A GIS-based Serious Game Interface for Therapy Monitoring

Ahmad M Qamar[3], Imad Afyouni[1], Md. Abdur Rahman[3], Faizan Ur Rehman[2], Delwar Hussain[1], Saleh Basalamah[3], Ahmed Lbath[2]

[1]KACST GIS Technology Innovation Center, Umm Al-Qura University, Makkah, KSA
[2]Dept. of Computer Science, LIG, University of Grenoble Alpes, France
[3]College of Computer and Information Systems, Umm Al-Qura University, Makkah, KSA
{amqamar, marahman, fsrehman, smbasalamah}@uqu.edu.sa, iafyouni@gistic.org, ahmed.lbath@imag.fr, mdelwar@advancedmedialab.com

ABSTRACT

In this paper, we present a novel idea of a map-based therapy environment for people with Hemiplegia. The therapy environment is designed according to the suggestions of therapists, which consists of a spatial map browsing serious game augmented with our novel multi-sensory natural user interface (NUI). The NUI is based on 3D motion sensors that can recognize different hand and body gestures used for browsing a 3D or 2D map. The 3D motion sensors work in a non-invasive way; hence, they do not require any wearable body attachments and can be used at home without assistance from the therapists. The map-browsing environment provides an immersive experience to the disabled users, which helps in performing therapy in an interesting and entertaining manner. We have developed analytics for measuring certain quality of health improvement metrics from each type of spatial map browsing movements. The 3D motion sensors have been tested with Nokia, Google, ESRI, and a number of other maps that allow a subject to visualize and browse the 3D and 2D maps of the world. The map browsing session data shows the nature of big data; hence, the session data is stored in a cloud environment. Our developed serious game environment is web-based; thus anyone having the appropriate low cost sensor hardware can plug it in and start experiencing a natural way of hands free map browsing. We have deployed our framework in a hospital that treats Hemiplegic patients. Based on the feedback obtained, the developed platform shows a huge potential for use in hospitals that provide physiotherapy services as well as at patients' home as an assistive therapeutic service.

Categories and Subject Descriptors

H.2.8 [**Database Applications**]: Spatial databases and GIS
H.5.1 [**Multimedia Information Systems**]

General Terms

Design, Human Factors.

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Keywords

e-Health, GIS, Serious Games, Kinect, Leap, Therapy.

1. INTRODUCTION

Hemiplegia is a physical disability that affects joint movements in one half of the body [1]. People suffering from stroke or Hemiplegia often lose the normal Range of Motion (ROM) in different joints of the body. Early treatment of hemiplegia can help a patient recover from this disability in a short amount of time. When a patient undergoes treatment for Hemiplegia, her ROM is measured from time to time to measure improvement. Traditional treatment is time consuming and requires the supervision of a trained professional. Recently, researchers have been working on the development of automated environments for physical rehabilitation. These automated systems can use sensors to detect different kinematic metrics from a therapy session undertaken by a subject. These metrics include positions, velocities, angular velocities, time to finish a therapy, acceleration and angular acceleration of affected joints and parts of the body [2]. The automated gesture monitoring systems are envisioned to allow patients to perform therapy in a friendlier environment. Intelligent systems can also guide a patient in performing exercises more accurately and independently, without the supervision of the therapist [3]. To add to the physical rehabilitation, serious games have become quite popular in recent years for use in mental and physical rehabilitation. Research has shown the effectiveness of such games in improving the learning skills of subjects [4]. However, little work has been done in the GIS domain for the purpose of developing serious games [5]. For example, in [6] the authors have reported a significant potential for building serious games for treating patients with physical disability.

In this paper, we present a GIS-based serious game environment as a front end to an e-health framework that offers several advantages over traditional and state of the art systems for therapy design and monitoring. The GIS-based game provides a deeply immersive map navigation experience to the users. The map navigation activity is performed using the Leap Motion controller, which is used to detect 18 different primitive hand therapies [7]. We also use the Microsoft Kinect, which tracks movements of 20 major joints in the body at 30 frames per second. This gives our proposed system the ability to record the motion of each joint as well as its ROM multiple times per second in a non-invasive way. The gestures produced by the users are converted into game movements using an intelligent gesture mapping engine. The gestures are natural and intuitive enough for the users to learn quickly and start using the immersive environment without a steep learning curve. The user also has the option of using our OpenStreetMap (OSM)-based local map server or internet-based map servers such as Nokia, Apple, Google, and ESRI, etc.

