Generic Document Image Dewarping by Probabilistic Discretization of Vanishing Points

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The document image dewarping problem





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Cologne s'affirme avre une originalité qui lui est propre. La ville, capitale d'un puissant archevèché, était le courr de la Basse-Lorbaringue et bénéficiait d'un long et brillant passé arraitique.

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Perspective distorsion









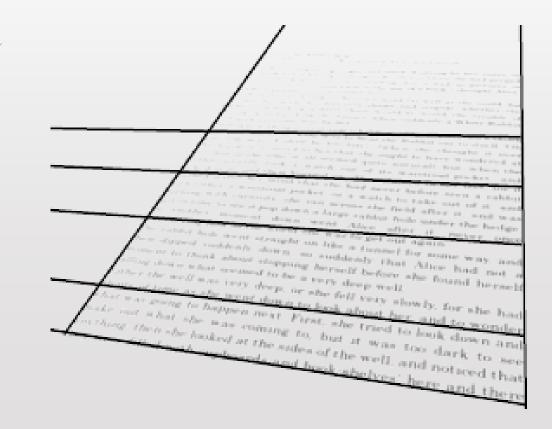
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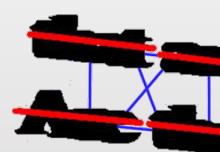
Previous methods

- Perspective distortion can be corrected by detecting vanishing points [Takezawa et al. 2016 & 2017]
- Not effective in case of curved pages



Previous methods

- Curved pages can be handled by classical image analysis (connected components, baseline fitting etc.) [Liu et al. 2015]
- Does not take into account the overall perspective of the document
- Not suited to non text regions



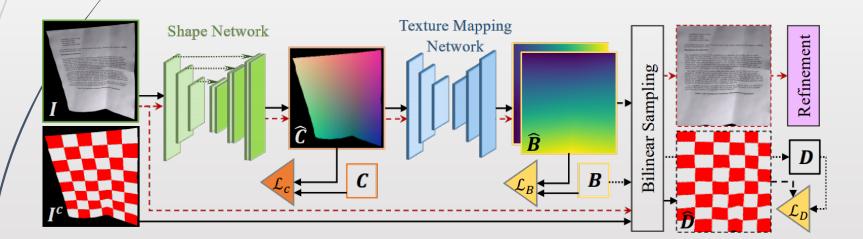
It is natural and intuitive to classify a pattern through a sequence of our It is nature in which the next question asked depends on the answer to the current questions, in which an event of the particularly useful for nonmetric data, because all of the questions can be asked in a "yes/no" or "true/false" or "value(property) \in of values" style that does not require any notion of metric. ch a sequence of questions is displayed in a directed decision tree or simply where by convention the first or root node is displayed at the top, connected by

successive (directional) links or branches to other nodes. These are similarly connected until we reach terminal or leaf nodes, which have no further links (Fig. 8.1). 8.3 and 8.4 describe some generic methods for creating such trees, but let us how they are used for classification. The classification of a particular

pattern because at the root node, which asks for the value of a particular property of the pattern. The different links from the root node correspond to the different possible values. Based on the answer, we follow the appropriate link to a subsequent or descendent node. In the trees we shall discuss, the links must be mutually distinct and exhaustive; that is, one and only one link will be followed. The next step is to make the decision at the appropriate subsequent node, which can be considered the

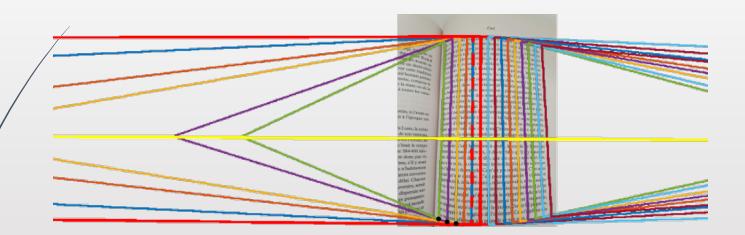
Previous methods

- Deep learning technique may solve both problems simultaneously [Das et al. ICCV 2019]
- Require an important number of learning samples
- Generally lack precision



