Ontology-based instruments detection in a context-aware framework for surgical assistance

H. Nakawala, G. Ferrigno, E. De Momi
Politecnico di Milano, Department of Electronics, Information and Bioengineering (DEIB), Milan, Italy

Keywords: Context-aware surgery, Ontology-based configuration, 3D object segmentation, Surgical assistance

Purpose

Knowledge-driven context-aware framework [1] interprets ontological surgical process models and provides assistance by providing decision support, e.g. contextual information, to the surgeon at a specific instance of a surgical activity, which could help to reduce procedure-related complications. To assist surgeons during the interventions (for example, to suggest the best available surgical instrument fitting the current step) accurate and consistent detection of instruments located on the surgical stand using vision-based sensors, can be indeed a useful approach. Data-driven approaches to object segmentation provide non-consistent segmentation due to different object features e.g. colour thresholds whose values have to be manually adjusted in the image processing algorithms for optimal results. The ontology-based configuration of such features might provide consistent results, which could integrate into the developed framework.

Methods

We have contextualised Thoracentesis, a procedure used to withdraw fluid from the chest. In order to obtain contextual information, we used image-processing algorithms for detection of instruments (as an example, a 50 ml syringe which is used to withdraw the fluid) [1]. Ontology for Thoracentesis was constructed using a top-down approach where information about Thoracentesis was obtained from a journal article and was analysed using the methodology described in [2] and an opinion from the physician. After identifying appropriate classes, the procedure was formalised using an approach similar to [3], where logical sentences were divided into triplets in the format of Phase (Instrument, Step, Body Structure). For example, withdrawal of a large syringe (50 ml) from the intercostal space is expressed as "Closure (LargeSyringe, WithdrawLargeSyringe, AreaOfInsertionIntercostal)". Thoracentesis instruments instances have been created in the ontology whose names are specified same as the name of the surface patches saved in the file system database. Each of these instrument's instances is linked with phases and steps of Thoracentesis using indicative prepositions (e.g. closure phase has instrument aspiration syringe). After analysing the requirements of an application-specific ontology, we have created classes for image processing algorithms such as "PlaneSegmentation", "RegionGrowingSegmentation" and so on. Each of these segmentation algorithms has a different set of parameters. During the "Pre-configuration" stage, we have manually segmented surgical instruments to obtain optimal configuration parameters for each instrument and verified the segmentation through the visual inspection. After doing five elaborations for each instrument in different positions, we have extracted the mean value of the parameters required for efficient segmentation. Subsequently, ontology has been updated with these parameters defined for each instruments instance and obtained parameters values are specified as a data-type property assertion. In order to segment the instruments, several pre-processing steps have been performed on the raw point-cloud, obtained by Microsoft Kinect, which includes geometric information (for example, points position i.e. XYZ). To downsample the point-cloud and to approximate the region of interest, voxel-grid and passthrough filters have been implemented respectively, which remove the outlier points such as walls [4]. After that, RANSAC-based plane segmentation [5] has been implemented to segment surgical instruments from the plane e.g. a surgical stand. We have tried to segment a 50 ml syringe and a surgical-swab in four different poses in two different illumination conditions e.g. in the cold white fluorescent tube-light and the warm yellow incandescent lamp. Furthermore, procedure ontology was queried at a particular surgical step, decided by the surgeon, to detect surgical instrument during Thoracentesis.

Results

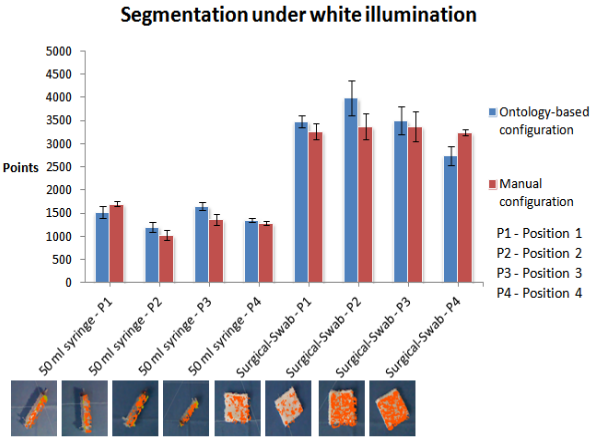

Fig 1. Segmentation of instruments in different positions under white illumination

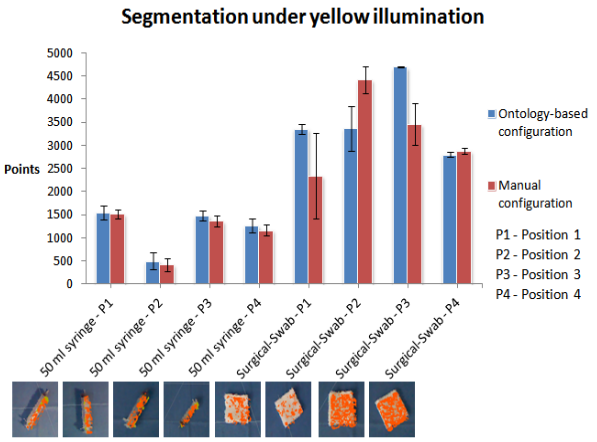

Fig 2. Segmentation of instruments in different positions under yellow illumination

Fig 1 and 2 shows a comparison of instruments, a 50 ml syringe and a surgical-swab, segmentation results under manual configuration/adjustment and ontology-based configuration of algorithm's parameters. The segmentation was assessed based on the number of points representing instrument's surface patches. We were able to detect the surgical-swab more efficiently in the yellow illumination. On the contrary, the syringe was segmented better in the white illumination. However, the approach comes with a limitation when instruments have specular reflections. In our experiments, the developed system was faster than manually adjusting the algorithm parameters, which improves system's usability.

Conclusion

The ontology-based configuration of algorithm parameters provides consistent segmentation of instruments, comparing the number of points within experiments in each pose, than manual configuration of the algorithm parameters. The ontology-based configuration also enables retrieval of context specific information and processes only required configuration parameters e.g. configuration parameters required to segment 50 ml syringe during withdrawal of the syringe from the chest cavity. However, the developed system experimented with one instrument only which can be further extended to multiple instruments segmentation.

References

[1] Nakawala H, De Momi E, Morelli A, Tomasina C, Ferrigno G (2015) Ontology-based surgical assistance system for instruments recognition, In Proceedings of CRAS: Joint Workshop on New Technologies for Computer/Robot Assisted Surgery. (In press)

[2] Natalya NF, McGuinness DL (2001) Ontology development 101: A guide to creating your first ontology, Stanford knowledge systems laboratory technical reports KSL-01-05 and Stanford Medical Informatics technical reports SMI-2001-0880.

[3] Neumuth T, Strauß G, Meixensberger J, Lemke HU, Burgert O (2006) Acquisition of process descriptions from surgical interventions, In DEXA LNCS, Springer, Bressan S., Kung J., Wagner R. (Heidelberg, Germany), 4080: 602-611.

[4] Gupta M, Sukhatme G (2012) Using manipulation primitives for brick sorting in clutter, Robotics and Automation (ICRA), IEEE International Conference On (Saint Paul, Minnesota, USA), 3883-3889.

[5] Fischler AM, Bolles CR (1981) Random sample consensus: a paradigm for model fitting with applications to image analysis and automated cartography, Communications of the ACM, 24(6): 381-395.