The system is cloud-based and hence can be used from anywhere and at any time according to the convenience of the patient. Cloud-based storage allows the gathering of big data from a very large number of users. A therapist can also track the improvement of the patient online without physical presence of the user. The web interface is lightweight and hence does not need complex and expensive setup on client machines. Patients only need to attach the inexpensive Kinect and Leap controllers to a PC to start recording data and playing games. The system also provides feedback to the user in the form of a live 3D view of body and hand movement consisting of angular and rotational data. To make the environment easy to use for the therapists, a novel authoring interface has been developed for therapy design. To design a therapy, the therapist marks the required joints by clicking on different parts of a model of the human body. The therapy designed in this manner can then be assigned to any patient. The patient can hence download the therapy and perform practice sessions. The system allows the patient to save therapy sessions in her own repository and share them with her community of interest through a dedicated cloud based environment. The recorded therapy sessions can also be played back for review. Finally a therapist, a patient or a caregiver can see live data plots consisting of quality of improvement metrics by comparing therapy session data for different sessions recorded over time.

The remainder of the paper is organized as following. Section 2 details the system architecture including different modules of the developed framework. Section 3 illustrates implementation details. Finally, section 4 outlines the demonstration scenario.

2. SYSTEM ARCHITECTURE

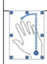
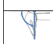
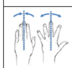
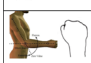
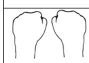
2.1 Mapping GIS Game with Therapeutic Gestures

We have developed a number of natural map browsing gestures to make the browsing experience simple and intuitive. Table 1 shows a gesture-mapping table, which outlines different gestures that have been implemented such as wrist ulnar and radial deviation for moving right and left and wrist flexion and extension for zooming in and out. We have taken these gestures from therapies suggested by therapists to patients suffering from Hemiplegia and other motor disability problems. Each gesture is detected by a specific algorithm, which parses the incoming sensory data stream and interprets hand position data to find the corresponding navigational movement. As shown in Table 1, we have selected both 2D and 3D map browsing gestures such that each primitive gesture can be converted into a primitive therapy. As an example of moving around a 2D map, a user has to grab the map by making a clenched fist gesture. Once the map has been grabbed, moving around requires the motion of the clenched fist towards right or left. To zoom into or out of the map, clenched fists of both the hands are used. A different set of gestures has been adopted in the case of 3D map browsing, which is shown in Table 1 and Figure 4c.

2.2 Framework Design

Our proposed system consists of three-layer architecture, namely, the storage layer, the core information processing and computational intelligence layer and the user interface layer. The storage layer stores data coming through the sensors for the purpose of analysis. The core information processing and computational intelligence layer interprets body gestures from the sensor data stream and forwards this information to the storage layer as well as the GIS game interface. The map engine and the gesture to therapy mapper component are also part of the core layer. The user interface layer provides an authoring environment for therapy design. The output part is made of different windows showing the Leap and Kinect screens as well as the Quality of Improvement metrics. An interactive graph generation screen is also part of the output interface. Three types of users exist for the system, i.e., the patient, the therapist and the caregiver. The therapist performs the job of designing and recording model therapies. The recorded therapy sessions are uploaded to the cloud for use by the patient. The patient can download these sessions and practice similar therapy sessions. These patient performance sessions can then be uploaded for comparison and analysis. Following are the details of the different components as illustrated in Figure 1.

Table 1: Gesture Mapping Table

Hand Gesture	Therapy	Navigation Activity	Normal ROM	Device	Body Part	Map Type
	Right Hand Radial Deviation / Left Hand Ulnar Deviation	Go Left	0→ 20	Leap	Wrist	3-D
	Left Hand Radial Deviation / Right Hand Ulnar Deviation	Go Right	0→ 30	Leap	Wrist	3-D
	Extension / Hyper Extension	Zoom Out	0→ 60	Leap	Wrist, Fingers	3-D
	Flexion	Zoom In	0→ 90	Leap	Wrist, Fingers	3-D
	Abduction/ Adduction	Move Up	0->20	Leap	Fingers	3-D
	Fist Clench	Hold and move the map up, down, left, right	Based on Multiple Joints	Leap, Kinect	Palm, Elbow and Shoulder	2-D
	Two hands with clenched fists	Zoom In and Zoom out	Based on distance between two hands	Leap, Kinect	Palm, Elbow and Shoulder	2-D

