[4] Akos Zarandy, Zoltan Nagy, Balint Vanek, Tamas Zsedrovits, Andras Kiss, Mate Nemeth, *A Five-Camera Vision System for UAV Visual Attitude Calculation and Collision Warning*, 9th International Conference, ICVS 2013, St. Petersburg, Russia, July 16-18, 2013. Proceedings

[5] David W. King, Allen Bertapelle, Chad Moses, *UAV Failure Rate Criteria for Equivalent Level of Safety*, International Helicopter Safety Symposium, Montreal, 2005

[6] Shane Degen, *Reactive Image-based Collision Avoidance System for Unmanned Aircraft Systems*, Thesis, Queensland University of Technology, 2011

[7] Dey, Debadeepta; Geyer, Christopher; Singh, Sanjiv; and Digioia, Matt, *Passive, long-range detection of Aircraft: Towards a field deployable Sense and Avoid System* (2009). Robotics Institute.Paper 962.

[8] Mejias, Luis and Ford, Jason J. and Lai, John S. (2010) *Towards the implementation of vision-based UAS sense-and-avoid* In: Proceedings of the 27th International Congress of the Aeronautical Sciences(ICAS 2010). 1924. September 2010, Acropolis Conference, Centre, Nice

[9] (2012, December 18). *Vivado Design Suite User Guide - High-Level Synthesis* [Online] http://www.xilinx.com/products/design-tools/vivado/integration/esl-design/

[10] (2013, April). *AN-1032 An Introduction to FPD-Link* [Online] Available: http://www.ti.com/lit/an/snla045b/snla045b.pdf

[11] (2011, March 7). *AXI Reference Guide* [Online] Available: http://www.xilinx.com/support/documentation/ip_documentation/ug761_axi_reference_guide.pdf

[12] Donald G. Bailey *Design for Embedded Image Processing on FPGA*, Massey University, New Zealand, JohnWiley & Sons (Asia) Pte Ltd., 2011

A mobile bio-signal measuring system on multiple limbs for rehabilitation purposes.

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***Abstract*—For any paralyzed or amputated patient rehabilitation is a necessary procedure. Rehabilitation for paralyzed patients is very important because of health protection and for amputated patients it helps to learn to control prosthetic. This paper presents the design of a mobile bio-signal measuring system. The goal of the project is to develop a robust mobile measuring system which can be used in several rehabilitation programs. The system is capable to measure ECG, EEG, EMG signals through multiple channels. At the moment the main scope is to measure EMG signals on the arm, and to optimize the signal condition and data compression through wireless data transmission. The current circuit and system designs are presented and a possible solutions for signal pre-processing is suggested.**

I. Introduction

Real-time motion capturing is a very frequent and important technique in biomedical signal processing, robotics and other applications based on human-computer interactions. The current state of electric and biological technologies led to a large variety of wearable systems capable of measuring and logging human body motion[1]. Such system is needed to measure and collect data from real life activity outside of a laboratory. Studies based on human motion analysis were carried out by many research laboratories[2]. After leaving the laboratory environment, this system can be used for rehabilitation purposes like relearning movement or for study gait, functional electrical stimulation, monitoring physical work processes and real life activity.

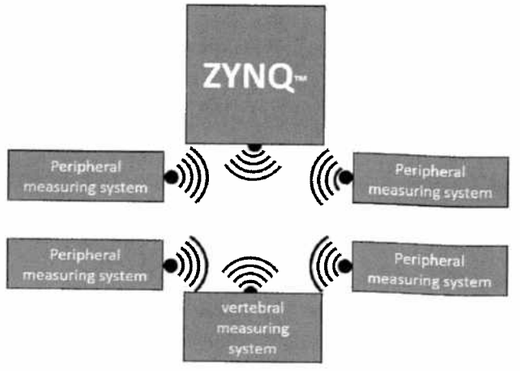
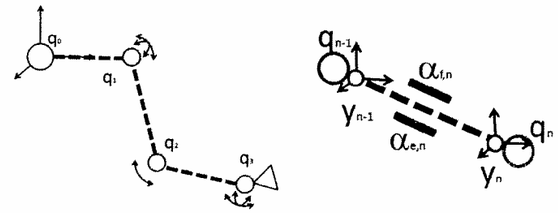


