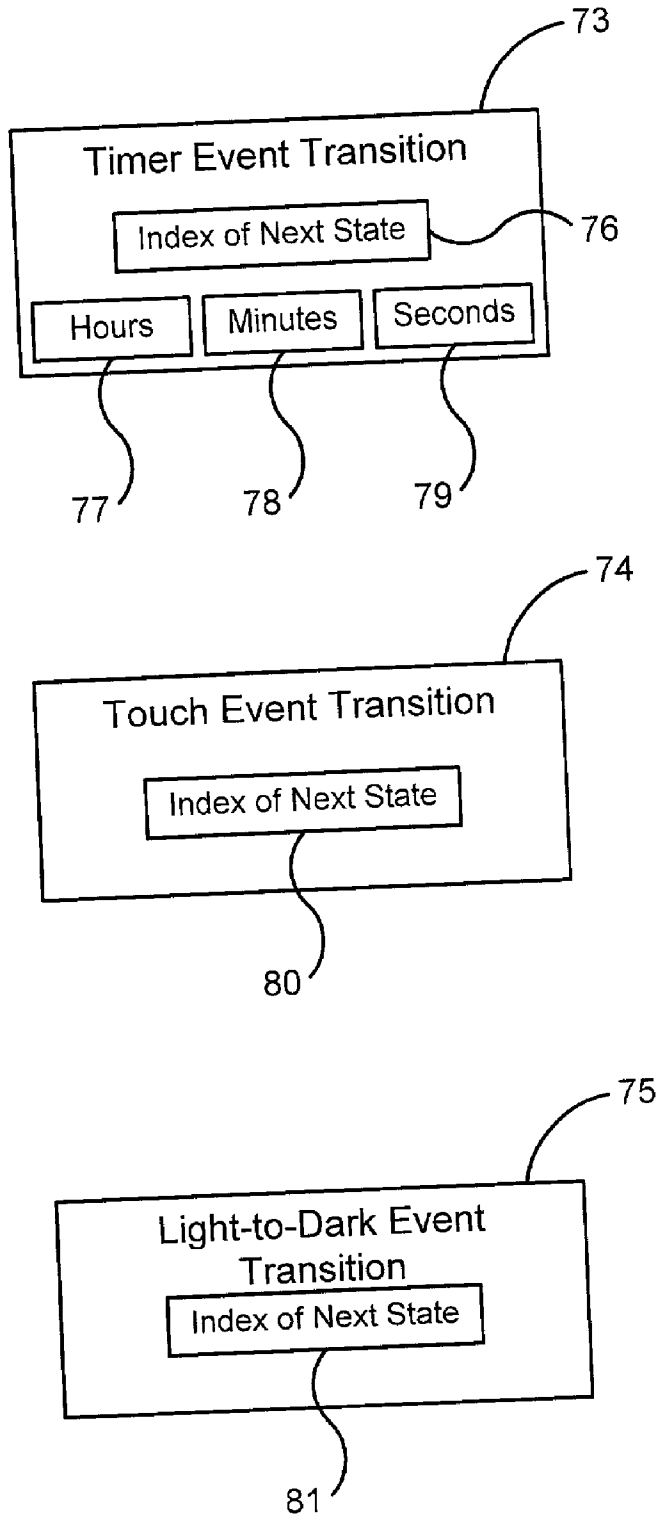

73
Timer Event Transition
Index of Next State
76
Hours
Minutes
Seconds
77
78
79
74
Touch Event Transition
Index of Next State
80
75
Light-to-Dark Event Transition
Index of Next State
81

FIG. 6

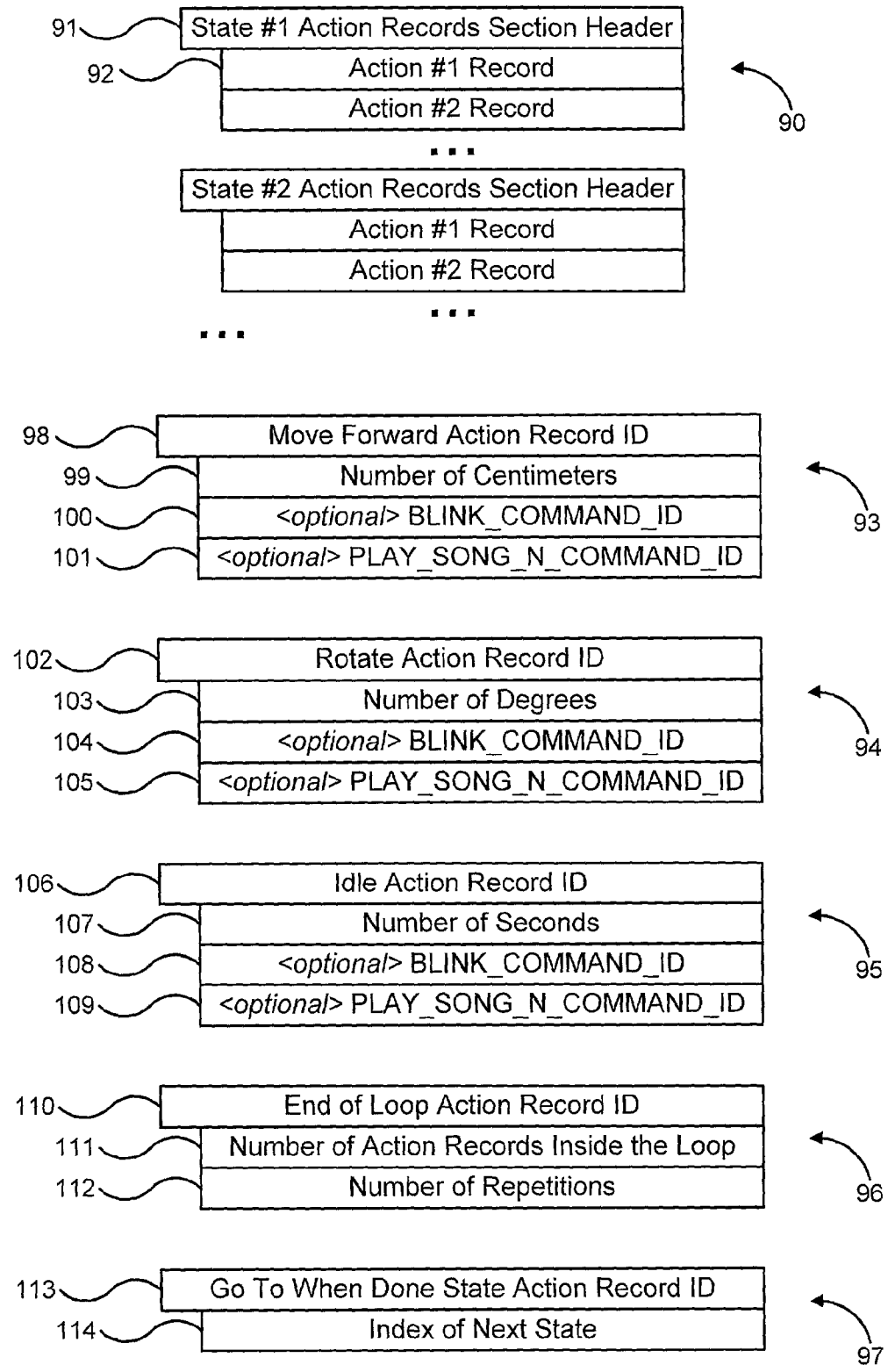

91
State #1 Action Records Section Header
92
Action #1 Record
Action #2 Record
90
State #2 Action Records Section Header
Action #1 Record
Action #2 Record
98
Move Forward Action Record ID
99
Number of Centimeters
100
<optional> BLINK_COMMAND_ID
101
<optional> PLAY_SONG_N_COMMAND_ID
93
102
Rotate Action Record ID
103
Number of Degrees
104
<optional> BLINK_COMMAND_ID
105
<optional> PLAY_SONG_N_COMMAND_ID
94
106
Idle Action Record ID
107
Number of Seconds
108
<optional> BLINK_COMMAND_ID
109
<optional> PLAY_SONG_N_COMMAND_ID
95
110
End of Loop Action Record ID
111
Number of Action Records Inside the Loop
112
Number of Repetitions
96
113
Go To When Done State Action Record ID
114
Index of Next State
97

FIG. 7

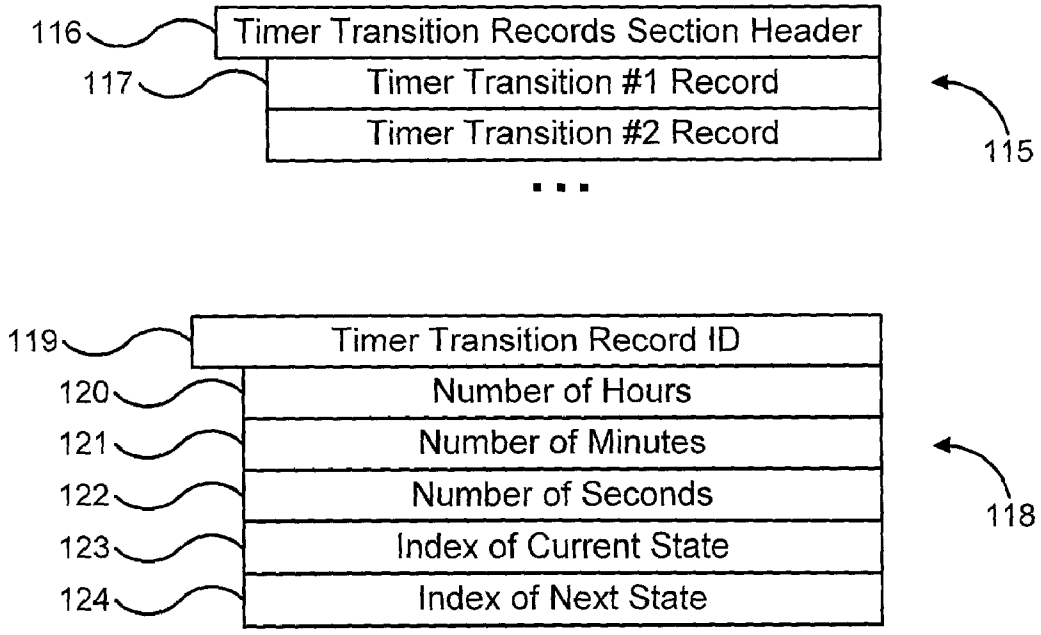

116
Timer Transition Records Section Header
117
Timer Transition #1 Record
Timer Transition #2 Record
115
119
Timer Transition Record ID
120
Number of Hours
121
Number of Minutes
122
Number of Seconds
123
Index of Current State
124
Index of Next State
118

FIG. 8

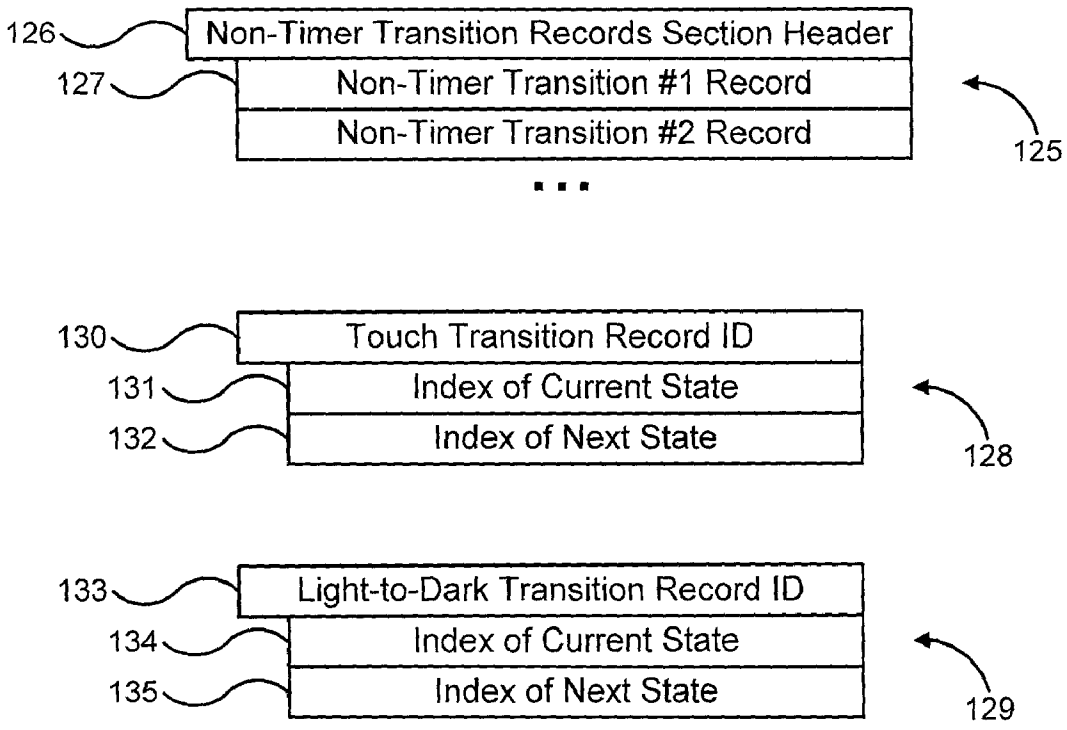
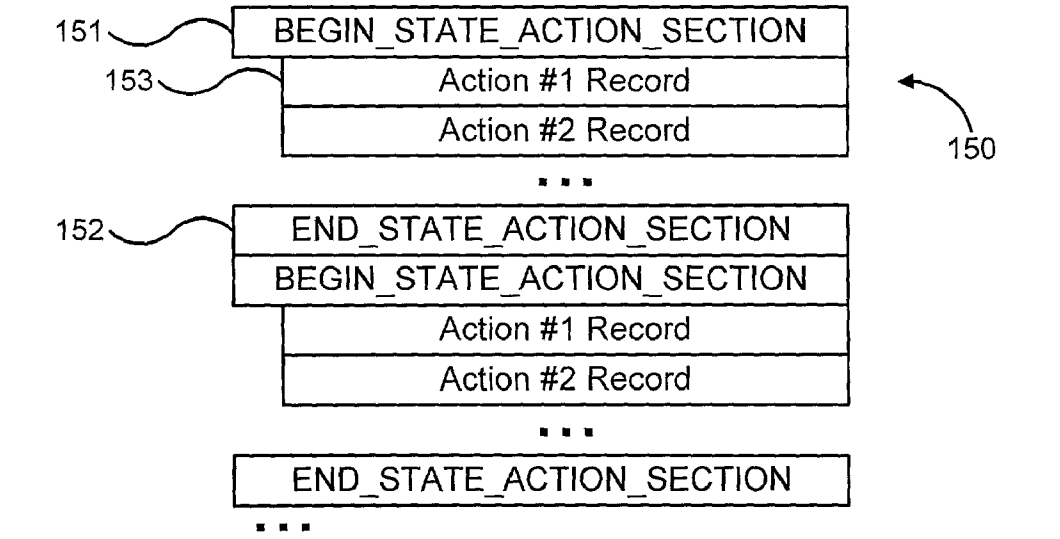
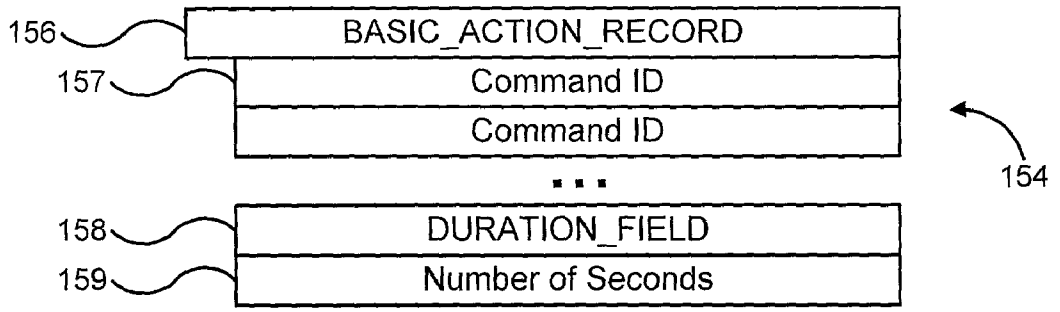

