An Interactive Sensory System to Record and Monitor Human Motion in Physical Rehabilitation

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ABSTRACT

This paper briefly presents the application of an interactive sensory system to sense, record, restore, and monitor the movement of objects such as the human body. The setup, consisting of a data streamer and a software development kit (SDK), has nine degrees of freedom (DoFs): three orientation (roll, pitch, and yaw angles), three linear accelerations, and three magnetic field components. The SKD is a graphical user interface (GUI) that records, restore, and analyzes the signal received from the data streamer and presents advanced statistical analysis such as predicting the behavior of the measured data in the future. An application claimed is to provide patients with an accurate measurement that simplifies the tracking of performance and effectiveness of physical exercises and treatments. To show the proof of concept, we conducted an experimental study on the human's hand at the iRobohabilitation Laboratory, and quantified the signals measured by the sensory system in real-time.

CCS CONCEPTS

• Applied Computing, Education, Life and Medical Sciences.

KEYWORDS

Real-time data transmitter, radio frequency stream processing, sensors, digital rehabilitation

1 Introduction

Physical Rehabilitation interventions and sport exercise prescriptions require continuous monitoring of the clients' physical activity over extended periods, to enable intervention evaluation and data-driven adjustments if required. The monitoring includes home-based exercises and periodic check-ups. Besides, given the wide variety of physical rehabilitation procedures with healthcare professionals, patients tend either to abandon the treatments quickly or to decrease the adherence to the proposed exercises progressively.

In recent years, the increasingly broad range of available technologies for physical activity monitoring enabled a face-paced advancement in these techniques. Digital rehabilitation employs several techniques including the use of information and communication technologies for boosting the efficacy of physical rehabilitation [1]. Application domains in the scope of digital rehabilitation include the usage of technologies ranging from video analysis [2], wearable technologies [3], robotics [4], sensing [5], to gamification [6].

The application, targeted in this paper, is to measure the real-time motion of the human body using a 9-DoF sensory system with monitoring capabilities such as capturing motion. The paper focuses on describing the development and implementation of DataRX-C™, an interactive and high-accurate sensing system (Tactile Robotics, Canada) that could be used in many applications including the measurement of human motion. We also demonstrate the results of a set of experiments conducted to measure the motion components of the palm while the object moving the hand. The sensing system plugs into a custom-designed software (RX-UI™) to read and statistically analyze sensor data. The software is able to restore and plot sensor data, interpret data in real-time, and provide advanced statistical data analysis during the experiment.

2 Technical Specifications

The sensing system includes two main parts, a data streamer that is surrounded by an enclosure and a software development kit (SDK) that has a graphical user interface (GUI) to portray the results of the experiments in real-time. DataRX-C™ can record, analyze, and plot data from a variety of sensor units (up to 54 sensors), which makes it a powerful and multipurpose tool. The sensing system provides crucial data and analysis for applications such as robotics, navigation, augmented reality, virtual reality, gaming, and more.

The data streamer, shown in the inset of Figure 1, provides orientation data and dynamic information in 3D that includes roll, pitch, and yaw (Euler) angles, linear accelerations along *x*, *y* and *z* axes (3 DoFs), angular accelerations about Euler axes (3), angular

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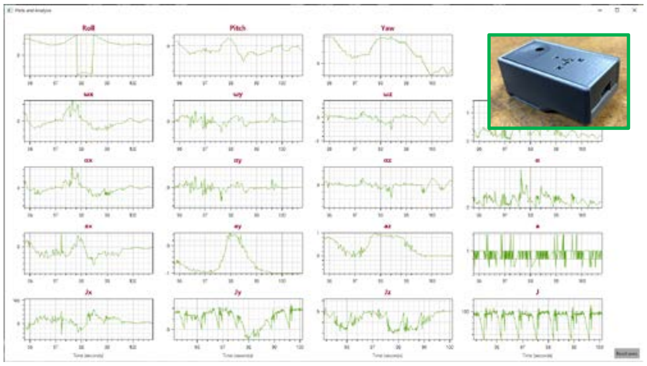
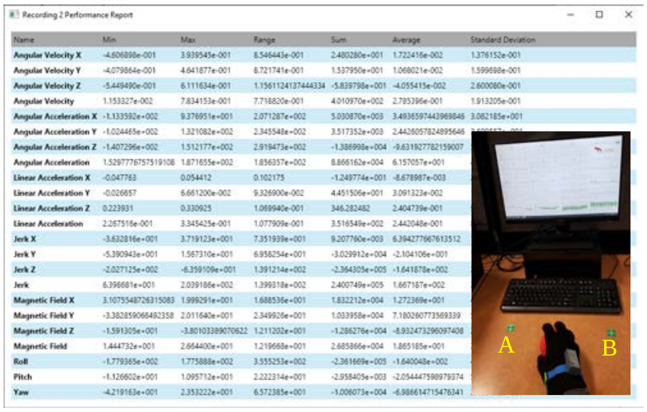


