

Introducing Wearable Accelerometers in the Surgery Room for Activity Detection

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Abstract :

Modern surgery rooms are becoming increasingly complex. Future systems are desired to address the need for intra-operative, intelligent presentation of various information sources and context-specific support of surgeons. This requires a reliable detection of surgical activity from sensor data obtained within the OR. We present our approach towards the usage of wearable accelerometers within ORs and intervention rooms for surgical activity detection. A method for attachment of accelerometers to the surgeon is proposed that is compliant with OR sterility regulations and which was applied at our partner medical institutions during several cases of minimally-invasive surgery and intervention. First results for activity detection during both simulated and real percutaneous vertebroplasty interventions are presented which indicate the usefulness of motion data for surgical activity detection.

Key Words: Surgical Workflow, Surgical Activity, Wearable Accelerometer, Hidden-Markov Model

1 Problem

Modern surgery rooms are becoming increasingly complex. Future systems are desired to address the need for intra-operative, intelligent presentation of various information sources and context-specific support of surgeons. Sensor data obtained from the OR contains much information which can be used for modeling, analyzing and monitoring of surgical workflow. In previous work, we extracted discrete signals representing the usage of surgical tools from video data for workflow recovery [1, 2]. In this work, we evaluate actibelt[®] accelerometers [3] for continuous recording of motion in order to detect surgical activity. Based on our interaction with six surgeons, we describe several requirements for the usage of accelerometers inside medical ORs concerning issues of hygiene, workflow conformity and clinical acceptance. We furthermore describe the compliant usage of actibelt[®] accelerometers during two different surgery types, laparoscopic cholecystectomy and percutaneous vertebroplasty.

Recordings of motion in laparoscopic cholecystectomy and percutaneous vertebroplasty followed different goals. Together with our medical partner institution for cholecystectomy, we derived the sterilization procedure which is further described in the next section. Apart from that, we expect that due to the nature of minimally-invasive surgery, only little hand motion is performed during laparoscopic maneuvers. However, the change of laparoscopic instruments should be well detectable from motion. Being a valuable piece of information [2, 7], the detection of surgical tool changes will be investigated upon in an upcoming project.

Finally, we present preliminary results from first experiments concerning activity recognition during percutaneous vertebroplasty. In vertebroplasty, a hollow or wedged vertebra (e.g. due to osteoporosis) is stabilized by insertion of a metallic trocar into the vertebra and injection of acrylic cement. Specific movements during vertebroplasty represent surgical work steps, e.g. a hammering motion indicates the insertion of the trocar through the pedicle. In a parallel project, ARAV (Augmented-Reality Aided Vertebroplasty) [8], we aim at using this information for adapting visualization parameters in AR or presenting valuable information to the surgeon during particular work steps, such as pre-operative imaging data, tool handling tips or the trocar trajectory. In a broader view, we aim at partly recovering surgical work steps from motion, which can then be used for workflow analysis as well as online workflow detection and context-specific support.

2 Methods

In order to test and evaluate accelerometer usage for activity detection in surgical environments, we attached actibelt[®] units to the waist and both forearms of participants during simulated and real surgical interventions. actibelts[®] [3] are stand-alone, 3-axis accelerometers recording acceleration data in the range [-6g, 6g] at a frequency of 100Hz, with 12bit resolution for up to 100 hours. Measured data were uploaded to the actibelt[®] web application¹ for centralized storage and subsequent analysis. In order to cope with the strict hygienic regulations in the OR, we attached actibelts[®] beneath the sterile surgical coat. The workflow for attaching actibelt[®] units to the surgeon has the following steps (cf. figure 1):

- The surgeon enters the preparation room and puts on the waist accelerometer using a provided belt.
- He prepares for sterilization as usual (washing and sterilizing hands etc...).
- Before putting on the surgical coat, a sterile person unpacks two pre-sterilized strip of TG tube bandages and puts one on each forearm of the surgeon. A non-sterile assistant can then attach the accelerometer units onto the tube bandage, using Velcro fasteners. By folding the sterile ends of the bandage strip onto the accelerometer, a sufficient level of sterility is achieved beneath the surgical coat. At the same time, the tube bandage ensures additional wear comfort.
- The surgeon puts on the sterile surgical coat and latex gloves. He approaches the sterile surgical scene and situs.

The above described procedure was conceived together with and given consent by the central authority for sterility compliance of our partner medical institution.