126
Non-Timer Transition Records Section Header
127
Non-Timer Transition #1 Record
Non-Timer Transition #2 Record
125
130
Touch Transition Record ID
131
Index of Current State
132
Index of Next State
128
133
Light-to-Dark Transition Record ID
134
Index of Current State
135
Index of Next State
129

FIG. 9


151
BEGIN_STATE_ACTION_SECTION
153
Action #1 Record
Action #2 Record
150
152
END_STATE_ACTION_SECTION
BEGIN_STATE_ACTION_SECTION
Action #1 Record
Action #2 Record
END_STATE_ACTION_SECTION


156
BASIC_ACTION_RECORD
157
Command ID
Command ID
154
158
DURATION_FIELD
159
Number of Seconds

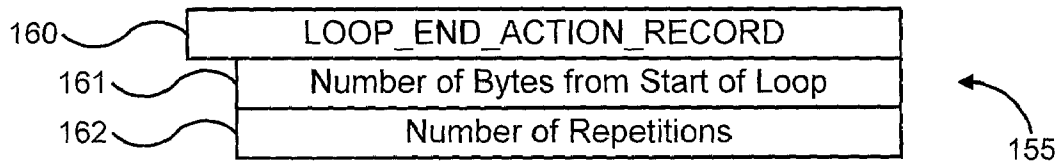

160
LOOP_END_ACTION_RECORD
161
Number of Bytes from Start of Loop
162
Number of Repetitions
155

FIG. 10

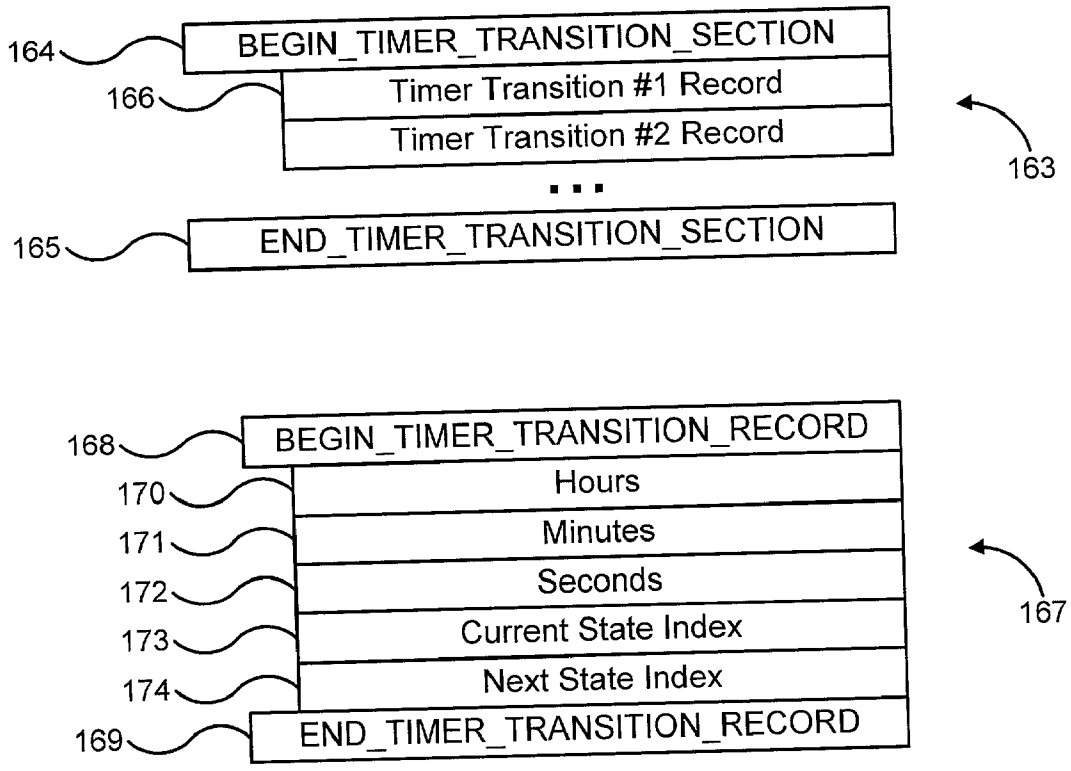

164
BEGIN_TIMER_TRANSITION_SECTION
166
Timer Transition #1 Record
Timer Transition #2 Record
...
165
END_TIMER_TRANSITION_SECTION
163
168
BEGIN_TIMER_TRANSITION_RECORD
170
Hours
171
Minutes
172
Seconds
173
Current State Index
174
Next State Index
169
END_TIMER_TRANSITION_RECORD
167

FIG. 11

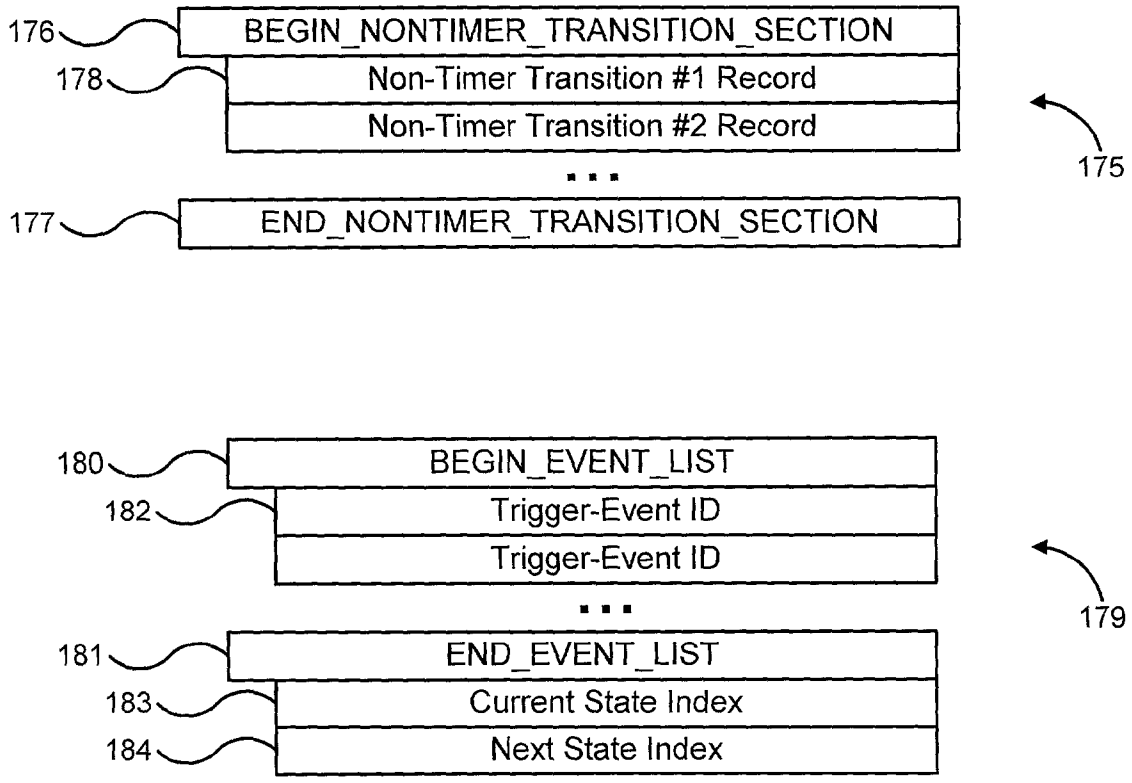

176
BEGIN_NONTIMER_TRANSITION_SECTION
178
Non-Timer Transition #1 Record
Non-Timer Transition #2 Record
177
END_NONTIMER_TRANSITION_SECTION
175
180
BEGIN_EVENT_LIST
182
Trigger-Event ID
Trigger-Event ID
181
END_EVENT_LIST
183
Current State Index
184
Next State Index
179

FIG. 12

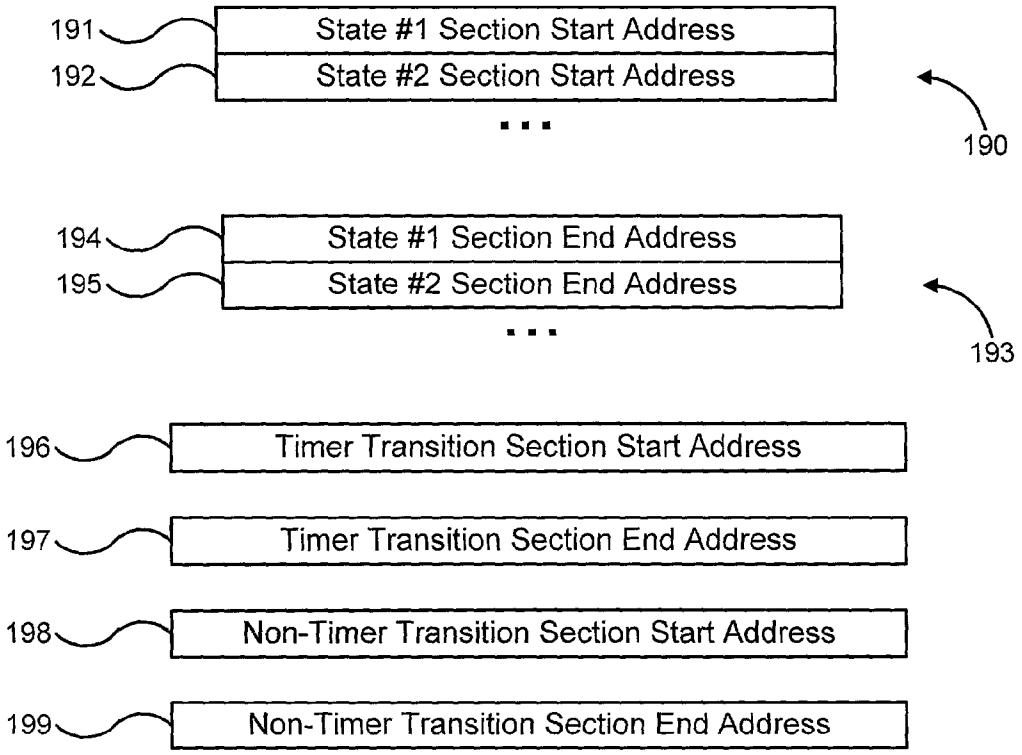

191
State #1 Section Start Address
192
State #2 Section Start Address
190
194
State #1 Section End Address
195
State #2 Section End Address
193
196
Timer Transition Section Start Address
197
Timer Transition Section End Address
198
Non-Timer Transition Section Start Address
199
Non-Timer Transition Section End Address

FIG. 13

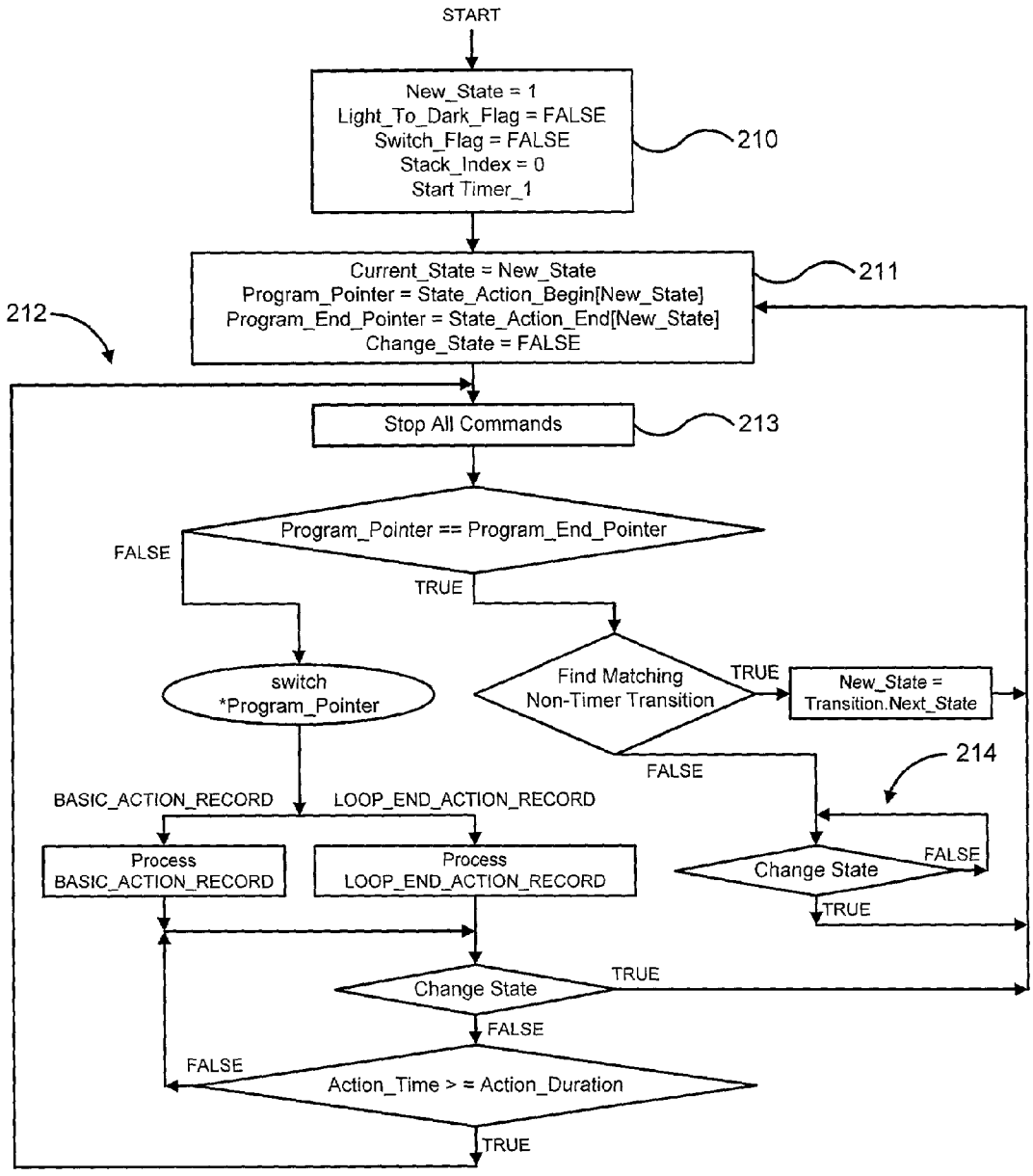

START
New_State = 1
Light_To_Dark_Flag = FALSE
Switch_Flag = FALSE
Stack_Index = 0
Start Timer_1
210
Current_State = New_State
Program_Pointer = State_Action_Begin[New_State]
Program_End_Pointer = State_Action_End[New_State]
Change_State = FALSE
211
212
Stop All Commands
213
Program_Pointer == Program_End_Pointer
FALSE
TRUE
switch
*Program_Pointer
Find Matching
Non-Timer Transition
TRUE
New_State =
Transition.Next_State
FALSE
214
BASIC_ACTION_RECORD
LOOP_END_ACTION_RECORD
Process
BASIC_ACTION_RECORD
Process
LOOP_END_ACTION_RECORD
Change State
FALSE
TRUE
Change State
TRUE
FALSE
FALSE
Action_Time > = Action_Duration
TRUE

