

Crowd-Assisted Polyp Annotation of Virtual Colonoscopy Videos

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ABSTRACT

Virtual colonoscopy (VC) allows a radiologist to navigate through a 3D colon model reconstructed from a computed tomography scan of the abdomen, looking for polyps, the precursors of colon cancer. Polyps are seen as protrusions on the colon wall and on the haustral folds, seen in the VC fly-through videos. A complete review of the colon surface requires full navigation from the rectum to the cecum in anterograde and retrograde directions, which is a tedious task that takes an average of 30 minutes. Crowdsourcing is a technique for non-expert users to perform certain tasks, such as image or video annotation. In this work, we use crowdsourcing for the examination of a complete VC fly-through video for polyp annotation by non-experts to potentially help the radiologist reach a diagnosis in a shorter period of time, and provide a stronger confirmation of the eventual diagnosis. The crowdsourcing interface includes an interactive tool for the crowd to annotate a suspected polyp in the video with an enclosing box. Using our workflow, we achieve an overall polyps-per-patient sensitivity of 87.88% (95.65% for polyps ≥ 5 mm and 70% for polyps < 5 mm). We also demonstrate the efficacy and effectiveness of a non-expert user in detecting and annotating polyps and discuss their possibility in aiding radiologists in VC examinations.

1. PURPOSE

Virtual colonoscopy (VC) employs CT scanning of the patient's abdomen and advanced visualization techniques to virtually navigate within a reconstructed 3D colon model searching for colorectal polyps, the precursor of cancer. VC is widely recognized as a highly sensitive and specific test for identifying polyps in the colon. It is a comfortable, inexpensive, very low risk, and fast procedure. One of the major issues with VC, though, is the required interpretation time by the radiologists. In order to ensure full coverage of the colon surface, a typical protocol is to acquire two scans of the patient in different positions (e.g., supine and prone) and to then virtually traverse each scan in both antegrade and retrograde directions. These multiple fly-throughs are used to ensure sufficient coverage of the colon surface, but are tedious and time consuming, as most regions of the colon are free of polyps. Computer-aided detection (CAD) algorithms have been developed to identify polyps automatically but these have false negative findings, missing lesions with adherent contrast medium, flat adenomas, and adenomas located on or adjacent to normal colonic folds. In order to increase sensitivity, specificity is usually sacrificed, thus increasing the number of false positive polyp candidates that must be rejected. This requires significant human intervention and time even though the majority of false positive candidates can be rejected even by individuals with minimal training.

Crowdsourcing seeks to engage the general masses, and previous studies have shown that most workers are forthright in their intentions. Crowdsourcing has been shown to be a good method for annotating endoscopic images. In the colon domain, there have been a few attempts to combine computer-aided detection with crowdsourcing to overcome some of the limitations. These initial attempts have shown that the crowd can be used to reject false positive polyp candidates, however little work has been done to determine if the crowd can be used for primary polyp detection or as a means of excluding the presence of a polyp within a segment of colon. Other work has shown that that workers who participated in two studies improved significantly in performance between the first and second study. One small study was also performed where workers were asked to identify whether or not a short video segment contained a polyp, and the crowd was generally successful in identifying which segments contained a polyp [Park et al., SPIE 2017]. In comparison to previous works, our study has two major differences: (1) we present the crowd workers with complete fly-through videos of the entire colon and (2) we require the workers to annotate the exact location of a found polyp in the video frame.

