CTGaming: A Problem-Oriented Registry for Clinical TeleGaming Rehabilitation and Intervention

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***Abstract*—A clinical telegaming registry, called CTGaming, has been added as a new Problem-Oriented Registry of Tags And Labels (PORTAL) to the collection of prototype PORTAL registries for ongoing development of the PORTAL-DOORS System (PDS). As a distributed system of interacting PORTAL registries and DOORS directories, PDS provides metadata management services for who-what-where metadata about both online and offline resources. For the CTGaming PORTAL, the scope of the problem-oriented specialty domain for the registry encompasses gaming in physiotherapy, rehabilitation and intervention via telecare, and in general, diagnostic and therapeutic telegaming. This new PORTAL registry has also been incorporated into the design of an existing clinical telegaming system (CTGS). Operating as an adaptive gaming application for telerehabilitation, the CTGS functions either locally in a clinical care setting or remotely in a telecare setting in patients' homes. Operating in concert with the CTGS, the CTGaming PORTAL has been established as a host for metadata representations of resources in the field of clinical telegaming with metadata representations for resources relevant to the CTGS served upon request. These resources may include external resources from the public web as well as internal resources such as telegaming session data from the private medical records associated with the CTGS.**

***Index Terms*—Home telecare, diagnostic and therapeutic telegaming, rehabilitation and intervention, finger-hand movement, motion tracking, semantic web, PORTAL-DOORS System.**

I. Introduction

Within the context of an updated review of an existing clinical telegaming system [1], this article introduces a problem-oriented registry for clinical telegaming rehabilitation and intervention systems, called the CTGaming Registry. This registry is presented as a new PORTAL for the PORTAL-DOORS System (PDS) reported in [2], [3].

The intent of the CTGaming Registry is to establish a collection of related resources for those interested in telegaming rehabilitation. The premise of this type of rehabilitation is to provide a platform that allows patients to receive treatment in the form of therapy at a remote location, either in the home or at a local community treatment facility. The inclusion of a gaming element is intended to provide extra motivation for the patients in the form of a challenge and a more enjoyable means of encouraging them to follow repetitive movements that are often a part of the rehabilitation process. In addition this can also be employed as a means to distract and help relax patients that may require more critical, immediate treatment.

As this form of treatment becomes more popular, a greater number of resources will be included as part of the CTGaming Registry. A few example resources consist of items such as articles, technical manuals, videos, group web pages and personal web pages to name a few, all relating to clinical telegaming and rehabilitation. Through the use of a semantic search client, a more intelligent means to discover a greater amount of related information to clinical telegaming and rehabilitation will be made possible.

A. Background

Telerehabilitation as defined by T. G. Russell [4] provides rehabilitation remotely via telecommunication technology. There are many different applications encompassed as part of telerehabilitation that engage the senses, including visual and audio stimuli [1], [5]–[8] with the more recent addition of haptic sensation or touch [9] resulting in systems that include physical sensation [10]–[12]. There are a number of target populations that have been the focus of research efforts for assessment and treatment of patients including post-surgical rehabilitation [12], speech therapy [6], physical therapy [10], gait assessment [13], post-stroke rehabilitation [10], [11], [14] and many others including the work at the University of Manitoba that focuses mainly on patients with arthritis [15].

There are different approaches being used to unite therapeutic rehabilitation and gaming. For example, virtual environments and virtual reality based games are one approach that is quite popular. The Telerehabilitation Institute has published a number of examples for virtual reality systems geared toward telerehabilitation [12], [16]–[18]. There are also a number of other groups working with virtual reality systems recently including [7], [19]–[22] to name a few. Another approach taken by occupational therapists at Glenrose Hospital in Alberta was to integrate gaming into their therapy programs using Nintendo® Wii™-based rehabilitation [23]. Others have also included or referred to the Wii™ as a possible part of rehabilitation programs [20], [24]. Another technique used in merging gaming with rehabilitation employs force-feedback (haptic) technology to assist and aid patients in sensing more of the gaming environment [11], [18], [25]. A natural extension from haptics moves into robotic rehabilitation with systems that can both assist and challenge users. Some examples of robotic assisted telerehabilitation systems include [26]–[29].

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The work discussed within this article takes a different approach with games and the user interface including a custom designed game for testing patient performance. For user control, a wide array of objects can be instrumented to operate as computer control devices in place of a mouse, keyboard or joystick. This approach provides a wide array of input object choices suited to varied patient capabilities and specific therapeutic movements. In all cases, combining rehabilitation and gaming together provides a helpful motivational tool for patients. Instead of potentially dull or uncomfortable situations, a gaming medium is substituted to maintain the patient's interest and help put them at ease. Often the underlying rehabilitation process is forgotten as the user focus is maintained by the gaming platform. The work discussed here is intended for use in both a clinical and remote setting either at a remote clinic or a patient's home.