FIG. 14

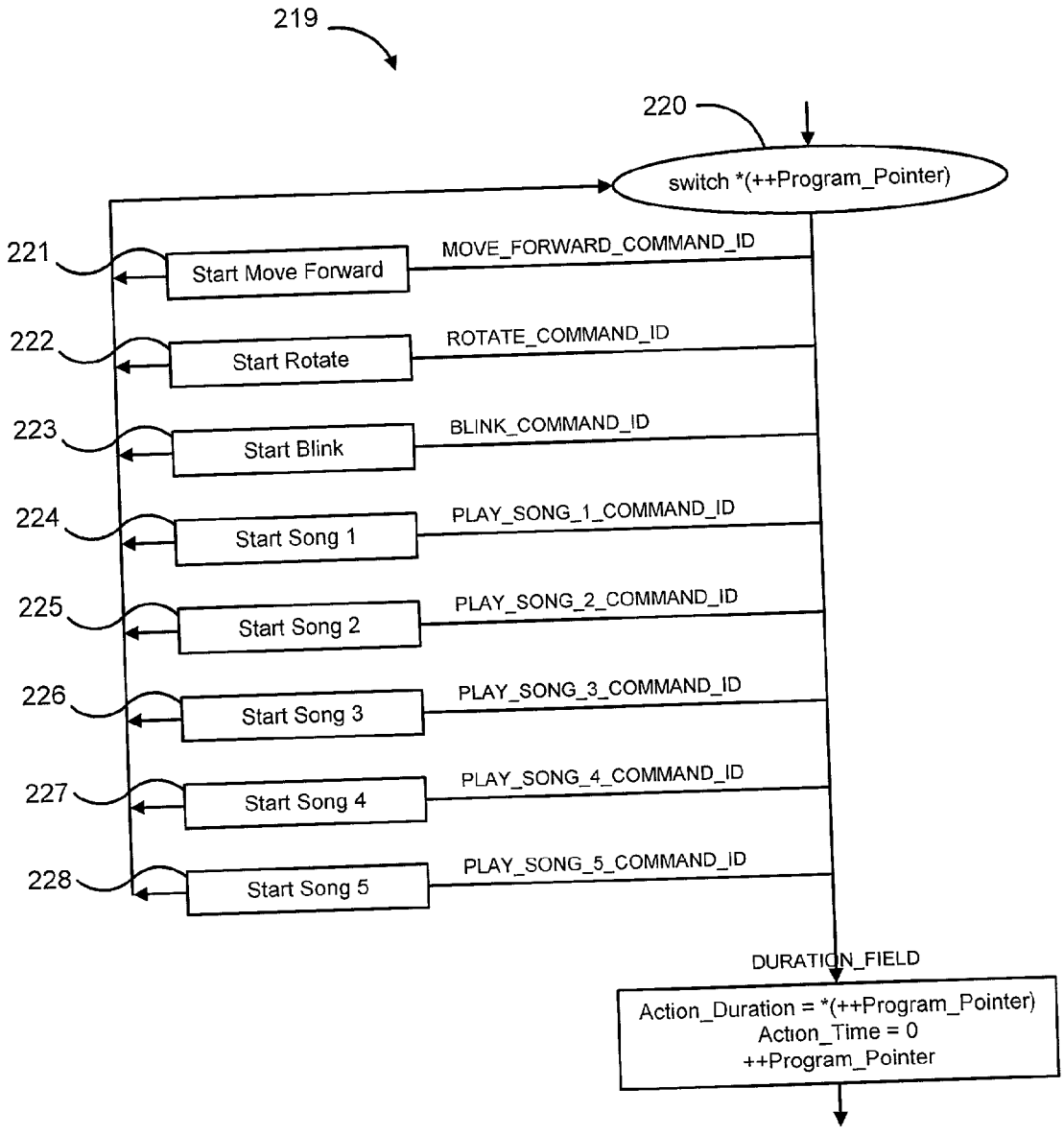

219
220
switch *(++Program_Pointer)
221
Start Move Forward
MOVE_FORWARD_COMMAND_ID
222
Start Rotate
ROTATE_COMMAND_ID
223
Start Blink
BLINK_COMMAND_ID
224
Start Song 1
PLAY_SONG_1_COMMAND_ID
225
Start Song 2
PLAY_SONG_2_COMMAND_ID
226
Start Song 3
PLAY_SONG_3_COMMAND_ID
227
Start Song 4
PLAY_SONG_4_COMMAND_ID
228
Start Song 5
PLAY_SONG_5_COMMAND_ID
DURATION_FIELD
Action_Duration = *(++Program_Pointer)
Action_Time = 0
++Program_Pointer

FIG. 15

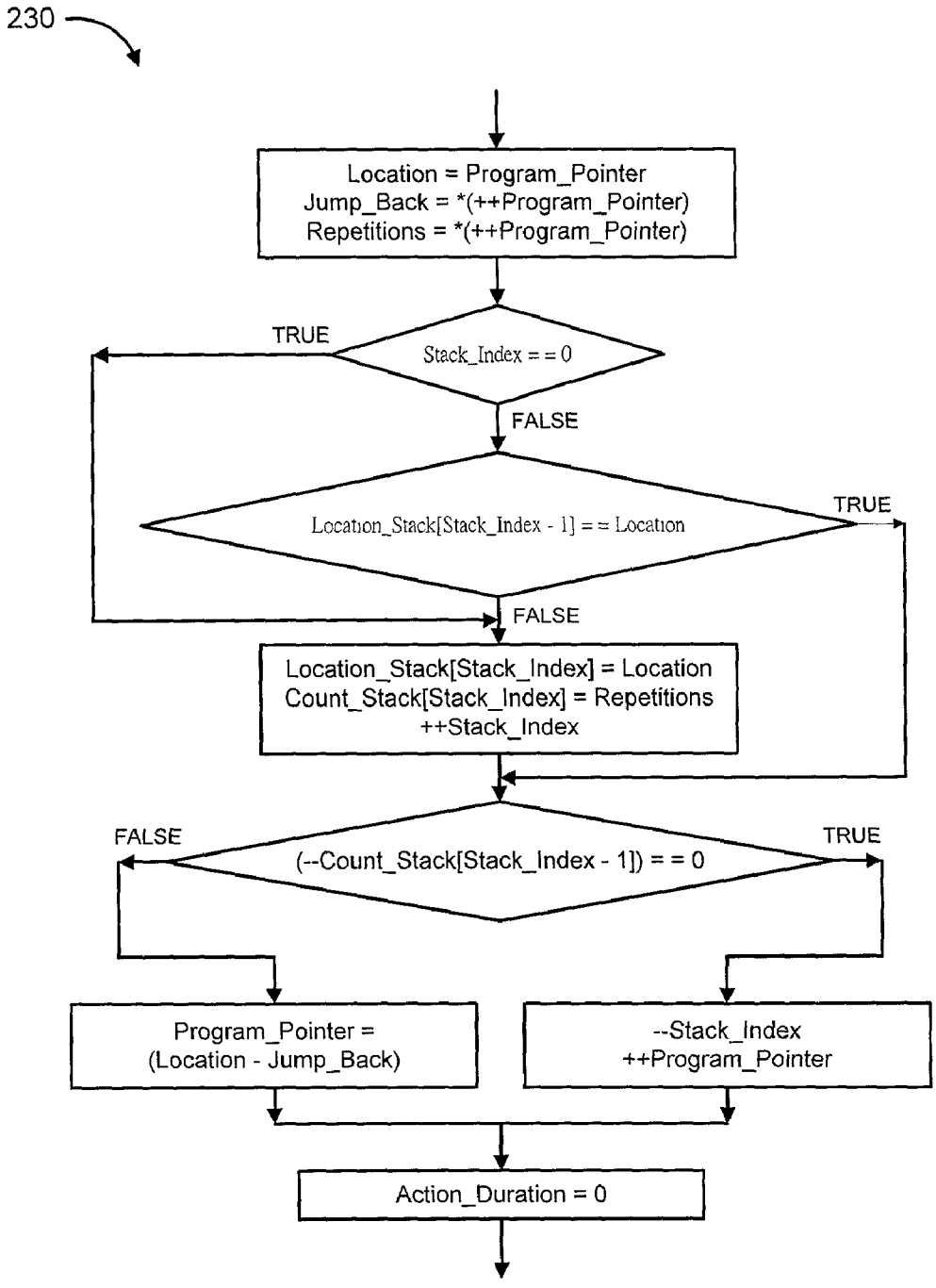

230
Location = Program_Pointer
Jump_Back = *(++Program_Pointer)
Repetitions = *(++Program_Pointer)
TRUE
Stack_Index = = 0
FALSE
Location_Stack[Stack_Index - 1] = = Location
TRUE
FALSE
Location_Stack[Stack_Index] = Location
Count_Stack[Stack_Index] = Repetitions
++Stack_Index
FALSE
(--Count_Stack[Stack_Index - 1]) = = 0
TRUE
Program_Pointer =
(Location - Jump_Back)
--Stack_Index
++Program_Pointer
Action_Duration = 0

FIG. 16

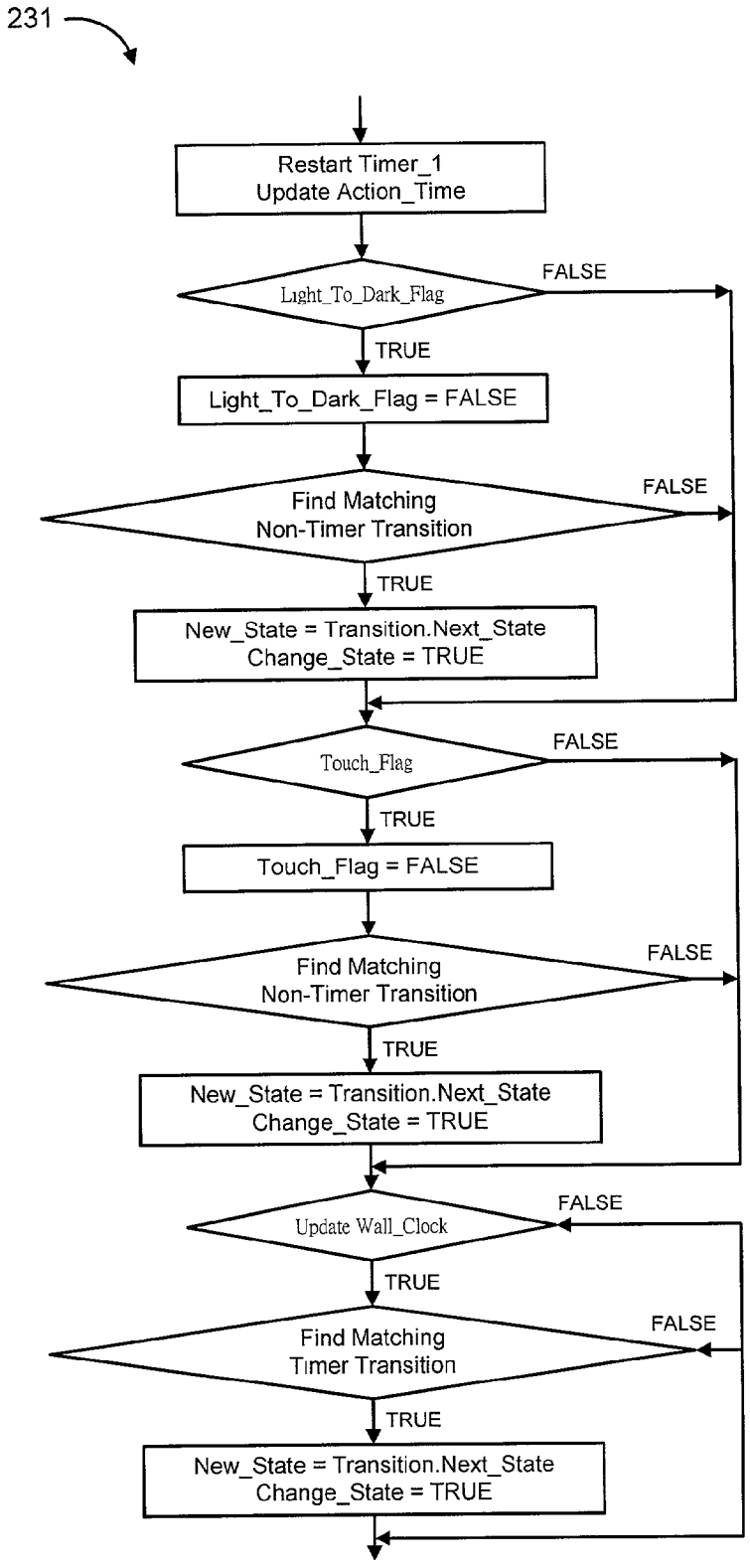

231
Restart Timer_1
Update Action_Time
Light_To_Dark_Flag
FALSE
TRUE
Light_To_Dark_Flag = FALSE
Find Matching
Non-Timer Transition
FALSE
TRUE
New_State = Transition.Next_State
Change_State = TRUE
Touch_Flag
FALSE
TRUE
Touch_Flag = FALSE
Find Matching
Non-Timer Transition
FALSE
TRUE
New_State = Transition.Next_State
Change_State = TRUE
Update Wall_Clock
FALSE
TRUE
Find Matching
Timer Transition
FALSE
TRUE
New_State = Transition.Next_State
Change_State = TRUE

FIG. 17

METHOD AND SYSTEM FOR PROGRAMMING DEVICES USING FINITE STATE MACHINE DESCRIPTIONS

BACKGROUND OF THE INVENTION

[0001] (1) Field of the Invention

[0002] The invention relates generally to control programming and, more specifically, to an improved method and system for creating device control programs.

