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February 19, 2007

Dr. Lakshman One
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Functional Specification for a Motion Capture System

Dear Dr. One,

The attached document, *Functional Specification for a Motion Capture System*, outlines the functional requirements and plans for our project for ENSC 440 (Engineering Science Project). We are in the process of designing and developing a real time system which captures the position and orientation of an object, providing a 2D digital representation and simulation of the object's movements on a computer. The system may be used later as an analysis tool to study the human body movements in different applications such as dance performances.

The purpose of this functional specification is to provide a list of the expected requirements and parameters that our completed Motion Capture System will fulfill. The document lists the specifications that will be completed for the project deadline in April and the specifications that will be left for future development.

SensIT Technology Ltd. consists of four inventive and devoted fifth-year engineering students: Azadeh Jamalian, Ata Naemi, Sa'ed Abu-Alhaija, and Ivan Lee. If you have any questions or concerns about our functional specification, please do not hesitate to contact me by phone at (604) 780-6583 or by e-mail at ajamalia@sfu.ca.

Sincerely,

Azadeh Jamalian
President and CEO
SensIT Technology Ltd.

Enclosure: *Functional Specification for a Motion Capture System*

Functional Specification for a

Motion Capture System

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Submitted Date: February 19, 2007

Revision: Version 1.0

Executive Summary

During the past decade, the technology of motion capture to trigger computer music based on the performance of dancers has been of interest for composers and choreographers, bringing together visual artists, composers, dancers and finally engineers. The SensIT Motion Capture System is the starting platform for the motion capture system which will be utilized by professional dancers as an analysis tool to study their dance movements. Our low cost system will be capable of capturing precision and real time movements of an object.

The development of the Motion Capture System will occur in two stages. After the completion of the first stage of development, the system will provide the position and orientation of only some specified joints of a doll's body sufficient to illustrate an overview of the motion in 2D. The device will have the following features:

1. Captures the position and orientation of different joints of a doll and writes the horizontal and vertical coordinates as well as the angle of each specified joint to a specific file.
2. Simulates the motion of the doll in the form of real time 2D animation on a computer monitor.
3. Provides a user friendly menu to start and end the application, change the location of the object on the screen for study purposes, and to visualize the coordinates of each joint.
4. Provides a document which outlines the resolution, precision, limitations and specifications of the system for potential users and perhaps future developments.

After the second phase of development, the device may also:

1. Be extendable for tracking more number of joints of a human body.
2. Provide the simulation of the motion in 3D, i.e. allow more degrees of freedom for the animation.
3. Have a bigger working volume and be more precise.
4. Have a wider range of applications such as music composition, biomedical and robotic researches, and video games development.

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1 Introduction

The objective of the Motion Capture System is to capture and simulate the movement of a dancer. Currently, at Simon Fraser University three departments of Computing, Music, and Engineering are intrigued by the project which focuses on studying dance movements and composing or conducting music inspired from these movements. Particularly, these departments are interested in our project since it has the potential to become the initial step of the bigger project involving the three departments. Our goal is to design a real time system which captures the 2D movement of an object (a small doll) and can be utilized as an analysis tool to study the movements of a dancer. The data obtained from the analysis tool can be fed to composition software to create composition data or directed to synthesizer software to generate the corresponding audio sounds.

The system uses infrared (IR) LED's which are mounted on the object, as well as a USB webcam which is connected to the computer that displays the animation. The images/frames obtained by the webcam will be analyzed by customized analytical software tools and the results are eventually used by the animation software for simulating movements. The project can later be developed to capture and study human movements, which will involve making a wearable suit with infrared (IR) LED's mounted on it.

1.1 Scope

This document describes the functional specifications of the Motion Capture System. A full list of functional requirements is provided for the proof of concept as well as to define the framework for the design and development of the system. The completed SensIT system may be modified to develop a more sophisticated system that can be used by an actual dancer. Minor modifications might be required upon further tests and analyses.