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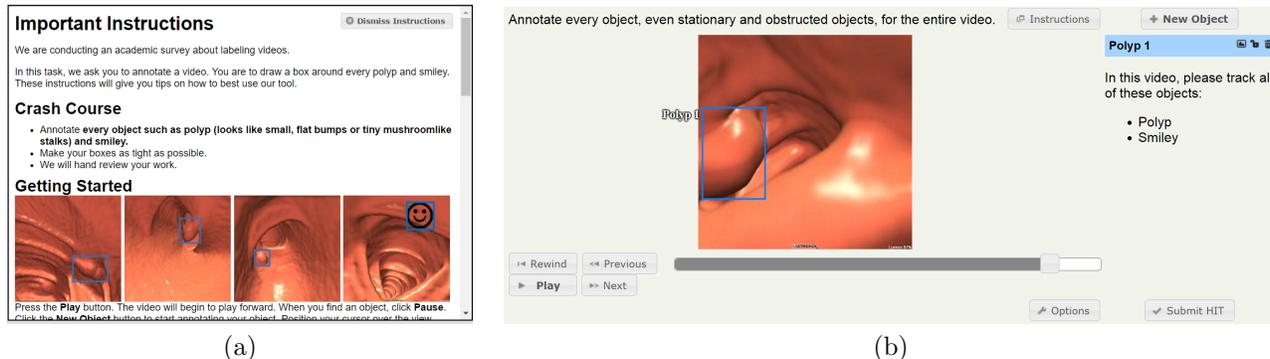


Figure 1. (a) Instructions presented to each user. (b) A view of our interface.

2. METHODS

Video Generation: We have used the commercially available FDA-approved Viatronix V3D-Colon virtual colonoscopy system to automatically generate four centerline fly-through videos for each patient VC dataset (from rectum to cecum and from cecum to rectum in both supine and prone orientations). We only use corresponding supine and prone VC datasets for which we can recover a complete single colon segment, since segmentation artifacts sometimes lead to multiple 3D colon segments corresponding to a single VC dataset. The videos are captured at 15 frames per second (fps) with a resolution of 256×256 pixels and a 90° field-of-view.

Datasets: This study utilized VC data from 14 patients, yielding a total of 56 VC videos (antegrade and retrograde directions in both supine and prone scans) and thus a total of 56 unique HITs. These 14 patients contained a total of 33 polyps, with the number of polyps per patient ranging from 1 to 5. Since not every polyp was visible in each of the four views, the 56 videos contained a total of 114 visible polyps. The datasets contained a selection of both large ($> 5mm$) and small ($< 5mm$) sized polyps. Of the 33 total polyps, 10 polyps were less than $5mm$ in diameter. The patients were chosen from an anonymized training database, and were ranked in difficulty from Level 1 (least difficult) to Level 4 (most difficult). Of the selected datasets, two were ranked as Level 1, three as Level 2, five as Level 3, and four as Level 4.

Crowd Task: To present our study to the non-expert crowd workers, we made use of the Amazon Mechanical Turk (MTurk) platform, which has become popular recently as a way of obtaining reliable crowd workers at modest cost while allowing us to reach a large and diverse population of users. We used an existing open source crowdsourcing video annotation tool. When users first select our advertised task, they are provided with brief instructions (see Figure 1a) such as the main objective of the study, how to use the system, some example polyps, and how the workers' results will be evaluated. The workers can then proceed to annotate a polyp or a smiley (for quality control purposes) in actual videos by drawing a rectangle around it; five smileys were added to each video and workers who did not annotate all five smileys were labelled spammers and discarded. An example of our interface with an annotation is shown in Figure 1b.

Ground Truth: We generated the ground truth to compare against the crowd results by marking polyps in the videos based on the expert radiologists' VC reports. We used the same annotation tool as the crowd workers to annotate polyps in the videos, where we annotate each polyp in every video frame it is visible in.