[0003] (2) Description of the Prior Art

[0004] Active toys, i.e. toys that move, make sounds, etc., are very popular. The wider the variety of behaviors an active toy is capable of, the more interesting it will be and the more revenue it will generate for the company marketing the toy. Toy companies can increase the behavioral variety of a toy by adding more types of atomic actions (such as particular arm movements), but this increases the complexity of the toy and thus its manufacturing cost. Besides, once a reasonable number of atomic actions are provided for a given type of toy, adding more atomic actions yields rapidly diminishing returns—the increase in play value achieved by adding more atomic actions becomes too small to justify the cost.

[0005] A cheaper and more effective way to increase the behavioral repertoire of an active toy is to combine the existing atomic actions in a wider variety of ways. (For example, a relatively limited set of notes can be combined in many different ways to yield a large number of different songs.) To achieve this, active toys are usually built with a micro-controller that can be programmed to carry out a complex sequence of atomic actions.

[0006] Many active toys today are sold with a single, fixed program "hardwired" into the toy. However, toy designers have recognized the potential to increase the play value and popularity of their active toys by making them reprogrammable. For example, a single robot could be used in a variety of different play scenarios by reprogramming it with different identities (cowboy, soldier, fireman, etc.). Several different approaches to providing reprogrammability are in use today.

[0007] One common way of making an active toy reprogrammable is to use the "fixed menu" approach. The toy company creates several different programs for the toy, and makes them available in any of several ways (downloads on a web site, plastic disks sold in retail stores, etc.). The child selects a program from the set of available alternatives, and loads it into the toy. This can be done in a variety of ways, as has been shown in the teachings of several prior art patents. For example, a toy can be designed so that a child can download a program from a web site to his PC, and from there send the program to the toy over an infrared link or over a USB link. The limitation of the "fixed menu" approach is not in the mechanics of loading a program into a toy. Rather, the limitation is in the number and variety of programs that the toy company can afford to create. Given the sales volumes and gross margins that are typical in the toy business, toy companies cannot afford to create a broad variety of programs for each of their active toys. This limits the potential play value of each toy. Furthermore, since the "fixed menu" approach restricts children to pre-built programs, they cannot exercise their creativity to make new and interesting programs of their own.

[0008] Ideally, a child buying a reprogrammable active toy would be provided with a means of creating his own programs for the toy. However, the methods usually used to create programs for micro-controllers require programming skills in assembly or in a higher-level language such as Basic or 'C'. Only a small percentage of adults are able to create programs in this manner, and almost no children can. Therefore it is necessary to provide a simpler, more intuitive way for children to create programs.

[0009] Several approaches to the problem of enabling children to create programs have been tried. One approach is to provide a keypad attached to the toy that a child can use to enter a sequence of desired actions. This sequence is then saved in the toy as a program. Experience in other fields has shown that such techniques are only practical for trivially short, simple programs. Even modest-size programs need to be developed iteratively. For a child, this means that a draft program needs to be visually presented in such a way that he can easily understand how it works. It also needs to be easy for him to change the program to fix problems or to add new behavior. Finally, it needs to be quick and easy for the child to try the improved program to see if he likes it. Keypad entry, which has no graphical program display and which requires the entire program to be re-entered every time a change is made, does not meet any of these three requirements. Some companies have tried to improve on the keypad entry approach by providing a small display screen with the keypad. However, cost constraints require the screen to be so small that the increase in the size of the program that can practically be created by a child is minimal. Therefore, the state of the art is to exploit the capability of personal computer (PC) to meet the requirements. Not only are personal computers far more powerful and easier to use than a keypad (with or without a small screen), they also have good market penetration in families that would buy a programmable toy, and most children in those families are already familiar with using a PC.

[0010] A few different approaches to using a PC for toy programming have been tried. One approach is to both create and run the program on the PC. While the child is playing with the toy, the PC acts as the "brains" of the toy, and sends a control message to the toy each time the toy is supposed to do something. This requires the PC to be in continuous communication with the toy, i.e. the toy doesn't work without the PC. Such a restriction is acceptable for something like a model train set, which is used in a fixed location for an extended period of time. However, this restriction is not acceptable for most toys, because children want to be able to play with their toys away from their PC. Besides, the "PC as central controller" approach leads to problems when children want to play with several toys of the same kind. Unless the children want all of their toys to be doing exactly the same thing at exactly the same time, the central controller PC needs to distinguish among the toys that are in range and send out individualized command sequences for each. Likewise, each toy needs to be able to distinguish among the various command sequences that the PC broadcasts, obeying commands meant for it and ignoring commands meant for the other toys in range. Technically it is possible to do this, but it adds to the complexity and cost of the product.

[0011] The limitations of the "PC as central controller" approach can be avoided by using a "distributed control" approach. In this method the power of the PC is used to create the program, but not to run the program. Instead, the program is compiled and downloaded from the PC to the toy, and the toy runs the program itself. This allows the child to play with the toy anywhere, without needing to be in range of the PC. It also allows children to play with several toys of the same kind at the same time without requiring complex multi-toy control technology.

[0012] Several child-programmable toys have been designed using the distributed control approach. While some of them offer graphical programming with artwork that is quite visually appealing, they all require the child to create programs at a fairly low level. The programs basically consist of a series of steps (e.g. walk forward 10 cm., turn left 90 degrees, beep twice, walk forward 5 cm., . . .) and "if X happens, then do Y" directives. There is no high-level conceptual framework for these programs, so it is difficult for a child to understand a program of any reasonable size that is written in this manner.

[0013] High-level conceptual frameworks make it much easier for people to create and understand programs. Their advantages have motivated extensive efforts to develop conceptual frameworks for creating programs in many different fields. For example, in the field of automated industrial process control, the "data flow diagram" conceptual framework has made it much easier for people to create and understand process control programs. A high-level conceptual framework that is intuitive enough to enable people without a technical background in software engineering or in hardware control to program devices would have many applications. Not only toys, but also climate control systems, cleaning robots, lighting control systems, television-program recorders, landscape sprinkler systems, and numerous other devices could be successfully programmed by their users instead of just by their manufacturers. As progress in embedded control, robotics and other fields increases the capabilities of devices, there will be increasing demand for an easy way to program these devices to satisfy the individual needs and interests of each user. It is an object of the present invention to provide a means of creating device-control programs using a conceptual framework that meets this demand.

SUMMARY OF THE INVENTION

[0014] The present invention comprises a system and method for capturing a Finite State Machine (FSM) description of desired behavior of a device, and compiling or otherwise converting that description into a program that is executable by the device. FSM descriptions have been defined and discussed in numerous publications, such as the Addison-Wesley book *Introduction to Automata Theory, Languages and Computation*, by John E. Hopcroft and Jeffrey D. Ullman. The FSM paradigm is a proven conceptual framework for organizing the details of a complex behavioral description in a modular, easy to understand form. The invention thus provides a method and apparatus for programming a device using a Finite State Machine (FSM) description of the desired behavior of the device.

[0015] The method includes the step of executing a user interface program (UI) on a computer, which displays a plurality of graphic objects on a display and captures user input, thereby enabling the user to specify the FSM. This step shall be referred to below as the Input Step.

[0016] The Input Step includes enabling the user to specify the desired states of the FSM (States). Each State corresponds to a particular state of the device as envisioned by the user. For example, in the case of a toy robot, the user may define a "Happy" state, a "Scared" state, an "Angry" state, etc. States are not limited to imaginary emotional states; they can correspond to any concept or situation that is of interest to the user. In other words, the user may create any States he wants (up to a numerical limit determined by the memory and other program resources available in the device). One State must be designated as the "Start State", which specifies which State the device will enter when it begins running the program. The invention contemplates that the UI may enable the user to create States in any of a variety of ways. User interface techniques to create a new object (such as a State) and to set the object's properties (such as the State's name) are well known to those skilled in the art. In the preferred embodiment, the UI displays a "New State" button. When the user selects this button, a new State is created. A dialog box enables the user to set the name of the State, and to assign it an icon that may help remind the user of the concept he had in mind when he created the State.

[0017] The Input Step also includes enabling the user to specify the desired transitions of the FSM (Transitions). Each Transition specification includes a Current State, a Next State, and a Trigger, where the Current State is a State, where the Next State is a State, and where the Trigger is an event whose occurrence can be detected. The Transition specification means that if the Transition's Trigger event is detected while the FSM is in the Transition's Current State, then the FSM will leave the Transition's Current State and enter the Transitions's Next State. The invention contemplates that the UI may enable the user to create Transitions in any of a variety of ways. Essentially the UI must enable the User to specify a triplet, where each element of the triplet is to be chosen from some set of possibilities for that element. User interface techniques to do this are well known to those skilled in the art. In the preferred embodiment, the UI enables the user to specify which State he is currently working on. Then the UI displays a plurality of graphic objects, one for each possible Trigger. When the user selects one of the graphic objects that corresponds to a Trigger, a Transition is created using that Trigger. The Current State of the Transition is the State the user is currently working on, and the Next State of the Transition is selectable by the user from a list of all of the States.

[0018] The Input Step also includes enabling the user to specify sequences of Actions that he wishes the device to perform (Action Sequences). An Action can be any device behavior that the device designer has chosen to make programmatically available to the user. For example, in the case of a toy robot, an Action can be moving forward, turning around, saying a word, etc. An Action can also be a control construct, such as "if . . . then . . . " or "while . . . do . . . ", which enables the user to control how the sequence is executed. The invention contemplates that the UI may enable the user to specify an Action Sequence in any of a variety of ways. Essentially the UI must enable the user to specify an ordered list, where each element of the list is to be chosen from a set of possible elements. User interface

techniques to do this are well known to those skilled in the art. In the preferred embodiment, the UI displays a plurality of graphic objects, one for each possible Action. The user is enabled to select one of the objects, thereby creating an instance of the corresponding Action which is displayed as a new graphic object. The user is enabled to drag this new graphic object into an ordered list of Action instance graphic objects. Then the user is enabled to set any properties that can be used to customize the Action, such as duration.

[0019] The Input Step also includes enabling the user to associate each Action Sequence with a State or a Transition. The invention contemplates that, depending on the resource constraints of each device, the target market for the device, and various other considerations, a particular embodiment may allow the user to associate Action Sequences only with States, only with Transitions, or with both States and Transitions. If an Action Sequence is associated with a State, it means that the Action Sequence will begin to execute whenever the FSM enters that State. If the FSM leaves that State before the Action Sequence is completed, the Action Sequence will be halted. If an Action Sequence is associated with a Transition, it means that whenever the Transition occurs, the Action Sequence will begin after the FSM leaves the Transition's Current State, and will complete before the FSM enters the Transition's Next State. The invention contemplates that the UI may enable the user to associate an Action Sequence with a State or with a Transition in any of a variety of ways. Essentially the UI must enable the user to link an object of a particular type (a State or a Transition) to an object of another particular type (an Action Sequence). User interface techniques to do this are well known to those skilled in the art. In the preferred embodiment, the UI only allows Action Sequences to be associated with States. The association between a particular Action Sequence and a particular State is achieved by enabling the construction or modification of an Action Sequence only when the user has chosen the associated State as his working context.

[0020] The Input Step also includes enabling the user to view the FSM. This has several advantages for a typical user who will be using the iterative development approach, including making it easier for the user to understand the FSM and making it easier for him to determine how to change the FSM to improve the programmed behavior of the device. The invention contemplates that the UI may enable the user to view the FSM in any of a variety of ways. Those skilled in the art of hardware control programming will be familiar with several techniques for displaying an FSM, including a state-transition table and a state-transition diagram. In the preferred embodiment, the UI displays the FSM using a state-transition diagram.

[0021] A further step of the method is compiling the FSM into a program that is executable by the device. The invention contemplates that this step may be done in any of a variety of ways. Those skilled in the art of compiler design will be familiar with several implementation techniques that are suitable for carrying out this step. In the preferred embodiment, the FSM is compiled to a set of instructions and jump tables that can be read and executed by a virtual machine that runs on the device's micro-controller.

[0022] A further step of the method is sending the compiled program to the device. The invention contemplates that this step may be done in any of a variety of ways. Those skilled in the art of data transfer will be familiar with several implementation techniques that are suitable for carrying out this step, including physical media transfers (e.g. floppy disks), wireless transfers (e.g. Bluetooth) and wired transfers (e.g. 10 BaseT Ethernet). In the preferred embodiment, the compiled program is sent through the serial port of a personal computer to an infrared transmitter. The transmitter emits an infrared signal containing the program, which is received by an infrared sensor on the device. The program is then stored in the device for later execution.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] **FIG. 1** is a schematic block diagram illustrating the principal hardware components of the preferred embodiment: a personal computer connected to an infrared transmitter via a serial cable, and an Intelliboy robot modified to include an infrared receiver and a micro-controller.

[0024] **FIG. 2** illustrates an exemplary display screen for the preferred embodiment's User Interface in "edit the FSM" mode, showing a State, the State's Action Sequence, the State's Event-Triggered Transition List, and the menus and buttons available for the user to modify this State and perform other tasks.

[0025] **FIG. 3** illustrates an exemplary display screen for the preferred embodiment's User Interface in "view the State Diagram" mode, showing a drawing of the States and Transitions in an FSM.

[0026] **FIG. 4** is a schematic block diagram illustrating the data structures used by the preferred embodiment's User Interface to store State information.

[0027] **FIG. 5** is a schematic block diagram illustrating the data structures used by the preferred embodiment's User Interface to store Action Instance information.

[0028] **FIG. 6** is a schematic block diagram illustrating the data structures used by the preferred embodiment's User Interface to store Event-Triggered Transition Instance information.

[0029] **FIG. 7** is a schematic block diagram illustrating the State Action Records Sections in the Compiler Input File created by the preferred embodiment's User Interface.