Main contribution

Under a generalized cylinder shape assumption, perspective and page curl can be dewarped simultaneously by detecting vanishing points along the "horizon line"





- 1 A line segment dectector [Grompone et al. IPOL 2012] is applied to the image
 - Letter strokes as well as pictures and page boundaries provide a lot of lines, some of which are "vertical" (in 3D), others "horizontal"



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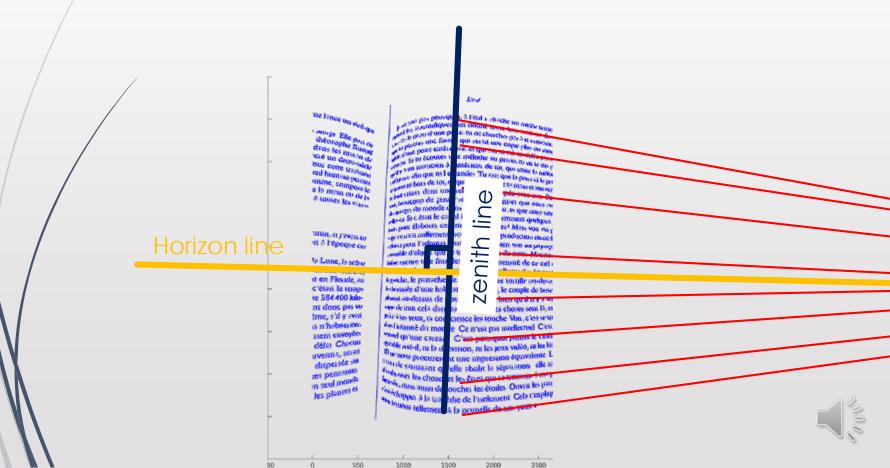
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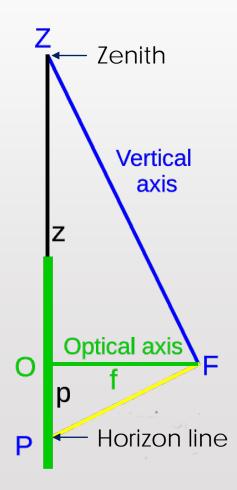
2 The vertical line segments allow to compute the zenith and the zenith line