1.2 Glossary

CPU	Central Processing Unit
D	Depth
ESD	Electrostatic Discharge
H	Height
I/O	Input/Output
IR	Infrared
LED	Light Emitting Diode
MTBF	Mean Time Between Failure
RAM	Random Access Memory
RH	Relative Humidity
RoHS	The Restriction of the Use of Certain Hazardous Substances
STP	Standard Temperature and Pressure
USB	Universal Serial Bus
W	Width

1.3 Referenced Documents

[1] Proposal for Motion Capture System. SensIT Technology Ltd.

[2] Knight Lite Infrared Emitter Datasheet.

[3] Logitech QuickCam Technical Manual.

1.4 Intended Audience

This document provides the framework for the hardware and software engineers to develop their modules and create the complete system. All of the design modules shall meet the requirements as specified here.

Through the use of this document, the CEO can manage the group and ensure that each required task is completed on time. The hardware and software managers will also find this document valuable since it provides the expected features and limitations of each module.

Finally, knowing the specifications of the system, the marketing manager can advertise the system in order to receive funding and to find more interested organizations.

1.5 Objectives

The following convention is used throughout the functional specification to indicate the functional requirements:

R[#] A functional requirement

The priority of each functional requirement will be denoted by a number (n) which will be appended to the front of each functional requirement. The symbol (n) shall signify:

(1) A functional requirement for both the proof of concept system and the production system.

(2) A functional requirement for only the proof of concept system.

(3) A functional requirement for only the production system.

2 System Overview

The system can be divided into four sub-systems: a control unit, an optical capture unit, image analysis software, and 2D animation software. The control unit consists of the microcontroller and the IR LED's which are attached to the object under study. The control unit sends infrared radiation to the optical capturing device, which consists of a USB webcam. The raw information captured by the USB webcam is then sent to the main computer. The image analysis software analyzes the raw data and finally sends the calculated coordinates of the object to the 2D animation software. The functional description of the 2D motion capture system can be illustrated in the following diagrams.