Figure 1: Developed sensing setup including a data streamer (the inset) and associated software. The SDK plots up to 19 plots in real-time and provides an advanced statistical report.



Recording 2 Performance Report

Name	Min	Max	Range	Sum	Average	Standard Deviation
Angular Velocity X	-4.606898e-001	3.939545e-001	8.546443e-001	2.480280e+001	1.722416e-002	1.376152e-001
Angular Velocity Y	-4.079864e-001	4.641877e-001	8.721741e-001	1.537950e+001	1.068021e-002	1.599698e-001
Angular Velocity Z	-5.449490e-001	6.111634e-001	1.1561124137444334	-5.839798e+001	-4.055415e-002	2.600080e-001
Angular Velocity	1.153327e-002	7.834153e-001	7.718820e-001	4.010970e+002	2.785396e-001	1.913205e-001
Angular Acceleration X	-1.133592e+002	9.376951e+001	2.071287e+002	5.030870e+003	3.4936597443969846	3.082185e+001
Angular Acceleration Y	-1.024465e+002	1.321082e+002	2.345548e+002	3.517352e+003	2.4426057824895646	
Angular Acceleration Z	-1.407296e+002	1.512177e+002	2.919473e+002	-1.386998e+004	-9.631927782159007	
Angular Acceleration	1.5297776757519108	1.871655e+002	1.856357e+002	8.866162e+004	6.157057e+001	
Linear Acceleration X	-0.047763	0.054412	0.102175	-1.249774e+001	-8.678987e-003	
Linear Acceleration Y	-0.026657	6.661200e-002	9.326900e-002	4.451506e+001	3.091323e-002	
Linear Acceleration Z	0.223931	0.330925	1.069940e-001	346.282482	2.404739e-001	
Linear Acceleration	2.267516e-001	3.345425e-001	1.077909e-001	3.516549e+002	2.442048e-001	
Jerk X	-3.632816e+001	3.719123e+001	7.351939e+001	9.207760e+003	6.394277667613512	
Jerk Y	-5.390943e+001	1.567310e+001	6.958254e+001	-3.029912e+004	-2.104106e+001	
Jerk Z	-2.027125e+002	-6.359109e+001	1.391214e+002	-2.364305e+005	-1.641878e+002	
Jerk	6.398681e+001	2.039186e+002	1.399318e+002	2.400749e+005	1.667187e+002	
Magnetic Field X	3.1075548726315083	1.999291e+001	1.688536e+001	1.832212e+004	1.272369e+001	
Magnetic Field Y	-3.382859066492358	2.011640e+001	2.349926e+001	1.033958e+004	7.180260773569339	
Magnetic Field Z	-1.591305e+001	-3.80103389070622	1.211202e+001	-1.286276e+004	-8.932473296097408	
Magnetic Field	1.444732e+001	2.664400e+001	1.219668e+001	2.685866e+004	1.865185e+001	
Roll	-1.779365e+002	1.775888e+002	3.555253e+002	-2.361669e+005	-1.640048e+002	
Pitch	-1.126602e+001	1.095712e+001	2.222314e+001	-2.958405e+003	-2.054447598979374	
Yaw	-4.219163e+001	2.353222e+001	6.572385e+001	-1.006073e+004	-6.986614715476341	

Figure 2: Data streamer was used to measure the motion characteristics when the operator moved a ball from the left green point to the right green point (the inset). The inset shows the statistical metrics measured by SDK after task completion.

velocities along *x*, *y* and *z* axes (3), the magnetic field in *x*, *y* and *z* directions (3), jerk components along *x*, *y* and *z* axes (3), and several scalar/vector key performance indicators (KPIs).

