Improving Camera Travel for Immersive Colonography

Soraia F. Paulo[1,2], Daniel Medeiros[3], Pedro B. Borges[2], Joaquim Jorge[1,2] and Daniel S. Lopes[1,2*]

[1]INESC-ID Lisboa, [2]Instituto Superior Técnico, ULisboa, [3]CMIC, Victoria University of Wellington

Abstract

Colonography allows radiologists to navigate intricate subject-specific 3D colon images. Typically, travel is performed via Fly-Through or Fly-Over techniques that enable semi-automatic traveling through a constrained, well-defined path. While these techniques have been studied in non-VR desktop environments, their performance is yet not well understood in VR setups. In this paper, we study the effect of both techniques in immersive colonography and introduce the Elevator technique, which maintains a fixed camera orientation throughout navigation. Results suggest Fly-Over was overall the best for lesion detection at the cost of slower procedures, while Fly-Through may offer a more balanced trade-off between speed and effectiveness.

Index Terms: Human-centered computing—Human computer interaction—Interaction paradigms—Virtual reality;

1 Introduction

Colorectal cancer is the second leading cause of cancer-related death in the western world with an estimated 1.4 million new cases every year worldwide, half of which end in death [1]. Computed Tomography Colonography (CTC) is an imaging technique that has been widely adopted for colonic examination for diagnostic purposes. Still, the colon is an organ with several inflections and numerous colonic haustral folds along its extension, which make navigation inside CTC 3D models a hard task [8]. While analyzing CTC content, radiologists work in 2D workstations, which rely on 2D input devices and stationary flat displays. However, they often struggle to obtain the desired camera position and orientation, which requires several cumulative rotations, hence, making it hard to perceive the colon structure in 3D and potentially miss information [6]. To interpret such anatomically complex data, Virtual Reality's (VR) immersion and freedom of movement bare the promise to assist clinicians in enhancing 3D interpretation and allowing more expedite diagnosis.

Considering the complexity of the colon's structure, travel follows a semi-automatic procedure which relies on centerline estimation to constrain the direction of movement, while users are given control over speed. The most conventional way of CTC travel consists of the Fly-Through technique [3] (Figure 1(a)), where camera orientation follows the centerline's direction. Nonetheless, the use of VR could enable more natural means of travel by decoupling camera orientation from direction of movement, in the sense that relative orientation can differ from the centerline's direction. That is the case of the Fly-Over technique, where relative orientation is perpendicular to the centerline's direction [2](Figure 1(b)). Although these techniques are commonly used in conventional setups, they have yet to be fully investigated in VR settings. Our work focuses on camera travel as a key component on surveying and identifying pathological features in CTC datasets. The semi-automatic nature of the process combined with the abrupt movements caused by the complexity of the colon's structure, may cause unwanted side-effects due to the difference between camera orientation in the virtual world and the user's real orientation. To overcome this issue, we propose a novel technique called Elevator (Figure 1(c)), where camera orientation is changed in order to match the user's real orientation. Using an immersive colonoscopy prototype [5] we studied camera control techniques and their effectiveness on comprehensive landmark identification in order to address the following question: *Which of the tested visualization techniques is the most suitable to navigate inside the 3D reconstructed model of the colon?*

*e-mail: daniel.lopes@inesc-id.pt

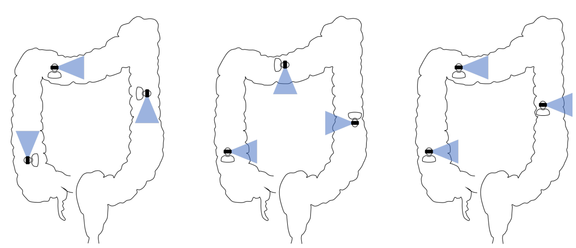
2 Evaluating Immersive Navigation inside a 3D Virtual Colon

We compared three camera travel techniques (Fly-Through, Fly-Over and Elevator) using both quantitative and qualitative metrics. Efficiency was measured based on task completion time, as efficacy corresponded to the success rate, i.e. the percentage of specific marks that were correctly identified. Questionnaires were used to assess the subjective feeling of usefulness, ease of use and disorientation of all three techniques, as well as cybersickness [4]. Our setup relies on the off-the-shelf HTC Vive device, including two lighthouses for 6DoF tracking of head and controllers within a 3x3 m play area.