3. The horizontal line segments allow to compute the horizon line perpendicular to the zenith line



4 The focal length *f* is deduced from the positions of the zenith and horizon line relative to the principal point





5. Vanishing points are detected along the horizon line by performing a binary-tree descent search

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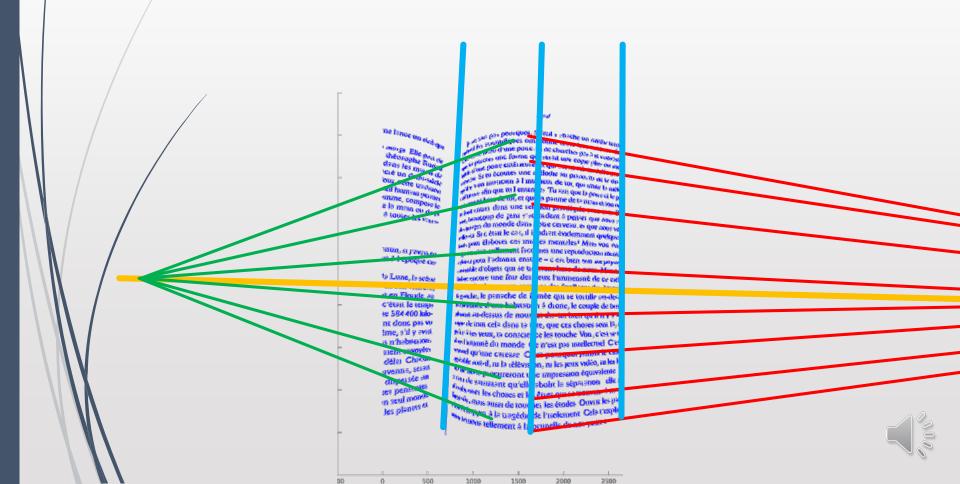
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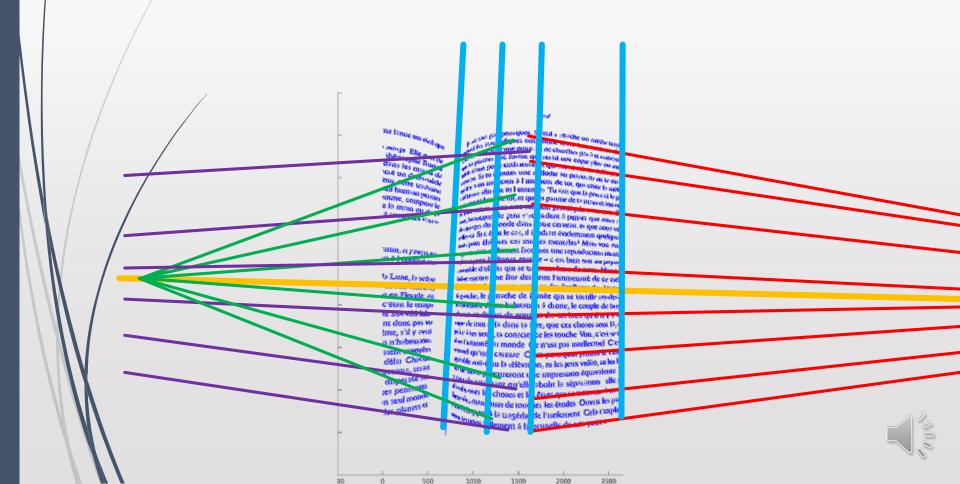
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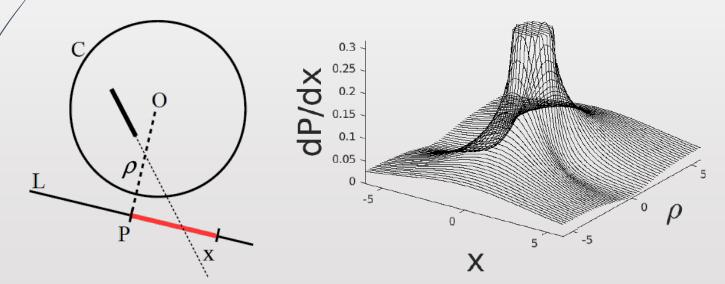
5 Vanishing points are detected along the horizon line by performing a binary-tree descent search



5 Vanishing points are detected along the horizon line by performing a binary-tree descent search based

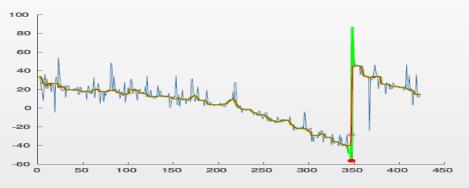


- 5 Vanishing points are detected along the horizon line by performing a binary-tree descent search
 - A probabilistic criterion is used to decide when to stop cutting: a vanishing point is said meaningful if it cannot be obtained (at least once) by chance



Probability distribution that a chord of circle C meets a line L at position x by chance