3. RESULTS

Each VC video was viewed by ten workers, except for two which were viewed by eleven workers. A worker was not allowed to complete the same task multiple times, but was allowed to complete multiple tasks, each with a different VC video. A total of 125 workers participated in our study. While most workers completed a single task, several performed multiple tasks, including one worker who completed 45 tasks. We have used the Dice similarity coefficient (DSC) to determine whether or not a worker annotation W corresponds to an actual ground truth annotation T . The DSC is calculated as

$$DSC_{WT} = \frac{2|W \cap T|}{|W| + |T|} \quad (1)$$

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Figure 2. Examples of polyps in VC videos, and the corresponding annotations made by the crowd. All of the crowd’s annotations for each polyp are superimposed here for illustrative purposes on a single selected frame containing the polyp, with each worker’s annotation box in a different color.

and a worker annotation is considered a match to the ground truth annotation if $DSC_{WT} > 0.5$. When considering if a polyp or a smiley is matched, only one frame of the polyp/smiley needs to be annotated by the crowd worker. Figure 2 shows three examples of the various annotations made for three polyps from three different videos (since the annotations were in different frames, not all boxes are aligned tightly illustrated view).

We have eliminated “spammers” (or low quality workers) by eliminating tasks in which the worker did not match all five of the smileys that were inserted. This quality control measure removed 57 video tasks from the total number of 562 video tasks ($54 \text{ HITs} \times 10 + 2 \text{ HITs} \times 11$) that were performed in our study. Unless otherwise indicated, our discussion of the results considers only these remaining 505 tasks. The accuracy of the crowd in properly annotating polyps is shown in Figure 3. Broken down by individual video, our results showed that not all polyps were found by at least single worker; 106 of the 114 polyps were annotated by at least one worker. At the 50% threshold, 69 of the polyps were annotated by at least five workers.

Since some polyps are not visible in the default fly-through in a particular orientation, it is more important to look at the accuracy of the crowd in relation to physical polyps per patient (rather than per video, of which there are four videos generated per patient). By this measure, there were a total of 33 polyps between the 14 patients. Broken down by polyp per patient, our results show that all of the polyps were identified by at least three workers in a single video. By this, we mean that if a polyp was visible in multiple videos, at least three workers annotated the polyp in the same video; in most cases, the polyp was annotated accurately in multiple videos and by more than three workers. At the 50% threshold, 29 of the 33 total polyps were annotated by at least five workers (22 of the 23 large polyps, and 7 of the 10 small polyps). This gives an overall polyps-per-patient sensitivity of 87.88% (95.65% for polyps $\geq 5\text{mm}$ and 70% for polyps $< 5\text{mm}$).

Removing the “spammer” workers reduced the total number of annotated frames resulting from the tasks. The 56 videos contained a total of 125,182 frames. Using the results of all workers resulted in a total of 3,754 annotated frames. By removing the “spammer” workers, this number of annotated frames was reduced to 3,342, eliminating more than 10% of the annotated frames and resulting in only 2.7% of all frames in the original videos containing annotations. We believe that the crowd results could be used to assist radiologists in VC screenings. Since we have only a few crowd-annotated frames per video, they can be shown to the expert radiologist, prior to the fly-through, who can quickly skim through and discard the false positives. Moreover, the overlapping crowd annotations between successive frames can be grouped together to further reduce the total number of annotated frames. This can help control the automatic centerline flythrough by cleaning up large swathes of regions with crowd-annotated false positives and allow the radiologist to speed through the regions void of polyps and slow down in regions with high-consensus crowd polyp annotations. Figure 4 gives an example of where annotated frames are located within a colon video and in relation to the polyps, with non-annotated regions possibly being able to be reviewed more quickly by the radiologist in order to save time.

In addition to the insights gained regarding the crowd’s ability to locate polyps in VC videos, this study reinforced the importance of performing VC fly-throughs in both antegrade and retrograde directions in both the supine and prone scans. In several cases, the crowd was successful in locating a polyp in one of these four views, but not in the other three. Indeed, even for the ground truth annotations, three polyps were visible in only one view, two were visible in only two views, and five were visible in only three of the four views.