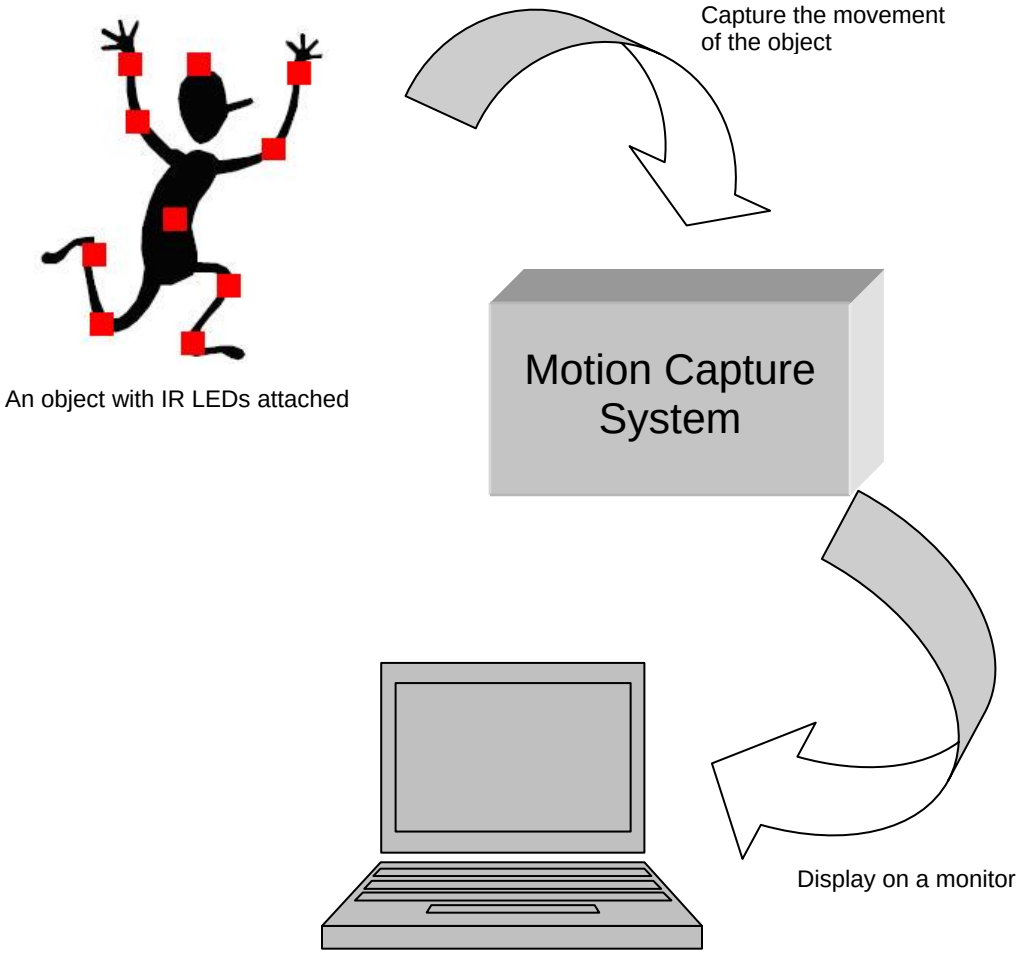

Figure 1: Graphical description of the system

3 System Requirements

The following section describes the overall requirements of the entire system.

3.1 Overall Performance

R[1] The system shall simulate the motion in real time. (1)

R[2] The position of each IR LED shall be updated at a frequency of 50Hz. (2)

R[3] The system shall be able to determine the coordinates of an object accurate to ±0.01m at STP. (1)

R[4] The system shall be able to track the object within a $1m^3$ volume. (2)

3.2 Reliability and Serviceability

R[5] The system shall have a minimum of 1,000 hours MTBF. (1)

R[6] The system shall have a minimum duty cycle of 1,000,000 cycles. (1)

R[7] The system should not be serviceable by the end user. (3)

3.3 Safety Requirements

R[8] The system shall not emit any IR radiation above 300mW. (1)

R[9] The user shall not look directly at the IR LED's for long periods of time. (1)

R[10] The system shall not produce any harmful effects on wildlife. (1)

R[11] The system shall have no exposed wires or terminals that can harm the user. (1)

R[12] The system shall be RoHS compliant. (3)

R[13] The wearable suit shall be made out of lightweight and breathable material. (3)

3.4 Packaging

R[14] The user shall be able to use a wearable suit with the control unit attached to it. (3)

R[15] The wearable suit shall be available in different sizes. (3)

R[16] The wearable suit shall be light and shall not effect the movement of the user. (3)

R[17] The wearable suit shall have no exposed wires or terminals. (3)

R[18] The control unit shall be attached to the object under study. (2)

R[19] The webcam and the control unit shall be protected from ESD. (3)

R[20] The system shall have no sharp points or edges. (1)

3.5 Environmental Requirements

R[21] The system shall be capable of operating in the normal consumer temperature range of 0°C to 40°C. (1)

R[22] The system shall be capable of operating under humidity range of 10 - 90% RH and domestic pressure range. (1)

R[23] The system shall be capable of operating at any altitude less than 3km. (1)

R[24] The system shall not have any significant heat dissipation such that no heat sink will be required. (1)

R[25] No infrared radiation sources other than the system's IR LED's shall be present within the working volume. (1)

R[26] The system shall have a clear line of sight between the webcam and the IR LED's of the control unit. (1)

3.6 Power Requirements

R[27] The system shall use two lithium ion batteries. (2)

R[28] The webcam shall be powered by the computer through the USB cable. (1)

R[29] A power switch and a power LED shall be implemented for the control unit. (3)

4 Hardware Requirements

The following section describes the technical and operating specifications of the system's hardware which consists of the control unit and the webcam.