6 The 3D directions of the vanishing points are computed and their angles with the camera x-axis are median filtered



wais pas pourquoi, à l'œil s'attaches les scientifiques ont donné toute ICHT s la peau d'une poire, tu ne ch erçois une forme qui serais neire extérieure, et qui aurait u. Si tu écoutes une mélodie au pia a un musicien à l'interieur de toi, afin que tu l'entendes. Tu sais que le nuvent hors de toi, et que la paume ion entrer dans une relation privilégiée av it beaucoup de gens s'accordent à penser que una sup to .us In monde dans notre cervi in anore its-ci. Si c'était le cas, il faudrait évidemment quelo ints pour claborer ces images mentales! Mais voir un ge, ce n'est nullement façonner une reproduction mente duici pour l'admirer ensuite - c'est bien coir un pu memble d'objets qui se trouvent hors de nous. Mainten alsie encore une fois des yeux l'immensité de ce ciel d'un blaurendre, les masses sombres des feuillages de aguiche, le panache de fumee qui se tornile au-de cheminée d'une habitation à droite, le couple de buses o planat au-dessus de nous, et dis-toi bien qu'il n'y a aucur opie de tout cela dans ta tête, que ces choses sont là, et qu atee a tes yeux, ta conscience les touche. Voir, c'est se trouv as l'intimité du monde. Ce n'est pas intellectuel. C'est aus ¹⁸uel qu'une caresse. C'est pourquoi jamais le cinéma, s steable soit-il, ni la télévision, ni les jeux vidéo, ni les luncttes ^{3D}fic nous procureront une impression équivalente. La vue erer de saisissant qu'elle abolit la séparation : elle m'offre The second of the second is separation i and portee ^{28,807} mais aussi de toucher les étoiles. Ouvrir les paupières atéchapper à la tragédie de l'isolement. Cela t'explique que ilisienions tellement à la prunelle de nos yeux.»

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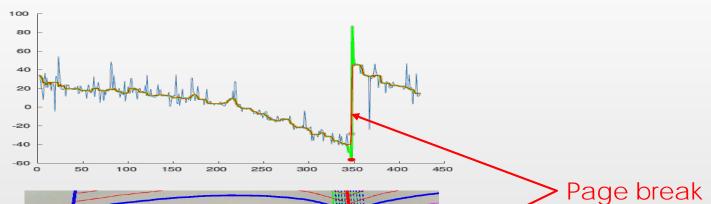
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6 The 3D directions of the vanishing points are computed and their angles with the camera x-axis are median filtered



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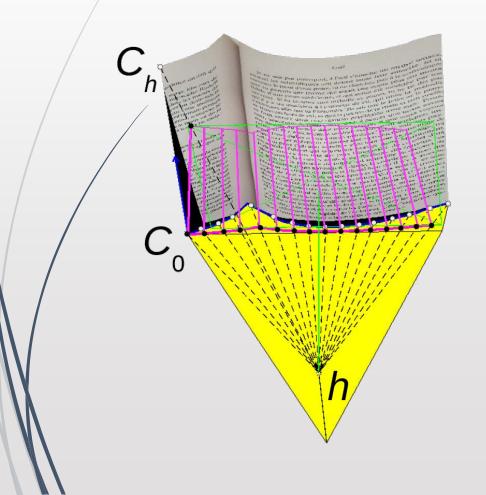
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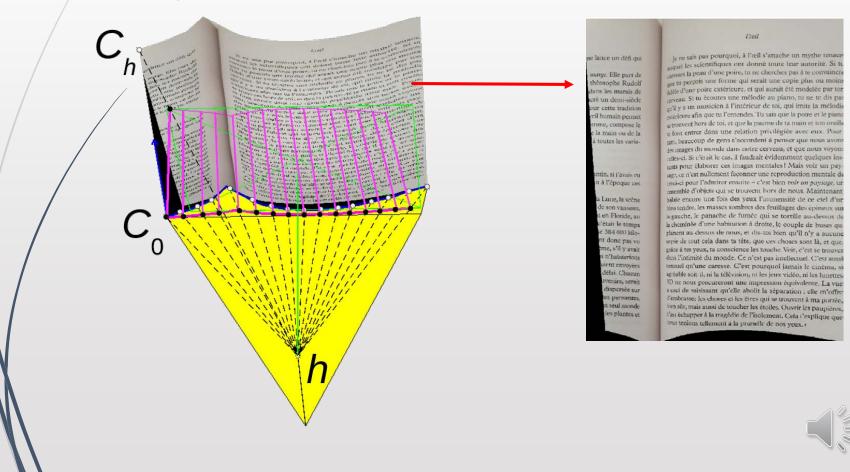
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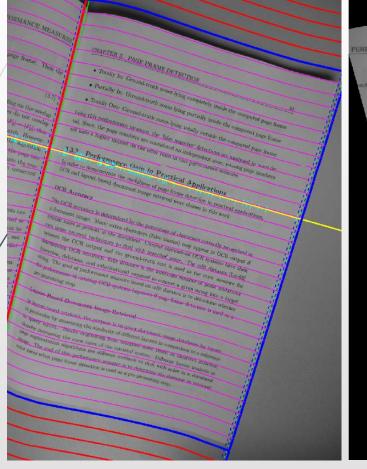
7 The filtered bottom curve then the full document are reconstructed in 3D