Fig. 1: Main processing system design

This paper presents a system design of a mobile multi-channel bio-signal measuring system for rehabilitation purposes. After diseases like stroke or TIA (Transitoricus Ischaemias Attack) aftermath like paralysis or partial loss of ability to move are common and the patients require intensive rehabilitation. The rehabilitation dose not end after leaving the clinic it has to be continued also at home. This system achieves the simultaneous measurement of orientation and muscle activity of the specific limb, and can be used for relearning of the lost movement, to improve the training of athletes, to analyze the movement of healthy people which can be used in physiotherapy, occupational safety and health, in robotic applications and tele-operation.

At the moment the whole work focus on measuring of an arm's kinetics and muscle activity.

II. System Design



(a) The full arms kinematic model. (b) A limb segment.

Fig. 2: Fig.2a shows the kinematic model of the full arm, where q_i represents the joints. In Fig.2b a general limb segment is shown where y_i represents the 9-axis MEMS sensor and $\alpha_{i,n+1}$ the differential EMG electrodes for the flexor and extensor muscle parts.

This section discusses how to construct a system which is capable of simultaneously measuring the orientation and muscle activity of an arm, within it the individual components and their main parameters. Fig.1 shows the main system design, the core module being a Zynq-7000 architecture and the required peripheral device for measure arms, legs and back. The raw and preprocessed data is transferred wirelessly from peripheries to the core module which implements complex data processing. Every periphery implements basic Kalman

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filtering[3] on the data of the 9-axis Motion sensor and the EMG, which is shown in Fig.6

In order to fully understand what do we want to measure, we have to define the kinematic structure and the placement of the sensors. In Fig.2a we can see that the measuring is made on the whole arm from the shoulder(q_0) to the hand(q_3). Fig.2b shows the scenario of the placement of the sensor on a segment. At the end of a segment there is a 9-axis MEMS sensor(y_{n-1}, y_n) and a pair of differential EMG electrodes($\alpha_{i,n+1}$).

The 9-axis MEMS sensor stretches out a vector in the space which shows the orientation of the limb segment. The EMG electrodes $\alpha_{i,n+1}$ are for measuring of extensor and flexor muscle activity for the next actuated segment.

For an arm we need at last eight 9-axis MEMS sensors and six pairs of differential EMG electrodes. The communication between the peripheral devices micro-controller and the 9-axis MEMS sensors are realized through I^2C bus and with the EMG front end with SPI. The design of the peripheral measuring system is shown in Fig.3. If the research requires a more complex telemetry than the EMG sensor can be changed to an EEG or to an ECG front-end or we can daisy chain tham on the same SPI port.

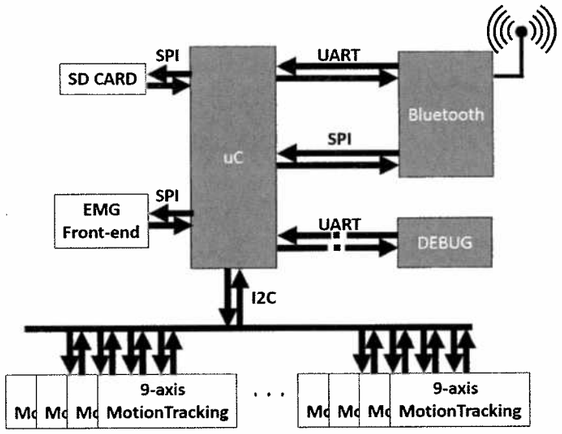

Fig. 3: Peripheral measuring system design.

A. Used parts in the peripheral module.

1) Micro controller: The peripheral devices computation is accomplished with a Microchip micro controller pic24FJ256GB108 [4], which is a 16-bit system with a maximal speed of 16 MIPS.

2) EMG Front-end: The EMG measurment are executed with TI's ADS1298 [5] device, which has 8 channels, 24-bit resolution, and a 32 KSPS maximal sample rate. If it necessary we can increase the amount of input of the front and and can change it to measure ECG and EEG signals to.