[0030] **FIG. 8** is a schematic block diagram illustrating the Timer Transition Records Section in the Compiler Input File created by the preferred embodiment's User Interface.

[0031] **FIG. 9** is a schematic block diagram illustrating the Non-Timer Transition Records Section in the Compiler Input File created by the preferred embodiment's User Interface.

[0032] **FIG. 10** is a schematic block diagram illustrating the State Action Sections in the Compiled Program Description File created by the preferred embodiment's Compiler.

[0033] **FIG. 11** is a schematic block diagram illustrating the Timer Transition Section in the Compiled Program Description File created by the preferred embodiment's Compiler.

[0034] **FIG. 12** is a schematic block diagram illustrating the Non-Timer Transition Section in the Compiled Program Description File created by the preferred embodiment's Compiler.

[0035] **FIG. 13** is a schematic block diagram illustrating part of the preferred embodiment's micro-controller memory in which the preferred embodiment's Virtual Machine records the addresses of some locations in the Compiled Program Description so that these locations can be accessed efficiently.

[0036] **FIG. 14** is a high-level flow chart for part of the preferred embodiment's Virtual Machine.

[0037] **FIG. 15** is a flow chart illustrating how the preferred embodiment's Virtual Machine executes the Process BASIC_ACTION_RECORD step shown as a single block in **FIG. 14**.

[0038] **FIG. 16** is a flow chart illustrating how the preferred embodiment's Virtual Machine executes the Process LOOP_END_ACTION_RECORD step shown as a single block in **FIG. 14**.

[0039] **FIG. 17** is a flow chart illustrating how the preferred embodiment's Virtual Machine checks for the occurrence of an event that would trigger an FSM transition.

DESCRIPTION OF THE PREFFERRED EMBODIMENT

[0040] In **FIG. 1**, an exemplary preferred embodiment of the invention is illustrated. A personal computer **10** includes at least on central processing unit (CPU) **11** including a microprocessor **12** coupled to memory (such as RAM and hard disk) **13**. Computer input and output may be displayed on a monitor **14** or other output device. User input is provided via a keyboard **15**, a mouse **16**, and other standard input devices. Attached to an RS-232 port **17** of personal computer **10** is an RS-232 cable **18**. The other end of cable **18** is connected to an RS-232 port of an infrared transmitter **19**. A modified Intelliboy robot **20** includes an infrared receiver **21** to receive information from infrared transmitter **19**, and an ATMEL AT89S8252 Micro-controller **22** to control the robot toy. Personal computer **10** runs a user interface program (UI) which enables the user to create a Finite State Machine (FSM) that describes the desired behavior of the toy. Personal computer **10** also runs a Compiler which converts the FSM into a Compiled Program Description. Micro-controller **22** runs a Virtual Machine which executes the Compiled Program Description in a manner that causes the toy to exhibit the desired behavior. Personal computer **10** is conventional, and may be a microprocessor system, a personal digital assistant or other handheld computer, a workstation, a server, a network providing access to computation and input/output devices, or any of a variety of other apparatus providing computing and input/output capabilities.

[0041] All of the method steps described below are carried out using the apparatus shown in **FIG. 1** together with the UI, the Compiler and the Virtual Machine. Thus the apparatus of **FIG. 1** together with the UI, the Compiler and the Virtual Machine carry out all of the steps of the invention. Given the following detailed description of the method of the invention, it will be a routine matter for an engineer skilled in the art to produce code and assemble hardware to carry out all of the described steps.

[0042] As noted above, the preferred embodiment enables the user to create an FSM that describes the desired behavior of the toy by using a user interface program (UI) running on personal computer **10**. The UI is illustrated in **FIG. 2** and **FIG. 3**. To create an FSM, the user needs to specify the FSM's states (States), the FSM's transitions (Transitions) and the sequences of actions that he wishes the toy to perform in each State (Action Sequences).

[0043] Specifying States Using the UI

[0044] When the UI is first invoked, it automatically creates the FSM's start State (i.e. the State which the toy will enter each time it begins running the program that the user is creating). For each additional State that the user wants to create, he clicks New State Button **25**. This causes the UI to bring up a dialog box which allows the user to type in the name of the new State, and also allows the user to assign an icon to the new State to make it easier to remember what the State is for.

[0045] For each State, the UI enables the user to specify an Action Sequence **29** and an Event-Triggered Transition List **32** of Transitions to other States. To keep the process simple and easy to understand, the UI allows the user to work on only one State at a time. This State shall be referred to as the Currently-Editable State **33**. After a new State is created, it automatically becomes the Currently-Editable State. To choose a different State to be the Currently-Editable State, the user clicks the name of that State in Tabbed List of States **26**.

[0046] Specifying Action Sequences Using the UI

[0047] Each new State is created with an empty Action Sequence **29**. To add an Action to the Action Sequence for the Currently-Editable State, the UI enables the user to select one of the Action boxes on Basic Action Menu **27** or Control Action Menu **28** and drag it to the Action Sequence. This causes the UI to create an instance of the corresponding Action (an Action Instance) in the Action Sequence at the location in the Action Sequence where the user stops dragging the Action box and drops (i.e. releases) it. The location of the Action Instance in the Action Sequence corresponds to the order in which the Action will be performed—the Virtual Machine will begin at the top of the Action Sequence and execute the Action Instances in descending order. The UI enables the user to change the execution order of any Action Instance in an Action Sequence by dragging it to a new location. The UI also enables the user to delete any Action Instance in an Action Sequence by dragging it to Trash Can **30**.

[0048] While the invention does not place any limit on the number or variety of Actions that can be programmed, the preferred embodiment supports only four types of Basic Actions (accessible on Basic Action Menu **27**) and one type of Control Action (accessible on Control Action Menu **28**) because of the limitations of the toy's hardware. Each Action Instance on Action Sequence **29** has a property widget (e.g. Property Widget **34**). The UI enables the user to click on any Action Instance's property widget to bring up a dialog box that offers various settings depending on the type of the Action Instance.

[0049] Three of the Basic Actions that can be instantiated from Basic Action Menu **27** are characterized by the motion of the toy while it is performing the Action: "Move Forward", "Rotate" or "Idle". For a Move Forward Action Instance, the property dialog box enables the user to specify the magnitude of the distance that the toy will move forward,

the units of the distance that the toy will move forward (i.e. centimeters or inches) whether the toy will blink while it is moving, and whether the toy will play any of five different songs while it is moving. For a Rotate Action Instance, the property dialog box enables the user to specify how many degrees the toy will turn, whether the toy will blink while it is turning, and whether the toy will play any of five different songs while it is turning. For an Idle Action Instance, the property dialog box enables the user to specify how many seconds the toy will idle (i.e. remain motionless), whether the toy will blink while it is idling, and whether the toy will play any of five different songs while it is idling.

[0050] The fourth Basic Action that can be instantiated from Basic Action Menu **27** is a "Go To State" Action. The UI only allows one "Go To State" Action Instance on each Action Sequence **29**, and it must appear at the end of the sequence. For a "Go To State" Action Instance, the property dialog box allows the user to specify which State the FSM will enter if it finishes executing the Action Sequence without taking an Event-Triggered Transition (see below). The UI does not require the user to specify a "Go To State" Action Instance for every Action Sequence. If an Action Sequence which has no "Go To State" Action Instance finishes, the Virtual Machine will stop the toy and wait for an Event-Triggered Transition to occur.

[0051] The Control Action that can be instantiated from Control Action Menu **28** is a "Loop" Action. Unlike all other Action Instances, each "Loop" Action Instance consists of two separately moveable pieces: one to mark the beginning of the loop and one to mark the end of the loop in an Action Sequence. For a "Loop" Action Instance, the property dialog box allows the user to specify the number of times that the Action Instances inside the Loop will be executed. The UI allows nesting of loops up to a maximum of depth of eight.

[0052] Specifying Transitions Using the UI

[0053] Each new State is created with an empty Event-Triggered Transition List **32**. To add an Event-Triggered Transition to the Event-Triggered Transition List for the Currently-Editable State, the UI enables the user to select one of the Event-Triggered Transition boxes on Event-Triggered Transition Menu **31** and drag it to the Event-Triggered Transition List. This causes the UI to create an instance of the corresponding Event-Triggered Transition (an Event-Triggered Transition Instance) in the Event-Triggered Transition List. The Event-Triggered Transition Instance will be enabled whenever the FSM is in the Currently-Editable State, and disabled whenever the FSM is not in the Currently-Editable State. The UI also enables the user to delete any Event-Triggered Transition Instance in an Event-Triggered Transition List by dragging it to Trash Can **30**.

[0054] While the invention does not place any limit on the number or variety of Transitions that can be programmed, the preferred embodiment supports only three types of Event-Triggered Transitions (accessible on Event-Triggered Transition Menu **31**). Each Event-Triggered Transition Instance on Event-Triggered Transition List **32** has a property widget (e.g. Property Widget **35**). The UI enables the user to click on any Each Event-Triggered Transition Instance's property widget to bring up a dialog box that offers various settings depending on the type of the Event-Triggered Transition Instance.

[0055] The Transitions that can be instantiated from Event-Triggered Transition Menu **31** are characterized by the event that could trigger (i.e. cause) the FSM to execute the Transition: "Timer", "Touch", or "Light-to-Dark". For a Timer Event-Triggered Transition Instance, the property dialog box enables the user to specify at what time (on a 24-hour clock) the FSM will execute the Transition if the Event-Triggered Transition Instance is enabled, and which State the FSM will enter when the Transition is executed. For a Touch Event-Triggered Transition Instance, the property dialog box enables the user to specify which State the FSM will enter if the Event-Triggered Transition Instance is enabled and the toy is touched on the head so as to activate its touch sensor, thereby causing the Transition to be executed. For a Light-to-Dark Event-Triggered Transition Instance, the property dialog box enables the user to specify which State the FSM will enter if the Event-Triggered Transition Instance is enabled and the toy leaves an area with a highly reflective surface and enters an area with a poorly reflective surface in such a way as to toggle its photoreceptor, thereby causing the Transition to be executed.

[0056] Viewing the Finite State Machine

[0057] The UI enables the user to see an overview of the FSM, in the form of a State Diagram **37**. A State Diagram can be a useful aid to understanding the overall design of the FSM, and thus the relationships of the concepts underlying the toy program. An example of the State Diagram that the UI draws for the user is illustrated in **FIG. 3**. To view a State Diagram, the user clicks the State Diagram button **36**.

[0058] State Diagram **37** shows a box **38** for each State, labeled with the State's name. The State Diagram also shows an arrow **39** for each Event-Triggered Transition and Go To State Action illustrating the State that the FSM will leave (at the beginning of the arrow) and the State that the FSM will enter (at the end of the arrow). Each arrow has a label **40**: for an Event-Triggered Transition arrow the label is the event that will trigger the Transition (if it is enabled), and for a Go To State Action arrow the label is the word "Done" (because the completion of an Action Sequence is what will trigger the State change indicated by the arrow).

[0059] The UI enables the user to easily change from the "view the State Diagram" mode illustrated in **FIG. 3** to the "edit the FSM" mode illustrated in **FIG. 2**: double-clicking on any State box in State Diagram **37** will cause the UI to switch to the "edit the FSM" mode with the clicked-on State as the Currently-Editable State.

[0060] The preferred embodiment uses the "dot" program (from the Graphviz suite of tools version 1.7, copyright AT&T and Lucent Bell Labs) to compute an appropriate layout for State Diagram **37**. To generate a State Diagram, the UI first scans its data structures to find all of the components of the FSM that need to be drawn, and prepares an input file for dot. After dot computes the layout, the UI uses a dot output file to display the drawing. The invention contemplates that any place-and-route program capable of producing such a diagram could be used instead of dot.

[0061] UI Data Structures for the Finite State Machine

[0062] The preferred embodiment's UI stores the FSM in data structures in memory while it is running. The UI's State List **49** is illustrated in **FIG. 4**. Each State is represented by

a State Object **50** on State List **49** that stores the State's Name **51**, the State's Icon **52**, an Action Object List **53** that represents the State's Action Sequence **29**, and an Event-Triggered Transition Object List **54** that represents the State's Event-Triggered Transition List **32**. The first State on State List **49** is the Start State, which the FSM will enter each time the toy program begins executing.

[**0063**] The UI's data structures for Action Objects are illustrated in **FIG. 5**. Each Move Forward Action Instance on Action Sequence **29** is represented by a Move Forward Action Object **55** that stores the Unit of Movement **62** (centimeters or inches), the Magnitude of Movement **61** (e.g. 7), a boolean Blink Flag **63** to indicate whether the toy should blink while it is moving, and a Song ID **64** which is the index of the song that the toy should play while moving (0 means don't play any song). Each Rotate Action Instance on Action Sequence **29** is represented by a Rotate Action Object **56** that stores the Number of Degrees **65** that the toy should turn clockwise, a boolean Blink Flag **66** to indicate whether the toy should blink while it is turning, and a Song ID **67** which is the index of the song that the toy should play while turning (0 means don't play any song). Each Idle Action Instance on Action Sequence **29** is represented by a Idle Action Object **57** that stores the Number of Seconds **68** the toy should idle, a boolean Blink Flag **69** to indicate whether the toy should blink while it is idling, and a Song ID **70** which is the index of the song that the toy should play while idling (0 means don't play any song). Each Loop Action Instance on Action Sequence **29** is represented by two objects: a Start Loop Action Object **58** that marks the location of the beginning of the loop, and an End Loop Action Object **59** that marks the location of the end of the Loop and stores the Number of Repetitions **71** which indicates the number of times the Actions within the Loop should be executed. Each Go To State Action Instance on Action Sequence **29** is represented by a Go To State Action Object **60** that stores the Index of Next State **72**, which is the index of the State that the FSM should enter when the Action Sequence in which this Go To State Action Instance is stored is completed.

[**0064**] The UI's data structures for Event-Triggered Transition Instances are illustrated in **FIG. 6**. Each Timer Event-Triggered Transition Instance on Event-Triggered Transition List **32** is represented by a Timer Event Transition Object **73** that stores the time (24-hour-clock time in Hours **77**, Minutes **78** and Seconds **79**) at which the FSM will execute the Transition if it is enabled, and the Index of Next State **76** which is the index of the State that the FSM will enter if the Transition is executed. Each Touch Event-Triggered Transition Instance on Event-Triggered Transition List **32** is represented by a Touch Event Transition Object **74** that stores the Index of the State **80**, which is the index of the State that the FSM will enter if the Touch Event-Triggered Transition Instance is enabled and the toy is touched on the head so as to activate its touch sensor, thereby causing the Transition to be executed. Each Light-to-Dark Event-Triggered Transition Instance on Event-Triggered Transition List **32** is represented by a Light-to-Dark Event Transition Object **75** that stores the Index of Next State **81**, which is the index of the State that the FSM will enter if the Light-to-Dark Event-Triggered Transition Instance is enabled and the toy leaves an area with a highly reflective surface and enters an area with a poorly reflective surface in such a way as to trigger its photoreceptor, thereby causing the Transition to be executed.