Eighteen participants (13 male, 5 female) took part in our study, with ages ranging from 18 to 25 years old (Mean (M) = 21.94; Standard Deviation (SD) = 1.98). Most participants had a Computer Science (38.89%) or Biomedical Engineering (27.78%) background and had no previous experience with VR systems. Participants were asked to complete a demographic questionnaire to survey their personal profile and previous experience regarding VR and medical tools. This was followed by performing a training task with the technique they were assigned, in order to familiarize themselves both with the technique and the virtual environment. After that, they performed the test task followed by a post-test questionnaire to assess qualitative metrics. The task consisted in finding eighteen specific marks, in the form of orange capsules, along the colon. These capsules were placed in both easy and hard to find locations in the colon to simulate the visibility of real lesions. This procedure was repeated for all three techniques, which were assigned according to a balanced latin-squares arrangement to avoid learning effects.

3 Results

This section presents the results of our statistical analysis to evaluate quantitative and qualitative metrics of the three techniques tested. For task completion time and success rate, which are continuous



(a) Fly-Through (b) Fly-Over (c) Elevator

Figure 1: Camera orientation during (a) Fly-Through, (b) Fly-Over and (c) Elevator techniques.

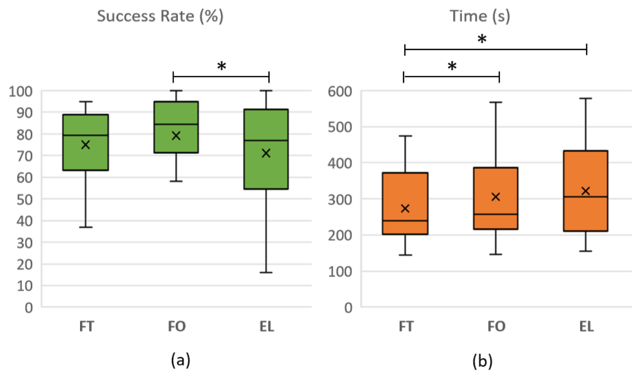


Figure 2: Results per condition: (a) Success Rate; (b) Task Completion Time. FT: Fly-Through, FO: Fly-Over and EL: Elevator.

Table 1: Summary of the questionnaires used in our test, split by question and technique (FT: Fly-Through, FO: Fly Over, EL: Elevator). Results are shown as Median (Interquartile Range).

	FT	FO	EL
Q1: Navigation was useful*	6(1)	5(2)	6(2)
Q2: Direction of travel was easy to understand	6(0.25)	5(2)	5(2.25)
Q3: I was disoriented*	1(1.5)	3.5(3.25)	3(3.25)
Q4: It was easy to find the marks	5(2)	4.5(1.5)	5(2)
Q5: I felt that I found the same mark twice	2(2.25)	2.5(2.25)	1.5(2.25)

variables, a Shapiro-Wilk test revealed that data was not normally distributed. We thus applied a Friedman non-parametric test for multiple comparisons and Wilcoxon Signed-Ranks post-hoc tests with a Bonferroni correction, setting a significance level at $p <= 0.017$. Such tests were also applied to Likert-scale data collected via questionnaires and cybersickness scores.

There were statistically significant differences in the success rate values depending on the camera travel technique used, $\chi^2(2) = 7.6$, $p = 0.022$. Post-hoc analysis showed no statistically significant differences between the Fly-Through and Fly-Over techniques , nor between the Fly-Through and the Elevator. However, there was a significant increase of the success rate between the Elevator and the Fly-Over technique ($Z = -2.386, p = 0.017$).

Regarding task completion time, there were statistically significant differences depending on the camera travel technique used, $\chi^2(2) = 10.333$, $p = 0.006$. Post-hoc analysis showed no significant differences between the Fly-Over and Elevator techniques ($Z = -1.328, p = 0.184$). Still, there were statistically significant increases between the Fly-Through and the Fly-Over techniques ($Z = -2.548, p = 0.011$), as well as between the Fly-Through and the Elevator technique ($Z = -2.548, p = 0.011$). We also found no statistical significance between techniques regarding cybersickness scores. As for qualitative metrics, we found significant differences in the perceived usefulness of the navigation technique (Q1) ($\chi^2(2) = 7.35$ $p = 0.025$), as users found Fly-Through more useful than the Fly-Over technique ($Z = -2.588$ $p = 0.01$). We also found statistical significance regarding the ease of understanding the direction of movement (Q2) ($\chi^2(2) = 9.529$ $p = 0.009$), but with no significance between pairs after performing a Bonferroni correction. Finally, results indicate statistically significant differences in perceived disorientation (Q3) ($\chi^2(2) = 11.111$ $p = 0.004$). In effect, users felt less disoriented by the Fly-Through technique when compared either to the Elevator ($Z = -2.541$ $p = 0.011$) or the Fly-Over ($Z = -2.634$ $p = 0.008$) methods.