As a new problem-oriented registry in PDS, the CTGaming PORTAL contributes to the ongoing development, implementation and revision of PDS [30], [31]. The PORTAL-DOORS System was originally designed [2] to help bridge the gap between the current web and the vision of a semantic web as described by Berners-Lee [32]. The semantic web is intended to improve upon current web technology where humans are largely responsible for searching and finding documents and data. This improvement is intended to come in the form of a data-driven web [32] where data is marked semantically with sufficient metadata to describe documents in a manner that computers that will be able to decide if they meet search criteria based on logic. The end result is a more intelligent web experience that eliminates some common problems users face such as incorrect search results (via ambiguous wording) or longer time durations for multi-faceted problems where schedules need to be synchronized (instead of doing this manually, individual software agents can be submitted from the original user query).

B. Overview

Table I summarizes terms, acronyms, definitions, and names for all associated telecare systems for clinical telegaming. The University of Manitoba, Canada (UMbC) implemented systems result from a collaborative effort between students and faculty of the Computational Intelligence Laboratory and the School of Medical Rehabilitation in developing a telegaming system for rehabilitation. This UMbC telegaming rehabilitation system named STIM (from "System for Telerehabilitation and Interest Maintenance and Management") adopts a non-acute treatment approach, employing the hardware described in [33] and extending it with customized software implemented as an electronic medical record system [1]. This UMbC medical record system named DRUM (from "Data Repository for User Management") has been developed for secure containment of patient health records and telegaming session performance [1].

Thus, the overall clinical telegaming system implemented at the University of Manitoba is comprised of the subsystems UMbC STIM, UMbC DRUM and the CTGaming Registry as summarized in the named instance column of Table I. The rehabilitation subsystem called STIM makes it possible to

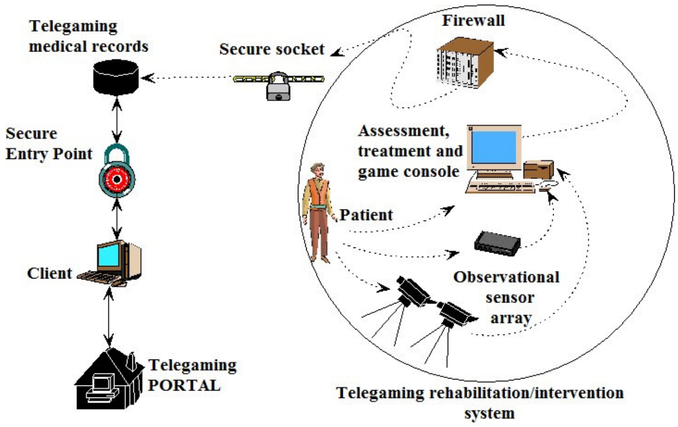

Fig. 1. Generic telegaming system.

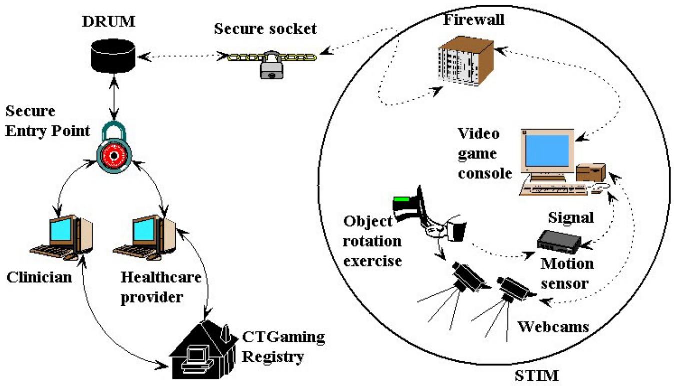

Fig. 2. Specific telegaming system implemented at University of Manitoba.

monitor hand-finger movement during rehabilitation exercise sessions (see Figure 1 for an overview of a generic CTGS, and Figure 2 for an overview of the specific CTGS implemented at the University of Manitoba). For example, an arthritis patient manipulates a common household object (*e.g.*, coffee cup) that has been instrumented with a motion-tracking sensor. Movements of an instrumented object (used instead of a joystick or mouse) produce motion signals used to control such things as a gaming paddle while playing a video game. Video gaming provides a good source of motivation for patients to continue and complete their prescribed exercise regime. Player performance is assessed using a custom-built gaming platform that gathers performance data from three sources: gaming actions such as paddle movements, a magnetic motion tracker and a pair of cameras that record streaming video of each physiotherapy exercise session. At the end of each game, recorded data is then compiled into several files that provide a record of game events and user responses. After STIM signal and video data is recorded during a rehabilitation exercise session, it is forwarded to the DRUM record system as unverified data.