8. The image is back-projected onto the 3D model which finally only has to be unfolded to get the dewarped image





ERFORMANCE MEASURES excited page frame. Then the (3.7)

tepending on the overlap frames do not overlap $F_{ab}^{a} = |F_{a}| + |F_{a}|$, then new match. However, is by the algorithm, rom of the page into a evaluate the page world on corrected

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CHAPTER 3. PAGE FRAME DETECTION

- · Jotally In: Ground-truth zones lying completely inside the computed page frame
- · Partially In: Ground-truth zones lying partially inside the computed page frame
- Totally Out: Ground truth zones lying totally autside the computed page frame.

Using the a performance measure, the 'inlast negative' detections are analyzed in more detail. Since, the page manders are considered an independent zone, mixing page numbers will have a higher impact on the error rates in this performance measure.

3.3.2 Performance Gain in Practical Applications

In order to demonstrate the usefulness of page frame detection in practical applications, OCR and layout-based document image retrieval were chosen in Mix work.

OCR Accuracy

The OCR accuracy is determined by the percentage of characters convertly isopprised in a accuracy image. Many extra characters (false alarms) may appear in OCR output in textual noise is present in the document. Current continencial OCR works have their even noise removed techniques to deal with marginal noise. The edit distance [Lewig] between the OCR comput and the ground-truth text is used as the error measure for elsewhing OCR accuracy. Felt distance is the minimum number of point mutations (intertion, deletions, and sub-diminishing output distance) a given string into a target string. The goal of performance measure based on odd distance is to determine whether the performance of existing OCR systems improves if page frame datection is used as a pre-processing step.

Layout-Based Document Image Retrieval

In hyper-based retrieval, the purpose is to query contrast image databases by layout, in particular by meaning the similarity of different layout in comparison to a reference or curry ignoreasing the error rates of the retrieval system. Different hypothanges is page segmentation algorithms use different methods to that with rotes in a document image. The goal of this performance measure is to determine the decrease in retrieval arror rates when page leans determine is used as a preparonasing sign.

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be obtained over under significant scene motion (in fact, feature matching is shown and the matching is shown and the matching is shown as the second state of the sec to obtained, one obtained store matching [MCMP02]). The problem of sparseness appled for twee restrictions of a postprocessing that infers dense flow representations ran se overcome of all WABOS start from a feature point matching and he example, Belongin et al. WABOS start from a feature point matching and he semple Beingr et an interest of assign pixels to coherent motion layer. By a gapa as technique bound methods, please refer to 17200 years. By a apply a graphic of feature-based methods, please refer to [T2001

Direct Motion Segmentation

waterapparters of feature-based methods argue that a selection of weil-tracker fatures leads to a more robust motion retination [17200], a problem is that tentre estimation and interpretation are separated - a tecovery from errors (1) as much sector and the motion estimation stop is difficult. This is particularly true as the estimation of motion is intertwined with knowledge of region boundaries, which the where postion segmentation is also called a "chicken-egg problem" (CS651, They ited in a joint process operating directly on image intensities. A variety of methods to tillors the test of them based on the optical flow equation (6.1), we experime for such fixed x that $\nabla I(x) \cdot v + I_t(x) \approx 0$, and the quantity $\nabla I(x) \cdot v + I_t(x)^{1/2}$ is called the optical flow error. A minimization of this error is the key idea of and direct domainst mation patimetion methods: it is assumed that the majority the frame (spically, the background region) follows a parametric global motion The entropy of the background region) follows a parameter group of the entropy of the associated region by minimizing flow error birth a table for a more support. d mor a robust formal process [IRP94]. Black and Anandrat [RA96] propose to replace In an quedate flow error as used previously [HS80] with error measures from robust in the statistic [[ab74], which are 1 param statisticalitation is used previously [JIS80] with error measures summarized by obtained to shall aver less plane to the influence of outliers. A segmentation of earth Both the best and a which are less prime to the influence of outliers. A second of the second seco formul Annual solar estimation until the whole frame is fitted disconti Anothe subjects of direct methods views motion segmentation as a parameter motion to the second segmentation as a parameter motion to the second segmentation as a parameter second segment and set 1 is or entrance setupty of direct methods views motion segmentation as a parameter of a strain of parameters of a parameter setup. Assuming image data f is being strained species of parameters of a setup of the set restrict timizati

