Emotion Embodiment in Robot-Assisted Rehabilitation System using Hybrid Automata

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***Abstract*—The embodiment of emotions in the paper is structured under hybrid automata framework. In particular, the paper focuses on the description of the automata model designed for robot-assisted rehabilitation system in term of its initialization value, modes, condition for each mode, guard conditions, and transition between modes. A structured experimental setup was designed to evaluate the performance of the hybrid automata proposed. The result demonstrates the efficacy of hybrid automata approach in the rehabilitation application where emotion of the subject is taken into consideration in deploying suitable rehabilitation tasks.**

Keywords—hybrid automata; emotion embodiment; rehabilitation platform

I. INTRODUCTION

Hybrid automata is defined as a mixed, formal model of system consisting of discrete and continuous elements [1]. Hybrid system also known as model of computation is extensively used for modeling and design of embedded system. It has been widely used in various fields of applications especially in control engineering and information technology to name a few. For example, an integrated motor-transmission power-train for an automatic gear shift in electric vehicle shows that hybrid automata is able to give high quality result in shifting process which leads to a better vehicle performance [2]. In mobile robot control, hybrid cellular automata controller is applied in the modeling of non-convex obstacle detection and avoidance for robot exploration in the specific environment [3].Other applications are longitudinal control of intelligent vehicle [4], Cyber-Physical Systems (CPS) control [5], modelling of human driving behavior [6], and even in a stage stunt system [7].

The main characteristic of hybrid system is event triggered where each event or mode is treated as separate, continous systems. In rehabilitation robot application [8], the mode of the system operation is based on the subject muscle recovery rate that is accessed on the percentage of effort the subject can exert against normal averaged muscle strength. In the field of emotion embodiment especially found in the Human-Machine Interaction (HMI) systems, there are quite a few formalisms found in the literature survey in constructing the emotion recognition module for the systems. Fuzzy min-max neural network is designated as the control scheme for the Kaist Motion Expressive Robot (KaMERo) that is mend to make the robot responds differently to a variety of emotions so to increase the degree of believability of the robot [9]. In [10], Nao robat was programmed with hybrid controller to react accordingly to the subject emotion based on the EOG signal and event-related potential (ERP) signal generated by the subject. PHYSIOBOT [11], a rehabilitation platform could relate the psychophysiological feedbacks in a cooperative manner where a virtual neuro-rehabilitation task that is controlled by Fuzzy logic inference system (FIS) is used in giving several commands from the psychophysiological data input that is translated into 0 for no assistance and 1 for full assistance.

The objective of this paper is to discuss a way to embody the emotion recognizer module into the controller of a dedicated robot assisted rehabilitation platform. The emotion is treated as discrete event that triggers different set of rehabilitation tasks by the mean of hybrid automata model.

II. SYSTEM DESCRIPTION

Fig. 1 shows the overall block diagram of robot-assisted rehabilitation system with emotion embodiment module. It consists of three major blocks. The first block is the emotion recognition system where the emotion is identified, the second block is the hybrid automata based controller which formalize the emotion embodiment into machine code and the third block is rehabilitation platform which serves to study the performance of the controller. In the next sections, each of the blocks will be discussed further.

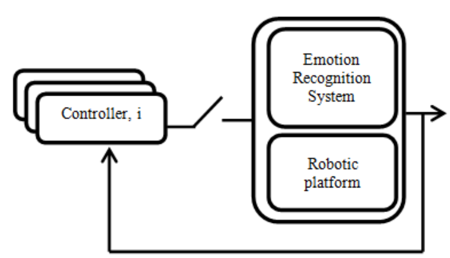

Figure 1: Block Diagram of Rehabilitation Robot with Emotion Embodiment System

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A. Emotion Recognition System

Basically, the emotion model developed for the system is based on Bayesian network model. A properly designed experiment was conducted to invoke the intended emotions. In particular, a series of ten minutes audio visual stimuli is given to the subject before the radiated pattern of electromagnetic (EM) fields from the subject is captured and recorded [13]. A handheld device called Resonant Field Imaging (RFI^{TM}) is used in capturing the EM wave signal. There are 10 points on the body where the signals are measured from, namely the right and left palms, thighs, forearms, arms, and head as shown in Fig. 2 [12].