A high-level view of DRUM records in relation to the STIM data stream and CTGaming PORTAL Registry is shown in Figure 2. The overall system implemented at UMbC makes it possible for clinicians and other healthcare providers to log in remotely and review gathered data using online tools

TABLE I
TERMS DEFINITIONS AND NAMES FOR CLINICAL TELEGAMING AND ASSOCIATED TELECARE SYSTEMS

Acronym	Term	Definition	Named Instance
CTG	clinical telegaming	medical subspecialty focused on delivery of telecare involving diagnostic and therapeutic telegaming	
CTGS	clinical telegaming system	telecare system enabling videogame-monitored diagnosis and/or videogame-guided therapy by incorporating one or more associated subsystems (TGRS, TGIS, TGMR, TGP)	
TGRS	telegaming rehabilitation system	telecare hardware system enabling videogame-driven exercise therapy for rehabilitation in non-acute setting	UMbC STIM
TGIS	telegaming intervention system	telecare hardware system enabling videogame-driven monitoring and biofeedback for intervention in sub-acute setting	
TGMR	telegaming medical record	telecare software system enabling management of private computerized records for patients' health-related information and telegaming sessions	UMbC DRUM
TGP	telegaming portal	public web portal application and/or service enabling access to non-private telegaming resources	CTGaming Registry

that are provided to analyze signals and videos for hand-finger motion sequences with various numerical measures and plotting functions used to detect motion patterns and client performance during rehabilitation therapy [8], [34]–[37]. Due to the complexity of capturing hand movements, performance data is gathered using three approaches in a clinical setting, namely, magnetic motion tracker, video capture and a custom gaming platform. Once verified, the data is placed in appropriate folders and made available to registered users who log in, search for and either acquire copies of the files or perform analyses using tools provided by the UMbC systems.

In addition to the clinical version of UMbC STIM, provisions have been made to allow patients to take a simplified version of the system home to continue their treatment program remotely. The components necessary for remote care include a copy of the game, a specific user input device that matches operation with a desired therapeutic movement and an account on UMbC DRUM. In the event of any problems during setup or use, a therapist or someone from technical support is available for consultation by either email or phone. Session data is recorded and uploaded upon completion to maintain a record of performance over time.

The current UMbC system is associated with a public registry hosting resource representations defined for clinical telegaming in a manner consistent with the specifications for a PORTAL in the PORTAL-DOORS System and thus described with metadata, consisting of tags, labels and other elements as required by the PDS schema [2], [31]. This problem-oriented specialty domain registry, called the CTGaming Registry or CTGaming PORTAL, stores and serves resource records useful for clinical telegaming investigations.

Use of the CTGaming Registry offers a simplified approach to accessing resource representations each of which includes a label identifying the resource and other elements that help locate and describe the resource and the owner of each resource. The term *clinical telegaming* within the context reported here refers to video game-driven exercise therapy that includes the use of telecommunication for transfer of performance data[1].

[1]The current CTGS implemented is single player-centered and differs from the usual form of telegaming, where multiplayer gaming is carried out over a telecommunication system

See also the scope defined for CTGaming in Section III for the more general use of the term *clinical telegaming* as a field of investigation.

The basic components of the CTGS including hardware and software are presented in greater detail in Section II followed by the associated CTGaming PORTAL in Section III. The contribution of this article is the introduction of the CTGaming PORTAL as a public registry for the field of clinical telegaming and as a means of interfacing between the private medical record system DRUM and the public web.

II. UNIV. OF MANITOBA CLINICAL TELEGAMING SYSTEM

The current clinical telegaming system developed at the University of Manitoba can be divided into four parts consisting of a miniBIRD® 500 magnetic motion tracking system, a video capture setup with two viewpoints, a telegaming virtual environment for rehabilitation, and a telegaming medical record operating as an online data repository.

A. Magnetic Motion Tracker

The magnetic motion tracking system was used to capture movement consisting of six degrees-of-freedom. The miniBIRD® 500 from Ascension Technology [38] is a commercially available device that supports a wired motion tracking solution. The miniBIRD® includes a small sensor (10mm x 5mm x 5mm) containing three orthogonal coils [38] that are connected by wire to the miniBIRD® console. The console is also responsible for generating a magnetic field that the sensor travels through. Motion of the sensor within the magnetic field is subsequently translated into motion coordinates. Movement information is transmitted serially from the miniBIRD® to a Teracade interface which is a custom built hardware interface. This interface converts sensor motion coordinates into computer control signals to replace a combination of joystick, keyboard and mouse input (see [33] for a detailed description of the Teracade interface).