4.1 Control Unit

4.1.1 Technical Specifications

R[30] The microcontroller shall have a minimum of ten I/O pins. (2)

R[31] The microcontroller shall have a low power consumption. (1)

R[32] The microcontroller shall be able to handle timer interrupts. (1)

R[33] The IR LED's shall be high efficient to reduce the power consumption of the system. (3)

R[34] The IR LED's shall have infrared radiation source producing minimum peak spectral wavelength of 840nm and spectral bandwidth of 50nm. (2)

R[35] The IR LED's shall have a minimum viewing angle of 45°. (1)

R[36] The IR LED's shall have a maximum radiant intensity of 100mW/sr. (1)

R[37] The IR LED's shall have a reverse voltage of maximum of 5V. (1)

R[38] The IR LED's shall have a forward current of maximum of 50mA. (1)

R[39] The IR LED's shall have a maximum power dissipation of 100mW. (1)

4.1.2 Operating Specifications

R[40] The microcontroller shall be compatible with Assembly Language. (1)

R[41] The microcontroller shall use a 4MHz crystal. (1)

R[42] The control unit shall be programmed to synchronize with the webcam during the motion capture. (1)

4.2 Webcam

4.2.1 Technical Specifications

R[43] The infrared filter shall be removed from the webcam and a film negative shall be placed in front of its lens to block the visible light. (2)

R[44] The webcam shall have a maximum power consumption of 5W. (1)

R[45] The webcam shall have a minimum frame rate of 30 frames per second. (1)

R[46] The webcam shall have a minimum viewing angle of 90°. (1)

4.2.2 Physical Conditions

R[47] The dimensions (W × D × H) of the webcam shall be no larger than 10cm × 6cm × 10cm. (1)

R[48] The webcam shall have a maximum weight of 0.5kg. (1)

R[49] The USB cable shall have a minimum length of 3ft. (1)

4.2.3 Operating Requirements

R[50] The webcam shall have a USB connection. (1)

R[51] The webcam shall be compatible with Platform SDK. (1)

5 Software Requirements

5.1 Operating Conditions

R[52] The system shall run on Windows® 98SE, ME, 2000, and XP. (1)

R[53] The system shall require one USB port (1.1 or 2.0). (1)

R[54] The system shall require a CD-ROM drive. (1)

R[55] The system shall run on a PC computer with the following minimum specifications: 266MHz CPU, 32MB RAM 2MB Graphics Card, 10MB Free Hard-Drive space. (1)

R[56] The system software shall be installed through an executable install file provided with the SenseIT install CD. (3)

5.2 User Interface

R[57] The system shall provide a 2D representation of the object under study while updating the animation in real-time. (2)

R[58] The window size can be set to “full-screen” mode or to a normal resizable “window”. (1)

R[59] The position and orientation data can be logged into a text file with a file name chosen by the user. (3)

R[60] The application can be exited through the File menu, or by pressing the ‘X’ button on the right-hand top corner of the window. (1)

R [61] The 2D animation model will be proportional in size to the user. (3)

R [62] The user shall be able to modify the light and environment settings of the animation interface. (1)

6 Documentation and User Training

R[63] The documentation for the proof of concept system shall consist of a user manual with instructions in English. (2)

R[64] The documentation for the production system shall consist of a user manual with instructions in English, Spanish, Japanese, French, and Chinese. (3)

R[65] The user manual shall be written for an audience with minimal experience with electronics devices, and shall include descriptions of all basic functionalities. (3)

R[66] The manual shall include materials for more experienced users to implement features such as advanced animation features and graphics manipulation. (3)

R[67] The manual shall include a troubleshooting section. (3)

R[68] Minimal user training shall be necessary to operate the system. (1)

R[69] Training for the production system shall be provided by the unit's documentation and trained service personnel. (3)

R[70] Users of the proof of concept system shall be instructed and supervised by the project developers. (2)