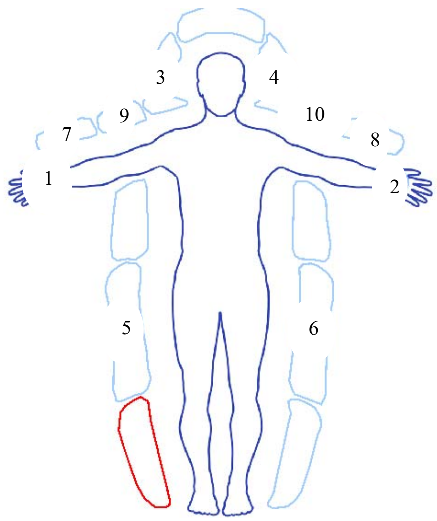

Figure 2: Region of EM wave measurements

The collected dataset were then trained and classified using Bayesian Network (BN). In addition, the results were verified by a set of questionnaire which were discussed comprehensively in [13]. In the study, the types of emotions under investigation are sad, happy, and nervous which are captured from twenty one subjects and consists of fifty datasets.

B. Hybrid Automata

The set of discrete input for the hybrid automata model is the ten EM signal values from the ten body points that is eventually classified into a particular emotion. The output which is continuous in nature, is the desired speed of the rehabilitation platform. The basic structure of the hybrid automata model of the system is shown in Fig. 3 where S_1 represents initial state.

There are two types of symbols used in the hybrid automata that are plant symbol and control symbol. These symbols are employed to represent the task assigned to the rehabilitation platform in changing the speed and direction of the gripper on the system based on the emotion of the subject. There are nine control states or modes described for the rehabilitation platform. Each of the modes represents the dynamic evolution of the system (i.e. speed, and direction of the platform and subject emotion) when given different desired speeds and directions to follow during rehabilitation session. The transition between modes happens once the guard condition detects any change in the current emotional state.

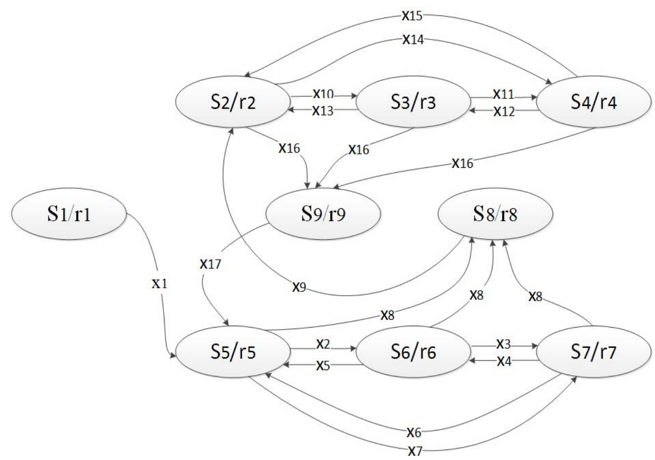

Figure 3: Hybrid Automata Model

C. Rehabilitation Platform

A robotic platform for robot assisted rehabilitation specifically used for the upper extremity has been developed to test the hybrid automata controller as shown in Fig. 4. The system consists of four major parts which are linear guide actuator, locking mechanism, gripper, and rotational axis actuator [8]. The linear actuator rehabilitates the affected arm by assisting the motion of the arm placed on the gripper back and forth repetitively while the unaffected arm is held constraint.

In this paper, the focus would not be on the health level of the affected muscle in deploying different rehabilitation tasks rather the speed and direction of the platform changes to adapt the subject varying emotions.