For motion capture, the sensor was instrumented on various common household objects. An example can be seen in Figure 3, of a martini glass. For most of the controlled

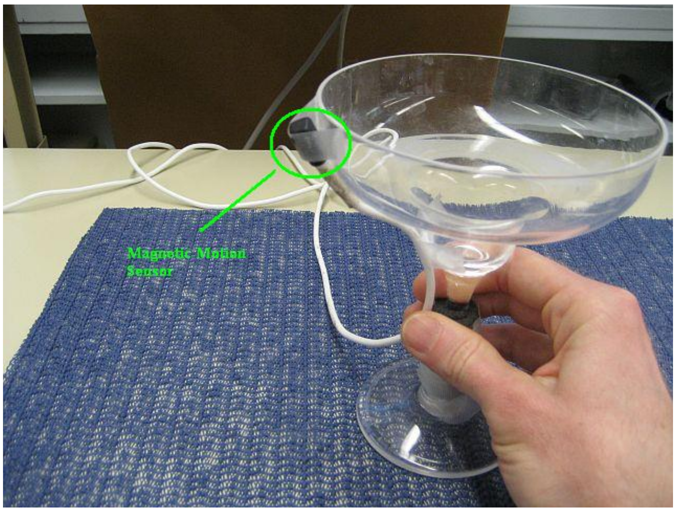

Fig. 3. Instrumented glass.

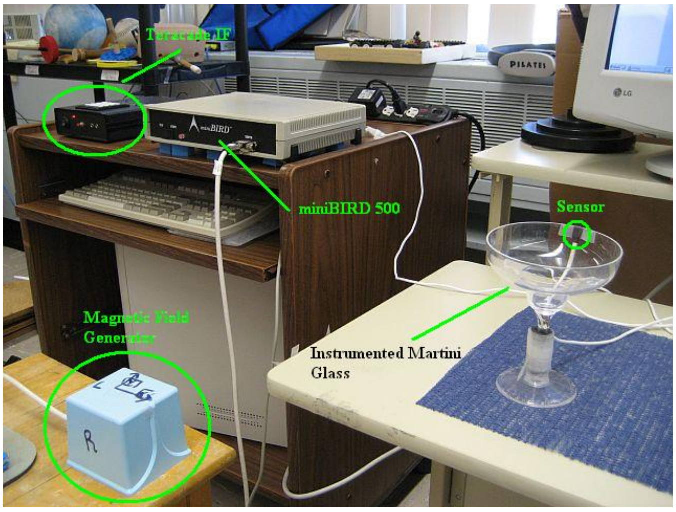

Fig. 4. Magnetic motion tracker hardware.

experiments, two types of motion were possible with the glass, rotation around the stem or tilting it back and forth. Motion of the sensor is picked up in the magnetic field which has a range of 0.5m and provides position (x,y and z) and rotation (roll, pitch and yaw) coordinates [38]. The sensor precision is 0.5mm for position and 0.1 degree of rotation, rated at a range of 30.5cm [38]. The miniBIRD® 500 has a range of +/-45.7cm for translational motion, +/-180° of attitude and +/-90° for azimuth and roll [38]. Based on the tracking window size, this system is well suited for a desktop environment. The hardware components are shown in Figure 4. This combination of devices allows capture of point source movement corresponding to the sensor moving in the magnetic field. When common objects are instrumented, user control capabilities are demonstrated by monitoring the reported 6 degrees of freedom. A typical task required slow controlled movement to accomplish, both on and off-axis motion can be monitored using this system, helping to provide a window into user capability.

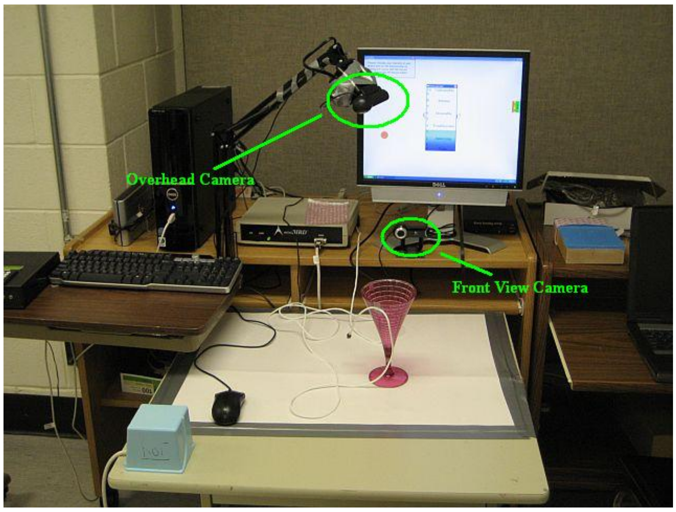

Fig. 5. UMbC STIM with dual cameras.

B. Video Capture System

To complement magnetic motion tracking, a video capture system is included in the UMbC STIM to help in tracking fine finger-hand movements and in detecting motion patterns during gaming sessions. After completion of a session, sequences of images are extracted from the video. Post-processing of the sequences provides features or indicators of supporting evidence for monitoring patient performance.