3) 9 Axis MEMS motion tracking module: is used, Invensense's MPU-9150 [6] module showen in Fig. 4 , which is a fully integrated system of 3-axis gyro, accelerometer and magnetometer all in one IC. The gyro's and the accelerometer's are sampled with 16-bit resolution and that of the magnetometer with 13-bit.

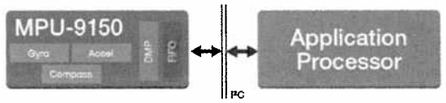

Fig. 4: 9 Axis MEMS motion tracking module.

The gyroscope measures the angular velocity which is linear to rate of rotation. It responds quickly and accurately and the rotation can be computed by time-integrating the gyroscope output. The accelerometer measure linear acceleration based on the acceleration of gravity.The problem with accelerometers is that they measure both acceleration due to the device's linear movement and acceleration due to earth's gravity, which is pointing toward the earth.

4) Communication and data storage: To get a flexible and convenient system, communication between the peripheries and the core module are achieved with Bluetooth.This allows to easily change or increase the number of devices. The data is saved to an SD Card on the devices.

B. Vertebral measuring system

For a complex measurement and to extend the telemetry at the same time measuring the movement of the limbs we can measure the muscle activity which allows the main spine movement. Because of the above-mentioned daisy chain we can add a front end to the vertebral measuring to measure ECG and the brain activity with EEG to obtain every data that is generated during their movement.

The measuring of the vertebral is similar to the limbs it contains measuring of the main muscle part which are responsible for its actuation and the movement of the spine to connect them to gather. The EMG electrodes are placed from bottom to top on the following muscel parts showen in Fig.5:

- Fascia thoracolumbar: the banding of the spine and fix the spine and the lumbar spine
- Latissimus dorsi: pulls the scapula away from the spine and keep them in the plane of the back
- Trapezius: moves up, down and towards each of the scapula

Simultaneously with the EMG the spatial movement of the spine and the upper body are measured with 9 Axis MEMS motion tracking module chain.

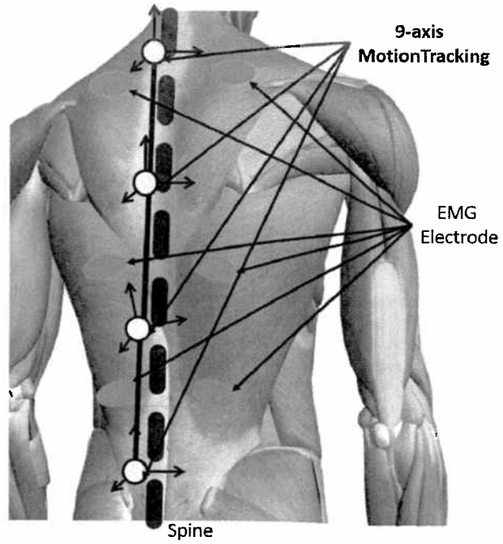

Fig. 5: The vbertebral measuring system design.

C. Core module of the motion analyzing system

The main processing to integrated the individual peripheral measurements are executed on Digilent's ZYBO development platform built around a Xilinx ZYNQ-7000 familly [7] the Z-7010. The big advantage is that this architecture tightly integrates an ARM Cortex-A9 processor with Xilinx 7-series Field Programmable Gate Array (FPGA).

The integration of the individual limb and vertebral measuring are realized with a cascade Kalman filter.

III. Kalman filter design to determine muscle activity for the actuation and the changing of the orientation of the limb.

The raw data not ready to use and they need to be calibrated. To calibrate these data it has to be scaled and the measuring bias has to be determined. Due to the reason that in our system data from many sensors are used and we want to reduce the error of the measurement and the integration of the data we implement a Kalman Filter for that purpose.In this section a Kalman filter model is introduced which which is based on the data of the peripheral measuring module.