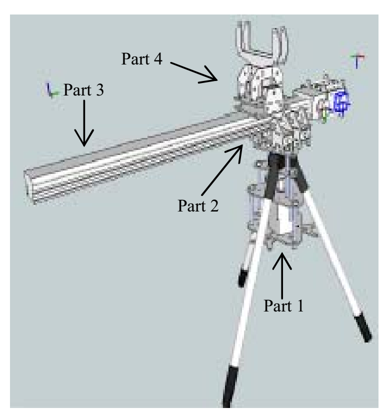

Figure 4: CAD model for robot assisted rehabilitation platform

III. HYBRID AUTOMATA WITH EMOTION EMBODIMENT

The scope of this paper is to present a hybrid automata model to control the operation of a dedicated rehabilitation platform. The continuous set of platform dynamics is governed by the discrete type of emotions. The intention here is to mimic the human therapist in adapting the type of rehabilitation tasks based on the emotional state of the subject or patient. This will enable the system to work more natural in autonomous form when the input from the muscle health measurement is also considered. However the later type of input is beyond the discussion of this paper.

The input to the system is the subject's emotion, E. The position of the gripper, X (c*m*) is obtained from potentiometer reading, and from that the speed, v of the gripper (*cm/s*), and the direction, *dir* the gripper moves are derived. The desired speed that is set for the gripper to move depends on the automaton that is triggered by the respective emotion. It is assumed the default state of the subject when he is about to initialize the system operation to be 'calm', thus the speed set is 1*cm/s*. For other emotional states, the speed is set accordingly, for example, the minimal speed of the gripper is set when the subject is sad. This is assumed due to the lack of subject's attention during the rehabilitation therapy session. The moderate speed is set if the subject is nervous. For this emotional state, the subject might give partial attention to the rehabilitation session. The maximal speed of the platform is set when the subject is happy, thus could give maximum attention to the rehabilitation session.

We define the operation of the system as different tasks of linear actuator or gripper to move at different speeds and directions when the affected arm is rehabilitated. In describing the hybrid automata model, the control states or modes, control symbols or conditions of the modes, and plant symbols of the system have to be identified.

TABLE I. LIST OF CONTROL STATES AND PLATFORM MODES

Control State	Platform Modes
State 1 (S_1)	Inital
State 2 (S_2)	Intro Mode Back
State 3 (S_3)	Rilex Mode Back
State 4 (S_4)	Advance Mode Back
State 5 (S_5)	Intro Mode Forth
State 6 (S_6)	Rilex Mode Forth
State 7 (S_7)	Advance Mode Forth
State 8 (S_8)	End Forth
State 9 (S_9)	End Back

Table I and Table II show the list of control states and control symbols for robot assisted rehabilitation platform. The control states represent different dynamics of the system. S_1, S_8, and S_9 are special states representing the positions of the gripper which are at initial position, the end position while the platform is moving forward, and the end position when the platform is moving backward. The control symbol specifies the speed in which the platform is moving the arm. Specifically, r_8 and r_9 represents the negation of the desired speed values after the end position has been reached.

All the nine states are dictated by the respected control symbols. For example in the initial state, S_1 the gripper moves backward to the home position at X=20 with the speed of 1*cm/s* from any position it previously rest. The gripper is then moved forward to the goal position located at X=5. The speed is set to decrease whenever the gripper is reaching the end point to minimize the momentum before the gripper switches direction and the operation continues until a stop command is sent to the system. Based on the emotional states detected during this process, the speed of the gripper changes accordingly.

TABLE II. LIST OF CONTROL SYMBOLS AND TASK ASSIGNED

Control Symbol	Task Assigned
r_1	The gripper moves backward to home position (X=20) with maximum speed of 1*cm/s*
r_2	Subject is sad (speed:0.5*cm/s* & direction : backward)
r_3	Subject is nervous (speed:0.667*cm/s* & direction: backward)
r_4	Subject is happy (speed:0.833*cm/s* & direction: backward)
r_5	Subject is sad (speed:0.5*cm/s* & direction: forward)
r_6	Subject is nervous (speed:0.667*cm/s* & direction: forward)
r_7	Subject is happy (speed:0.833*cm/s* & direction: forward)
r_8	Negate dir value (change direction from forward to backward with minimum speed: 0.333*cm/s*)
r_9	Negate dir value (change direction from backward to forward with minimum speed: 0.333*cm/s*)