Preliminary efforts began with a single camera approach. For simplicity and cost a webcam was used, the Logitech® Quickcam Pro 9000. After several trials and re-positioning the camera, a second was included to provide two simultaneous video feeds from different viewpoints. The cameras were mounted with separate viewpoints, one at desk height intended to capture the front view, the second was mounted on a light-stand intended to capture an overhead view. Although inexpensive, these cameras record in high-definition (720p) and at fast frame rates (30fps). Moving to two simultaneous video feeds became necessary to capture at a minimum, one good viewpoint of any instrumented object. As a result, the video capture system is better suited to a clinical setting where trained staff is responsible for setup. The camera setup is shown in Figure 5, including the entire system.

To simplify running two identical webcams with separate video feeds simultaneously, CamPanel™ Digital Surveillance Software is used [39]. Both webcam feeds were connected via USB ports. Recording uncompressed video resulted in large amounts of video data for gaming sessions of even a few minutes duration. As a result, the frame rate was reduced to 20 frames per second which was well suited to the slow controlled movements that were required from the users. In addition, the video resolution was dropped to 320x240 for the capture sequences. The lower resolution was found to provide sufficient information for post-processing and it also helped reduce the amount of information stored in video for improved portability.

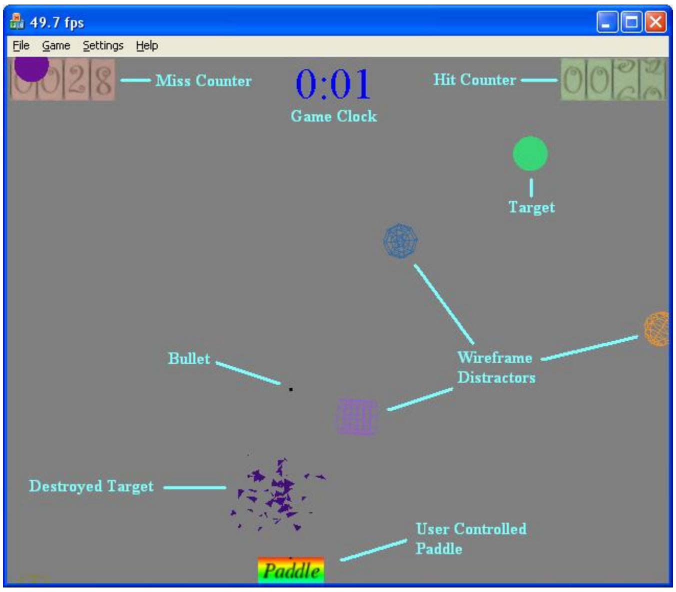

Fig. 6. Screenshot of telegaming virtual environment.

C. Telegaming Virtual Environment

Next is a brief description of the telegaming virtual environment that accompanies the data acquisition schemes described here (see [1], [15], [35] for a more detailed description). In addition to providing a virtual environment as a gaming experience for the patient, data collection occurs transparently at the same time for in-game movement and events. Output files are generated upon completion of a session, relating how gameplay unfolded and some insight into the patient's performance in the game environment. This provides a more complete picture of user hand-finger movements when considered along with the video and motion tracking data.

The gaming environment was built around a user controlled virtual paddle similar in nature to those used by the classic gaming genre typified by arcade games like Arkanoid™ and Breakout™. The user is given control of a virtual paddle and asked to destroy virtual targets that appear by either hitting them with the paddle or shooting them. There are also on-screen distractors which can be included that users must avoid running into or they suffer a 3 second penalty when their paddle is temporarily transparent and unable to score points. There are a wide variety of game settings to allow for difficulty level customization to suit almost any level of ability. A few examples of the difficulty adjustments include paddle size, paddle sensitivity, target speed, size, trajectory, and frequency (distractors have the same adjustable parameters as targets). A screen shot of the telegaming virtual environment during a game in progress is shown in Figure 6 which provides a visual description of what the user sees during the game session.

During a session, automated information gathering occurs regarding any in-game events. This includes user controlled paddle movement, appearance and disappearance of targets, distractors and bullets. Coordinates of all virtual objects on the game screen are logged at each refresh of the screen (refresh rate is typically set to 50fps but can be adjusted). The coordinate system used a normalized game screen from 0.00 to 1.00 (from top left to bottom right). To allow for a wide range of object movement tasks, the game provides either 1 or 2-axes of paddle motion. The preliminary experiments were done exclusively with single-axis control, having the paddle operate either in the East-West or North-South orientation (dependent upon the instrumented object characteristics). For example, the glass in Figure 3 is suitable for East-West movement if rotation about the stem is the desired task and conversely North-South is better suited for tilting the glass forward and backward. At the end of a gaming session, the resulting output file contains the coordinates of all on-screen objects present throughout the game. This helps provide a picture of why user movements were made by linking the motion to the gaming events.