The drifting rotation angle of the gyroscope signal is determined with trapezoid integration shown in equation (**??**).

$$\int_a^b f(x)\,\mathrm{d}x = (b-a)f(a) + (b-a)[\frac{f(b)-f(a)}{2}] \qquad (1)$$

Using the output of the accelerometer, a sensors rotation around the X -axis is the *Roll*, and the rotation around the Y -axis is the *Pitch* and can be calculated shown in equation (2) and (3) where acc_X, acc_Y and acc_Z are measurements in the X, Y and Z axes.

$$Roll = arctan(\frac{acc_Y}{(acc_Y)^2 + (acc_Z)^2}) \qquad (2)$$

$$Pitch = arctan(\frac{acc_X}{(acc_X)^2 + (acc_Z)^2}) \qquad (3)$$

Neither the accelerometer nor the gyroscope give accurate rotation measurements alone we have to combine the signals of the 3-axis gyroscope , the 3-axis accelerometer and the 3-axis magnetometer to determine the position of the endpoints show in Fig.2b (y_{n-1}, y_n) of a segment, and we combine the EMG signals($\alpha_{i,n+1}$) from the front end to reduce the error of the placement and to increase the signal quality.

The structure of the Kalman filter is shown in Fig.6. To achive the registration of data for the changing of a segment orientation in time and the necessary muscle activity, a third Kalman Filter will be implemented directly on the core modules FPGA.

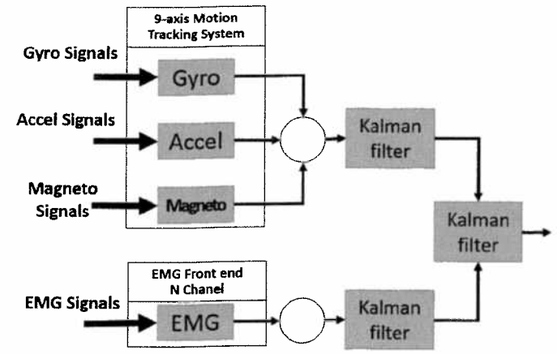

Fig. 6: The signal processing design.

IV. Conclusion

The system presented here is capable to measured limb orientation and muscle activity and to realize the goal of the project, complex motion analysis. With this measurement system we can follow down to the neuromuscular synapse the control signals from motor cortex and combine them with the movement of the actual limb.

Acknowledgment

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REFERENCES

[1] K. Lorincz, B.-r. Chen, G. W. Challen, A. R. Chowdhury, S. Patel, P. Bonato, M. Welsh *et al.*, "Mercury: a wearable sensor network platform for high-fidelity motion analysis." in *SenSys*, vol. 9, 2009, pp. 183–196.

[2] S. Corazza, L. Muendermann, A. Chaudhari, T. Demattio, C. Cobelli, and T. Andriacchi, "A markerless motion capture system to study musculoskeletal biomechanics: Visual hull and simulated annealing approach." *Annals of biomedical engineering*, vol. 34, no. 6, pp. 1019–1029, 2006.

[3] R. E. Kalman, "A new approach to linear filtering and prediction problems," *Journal of basic Engineering*, vol. 82, no. 1, pp. 35–45, 1960.

[4] M. T. Inc., accessed: 13.03.2014. [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/39897c.pdf

[5] T. I. Incorporated, accessed: 13.03.2014. [Online]. Available: http://www.ti.com/lit/ds/symlink/ads1298.pdf

[6] I. Inc., accessed: 13.03.2014. [Online]. Available: http://www.invensense.com/mems/gyro/documents/PSMPU9150A00v43.pdf

[7] X. Inc., accessed: 13.03.2014. [Online]. Available: http://www.xilinx.com/products/silicon-devices/soc/zynq-7000/silicon-devices/index.htm

Analysis Based Parameter Estimation of an *in vitro* Transcriptional-Translational System

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***Abstract*—Recent advances in mRNA measurement technology give us new insight into the dynamics of transcription activity in real time by measuring e.g. the Malachite Green Aptamers' fluorescent level. Thus, simultaneous measurements with fluorescent proteins in an easy-to-make cost effective *in vitro* transcriptional-translational system sets up a foundation for a molecular breadboard to test out biocircuits with various functions. In this paper we present a mass action type dynamic model for such an experiment and show the parameter estimation procedure, where the time series data contains information about both stages of gene expression. The identification process is supported by structural identifiability and sensitivity analysis.**