[**0065**] Compiling the FSM into a Toy Program and Sending it to the Toy

[**0066**] The UI enables the user to both compile the FSM into a program that will run on the toy and to send that program to the toy simply by clicking Send to Toy Button **41**. When the user clicks Send to Toy Button **41**, the preferred embodiment performs the following steps automatically: first converting the UI data structures to a Compiler Input File, second compiling the Compiler Input File to a Compiled Program Description File, and third sending the Compiled Program Description to the toy where it is stored for execution by the Virtual Machine.

[**0067**] The preferred embodiment assigns a unique number, called a Command ID, to each type of behavior that the toy is capable of performing under the control of the program. These are referred to as follows.

MOVE_FORWARD_COMMAND_ID	Move Forward
ROTATE_COMMAND_ID	Rotate
BLINK_COMMAND_ID	Blink
PLAY_SONG_1_COMMAND_ID	Play Song #1
PLAY_SONG_2_COMMAND_ID	Play Song #2
PLAY_SONG_3_COMMAND_ID	Play Song #3
PLAY_SONG_4_COMMAND_ID	Play Song #4
PLAY_SONG_5_COMMAND_ID	Play Song #5

[**0068**] The preferred embodiment also assigns a unique number, called a Trigger-Event ID, to each type of event that the toy's sensors are capable of detecting and the toy program is capable of using to trigger the execution of a Transition. These are referred to as follows.

TOUCH_EVENT_ID	toy is touched in such a way as to activate its touch sensor
LIGHT_TO_DARK_EVENT_ID	toy leaves an area with a highly reflective surface and enters an area with a poorly reflective surface in such a way as to toggle its photoreceptor

[**0069**] Converting the UI Data Structures to a Compiler Input File

[**0070**] In the first compilation step, the UI scans its data structures and creates a file called the Compiler Input File. The Compiler Input File stores the information needed to compile the toy program in records. The records are grouped into three types of sections: State Action Records, Timer Transition Records, and Non-Timer Transition Records.

[**0071**] State Action Records Sections in a Compiler Input File

[**0072**] State Action Records sections in a Compiler Input File are illustrated in **FIG. 7**. The UI creates one State Action Records Section **90** for each State in the FSM. Each State has a unique State Index Number, which is not part of its data structure, but can be used to unambiguously refer to the State (e.g. in a Transition Record). The State Index Number

of the Start State is always 1, and the other States are assigned consecutive State Index Numbers by the UI in the order in which the corresponding State Objects **50** are stored on State Object List **49**. The State Action Records Sections are written into the Compiler Input File in order by State Index Number, so it is not necessary to write the State Index Numbers into the file. The UI starts each State Action Records Section by writing a State Action Records Section Header **91**, which consists of a unique Section type number that distinguishes State Action Records Sections from other types of Sections. The UI then writes an Action Record **92** for each Action Object (except for a Start Loop Action Object **58**) in the State's Action Object List **53**, in order beginning with the first Action Object on List **53**. Each Action Record **92** is actually one of the five specific types of Action Record which are illustrated in **FIG. 7**: Move Forward Action Record **93**, Rotate Action Record **94**, Idle Action Record **95**, End of Loop Action Record **96**, or Go To When Done State Action Record **97**.

[**0073**] For a Move Forward Action Object **55**, the UI writes a Move Forward Action Record **93**. The UI begins the Record by writing Move Forward Action Record ID number **98**, which is a unique Action Record type number that distinguishes Move Forward Action Records from other types of Action Records. The UI then writes Number of Centimeters **99** into the Move Forward Action Record. If the Distance Unit **62** in the Move Forward Action Object is centimeters, the UI writes the Distance Magnitude **61** from the Move Forward Action Object into the Move Forward Action Record. If the Distance Unit is inches, the UI multiplies the Distance Magnitude by 2.54 and writes the result into the Move Forward Action Record. Next the UI checks the Blink Flag **63** in the Move Forward Action Object. If the Blink Flag is true, the UI writes BLINK_COMMAND_ID **100** into the Move Forward Action Record. Next the UI checks the Song ID **64** in the Move Forward Action Object. If the Song ID is not 0, the UI writes the PLAY_SONG_N_COMMAND_ID **101** that corresponds to the Song ID, e.g. PLAY_SONG_1_COMMAND_ID if the Song ID is 1.

[**0074**] For a Rotate Action Object **56** the UI writes a Rotate Action Record **94**. The UI begins the Record by writing Rotate Action Record ID number **102**, which is a unique Action Record type number that distinguishes Rotate Action Records from other types of Action Records. The UI then writes Number of Degrees **65** from the Rotate Action Object into Number of Degrees **103** in the Rotate Action Record. Next the UI checks the Blink Flag **66** in the Rotate Action Object. If the Blink Flag is true, the UI writes BLINK_COMMAND_ID **104** into the Rotate Action Record. Next the UI checks the Song ID **67** in the Rotate Action Object. If the Song ID is not 0, the UI writes the PLAY_SONG_N_COMMAND_ID **105** that corresponds to the Song ID, e.g. PLAY_SONG_1_COMMAND_ID if the Song ID is 1.

[**0075**] For an Idle Action Object **57**, the UI writes an Idle Action Record **95**. The UI begins the Record by writing Idle Action Record ID number **106**, which is a unique Action Record type number that distinguishes Idle Action Records from other types of Action Records. The UI then writes Number of Seconds **68** from the Idle Action Object into Number of Seconds **107** in the Idle Action Record. Next the UI checks the Blink Flag **69** in the Idle Action Object. If the Blink Flag is true, the UI writes BLINK_COMMAND_ID **108** into the Idle Action Record. Next the UI checks the Song ID **70** in the Idle Action Object. If the Song ID is not 0, the UI writes the PLAY_SONG_N_COMMAND_ID **109** that corresponds to the Song ID, e.g. PLAY_SONG_1_COMMAND_ID if the Song ID is 1.

[**0076**] For a Start Loop Action Object **58**, the UI does not write an Action Record.

[**0077**] For an End Loop Action Object **59**, the UI writes an End of Loop Action Record **96**. The UI begins the Record by writing End of Loop Action Record ID number **110**, which is a unique Action Record type number that distinguishes End of Loop Action Records from other types of Action Records. The UI then counts the number of Move Forward Action Objects, Rotate Action Objects, Idle Action Objects, and End Loop Action Objects that are between the End Loop Action Object and its corresponding Start Loop Action Object, and writes this count as Number of Action Records Inside the Loop **111** in the End Of Loop Action Record. The UI the writes Number of Repetitions **71** from the End Loop Action Object as Number of Repetitions **112** in the End of Loop Action Record.

[**0078**] For a Go To State Action Object **60**, the UI writes a Go To When Done State Action Record **97**. The UI begins the Record by writing Go To When Done State Action Record ID number **113**, which is a unique Action Record type number that distinguishes Go To When Done State Action Records from other types of Action Records. The UI then writes Index of Next State **72** from the Go To State Action Object as Index of Next State **114** in the Go To When Done State Action Record.

[**0079**] Timer Transition Records Section in a Compiler Input File

[**0080**] The Timer Transition Records Section **115** in a Compiler Input File is illustrated in **FIG. 8**. The UI starts the Timer Transition Records Section by writing a Timer Transition Records Section Header **116**, which consists of a unique Section type number that distinguishes the Timer Transition Records Section from other types of Sections. The UI then writes one Timer Transition Record **117** for each Timer Event-Triggered Transition Object in the FSM.

[**0081**] To accomplish this, the UI scans State Object List **49**. For each State Object **50** on List **49**, the UI scans its Event-Triggered Transition Object List **54**. For each Timer Event-Triggered Transition Object that the UI finds, the UI writes a Timer Transition Record **118** (which is the same thing as Timer Transition Record **117**; **118** merely shows additional details) as follows. The UI begins by writing a Timer Transition Record ID **119**, which is a unique type number that distinguishes the beginning of a Timer Transition Record from the beginning of a different section in the Compiler Input File. The UI then writes Hours **77** from the Timer Event-Triggered Transition Object as Number of Hours **120** in the Timer Transition Record. The UI then writes Minutes **78** from the Timer Event-Triggered Transition Object as Number of Minutes **121** in the Timer Transition Record. The UI then writes Seconds **79** from the Timer Event-Triggered Transition Object as Number of Seconds **122** in the Timer Transition Record. The UI then writes the State Index Number of the State Object currently being scanned as Index of Current State **123** in the Timer Transi-

tion Record. The UI then writes Index of Next State **76** from the Timer Event-Triggered Transition Object as Index of Next State **124** in the Timer Transition Record.

[**0082**] Non-Timer Transition Records Section in a Compiler Input File

[**0083**] The Non-Timer Transition Records Section **125** in a Compiler Input File is illustrated in **FIG. 9**. The UI starts the Non-Timer Transition Records Section by writing a Non-Timer Transition Records Section Header **126**, which consists of a unique Section type number that distinguishes the Non-Timer Transition Records Section from other types of Sections. The UI then writes one Non-Timer Transition Record **127** for each Touch Event-Triggered Transition Object **74** and each Light-to-Dark Event-Triggered Transition Object **75** in the FSM. Each Non-Timer Transition Record **127** is actually one of the two specific types of Non-Timer Transition Record which are illustrated in **FIG. 9**: Touch Transition Record **128** or Light-to-Dark Transition Record **129**.

[**0084**] To accomplish this, the UI scans State Object List **49**. For each State Object **50** on List **49**, the UI scans its Event-Triggered Transition Object List **54**. For each Touch Event-Triggered Transition Object **74** that the UI finds, the UI writes a Touch Transition Record **128** as follows. The UI begins by writing a Touch Transition Record ID **130**, which is a unique type number that distinguishes the beginning of a Touch Transition Record from the beginning of a Light-to-Dark Transition Record or the beginning of a different section in the Compiler Input File. The UI then writes the State Index Number of the State Object currently being scanned as Index of Current State **131** in the Touch Transition Record. The UI ends the record by writing the Index of Next State **80** from the Touch Event-Triggered Transition Object as Index of Next State **132** in the Touch Transition Record. For each Light-to-Dark Event-Triggered Transition Object **75** that the UI finds, the UI writes a Light-to-Dark Transition Record **129** as follows. The UI begins by writing a Light-to-Dark Transition Record ID **133**, which is a unique type number that distinguishes the beginning of a Light-to-Dark Transition Record from the beginning of a Touch Transition Record or the beginning of a different section in the Compiler Input File. The UI then writes the State Index Number of the State Object currently being scanned as Index of Current State **134** in the Light-to-Dark Transition Record. The UI ends the record by writing the Index of Next State **81** from the Light-to-Dark Event-Triggered Transition Object as Index of Next State **135** in the Light-to-Dark Transition Record.

[**0085**] Compiling the Compiler Input File to a Compiled Description File

[**0086**] In the second step, which is done after the UI completes the Compiler Input File, the UI calls a Compiler program that uses the contents of the Compiler Input File to create a corresponding Compiled Program Description File.

[**0087**] In the Compiled Program Description File, the preferred embodiment uses a set of unique identification numbers to indicate the beginning or end of particular types of information. This set of identification numbers and the set of Command ID numbers are disjoint. For clarity these identification numbers are referred to by the names listed below.

[**0088**] BEGIN_STATE_ACTION_SECTION

[**0089**] END_STATE_ACTION_SECTION

[**0090**] BASIC_ACTION_RECORD

[**0091**] DURATION_FIELD

[**0092**] LOOP_END_ACTION_RECORD

[**0093**] BEGIN_TIMER_TRANSITION_SECTION

[**0094**] END_TIMER_TRANSITION_SECTION

[**0095**] BEGIN_TIMER_TRANSITION_RECORD

[**0096**] END_TIMER_TRANSITION_RECORD

[**0097**] BEGIN_NONTIMER_TRANSITION_SECTION

[**0098**] END_NONTIMER_TRANSITION_SECTION

[**0099**] The Compiled Program Description File stores the information the Virtual Machine needs to execute the toy program in records. The records are grouped into three types of sections: State Action, Timer Transition, and Non-Timer Transition.

[**0100**] State Action Sections in a Compiled Program Description File

[**0101**] State Action sections in a Compiled Program Description File are illustrated in **FIG. 10**. The Compiler creates one State Action Section **150** in the Compiled Program Description File for each State Action Records Section **90** in the Compiler Input File, in the same order so that all State Index Numbers remain valid. The Compiler starts each State Action Section by writing BEGIN_STATE_ACTION_SECTION **151**. The Compiler then writes an Action Record **153** for each Action Record **92** in the State Action Records Section **90** (except for Go To When Done State Action Records **97**), in the same order so that the Action Sequence remains valid. Each Action Record **153** is actually one of the two specific types of Action Record which are illustrated in **FIG. 10**: Basic Action Record **154**, or Loop End Action Record **155**.After writing the last Action Record in the Section, the Compiler writes END_STATE_ACTION_SECTION **152**.

[**0102**] For a Move Forward Action Record **93**, the Compiler writes a Basic Action Record **154**. The Compiler begins the Basic Action Record by writing BASIC_ACTION_RECORD **156**. The Compiler then writes the Command ID's **157** needed to specify the desired behavior. The first Command ID the Compiler writes is MOVE_FORWARD_COMMAND_ID. Then, if the Move Forward Action Record **93** has a BLINK_COMMAND_ID **100**, the Compiler writes a copy of that Command ID. Then, if the Move Forward Action Record **93** has a PLAY_SONG_N_COMMAND_ID **101**, the Compiler writes a copy of that Command ID. Next the Compiler writes DURATION_FIELD **158**. Then the Compiler writes the Number of Seconds **159** that it will take the toy to travel Number of Centimeters **99** (from Move Forward Action Record **93**), which the Compiler computes by adding one to the Number of Centimeters.

[**0103**] For a Rotate Action Record **94**, the Compiler writes a Basic Action Record **154**. The Compiler begins the Basic Action Record by writing BASIC_ACTION_RECORD **156**. The Compiler then writes the Command ID's **157**

needed to specify the desired behavior. The first Command ID the Compiler writes is ROTATE_COMMAND_ID. Then, if the Rotate Action Record **94** has a BLINK_COMMAND_ID **104**, the Compiler writes a copy of that Command ID. Then, if the Rotate Action Record **94** has a PLAY_SONG_N_COMMAND_ID **105**, the Compiler writes a copy of that Command ID. Next the Compiler writes DURATION_FIELD **158**. Then the Compiler writes the Number of Seconds **159** that it will take the toy to rotate Number of Degrees **103** (from Rotate Action Record **94**), which the Compiler computes by multiplying the Number of Degrees by 0.083.