The **Authoring Interface** allows the therapist to design a therapy by marking the list of joints on a hotspot-based image of the human body and selecting their related movements from a tooltip box [8]. This therapy can be stored in the **Therapy Data** section of the secondary storage area. The sensor input includes the Kinect and the Leap Motion Controller that generate two streams of joint and motion data. The Kinect stream consists of data containing locations of up to 20 joints at 30 fps while the Leap stream is made up of 18 different gestures from two hands. The **Live Data Manager** saves a copy of the raw stream coming from the sensors to the **Session Data** component using the **Session Recorder**. A copy of the data is also forwarded to the inverse kinematics analyzer [9]. The **Inverse Kinematics Analyzer** infers inverse kinematic variables such as the state of different joints from the sensor stream and forwards this information to the

Quality of Improvement Display Window. The same data is also forwarded to the **Spatio-temporal Analyzer,** which detects gestures performed by the user and translates them into

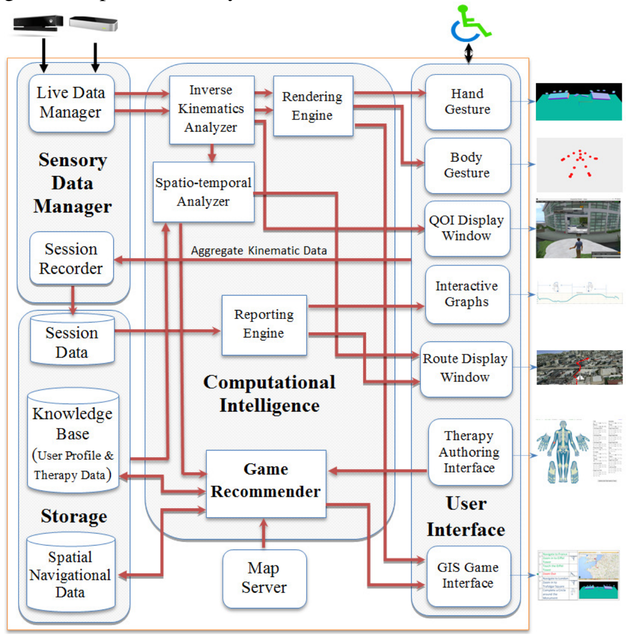


Figure 1: System Architecture

appropriate actions inside the game environment. The **Rendering Engine** displays data on the screen in different formats. The Kinect stream is shown as a stick figure while the Leap stream is presented as hands made up of 3D boxes (see Figure 4a). The web based **GIS Game Interface** displays a 2D/3D map that can be browsed by the patient using body gestures. A number of intuitive gestures have been defined for moving in different directions as well as zooming in and out of the map as shown in Table 1.

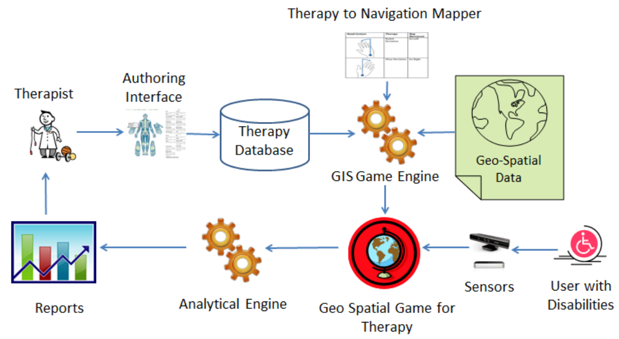


Figure 2: Serious Game-based therapy life cycle

Before the game is initialized by the **Game Recommender**, the user is given an option to select the required map interface through the **GIS Game Interface**. Once the user selects a local or cloud based map server, the **Game Recommender** sends a request to the appropriate **Map Server,** and data starts flowing towards the user's browser. At trajectories or the path that a user follows during the game session are stored in **Spatial Navigational Data**. The **Reporting Engine** uses data from the session storage as well as the information stored in the therapy database. The **Interactive Graphs** module plots the output in a visually attractive way to make it more intuitive and easy to understand for the therapist. The **Therapy Database** stores the therapies designed by the therapists. The **Reporting Engine** extracts the list of joints that need to be tracked for a particular therapy from the database.

Figure 2 shows the serious game-based therapy life cycle. A therapist uses the authoring interface to define a specific therapy. The interface displays a human body anatomy model, where each of the joints that are capable of being traced is displayed as a hotspot on the body. When a user clicks on a joint, a list of movements related to that joint is displayed with check boxes on the side. A therapist can associate a subset of body joints with a subset of primitive or high-level actions and other track-able metrics. After selecting joints and their related movements, a therapist is allowed to store the list in a database. The therapist associates the exercise to a specific therapy stored earlier in the database and uploads the data to the cloud. This exercise is then assigned to any patient suffering from a related disability. When the patient starts a therapy session using the GIS game, the game engine requests geo-spatial map data from the map server. The gestures performed by the user for playing the game are detected by the sensors and sent to the game engine. A therapy-mapping module then translates these gestures into appropriate movements in the game environment. While the user enjoys an immersive game playing experience, the data captured by the sensors in the background is stored in a cloud environment for later playback and processing. The reporting engine can then be used to generate reports and graphs for the related joints and movements.