4 Conclusions

In this paper, we study Fly-Through and Fly-Over techniques in immersive VR CTC, in terms of efficiency, ease of use, usefulness and effectiveness. We also compared these to the Elevator, a technique in this domain that combines both prior techniques to make virtual orientation match the user's direction of movement throughout navigation. Results suggest that Fly-Through is still the most efficient and easy to use technique for immersive VR CTC. The Elevator technique was found to be less effective and efficient than both Fly-Through and Fly-Over methods, but least disorienting than the Fly-Over approach, where users face the colon's walls instead of getting a perspective of the tubular structure of the colon.

The Fly-Over would be the technique of choice in order to provide a more accurate analysis and produce enhanced readings, as it helps users to identify lesions even in difficult-to-scan locations at the expense of a more time-consuming procedure. Indeed our experience suggests that each interaction technique could be useful in its own right, Fly-Through being most adequate to scan the colon in a quick preview, while Fly-Over would likely enable more reliable and comprehensive readings by clinicians. Improving the Fly-Over technique could perhaps be achieved by devising new means and interaction techniques for clinicians to visualize structures on their back without the need to physically turn. By doing this they could combine the observed effectiveness of the Fly-Over technique with more efficient means to support camera travel in immersive CTC navigation.

Still, our study had two main limitations. First, our experimental task only aims at reflecting the real clinical task to a certain extent, i.e. limited lesion visibility caused by the anatomical properties of the colon, while orange capsules may significantly differ from lesions such as polyps. Second, our participants had no clinical background, which may impact the selection of the ideal navigation technique to perform immersive VR CTC analysis. Future work will include validating such conclusions next to a group of medical professionals and the use of more generic flying to be able to generalize our results to a more broad area of cave-like structures [7].

Acknowledgments

This work was supported by Fundação para a Ciência e a Tecnologia through grants UIDB/50021/2020 and SFRH/BD/136212/2018, and by the Entrepreneurial University Program funded by TEC, New Zealand.

References

[1] J. Ferlay, I. Soerjomataram, R. Dikshit, S. Eser, C. Mathers, M. Rebelo, D. M. Parkin, D. Forman, and F. Bray. Cancer incidence and mortality worldwide: Sources, methods and major patterns in GLOBOCAN 2012. *International Journal of Cancer*, 136(5):E359–E386, 2015.

[2] M. S. Hassouna, A. A. Farag, and R. Falk. Virtual fly-over: A new visualization technique for virtual colonoscopy. In *MICCAI 2006*, pp. 381–388. Springer Berlin Heidelberg, Berlin, Heidelberg, 2006.

[3] L. Hong, A. Kaufman, Y.-C. Wei, A. Viswambharan, M. Wax, and Z. Liang. 3d virtual colonoscopy. In *Biomedical Visualization, 1995. Proceedings.*, pp. 26–32. IEEE, 1995.

[4] J. J. LaViola Jr. A discussion of cybersickness in virtual environments. *ACM SIGCHI Bulletin*, 32(1):47–56, 2000.

[5] D. S. Lopes, D. Medeiros, S. F. Paulo, P. B. Borges, V. Nunes, V. Mascarenhas, M. Veiga, and J. A. Jorge. Interaction techniques for immersive ct colonography: A professional assessment. In *MICCAI 2018*, pp. 629–637. Springer, 2018.

[6] K. Mirhosseini, Q. Sun, K. C. Gurijala, B. Laha, and A. E. Kaufman. Benefits of 3D immersion for virtual colonoscopy. In *2014 IEEE VIS International Workshop on 3DVis (3DVis)*, pp. 75–79, Nov 2014.

[7] P. Schuchardt and D. A. Bowman. The benefits of immersion for spatial understanding of complex underground cave systems. In *Proceedings of the 2007 ACM Symposium on Virtual Reality Software and Technology*, VRST '07, p. 121–124. Association for Computing Machinery, New York, NY, USA, 2007. doi: 10.1145/1315184.1315205

[8] J. Yao, A. S. Chowdhury, J. Aman, and R. M. Summers. Reversible projection technique for colon unfolding. *IEEE Transactions on Biomedical engineering*, 57(12):2861–2869, 2010.