***Keywords*-Nonlinear systems, system identification, Reaction Networks**

I. INTRODUCTION

The amount and available types of data are often seriously limited in systems and synthetic biology experiments. In many cases, time-resolution or the sensitivity of the measurement technique is a serious obstacle for effective parameter estimation besides the structural non-identifiability of the mathematical model [1], [2], [3]. However, recent developments in mRNA measurement with Malachite Green RNA Aptamers along with florescent proteins provide a more reliable foundation for real time tracking of concentrations of the labeled species. Thus, we can measure transcription and translation simultaneously with sufficiently high frequency and specificity to directly use the obtained time series data for parameter estimation [4]. Furthermore, in synthetic biology we have the freedom to stitch together DNA parts (e.g. promoters, terminators, genes) in a matter of hours and test them in either *in vivo* or *in vitro*. Thus, we can put together many combination of DNA parts to achieve certain functions which may have or may have not existed before in nature. The set of these DNAs is often called biocircuits.

Conducting experiments *in vitro* has the benefit of shorter incubation time, ability to work with linear DNA and very good repeatability [5]. From the system identification point of view having the DNA and inducer initial concentrations as manipulable parameters that helps us to perturb the system dynamics to get sufficient data for parameter estimation.

Our aim is to develop and validate an ODE-based model, that can be used not only to fit the current data and show the dynamics of unmeasured states, but within appropriate limits, it can be used for predictive modeling. In our previous paper we worked out a possible mass action based model where we validated some of the parameters via wetlab experiments [6]. Recently, we conducted a wide-spread study, where several experimental conditions were tested [7]. In this paper we reiterate the model in terms of reaction speeds, time scales, structural identifiability and parameters sensitivity. The applied parameter estimation method is also implemented as part of the a modeling toolbox called transcription-translation or TXTL toolbox.

II. EXPERIMENTAL BACKGROUND

In this section, we briefly describe the experimental background of the modeled process. Figure 1. shows the main steps for the preparations of the cell extract. The *E. coli* cell's internal milieu cell is preserved through series of chemical processes and with additional resources this extract is capable of expressing non-genomic circular DNA. The external DNA was simply mixed with the cell extract and then the transcription and translation were followed simultaneously by measuring the fluorescence emission of the mixture at two wavelength. The transcription was monitored through Malachite Green Aptamer (MGApt) which is a short RNA segment with the capability of binding the Malachite green (triphenylmethane) dye. The MGApt:MG interaction enhances the fluorescence of the dye and thus enables the monitoring of the mRNA concentration in the solution. Translation was followed by using Green Fluorescent Protein (GFP), which exhibits a green fluorescence when exposed to blue or ultraviolet light. The separated emission profiles give us the opportunity to monitor the concentration dynamics of both stages of gene expression in real time throughout the life time of the cell extract.

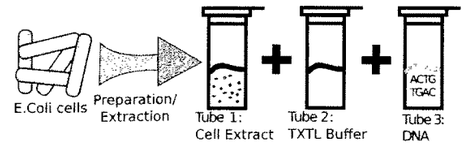

Figure 1. *in vitro* system overview: *E. coli* cell internal intent is processed through series of chemical procedure. The optimal cell condition and the missing resources are restored with the energy and buffer solution. The DNA tube represents our biocircuit which will be expressed in the *in vitro* system and the dynamics of certain parts are observed via fluorescent reporters. - taken from our CDC paper will be replaced in the camera ready version

A. *In vitro transcriptional and translational system*

All experiments were performed in a cell-free environment derived from *E. coli* crude extract. This extract contains all the endogenous system necessary for transcription and translation (e.g. ribosomes, RNA polymerase, translation initiation and elongation factors, etc.) but free from larger cellular compartments and from genomic DNA. For cell-free protein synthesis the cell extract needs to be supplemented with energy source, nuncleotides, amino

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