7 Compatibility with Other Systems

R[71] The system shall be compatible with any PC computer that meets the minimum requirements specified by R[55]. (1)

R[72] The system shall be compatible with any USB webcam that meets the required specifications in section 4.2 . (1)

8 Known System's Limitations

The known system's limitations that should be considered in the implementation and testing process are as follows:

1. **Line of sight:** The system is not capable of capturing the motion if there is not a clear line of sight between the IR LED's and the webcam.
2. **Angle of sight:** The system has a limited angle of sight associated with the IR LED's utilized. The capturing device, the USB webcam, will be able to observe the IR LED only within a limited range of tilt.
3. **Limited range of monitor:** The USB webcam is capable of detecting the IR LED's only within a certain limited distance. If the IR emitter is positioned too close to the webcam, a reflection of infrared light is created. On the other hand, if the emitter is too far, the infrared light will be too weak to be detectable since its intensity will be less than the adequate value.
4. **Interference from other IR sources:** Any other sources of significant IR radiation present in the area would interfere with the IR emitters and would result in corrupted data.
5. **Frequency limitation of object's motion:** The USB webcam utilized in the system is capable of detecting any motion up to a frequency of 100Hz. Any faster motion with higher frequency than the stated limit would not be detected by the system.

9 Test Plan

Several test plans have been devised to ensure the successful implementation of the functional specifications. The system shall pass the required conditions to function successfully as expected.

9.1 IR Emitters

Testing of the IR emitters will focus on their sensitivity to distance and orientation.

Procedure

An IR emitter will be positioned at different distances from the webcam (10, 50 and 100cm) and also with different orientations (0°, 10°, 40°, 65°, and 90°). The intensity of the IR emitter will later be analyzed using the data from the webcam.

Pass Condition

The intensity of the captured images by the webcam shall be at least with 20mW/sr.

9.2 Frequency and sampling rate of USB webcam

Motions with different frequency rates will be captured with the USB webcam to ensure that the frame rate of the webcam is adequate.

Procedure

For this test plan, a series of the object's movements with different frequency rates will be examined and captured by the USB webcam (e.g. at 2, 5, 10 Hz). Thereafter, the corresponding images will be tested to verify the proper capturing functionality of the webcam considering the webcam's frame rate limitation.

Pass Condition

The webcam should be able to detect all the motions with a frequency rate of less than 100Hz.

9.3 Power dissipation of IR LED's

Testing of the IR LED's power consumption to ensure that the batteries have a decent lifetime (minimum of 5 hours) and at the same time, the IR LED's are intense enough to be detected by the webcam.

Procedure

For this test case, the operating voltage and drawn current of the IR LED's will be measured and the operating power can be calculated. The dissipated power is then

compared to the nominal value to verify the minimal low power consumption of the system.

Pass condition

The dissipated power should be less than 100mW and at the same time with proper intensity of the IR LED's.

9.4 Timing requirement of the microcontroller

The microcontroller should be verified that it can control the IR LED's in a timely manner.

Procedure

A test bench can be set up with ten visible light LED's that can be turned on one at a time over a span of 10 seconds.

Pass Condition

The total running time of the test bench should be equal to ten seconds.

9.5 Real time requirement of Image processing Software

The processes of image analysis and calculation of the position should be carried out in real time.

Procedure

Calculate the elapsed time between capturing the image and obtaining the corresponding position of an IR LED.

Pass Condition

The time taken to process an image captured by the webcam should be less than 50ms.

10 Conclusion

The SensIT Motion Capture System is the starting platform for the motion capture system which will be utilized by professional dancers. Our system is capable of capturing precision and real time movements of an object and simulating the motion in 2D. The low cost characteristic opens the door to entirely new areas of applications.

The prototype model with the functional specifications denoted by (1) and (2) is scheduled to be completed by the beginning of April, 2007. The SensIT team believes that the project will be accomplished successfully and on time.