A few other game modes have been added to improve the functionality and make for a more robust gaming environment, including adaptive play, a force feedback mode, and a sinusoidal motion test. A number of different difficulty adjustment parameters were already in place, automating adjustment of those parameters was part of the effort to create adaptive game play. First, an optimal performance was selected (approximately 80%), this sets the standard for how well users are expected to perform to maintain interest. The session begins as usual but after a pre-selected length of time passes (an episode), user performance is evaluated and if necessary the difficulty of the game is adjusted to help the user achieve the optimal level of success. Support for reinforcement learning was added at the same time but was not used due to fast game speeds and larger computational requirements where learning slowed game play, annoying users (opposite of the goal).

The next modification for the gaming environment was made by adding a force feedback mode. The intent was to provide a means to give real time (or near real time) feedback regarding presence of targets on the screen through a force feedback controller. The target audience for this mode of play focused on post-stroke patients with right or left side loss of vision. A simple interface was developed to allow a remote clinician to monitor game events and send a force feedback pulse for events that occur on the side with vision loss. Remote issuing of force feedback commands were done using an Internet connection, implying that they could be issued from anywhere. The limiting factor for this game mode was the time delay in signal propagation. During the testing phase, experiments were run in separate rooms but from the same building. These distances worked well for typical slow controlled movements. However, it would not be suited to high speed gaming.

The final game mode added included a simple sinusoidal motion pattern for a target. The user goal was to follow a target as close as possible with the paddle. Only one target was present on screen at all times and it was indestructible and bullets were disallowed in this game mode. The orientation of the sinusoidal tracking operated like the game on either a North-South or East-West axis depending on the instrumented control object. The intent of providing this mode of play was to give a base line comparison for motion tracking. Game events occurred at random and users responded accordingly. Instead of using a random group of motions for comparison, a deterministic sinusoidal mode was added to provide meaningful results when comparing to other work.

In addition to the coordinates of all objects that appeared on screen during a game session, output data contained a header with all game settings and information. This includes date, time, user initials, instrumented control object and orientation of the game. After the header, each line of output includes coordinates of the paddle, any object on the screen (bullets, targets and distractors) and event notifications if a target was successfully destroyed. Once the output file was written, an in game setting allowed for direct upload to secure servers. After data files were uploaded, they are subject to validation before being released for post-processing analysis by authorized users of the medical record system.

D. Telegaming Medical Record

Once data has been recorded, the next part of the CTGS promotes being able to use the resulting remotely generated data for rapid analysis. This section discusses how data moves from the gaming platform to a remote medical record system for storing and analysing the telegaming session data, the telegaming medical record subsystem called DRUM in the UMbC telegaming system.

First, a brief look at how data moves from a user game session to the remote server is included. As part of the gaming platform, there is a setting that allows upload of session data. Once a user selects that option the game contacts the server hosting the DRUM application which was written in Java [40]. To minimize overhead, simple two byte commands were passed between the client and server to indicate start of a session and when data is ready to be transferred. Upon completion of a gaming session, the remote user's machine uploads the resulting data file.

The server stores the data file in a private directory that is flagged for validation before release to the DRUM application. At the time of writing, validation of data was performed manually, with administrators verifying content and then relocating data to appropriate repositories. To maintain privacy of users, no personal details are kept in the files. Initials are used as part of filenames rendering them largely meaningless to anyone who does not understand what each character in the filename indicates. In no specific order an example of filename characters include user initials, trial number, orientation, whether distractors are present and any other distinguishing features about the session. Once validated, data files are relocated to appropriate locations based on content.

After data files have been released for use, they can either be downloaded or processed online using analysis tools provided as part of the UMbC DRUM subsystem. To gain access, a user must register and be given a password, furthering security of records. Guests are able to access the system but only in a viewing capacity and they are unable to examine any of the data menus. In the event that a registered user takes advantage of some of the online processing tools, they have a few choices available including user motion trajectory, accuracy and numerical error measures. Each game has a number of individual movements that take place during a session. For longer duration games the amount of movements are cumbersome to handle if presented in single output plots.

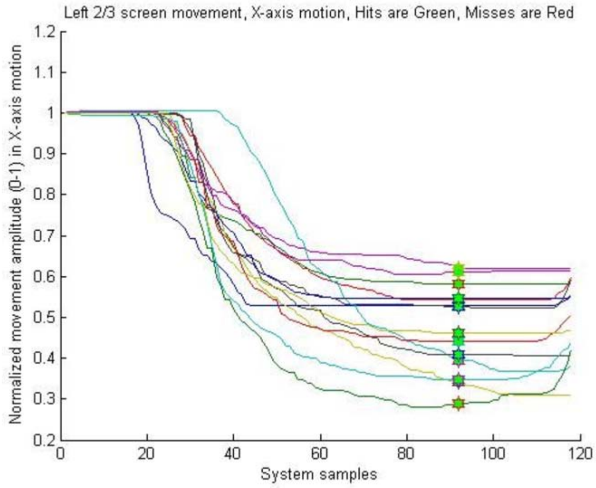

Fig. 7. Movement trajectory output plot for 2/3 left moves.