The plant symbols listed in Table III are generated based on the information from position sensor (potentiometer) of the robotic platform and the emotion of the subject. It represents the possible evolution of system dynamics (speed and direction) and the subject emotions. As these dynamics changes, new plant symbol is generated and fulfilled the requirement of the guard condition of the hybrid automata model. It then becomes the precondition before which the transition between one control state to another control state to occur.

TABLE III. LIST OF PLANT SYMBOLS AND DEFINITIONS

Plant Symbol	Type of Emotions and Gripper position (X in cm)
x_1	X=20
x_2	Subject emotion change from sad to nervous AND (X=5)
x_3	Subject emotion change from nervous to happy AND (X=5)
x_4	Subject emotion change from happy to nervous AND (X=5)
x_5	Subject emotion change from nervous to sad AND (X=5)
x_6	Subject emotion change from happy to sad AND (X>=5)
x_7	Subject emotion change from sad to happy AND (X>=5)
x_8	Gripper at goal position (X=5)
x_9	Gripper direction changes from forward to backward (5<X<6)
x_{10}	Subject emotion change from sad to nervous AND (X<=20)

x_{11}	Subject emotion change from nervous to happy AND *(X<=20)*
x_{12}	Subject emotion change from happy to nervous AND *(X<=20)*
x_{13}	Subject emotion change from nervous to sad AND *(X<=20)*
x_{14}	Subject emotion change from sad to happy AND *(X<=20)*
x_{15}	Subject emotion change from happy to sad AND *(X<=20)*
x_{16}	Gripper at home position (*X*=20)
x_{17}	Gripper direction changes from backward to forward (19<*X*<20)

IV. RESULTS AND DISCUSSIONS

The system employs *Arduino* microcontroller as data acquisition system (DAQ) between the sensors and actuators of the robotic platform, and the computer installed with *Matlab/Simulink* software. The hybrid automata model is developed using *Stateflow* tool in *Simulink* and the data/control interaction is done through *Arduino* support package, *Arduino IO* [14]. The '*Arduino Analog Read*' block is employed to record the value of the potentiometer reading in order to get the exact position of the gripper when it moves while the '*Arduino Digital Write'* block functions as the main switch for the hybrid automata in changing states. The '*Arduino Analog Write'* is used to command the DC motor to rotate according to the preset desired speed in the respected automaton and finally, the '*Flag*' block is used with *if-else* statement to control the direction of the gripper. The sampling time is set to 0.01*s*.

In order to study the efficacy of the system model and the performance of the system integration, a specific scenario is tested on the developed hardware. The ordered sequence of emotions is given as a set in Eq. 1;

$$E = \{1\ 3\ 1\ 2\ 2\ 3\ 1\} \qquad (1)$$

where *E*=1 (sad), *E*=2 (nervous), and *E*=3 (happy).

Fig. 5 captures the dynamics evolution between the emotion, the system state, position and speed of the system. For the first ten second which is from point A to B, the emotion of the subject is State 1 indicating sad emotion. However, regardless of the emotions, since the system is initializing, the gripper is moving backward to home position at *X*=20 from the previous resting position, with the speed of 1.0*cm/s*.

As the gripper reaches the home position at point B for the first time, the emotion is still sad (*E*=1), but the state now switch to S_5 to prepare the gripper to move forward at the speed of -0.5*cm/s*. At point C while moving forward the emotion switch to happy (*E*=3), thus the state switches to S_7 and the speed is made faster to -0.833*cm/s*.