[**0104**] For an Idle Action Record **95**, the Compiler writes a Basic Action Record **154**. The Compiler begins the Basic Action Record by writing BASIC_ACTION_RECORD **156**. The Compiler then writes any Command ID's **157** needed to specify the desired behavior. If the Idle Action Record **95** has a BLINK_COMMAND_ID **108**, the Compiler writes a copy of that Command ID. Then, if the Idle Action Record **95** has a PLAY_SONG_N_COMMAND_ID **109**, the Compiler writes a copy of that Command ID. Next the Compiler writes DURATION_FIELD **158**. Then the Compiler writes the Number of Seconds **159**, which is a copy of Number of Seconds **107** (from Idle Action Record **95**).

[**0105**] For an End of Loop Action Record **96**, the Compiler writes a Loop End Action Record **155**. The Compiler begins the Loop End Action Record by writing LOOP_END_ACTION_RECORD **160**. Then the Compiler scans all of the Records in State Action Section **150** that are inside the loop, adds up the number of bytes used to store them, and writes out the result as Number of Bytes from Start of Loop **161**. The Compiler uses Number of Action Records Inside the Loop **111** (from End of Loop Action Record **96**) to determine the number of prior Records it needs to scan to compute the correct result. Then the Compiler writes the Number of Repetitions **162**, which is a copy of Number of Repetitions **112** (from End of Loop Action Record **96**).

[**0106**] For a Go To When Done State Action Record **97**, the Compiler does not write a record into the State Action Section **150**. The information in the Go To When Done State Action Record **97** is used later to create a record in a different section of the Compiled Program Description File.

[**0107**] Timer Transition Section in a Compiled Program Description File

[**0108**] The Timer Transition Section **163** in a Compiled Program Description File is illustrated in **FIG. 11**. The Compiler starts the Timer Transition Section **163** by writing BEGIN_TIMER_TRANSITION_SECTION **164**. Next the Compiler writes one Timer Transition Record **166** for each Timer Transition Record **118** in the Timer Transition Records Section **115** of the Compiler Input File. Then the Compiler ends the Timer Transition Section **163** by writing END_TIMER_TRANSITION_SECTION **165**.

[**0109**] For each Timer Transition Record **118** in the Compiler Input File, the Compiler writes a Timer Transition Record **167** (which is the same thing as Timer Transition Record **166**; **167** merely shows additional details) as follows. The Compiler begins the Timer Transition Record **167** by writing BEGIN_TIMER_TRANSITION_RECORD **168**. The Compiler then writes Number of Hours **120** from the Timer Transition Record **118** as Hours **170** in the Timer Transition Record **167**. The Compiler then writes Number of Minutes **121** from the Timer Transition Record **118** as Minutes **171** in the Timer Transition Record **167**. The Compiler then writes Number of Seconds **122** from the Timer Transition Record **118** as Seconds **172** in the Timer Transition Record **167**. The Compiler then writes Index of Current State **123** from the Timer Transition Record **118** as Current State Index **173** in the Timer Transition Record **167**. The Compiler then writes Index of Next State **124** from the Timer Transition Record **118** as Next State Index **174** in the Timer Transition Record **167**. After that, the Compiler finishes the Timer Transition Record **167** by writing END_TIMER_TRANSITION_RECORD **169**.

[**0110**] Non-Timer Transition Section in a Compiled Program Description File

[**0111**] The Non-Timer Transition Section **175** in a Compiled Program Description File is illustrated in **FIG. 12**. The Compiler starts the Non-Timer Transition Section **175** by writing BEGIN_NONTIMER_TRANSITION_SECTION **176**. Next the Compiler writes one Non-Timer Transition Record **178** (which is the same thing as Non-Timer Transition Record **179**; **179** merely shows additional details) for each Non-Timer Transition Record **127** in the Non-Timer Transition Records Section **125** of the Compiler Input File. Then the Compiler ends the Non-Timer Transition Section **175** by writing END_NONTIMER_TRANSITION_SECTION **177**.

[**0112**] For each Touch Transition Record **128** in the Compiler Input File, the Compiler writes a Non-Timer Transition Record **179** as follows. The Compiler begins the Non-Timer Transition Record **179** by writing BEGIN_EVENT_LIST **180**. The Compiler then writes TOUCH_EVENT_ID as Trigger-Event ID **182**. The Compiler then writes END_EVENT_LIST **181**. The Compiler then writes Index of Current State **131** from the Touch Transition Record **128** as Current State Index **183** into the Non-Timer Transition Record **179**. The Compiler then writes Index of Next State **132** from the Touch Transition Record **128** as Next State Index **184** in the Non-Timer Transition Record **179**.

[**0113**] For each Light-to-Dark Transition Record **129** in the Compiler Input File, the Compiler writes a Non-Timer Transition Record **179** as follows. The Compiler begins the Non-Timer Transition Record **179** by writing BEGIN_EVENT_LIST **180**. The Compiler then writes LIGHT_TO_DARK_EVENT_ID as Trigger-Event ID **182**. The Compiler then writes END_EVENT_LIST **181**. The Compiler then writes Index of Current State **134** from the Light-to-Dark Transition Record **129** as Current State Index **183** into the Non-Timer Transition Record **179**. The Compiler then writes Index of Next State **135** from the Light-to-Dark Transition Record **129** as Next State Index **184** in the Non-Timer Transition Record **179**.

[**0114**] For each State Action Records Section **90** in the Compiler Input File, the Compiler finds each Go To When Done State Action Record **97**. For each such Record, the Compiler writes a Non-Timer Transition Record **179** as follows. The Compiler begins the Non-Timer Transition Record **179** by writing BEGIN_EVENT_LIST **180**. The Compiler then writes END_EVENT_LIST **181**. The Compiler then writes the State Index Number of the State Action Records Section **90** (implied by its order in the Compiler

Input File) as Current State Index **183** into the Non-Timer Transition Record **179**. The Compiler then writes Index of Next State **114** from the Go To When Done State Record **97**as Next State Index **184** in the Non-Timer Transition Record **179**.

[**0115**] Sending the Compiled Program Description to the Toy

[**0116**] The preferred embodiment sends the Compiled Program Description File bits (referred to below as the Compiled Program Description) through the RS-232 port **17** of personal computer and RS_**232** cable **18** to infrared transmitter **19**. From infrared transmitter **19** the Compiled Program Description bits are transmitted to infrared receiver **21** and are then sent to the ATMEL AT89S8252 Micro-controller **22** inside the toy for storage.

[**0117**] In the preferred embodiment, Micro-controller **22** is programmed to execute a Virtual Machine. The Virtual Machine has two main functions: to store the Compiled Program Description as it arrives from infrared receiver **21**, and to use the Compiled Program Description to control the toy so that it exhibits the behavior specified by the user.

[**0118**] As the Compiled Program Description bits reach Micro-controller **22**, the Virtual Machine writes the Compiled Program Description into contiguous memory in the Micro-controller. As it does so, the Virtual Machine records the address of the start of each Section and the address of the end of each Section as illustrated in **FIG. 13**. The Virtual Machine stores the address of the first Action Record in each State Section in State Section Start Array **190**. The start address of the first Action Record in the first State Section is stored in State #**1** Section Start Address **191**, the start address of the first Action Record in the second State Section is stored in State #**2** Section Start Address **192**, etc. The Virtual Machine stores the end address of each State Section in State Section End Array **193**. The end address of the first State Section is stored in State #**1** Section End Address **194**, the end address of the second State Section is stored in State #**2** Section End Address **195**, etc. The Virtual Machine stores the address of the first Timer Transition Record in Timer Transition Section **163** in Timer Transition Section Start Address **196**. The Virtual Machine stores the end address of Timer Transition Section **163** in Timer Transition Section End Address **197**. The Virtual Machine stores the address of the first Non-Timer Transition Record in Non-Timer Transition Section **175** in Non-Timer Transition Section Start Address **198**. The Virtual Machine stores the end address of Non-Timer Transition Section **175** in Timer Transition Section End Address **199**.

[**0119**] Execution of the Compiled Program Description by the Virtual Machine

[**0120**] The Virtual Machine uses several variables to execute the Compiled Program Description. These variables are described below.

Action_Duration	integer	the amount of time the Virtual Machine needs to continue running the current Action in order to completely finish it
Action_Time	integer	the amount of time that has elapsed since the Virtual Machine began running the current Action
Change_State	boolean	true if the Virtual Machine needs to change the State of the FSM
Count_Stack	integer	array number of repetitions remaining for each loop that is currently being executed (in order of nesting, with the number of repetitions for the outermost executing ioop stored at the beginning ofthe array)
Current_State	integer	State Index Number of the current State of the ESM
Light_To_Dark_Flag	boolean	true if a toy has just left an area with a highly reflective surface and entered an area with poorly reflective surface in such a way as to toggle its photoreceptor
Location_Stack	address	array holds the address of the Loop End Action Record 155 for each loop that is currently being executed (in order of nesting, with the address corresponding to the outermost executing loop stored at the beginning of the array)
New_State	integer	State Index Number of the next State the FSM will enter, valid only if Change State is true
Program_Pointer	address pointer	address in the current State Action Section from which the Virtual Machine will read the next Action information (unless the Action Sequence is done)
Program_End_Pointer	address pointer	address at which the Virtual Machine will stop reading Action information from the current State Action Section, because at that point the Action Sequence for the ESMs current State has been completed
Stack_Index	integer	the index of the first empty location on the loop-control stacks
Touch_Flag	boolean	true if the toy has just been touched in such a way as to activate its touch sensor
Wall_Clock	integer	array the current time represented as hours (Wall_Clock[0]), minutes (Wall_Clock[1]) and seconds (Wall_Clock[2]) on a 24-hour clock

[**0121**] A high-level flow chart for part of the Virtual Machine is shown in **FIG. 14**. When the toy program starts, the Virtual Machine executes Program Initialization **210**. The Virtual Machine sets New_State to 1 so that the FSM will enter State #**1** (the Start State) in State Initialization **211**. The Virtual Machine also sets Light_To_Dark_Flag and Touch_Flag to FALSE, and Stack_Index to **0**. In addition, the Virtual Machine starts Timer_**1** on Micro-controller **22**. Then the Virtual Machine proceeds to State Initialization **211**.

[**0122**] In State Initialization **211**, the Virtual Machine sets Current_State to New_State, and sets Change_State to FALSE. The Virtual Machine also sets Program_Pointer to the address of the first Action Record in the State, by using Current_State as the index to look up the address in State Section Start Array **190**. In addition, the Virtual Machine also sets Program_End_Pointer to the address of the end of the State Action Section for the State, by using Current_State as the index to look up the address in State Section End Array **193**. Then the Virtual Machine proceeds to executing Action Sequence Loop **212** for the State.

[0123] Each complete pass through Action Sequence Loop **212** performs one Action Record **153**. For each Action Record, the Virtual Machine first executes Stop All Commands **213** to stop any commands that are running because of the previous Action Record. This is necessary because once a command is started by the Virtual Machine, it continues to run until the Virtual Machine stops it. For example, if an Action Record causes the Virtual Machine to signal the toy's motor to move the toy forward, that signal will be continued until Stop All Commands **213** stops the signal. Stop All Commands **213** stops not only forward motion, but also rotation, blinking, and song playing.

[0124] After Stop All Commands **213**, the Virtual Machine checks whether Program_Pointer is equal to Program_End_Pointer.

[0125] If Program_Pointer is equal to Program_End_Pointer, the Action Sequence for the current State is completed. The Virtual Machine searches through the NonTimer Transition Section **175** to find any NonTimer Transition Record **179** that has no Trigger-Event ID **182** and has a Current State Index **183** equal to Current_State. If such a Record is found, the Virtual Machine sets New_State to the Record's Next State Index **184**, and goes to the next State of the FSM by executing State Initialization **211** again. If no such Record is found, the Virtual Machine goes into Wait for Change_State Loop **214**. Wait for Change_State Loop **214** continues until Change_State becomes TRUE, at which time the Virtual Machine will go to the next State of the FSM by executing State Initialization **211** again.

[0126] If Program_Pointer is not equal to Program_End_Pointer, the Virtual Machine checks the address that Program_Pointer is pointing to. If Program_Pointer is pointing to BASIC_ACTION_RECORD, the Virtual Machine executes Process BASIC_ACTION_RECORD, which is illustrated in **FIG. 15** and described below. If Program_Pointer is pointing to LOOP_END_ACTION_RECORD, the Virtual Machine executes Process LOOP_END_ACTION_RECORD, which is illustrated in **FIG. 16** and described below.

[0127] After executing either Process BASIC_ACTION_RECORD or Process LOOP_END_ACTION_RECORD, the Virtual Machine checks Change_State. If Change_State is TRUE, the Virtual Machine goes to the next State of the FSM by executing State Initialization **211** again. Otherwise the FSM compares Action_Time to Action_Duration. If Action_Time is greater than or equal to Action_Duration, then the current Action has run long enough, and the Virtual Machine prepares to perform the next Action in the Action Sequence (if any) by going back to Stop All Commands **213**. If Action_Time is less than Action_Duration, then the Virtual Machine continues running the current Action by looping back to check Change_State and then Action_Time again.