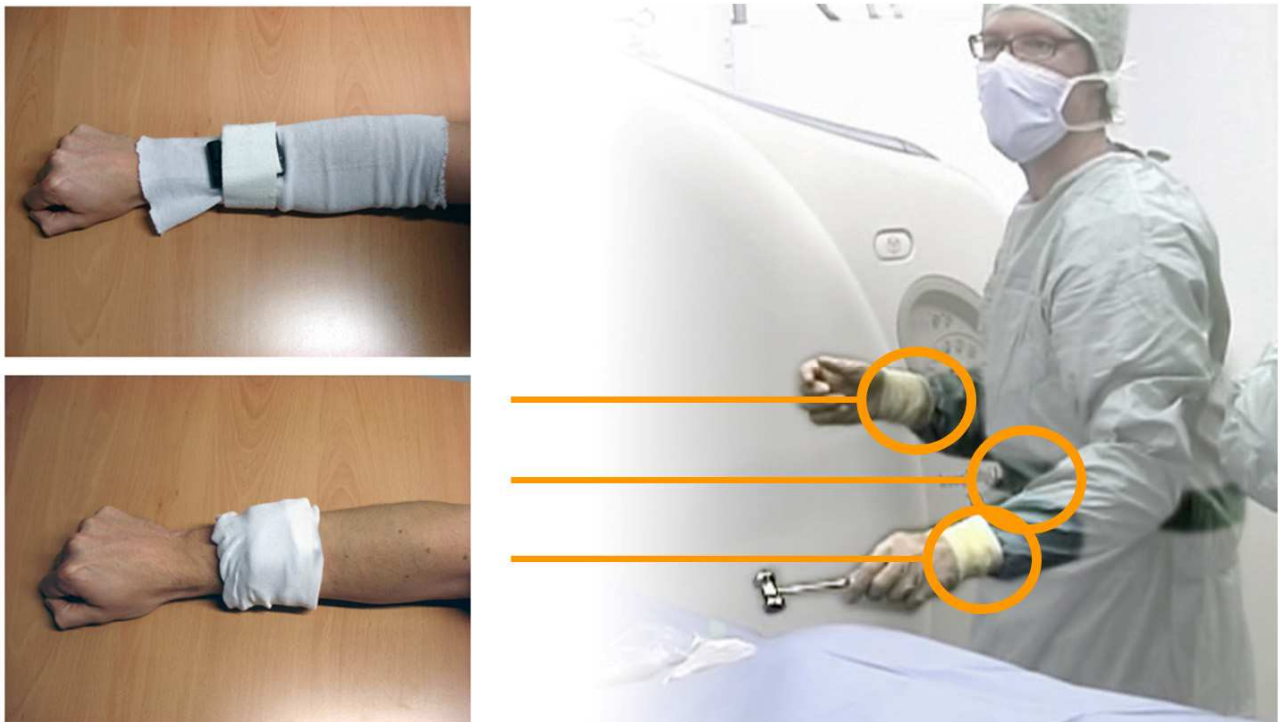


Figure 1: actibelt[®] accelerometers were attached beneath the sterile surgical coat for recording of surgical motion. Detection of particular motions during percutaneous vertebroplasty is intended to allow for context-specific support and adaptive user interfaces and visualization in upcoming projects.

actibelt[®] units store acceleration data onto internal flash memory. After recording data during surgical procedures, the data was downloaded and evaluated for detection of surgical activity.

For activity recognition, we took signal magnitudes, effectively reducing gravitational influences and representing movements as energy signals. The data was split into subsequences and evaluated in both time and frequency domain as input to Hidden Markov Models (HMMs). HMMs are widely used for efficient recognition of speech [4] or human activity [5, 6]. We varied several parameters of the HMM network, such as number of nodes and connection type (i.e. fully connected HMMs vs. left-right models) in order to evaluate a suitable topology. Characteristic movements representing activities in vertebroplasty, such as hammering, walking or cement stirring were manually labeled from video and used as HMM input training data, allowing detection of surgical activity in unknown surgeries. Table 1 gives an overview