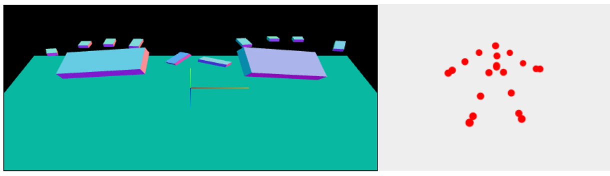
3. IMPLEMENTATION

The software environment (see Figure 3) has been tested on a PC with 8GB RAM. A Kinect for Windows device was used to collect data for 20 major joints. A Leap motion controller was used to track hand gestures. The software runs on a Windows 8 platform. The web based interface was developed using PHP, HTML5 and three.js 3D JavaScript framework for rendering Leap and Kinect frames in 3D WebGL. At the end of each therapy session, therapy data is stored in the form of a JSON or a BVH file. Therapy details are stored in a PostGreSQL database in Amazon Cloud. Map navigation through body gestures has been tested with Nokia, Google, ESRI, and 6 other map types (see Figure 4b). Figure 3 shows a complete setup of the system in a home environment. Figure 4 shows different views of the game interface. The two hands of the player as well as the 10 fingers are shown as 3D boxes. The whole body skeleton is rendered as a collection of joints representing the joints in the human body. The 2D map interface shows a grey ball as a pointer, which changes color to green once the map is locked. The 3D interface shows a kite like object flying in the 3D terrain following the user's hand movements. Figure 4c shows a trail of user navigation in a 3D map that is mapped to the therapies shown in Table 1 to produce therapeutic data. We use Amazon Elastic Compute Cloud (Amazon EC2) for horizontal and vertical storage facility. Our developed platform is available on Amazon EC2 for public demonstration at http://54.187.127.36/midmld/. Currently, our framework has been tested by two patients with mild Hemiplegia and their physiotherapists.

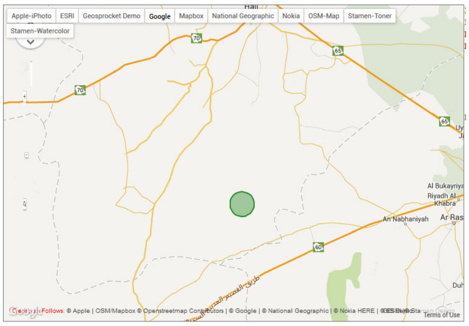
4. DEMONSTRATION SCENARIO

During the demonstration, we will show different two-dimensional maps and Nokia Here 3D map browsing scenario in which our therapy back end is connected. We will show a user browsing different maps using hand gestures.

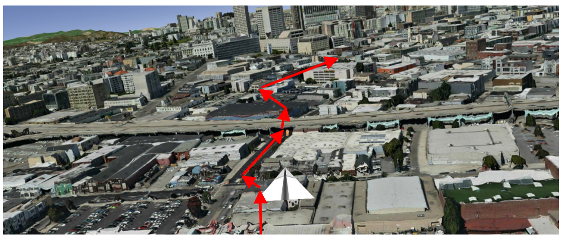
Figure 3: Experimental setup and user interface



(a) Live rendering of Leap stream showing hands and Kinect stream showing a dotted skeleton



(b) A 2D view of Google Maps with the green ball pointer showing that the map is locked for movement



(c) A 3D view of Nokia Here Maps with a freely moving kite

Figure 4: Different views of the game interface

The screen displays a pointer in the shape of a grey ball. The pointer moves with the movement of the hand. When the user plans to navigate the map, she can lock the map with a grip using a fist clench gesture. This turns the color of the circle to green indicating that the map has been locked. Once a map is locked, the user can move her hand left, right, up or down to move the map in the respective direction. For zooming in and out, two hands are used. We will show how data is recorded in the background while the patient plays the game by displaying graphs of the data recorded. We will also show the live feedback in the form of inverse kinematics that the game environment provides to patients, which serves as a visual cue about the primitive therapies she has been doing. Finally, we will show data analytics that show improvement of a patient over time as well as how deviated her movement is with respect to the movement of a normal person.

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