[0128] As mentioned above, Process BASIC_ACTION_RECORD **219** is illustrated in **FIG. 15**. The Virtual Machine first executes Step **220**, in which it increments Program_Pointer and then checks the address that it is pointing to, which will be either Command ID **157** or DURATION_FIELD **158**. If Program_Pointer is pointing to MOVE_FORWARD_COMMAND_ID, the Virtual Machine executes Start Move Forward **221**, and then goes back to Step **220**. In Start Move Forward **220**, the Virtual Machine begins driving a logic high value on the pin of Micro-controller **22** that is connected to the control pin of the toy's forward motion motor, causing the motor to begin to run and move the toy forward. If Program_Pointer is pointing to ROTATE_COMMAND_ID, the Virtual Machine executes Start Rotate **222**, and then goes back to Step **220**. In Start Rotate **220**, the Virtual Machine begins driving a logic high value on the pin of Micro-controller **22** that is connected to the control pin of the toy's rotation motor, causing the motor to begin to run and turn the toy clockwise. If Program_Pointer is pointing to BLINK_COMMAND_ID, the Virtual Machine executes Start Blink **223**, and then goes back to Step **220**. In Start Blink **223**, the Virtual Machine begins running a short routine which alternates driving a logic high value and a logic low value two times per second on the pin of Micro-controller **22** that is connected to the control pin of the toy's blink actuator, causing the toy's eyelids to alternately rise and fall. If Program_Pointer is pointing to PLAY_SONG_1_COMMAND_ID, the Virtual Machine executes Start Song **1224**, and then goes back to Step **220**. In Start Song **1224**, the Virtual Machine begins running a short routine which drives a sequence of logic values on the pin of Micro-controller **22** that is connected to the control pin of the toy's speaker so as to cause the speaker to play the notes of Song **#1**, which has been programmed into the toy's memory. If Program_Pointer is pointing to PLAY_SONG_2_COMMAND_ID, the Virtual Machine executes Start Song **2225**, and then goes back to Step **220**. In Start Song **2225**, the Virtual Machine begins running a short routine which drives a sequence of logic values on the pin of Micro-controller **22** that is connected to the control pin of the toy's speaker so as to cause the speaker to play the notes of Song **#2**, which has been programmed into the toy's memory. If Program_Pointer is pointing to PLAY_SONG_3_COMMAND_ID, the Virtual Machine executes Start Song **3226**, and then goes back to Step **220**. In Start Song **3226**, the Virtual Machine begins running a short routine which drives a sequence of logic values on the pin of Micro-controller **22** that is connected to the control pin of the toy's speaker so as to cause the speaker to play the notes of Song **#3**, which has been programmed into the toy's memory. If Program_Pointer is pointing to PLAY_SONG_4_COMMAND_ID, the Virtual Machine executes Start Song **4227**, and then goes back to Step **220**. In Start Song **4227**, the Virtual Machine begins running a short routine which drives a sequence of logic values on the pin of Micro-controller **22** that is connected to the control pin of the toy's speaker so as to cause the speaker to play the notes of Song **#4**, which has been programmed into the toy's memory. If Program_Pointer is pointing to PLAY_SONG_5_COMMAND_ID, the Virtual Machine executes Start Song **5228**, and then goes back to Step **220**. In Start Song **5228**, the Virtual Machine begins running a short routine which drives a sequence of logic values on the pin of Micro-controller **22** that is connected to the control pin of the toy's speaker so as to cause the speaker to play the notes of Song **#5**, which has been programmed into the toy's memory. If Program_Pointer is pointing to DURATION_FIELD, the Virtual Machine increments the Program_Pointer, reads Number of Seconds **159** from the current Basic Action Record **154** and stores the value in Action_Duration, sets the value of Action_Time to 0, and then increments the Program_Pointer again.

[0129] As mentioned above, Process LOOP_END_ACTION_RECORD **230** is illustrated in **FIG. 16**. Procedure **230** uses three local variables.

Location	address	address of the Loop End Action Record 155 being processed
Jump_Back	integer	copy of Number Of Bytes from Start of Loop 161 from the Loop End Action Record being processed
Repetitions	integer	copy of Number of Repetitions 162 from the Loop End Action Record being processed

[0130] The Virtual Machine begins procedure **230** begins by setting Location to the value of the Program_Pointer. The Virtual Machine then increments Program_Pointer and sets Jump_Back to the value Program_Pointer is pointing to. The Virtual Machine then increments Program_Pointer again and sets Repetitions to the value Program_Pointer is pointing to. Next, if the Stack_Index is 0 or the value stored in the Location_Stack at position [Stack_Index-**1**] is the not the same as the value of Location, the value of Location is stored in Location_Stack at position [Stack_Index], the value of Repetitions is stored in Count_Stack at position [Stack_Index] and then Stack_Index is incremented. Next, the Virtual Machine decrements the value stored at position [Stack_Index-**1**] in Count_Stack. Then, if the value stored at position [Stack_Index-**1**] in Count_Stack is 0, the Virtual Machine decrements Stack_Index and increments Program_Pointer; otherwise the Virtual Machine sets Program_Pointer to (Location—Jump_Back). Next, to complete procedure **230**, the Virtual Machine sets Action_Duration to 0.

[0131] In the preferred embodiment, the Interrupt **0** pin of Micro-controller **22** is connected to the output pin of the toy's photoreceptor. If Micro-controller **22** receives a signal on its Interrupt **0** pin, the Virtual Machine sets Light_To_Dark Flag to TRUE.

[0132] In the preferred embodiment, the Interrupt **1** pin of Micro-controller **22** is connected to the output pin of the toy's touch sensor. If Micro-controller **22** receives a signal on its Interrupt **1** pin, the Virtual Machine sets Touch_Flag to TRUE.

[0133] The Virtual Machine uses Timer_**1** on Micro-controller **22** in Procedure **231** to interrupt the procedure illustrated in **FIG. 14**, **FIG. 15** and **FIG. 16** approximately once every 50 milliseconds to determine whether an event that might trigger a Transition has occurred, as illustrated in **FIG. 17**. Procedure **231** runs whenever Timer_**1** reaches 0. The Virtual Machine first resets Timer_**1** to run for 50 more milliseconds. Then the Virtual Machine increases Action_Time by the equivalent of 50 milliseconds. Next the Virtual Machine checks Light_To_Dark_Flag. If it is TRUE, the Virtual Machine resets Light_To_Dark_Flag to FALSE, and then searches through the NonTimer Transition Section **175** to find any NonTimer Transition Record **179** that has a Trigger-Event ID **182** equal to LIGHT_TO_DARK_EVENT_ID and a Current State Index **183** equal to Current_State. If such a Record is found, the Virtual Machine sets New_State to the Record's Next State Index **184**, and sets Change_State to TRUE. Next the Virtual Machine checks Touch_Flag. If it is TRUE, the Virtual Machine resets Touch_Flag to FALSE, and then searches through the NonTimer Transition Section **175** to find any NonTimer Transition Record **179** that has a Trigger-Event ID **182** equal to TOUCH_EVENT_ID and a Current State Index **183** equal to Current_State. If such a Record is found, the Virtual Machine sets New_State to the Record's Next State Index **184**, and sets Change_State to TRUE. Next the Virtual Machine determines whether Procedure **231** has been called 20 times since the last time Wall_Clock was updated. If so, the Virtual Machine advances Wall_Clock by one second, and then searches through the Timer Transition Section **163** to find any Timer Transition Record **167** that has Hours **170** equal to Wall_Clock[**0**], Minutes **171** equal to Wall_Clock[**1**], Seconds **172** equal to Wall_Clock[**2**], and Current_State_Index **173** equal to Current_State. If such a Record is found, the Virtual Machine sets New_State to the Record's Next State Index **174**, and sets Change_State to TRUE.

[0134] Correspondance of the Preferred Embodiment to the Claims

[0135] 1) In the preferred embodiment, the "input means" referred to in the claims is the user interface program (UI) running on personal computer **10**, as described above.

[0136] 2) In the preferred embodiment, the "device" referred to in the claims is the modified Intelliboy robot **20** including the infrared receiver **21**, the ATMEL AT89S8252 Micro-controller **22**, and the Virtual Machine as described above.

[0137] 3) In the preferred embodiment, the means referred to in the claims of converting a finite state machine description to a program which the device can execute is the part of the UI that creates the Compiler Input File as well as the Compiler itself, as described above.

[0138] 4) In the preferred embodiment, the means referred to in the claims of sending the program to the device is RS-232 port **17** of personal computer **10** which is connected via RS-232 cable **18** to an RS-232 port of infrared transmitter **19**, which sends the program using infrared signals to infrared receiver **21** which is connected to Intelliboy robot **20**, as described above.

[0139] 5) In the preferred embodiment, the means referred to in the claims of storing the program in the device is the part of the Virtual Machine which accepts the program from infrared receiver **21** and stores it in the memory of ATMEL AT89S8252 Micro-controller **22**.

[0140] Conclusion, Ramifications, and Scope of Invention

[0141] Thus the reader will see that the invention enables people who are not familiar with software engineering or hardware control technology to easily program a device to behave as desired. While the above description contains many specifics, these should not be construed as limitations on the scope of the invention, but rather as an exemplification of one preferred embodiment thereof. Many other variations are possible.

[0142] For example, the controlled device may be a furnace, an air conditioner, a washing machine, a house lighting controller, a landscape sprinkler system, a television-pro-

gram recorder, a music player, a cleaning robot, a doll, a toy robot, a toy train, a toy airplane, a toy car or other toy vehicle, or any other machine that people want to program to operate autonomously or semi-autonomously.

[0143] For example, a controlled-device action can be moving, speaking, singing, playing music or sound effects, heating, cooling, spraying water, recording a television program, or anything else that the controlled device is capable of doing under program control.

[0144] For example, an action sequence can include controlled-device actions, loops, "if then else" statements, boolean operators, relational operators, arithmetic operators, expressions, macros, functions, random number generators, arrays, stacks, or any other programming construct.

[0145] For example, controlled-device actions can be programmed to occur while the FSM is in a state, while the FSM is executing a transition, or both.

[0146] For example, FSM transitions can be triggered by touch, temperature, pressure, humidity, time, emptiness or fullness of a container, scent, smoke, chemicals, visible light, infrared light, radio waves, sounds, speech, or any other events, conditions, or physical entities that the device can detect. FSM transitions can also be triggered by any function of one or more such events, conditions or physical entities.

[0147] For example, the priority of the FSM transitions from each state (i.e. which transition will be executed if more than one transition is triggered while the FSM is in that state) can be predetermined by the implementation based on the type of trigger, can be set by the user, can be random or pseudo-random, can be set by an algorithm, or can be set by any combination of these methods.

[0148] For example, entry of the FSM may be done graphically, by text, by speech, by starting with a different FSM and modifying it, or by any other means sufficient to specify an FSM.

[0149] For example, entry of the FSM may be done on a desktop personal computer, a workstation, a handheld computer, a personal organizer, a game console, a cellphone, a custom-made FSM entry device, the controlled device itself, or any other device capable of accepting a description of an FSM from a user and capable either of sending it to another device or of using it to control itself.

[0150] For example, the input FSM can be optimized to remove unreachable states and make other improvements in such a way as to reduce the size or improve the speed of the FSM without changing the observable behavior of the controlled device.

[0151] For example, the input FSM can be stored so that it can be retrieved and viewed, edited or otherwise used at any time after it was created.

[0152] For example, the input FSM can be converted to a compiled description executable on a micro-controller running a virtual machine, to a compiled description executable on a micro-processor running an operating system, to an FPGA programming file, or to any other form capable of configuring the controlled device so that it will behave in accordance with the FSM (referred to below as a control-capable form).

[0153] For example, the FSM description may be converted to a control-capable form directly, or it may first be converted to any number and/or sequence of intermediate forms before the control-capable form is generated.

[0154] For example, any form conversion may be done on the entry device, the controlled device, or any intermediate device capable of performing the conversion.

[0155] For example, the FSM description, the control-capable form or any intermediate forms can be sent from one device to another device using removable media such as a floppy disk, audible sound, ultrasound, cables, infrared, radio or any other physical means for conveying information from one device to another.

[0156] For example, the protocol for conveying information from one device to another may be USB, Ethernet, Bluetooth, or any other protocol capable of conveying that amount of information.

[0157] For example, the control-capable form can be stored in the controlled device in RAM, in EEPROM, on a hard disk, or in any other media capable of recording the compiled description and making it available to the rest of the controlled device so that it can be used to control the controlled device.

[0158] Accordingly, the scope of the invention should be determined not by the preferred embodiment illustrated, but by the claims and their legal equivalents.

What is claimed is

1. A method of programming a device, comprising:

(a) providing an input means which a human operator can use to enter a specification of desired behavior of said device as a finite state machine description;

(b)converting said finite state machine description to a program which said device can execute;

(c) sending said program to said device, if said input means is not running on said device ; and

(d) storing said program in said device, said program being thereby enabled to control said device in accordance with said finite state machine description;

whereby a person who is not familiar with software or hardware control technology can easily program a device to behave as desired.

2. The method of programming a device of claim 1, wherein said input means displays a plurality of graphical objects on a display and enables said human operator to manipulate said graphical objects to enter all or part of said finite state machine description.

3. The method of programming a device of claim 1, wherein said human operator is a user of said device.

4. The method of programming a device of claim 1, wherein said device is a consumer product.

5. The method of programming a device of claim 1, wherein said device is a toy.

6. The method of programming a device of claim 2, wherein said human operator is a user of said device.

7. The method of programming a device of claim 6, wherein said device is a consumer product.

8. The method of programming a consumer product of claim 7, wherein said consumer product is a toy.

9. An apparatus for programming a device, comprising:

(a) an input means which a human operator can use to enter a specification of desired behavior of said device as a finite state machine description;

(b) a conversion means which will convert said finite state machine description to a program which said device can execute;

(c) a transmission means for sending said program to said device, if said input means is not running on said device; and

(d) a storage means for storing said program in said device, said program being thereby enabled to control said device in accordance with said finite state machine description;

whereby a person who is not familiar with software or hardware control technology can easily program a device to behave as desired.

10. The apparatus for programming a device of claim 9, wherein said input means displays a plurality of graphical objects on a display and enables said human operator to manipulate said graphical objects to enter all or part of said finite state machine description.

11. The apparatus for programming a device of claim 9, wherein said human operator is a user of said device.

12. The apparatus for programming a device of claim 9, wherein said device is a consumer product.

13. The apparatus for programming a device of claim 9, wherein said consumer product is a toy.

14. The apparatus for programming a device of claim 10, wherein said human operator is a user of said device.

15. The apparatus for programming a device of claim 14, wherein said device is a consumer product.

16. The apparatus for programming a consumer product of claim 15, wherein said consumer product is a toy.

17. A system for programming a device, comprising:

(a) an input means which a human operator can use to enter a specification of desired behavior of said device as a finite state machine description;

(b) a conversion means which will convert said finite state machine description to a program which said device can execute;

(c) a transmission means for sending said program to said device, if said input means is not running on said device ; and

(d) a storage means for storing said program in said device, said program being thereby enabled to control said device in accordance with said finite state machine description;

whereby a person who is not familiar with software or hardware control technology can easily program a device to behave as desired.

18. The system for programming a device of claim 17, wherein said input means displays a plurality of graphical objects on a display and enables said human operator to manipulate said graphical objects to enter all or part of said finite state machine description.

19. The system for programming a device of claim 17, wherein said human operator is a user of said device.

20. The system for programming a device of claim 17, wherein said device is a consumer product.

21. The system for programming a device of claim 17, wherein said consumer product is a toy.

22. The system for programming a device of claim 18, wherein said human operator is a user of said device.

23. The system for programming a device of claim 22, wherein said device is a consumer product.

24. The system for programming a consumer product of claim 23, wherein said consumer product is a toy.

* * * * *