DataRX-C™ includes a custom-designed interactive Software Development Kit (SDK), which is compatible with Windows, macOS, and Linux, and allows the operator to *i*. record and restore sensor data from the connected DataRX-C™ sensor reader for future use, *ii*. view the performance report for each sensor recording at any time, and *iii*. calibrate sensors to provide the most accurate results for your environmental setup. The SDK package restores and plots sensor data, interprets data in real-time, and provides advanced intra/inter-subject statistical data analysis as requested bu the user, *i.e.*, calculating statistical indices, determine the type of each set of data distribution and predict whether the data is statistically significant. A screenshot of the plotting area is illustrated in Figure 1. As observed, the SKD can present the measured data, including orientation, velocity, and acceleration, in the form of real-time plots (up to 19 parameters). In addition to basic statistical values, the SDK gives the type of the data distribution, is the measured data are statistically significant, and predicts the behavior of data in the future experiments. The data streamer is able to mount to any surface, ranging from a finger (smallest) to full body (*e.g.*, back waist), and transfers to a computer by using a USB/mini-USB cable. A newer version of this setup communicates with the host computer wirelessly and is called DataRX-W™.

The recorded data are exportable to common formats such as an Excel Workbook or comma-separated values (CSV) file. The sensing system is provided with an SDK package, developed in .NET standard, which is available for all supported OS platforms. The SDK connects DataRX-C™ to any desired development environment, such as the Unity™ game development engine.

3 Case Study

To show the proof of concept, an experiment was conducted to measure the data explained in Section 2. As shown in Figure 2, the data streamer was mounted onto the right palm to monitor a reaching task (namely, pick the ball from point A and place it at point B) following different strategies and velocities as instructed by the experimenter (*i.e.*, faster, slower, preferred speed). We aim to measure the angular displacement and its derivatives as well as the linear velocity and acceleration of the palm during the task execution. A screenshot of the plots shown by the software in real-time in illustrated in Figure 1.

Figure 2 illustrates the statistical indices that were measured by the SDK at the end of the experiment. The indices are min, max, range, algebraic summation, the mean and standard deviation of each component. For instance, the components of the angular velocity$\pm$SD are 0.017$\pm$0.013 rad.s^{-1}, 0.011$\pm$0.016 rad.s^{-1} and -0.041$\pm$0.026 rad.s^{-1}, respectively. The negative sign in Figure 2 shows the direction of the mechanical component.

4 CONCLUSIONS

In this paper, we reported the technical specifications of a sensing system that is used to measure the motion characteristics of objects. A set of experiments was conducted, as proof of concept, to show the motion components of the human's hand during reaching objects. This interactive and accurate sensing system could be used for different applications including the treatment of patients. An advantage of this setup compared to existing ones is its superior accuracy and presenting statistical results at during, and at the end of, the experiment.

REFERENCES

[1] Reisdorf, B.C.; Rikard, R. Digital rehabilitation: a model of reentry into the digital age. American Behavioral Scientist 2018, 62, 1273-1290.

[2] Munro, A.; Herrington, L.; Carolan, M. Reliability of 2-dimensional video assessment of frontal-plane dynamic knee valgus during common athletic screening tasks. Journal of Sport Rehabilitation 2012, 21, 7-11.

[3] Buonocunto, P.; Giantomassi, A.; Marinoni, M.; Calvaresi, D.; Buttazzo, G. A limb tracking platform for tele-rehabilitation. ACM Transactions on Cyber-Physical Systems 2018, 2, 30.

[4] Burgar, C.G.; Lum, P.S.; Shor, P.C.; Van der Loos, H.M. Development of robots for rehabilitation therapy: The Palo Alto VA/Stanford experience. Journal of Rehabilitation Research and Development 2000, 37, 663-674.

[5] Zhang, W.; Gao, J.; Shi, B.; Cui, H.; Zhu, H. Health monitoring of rehabilitated concrete bridges using distributed optical fiber sensing. Computer-Aided Civil and Infrastructure Engineering 2006, 21, 411-424.

[6] Alimanova, M.; Borambayeva, S.; Kozhamzharova, D.; Kurmangaiyeva, N.; Ospanova, D.; Tyulepberdinova, G.; Gaziz, G.; Kassenkhan, A. Gamification of hand rehabilitation process using virtual reality tools: Using leap motion for hand rehabilitation. In Proceedings of 2017 First IEEE International Conference on Robotic Computing (IRC), Taichung, Taiwan, 10–12 April 2017; pp. 336-339.