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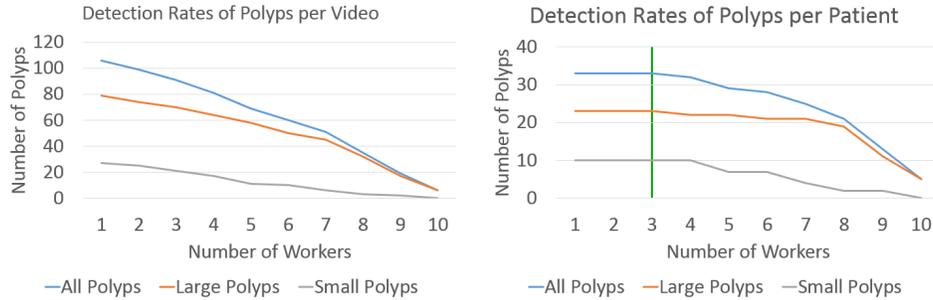


Figure 3. Detection rates based on the number of workers with a matched annotation required to consider a polyp found. There were a total of 114 polyps (79 large, 35 small) on a per-video basis, and a total of 33 polyps (23 large, 10 small) on a per-patient basis. The green line in the per patient chart indicates the threshold for a 100% polyp detection rate.

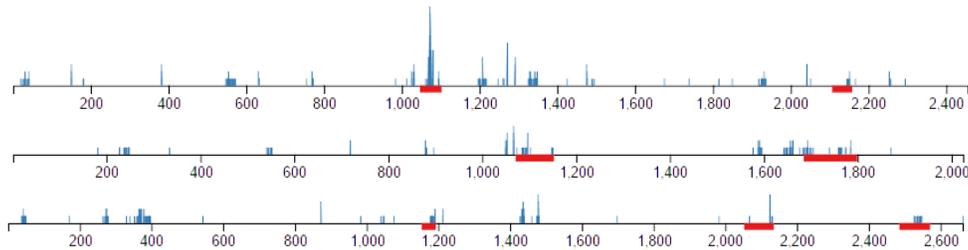


Figure 4. Timelines of three of the VC videos used in our study. The blue bars above the line are worker annotation positions; the height of the line corresponds to the number of workers who annotated that specific frame. The red regions below the line indicate the range of frames in which a ground truth polyp appears.

We believe that the crowd results could be further improved in future studies. Most of the missed polyps fell into one of three categories: the polyp was occluded, the polyp was visible in only a few frames, or the polyp looked like a fold. For occluded polyps, the multiple fly-throughs generally solve this issue. In cases where the polyp is visible only briefly, adjusting the navigation speed to a slower rate might help to increase crowd performance in spotting these polyps. Additional training and more examples of tricky polyps might also help improve the ability of the crowd in identifying polyps which look like folds.

4. NEW WORK TO BE PRESENTED

To the best of our knowledge, this work is the first crowdsourcing study in which non-expert crowd workers are requested to annotate colonic polyps directly from VC videos. Our results have shown that the crowd is quite adept at this task, even with only a modicum of training. All polyps from each patient were identified by at least three workers. The number of frames annotated by the workers was only 2.7% of the total number of frames in the videos, yielding the potential to greatly reduce the required effort of the radiologist.

5. CONCLUSION

An issue with VC is the interpretation time required of radiologists to perform virtual fly-throughs. Notably, as compared to previous works, we tested the ability of the crowd to identify and annotate these polyp locations in pre-generated full length fly-through videos of the entire colon. Using a consensus level of 50%, the crowd achieved an overall sensitivity of 87.88% in locating the 33 polyps among 14 patient datasets. Broken down by size, the sensitivity was 95.65% for polyps ≥ 5 mm and 70% for polyps < 5 mm. In the consensus level was reduced to 30% (i.e., at least three of the ten workers on a video identified a polyp), then all polyps were found.

While this study was focused on determining whether or not crowd annotations of polyps was feasible, future work will focus on how these results can be best used when the ground truth is not known. Further research in this area will lead to a better understanding of how crowd results can be optimally utilized for assistance in VC.

6. SUBMISSION STATUS

This work is not under submission or being submitted elsewhere for publication or presentation.