As a result, in-game user movements were broken up into distances relating to normalized screen distance (from 0.00 to 1.00).

Three classifications were used, distances from 0 to 1/3 of the screen, from 1/3 to 2/3 of screen distance and finally 2/3 to full screen displacements. In addition, all movements were categorized as either right/left or up/down, providing six distinct types of single-axis movements. Visually, this provides a more meaningful and less cluttered output. An example output plot is shown in Figure 7. The output plot contains the left-going movements that were from 1/3 to 2/3 of the screen size in distance. Each trajectory has either a green star or a red box indicating a successful hit or a miss respectively (there are no misses in this example). The other analysis tools provide alternate perspectives of the same data for different performance measures. These are given to help compare and monitor trends in patient performance over time.

In addition to data storage, analysis tools and a secure user interface, there are a few other important parts of the UMbC DRUM application. A set of help files detailing use of the analysis tools and where to find the data provide users with a simple description of how to get up and running quickly. In addition, a few example image sequences from the video cameras are included to provide some insight into the future evolution of what will be available along with data files.

III. CTGAMING PORTAL REGISTRY

The PORTAL-DOORS System specifies a set of data exchange interface requirements that facilitate interoperability and search across problem domains for both the original web and semantic web [2], [31]. PDS is designed as a distributed online system comprised of an interacting network of PORTAL registries and DOORS directories. The PORTAL servers operate as a resource label and tag registering system while the DOORS servers operate as a resource location and description publishing system. The names PORTAL and DOORS were derived respectively from the phrases "Problem Oriented Registries of Tags And Labels" and "Domain Ontology Oriented Resource System" that summarize their intended purposes.

The administrators for any PORTAL registry implemented for PDS may declare a set of constraints which define the focus of its problem scope as a *Problem Oriented Registry of Tags And Labels*. Resource representations entered as records for a given PORTAL registry should be validated against the set of constraints defined for the registry and expunged if not valid within the time period required by that registry [2].

For the CTGaming PORTAL introduced here, the problem scope is declared as *clinical telegaming* and defined by requiring that records entered in the registry be related to the following concept groups:

1) clinical, medical, diagnostic, therapeutic, health care, rehabilitation
2) telemedicine, telecare, telemonitoring, remote interaction, remote intervention
3) telegaming, gaming, games, simulations

where validation requires logical `and` between all three concept groups and logical `or` for concepts within each group.

There are obvious special cases for which concepts from only two groups (for example, the pair of concepts "telecare `and` telegaming") are sufficient for validation. Records entered for the CTGaming Registry are validated against these concepts by testing whether the PDS Supporting Tags of each record contain phrases with word stems matching the required concepts. This mechanism assures that records entered in the CTGaming PORTAL remain true to its specialty problem domain defined as clinical telegaming.

A. Example Resource Representation

Public records in the CTGaming PORTAL are accessible via a RESTful web service available at

pds.clinicaltelegaming.net/ctgaming

with server responses returning resource representations in XML format. An example of a resource representation with PDS Principal Tag "WATTGaming" is available at

http://pds.clinicaltelegaming.net/ctgaming/wattgaming

for which the service returns an XML formatted representation as displayed in Figure 8. This example also demonstrates some of the new enhancements and revisions to the PDS specifications detailed elsewhere [30], [31], especially the new PDS schema for representing the metadata for a resource with a hierarchical formulation of *metadata about metadata* that distinguishes the entity, record, and infoset [31].

B. Alternative Integration Scenarios

As currently implemented, the CTGaming PORTAL operates in a manner similar to the other registries in the collection of prototype PORTAL registries for ongoing development of the PORTAL-DOORS System [31], [41], [42]. It serves primarily as a public PORTAL registry, applications of which can facilitate scientific discourse with colleagues (ie, social networking with resource and bibliography sharing, etc) in the field of clinical telegaming. It also serves as an interface between the public semantic web and the private medical record system that maintains the patient rehabilitation exercise data and clinical care records.

In addition to the current implementation, there are other alternative integration scenarios that are possible. While each of the metadata and/or data management systems involved could be construed generically as content management systems, applying distinct names to the functional layers promotes clarity of concepts and readily enables design and implementation of alternative architectures. Thus, the exercise data may be managed in a separate *Research Data* system for the signal, image and video data, while the doctors and patients may be managed in a separate *Clinical Care* system for managing their interactions and records. Each of these may be implemented as a database with a schema that is an extension of the PORTAL schema (and thus can also operate directly as a private PORTAL registry for the research data and/or clinical care), or alternatively with a schema that is independent and unrelated to the PORTAL schema.