¹ www.actibelt.com

Real Vertebroplasties		1	2	3	4	5	6	7	8	9	10
Silence	1	0.41	0.08	0.11	0.02	0.2	0.01	0.03	0.03	0.01	0.11
Random move	2	0.07	0.35	0.13	0.03	0.11	0.02	0.03	0.05	0.05	0.17
Place trocar	3	0.14	0.08	0.47	0.01	0.21	0	0.03	0	0.04	0.02
Hammering	4	0	0.04	0.04	0.86	0	0	0.02	0	0.04	0
Trocar retraction	5	0.17	0.03	0.37	0	0.34	0	0.03	0.04	0.01	0.03
Stirring	6	0.11	0.27	0.1	0.07	0.1	0.02	0.33	0	0	0
Syringe filling	7	0	0.67	0.17	0	0	0	0.17	0	0	0
Bend down	8	0.05	0.09	0.04	0.04	0.06	0.01	0.04	0.59	0.04	0.04
Get up	9	0.06	0.08	0.09	0	0.04	0.01	0.01	0.09	0.56	0.06
Whole body move	10	0.04	0.08	0.04	0	0.03	0.01	0	0.13	0.14	0.53

Table 1: Confusion tables for activity detection in simulated percutaneous vertebroplasties (top table) and real vertebroplasties (bottom table). Average detection rates in simulated and real vertebroplasties are 92% and 44%, respectively. Highlighted activities are more relevant to vertebroplasty workflow than others.

4 Discussion

Having conducted 11 real-life studies with our partner surgeons, we recorded around seven hours of accelerometer data in the OR. We identified several requirements for accelerometer usage concerning safety, comfort and non-obtrusiveness of surgical workflow. These are not specific to accelerometers but should be regarded as general guidelines for wearable devices in the OR, potentially leveraging future clinical acceptance of systems incorporating such sensors. Future attachments for actibelts[®] are conceived as fully sterilizable armbands, further reducing setup time and increasing wear comfort. Furthermore, future actibelt[®] versions will have additional sensors and feature wireless transmission allowing online monitoring of motion data. Using accelerometer signals alone, preliminary results showed around 92% and 44% redetection accuracies of surgical activity, respectively in simulated and entirely unconstrained, real-life surgery settings. In upcoming work, we will combine actibelt[®] data with further OR sensor data, allowing for much higher recognition rates with the overall goal of creating context-sensitive, intelligent systems in future ORs.

5 References

- [1] Seyed-Ahmad Ahmadi, Tobias Sielhorst, Ralf Stauder, Martin Horn, Hubertus Feussner and Nassir Navab, "Recovery of Surgical Workflow Without Explicit Models", International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI), pp. 420-428, 2006
- [2] Tobias Blum, Nicolas Padoy, Hubertus Feussner and Nassir Navab, "Modeling and Online Recognition of Surgical Phases using Hidden Markov Models", International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI) (to appear), 2008
- [3] Martin Daumer, Kathrin Thaler, Esther Kruijs, Wolfgang Feneberg, Gerhard Staude and Michael Scholz, "Steps towards a miniaturized, robust and autonomous measurement device for the long-term monitoring of patient activity: ActiBelt", Biomedizinische Technik, vol. 52, pp. 149-155, 2007
- [4] Lawrence R. Rabiner, "A tutorial on hidden Markov models and selected applications in speech recognition", Proceedings of the IEEE, vol. 77, pp. 257-286, 1989
- [5] David Minnen, Tracy Westeyn, Peter Presti, Daniel Ashbrook and Thad Starner, "Recognizing Soldier Activities in the Field", Proceedings of International IEEE Workshop on Wearable and Implantable Body Sensor Networks (BSN), vol. 13, pp. 236-241, 2007
- [6] Jonathan Lester, Tanzeem Choudhury, Nicky Kern, Gaetano Borriello and Blake Hannaford, "A Hybrid Discriminative/Generative Approach for Modeling Human Activities", Proceedings of the Nineteenth International Joint Conference on Artificial Intelligence (IJCAI), pp. 766-772, 2005
- [7] Nicolas Padoy, Tobias Blum, Hubertus Feussner, Marie-Odile Berger and Nassir Navab, "On-line Recognition of Surgical Activity for Monitoring in the Operating Room", Proceedings of 20th Conference on Innovative Applications of Artificial Intelligence (IAAI), 2008
- [8] Christoph Bichlmeier, Ben Ockert, Sandro M. Heining, Seyed-Ahmad Ahmadi and Nassir Navab, "Stepping into the Operating Theater: ARAV - Augmented Reality Aided Vertebroplasty", Proceedings of the 7th International Symposium on Mixed and Augmented Reality (ISMAR), 2008