At point D, the emotion switches to sad again (*E*=1), prompting the state to switch to S_5 and the speed to -0.5*cm/s* while the gripper is sill moving forward until goal position. At point E, the goal position is reached so the state switches to S_8 to negate the speed value. In order to provide some 'cushion' on the drastic change in the direction, the speed for this state is set to 0.333*cm/s* (the minimum speed). Now the gripper is moving backward to home position. At point F, the emotion is detected to be nervous (*E*=2) and this causes the state to switch to S_3, thus changing the speed to 0.667*cm/s*. The state remains the same at point G and continues until the home

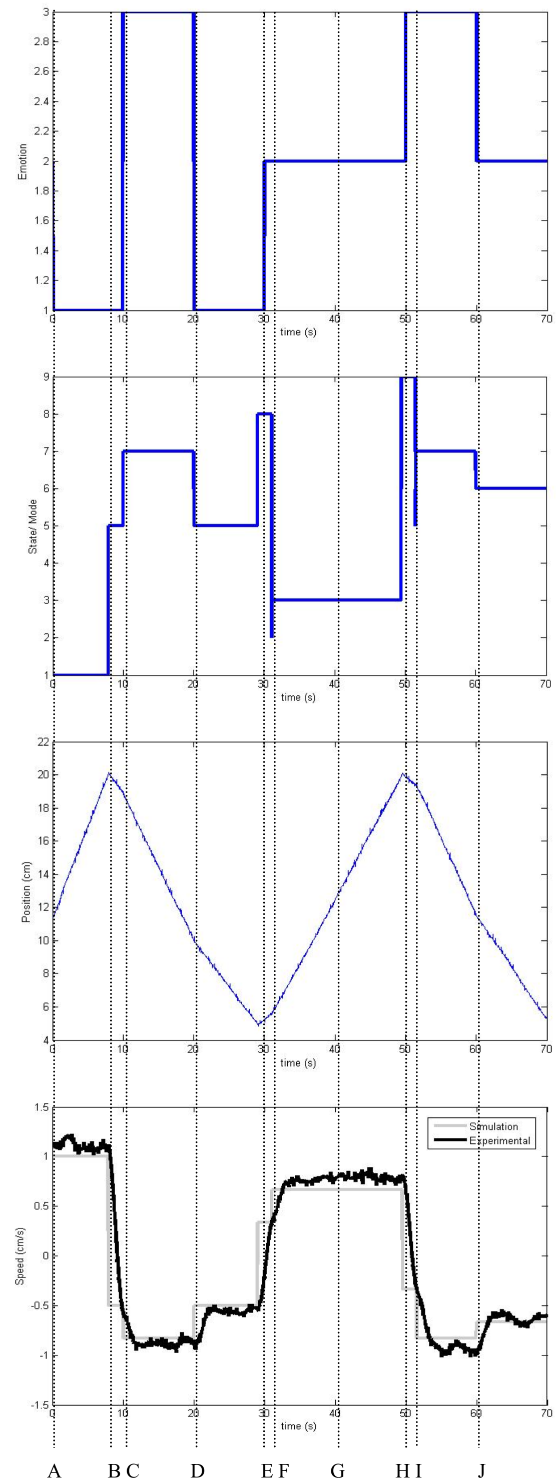

Figure 5: Emotion, State, Position, and Speed Dynamics

position is reached. As it reached the position, the state S_9 is activated, thus negating the direction and set the new speed of -0.333*cm/s* as can be seen at point H.

At point I the state switches to S_7, denoting happy emotion is detected (E=3) and the speed of the gripper is set at -0.833*cm/s*. Finally at point J, S_6 is activated (E=2) and the speed of the gripper is set -0.667*cm/s* until the gripper reached the goal position.

V. CONCLUSION

In this paper, a hybrid automata model is developed and tested on robot-assisted rehabilitation specifically for upper-extremity part. The proposed hybrid automata model embodies the emotion of the subject which results in deployment of different rehabilitation tasks. The simulation and experimental results show the efficacy of hybrid automata model to be applied on a rehabilitation platform with different type of emotions as input to the system. For the future work, the model of hybrid automata can be improved to include the degree of probability and time of the emotions. The stability of the controller can also be investigated to ensure the system is stable throughout the switching of modes in the hybrid automata model.

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