In the latter case, a separate private CTGaming PORTAL registry that tracks metadata for the data in the private databases can be established as a direct interface to the public semantic web for retrieval of external public data and information including from the currently implemented public CTGaming PORTAL. Alternatively, an indirect interface of the private Research Data and Clinical Care systems can be established via the current public CTGaming PORTAL. In this case, the same PORTAL registry stores both private and public records with access restricted to private records by the requisite authentication and authorization of users. In all of these scenarios, the primary function of any PORTAL used in one of the alternative scenarios (whether private only, public only, or mixed with both private and public records) is to address the data integration challenge of the problem under study, interfacing between multiple different database systems each optimized for storage of their own data types, while at the same time interacting with the public semantic web.

In a future version of the CTGS developed at the University of Manitoba, the private DRUM medical record subsystem will be re-implemented as a set of private PORTAL registries so that the interface with the semantic web for each one can be achieved more directly instead of indirectly via the current CTGaming PORTAL. Doing so will also enable most importantly the elimination and avoidance of the current mixed scenario that permits both private and public records in the same registry (see Section III-B). It will then be possible to maintain a higher level of security and privacy even more reliably for the separate private PORTAL registries under management for clinical trials and clinical care, while at the same time, maintain the current CTGaming PORTAL as a separate public PORTAL registry devoted exclusively to resources relevant for public discourse in the medical scientific field of clinical telegaming.

IV. Conclusions

A new problem-oriented registry, called the CTGaming PORTAL, has been introduced for the specialty domain of *clinical telegaming* and added to the growing collection of prototype PORTAL registries for ongoing development of the

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- <PDS xmlns="http://pds.portaldoors.org/xmlns/2006/npdsystem#">
    <!-- PORTAL-DOORS System (c) 2006-2010 Carl Taswell and Global TeleGenetics, Inc. -->
  - <ServerResponse>
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    - <Answer>
      - <NEXUS>
        - <ResourceRepresentation>
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              <Nature>Pervasive Computing Book Chapter by Peters et al</Nature>
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                <SupportingTag>physical medicine and rehabilitation</SupportingTag>
                <SupportingTag>adaptive learning, automatic tracking, pervasive computing</SupportingTag>
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            - <CrossReferences>
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Fig. 8. Resource Representation for WATTGaming Record.

PORTAL-DOORS System [31], [41], [42]. This new PORTAL registry has been presented for use in association with an existing clinical telegaming system [1]. The scope of the specialty domain for the CTGaming PORTAL encompasses clinical telegaming for rehabilitation and intervention, and more generally, diagnostic and therapeutic telegaming. This public CTGaming PORTAL serves as a repository for metadata representations of resources pertaining to the problem-oriented domain of clinical telegaming. The CTGaming PORTAL also serves as an interface to the semantic web for the private medical record subsystem DRUM used for clinical care records, research data, and telegaming sessions from the custom videogame subsystem STIM used for exercise therapy in the overall UMbC system.

Associating the public CTGaming PORTAL with the private UMbC DRUM enables the private system to access relevant external resources from the public web, and facilitates semantic data integration of the private internal data with public external data. This integration encourages investigators and health care providers using the CTGaming PORTAL to view and access appropriate resources that are available and relevant to the care of patients, assessment of their performance during rehabilitation telegaming exercise, and the efficacy of this exercise as well as any accompanying drug therapy regimens throughout the course of treatment. Increasing the ease of access for healthcare providers to the specific resources needed to assess and treat patients remotely yet routinely provides a more personalized healthcare experience for the end users.

With the current system in place, a few areas of expansion have been planned. The CTGaming PORTAL will be mirrored locally at the University of Manitoba to provide some redundancy and speed up local search times. The UMbC STIM will be enhanced to include a wider range of control objects that can be sent home with patients to help with remote rehabilitation to better suit any ability or skill level. Finally, work continues on improving analysis of output data to present a more comprehensive picture of patient performance and potential resources. This latter effort incorporates artificial intelligence predictor methods in the UMbC DRUM for examining patient data records in order to make both quantitative and qualitative statements regarding an individual in reference to a knowledge base.

The artificial intelligence utility methods will be provided to authorized users as a service to help with patient performance updates at a glance, simplifying and automating the gathering and analysis of patient results for clinicians. The long range goal of this approach envisions sending automatic alerts to primary caregivers when a patient requires a modification to their current treatment program. These improved analyses and utilities will help healthcare practitioners employing the clinical telegaming system implemented at the University of Manitoba to streamline patient healthcare and personalize individual treatment in a combined local and remote setting dependent upon individual needs.

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