and the field L (representing a segmentation) is obtained using a Bayes $\frac{V_{i,L} \sim \arg\max_{U,V_{i,L}} P(V, U_{i}) \simeq \arg\max_{U,V_{i,L}} F(U_{i}V_{i,L}) \cdot P(V_{i}L) \cdot P(L)$ University of a station and a state of the station of the station

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6.3. STATE OF THE ARP

he obtained, even under significant seene motion (in fact, feature matching is also applied for wide baseline storeo matching [MCMP02]). The problem of sparseness can be exercised by a protomovating that inters dense flow representations for example, Helongie et al. [WABC0] start from a feature point matching and then apply a graph cut technique to assign pixels to coherent motion layers. For a detailed discussion of leafure-based methods, please refer to [TZ00].

Direct Motion Segmentation

While supporters of feature-based methods argue that a selection of well trackable. features basis to a more robust motion estimation [TZ00], a problem is that as motion estimation and interpretation are separated --- a recovery from errors made in the motion estimation step is difficult. This is proticularly true as the estimation of motion is intertwined with knowledge of region boundaries, which is why motion segmentation is also called a "chicken-egg problem" [CS05]. This insight motivates direct methods, which estimate motion boundaries and motion itself in a joint process operating directly on image intensities. A variety of methods follows this idea, must of them based on the optical flow equation (6.1): we expect for each pixel x that $\nabla I(x) \cdot c = I_t(x) \approx 0$, and the quantity $\nabla I(x) \cdot v + I_t(x)$ is called the aption flow error. A minimization of this error is the key alea of direct dominant motion estimation methodic it is assumed that the majority of the frame (typically, the background region) follows a parametric global motion. This is estimated together with the associated regime by minimizing flow error in a robust fitting process [IRP94] Black and Anamian [BA96] propose to replace quadratic flow error as used previously [11880] with error measures from robust statistics [Hub74], which are less prone to the influence of outliers. A sugmentation can be obtained by remaining already explained regions and repeating dominant motion estimation casil the whole frame is litted.

Another category of direct methods views motion segmentation as a parameter estimation problem in a probabilistic setting. Assuming mage data J to be given in form of spatic-temporal derivatives, a joint evaluation of the motion field V and tabel field L (representing a segmentation) is obtained using a Boyesian formulation:

 $V, \tilde{L} = \arg\max P(V, L|I) = \arg\max P(I|V, L) \cdot P(V|L) \cdot P(L)$ (6.3)

If taking the logarithm, such formulations lead to the minimization of energy frame time consisting of additive terms. A data fit term represents $-\log P(I|V,L)$, the negative log-likelihood of the image data given the motion field. This is balanced

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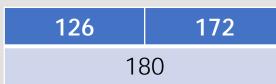
However, the situation was found to be different when generalizing to a However, the situation is a significant overfitting was a key problem for all surunseen in training, iters, as an index of the video performed about as well as the underprisingly detectors trained on web video detection and about as well as the and surprisingly detection taked data. Also, detection rates could be improvtrained on surplementing conventional training sets with YouTube is situation by sopport of the second s overall, incontaction training. With large-scale readily annotated day end by services like YouTube, concept detection systems can be trained und ess supervision, can scale up to more concepts, and thus provide better superor video search. Compared to the proposed web-based concept learning a market al annotation of training sets may not really be worth the effort, as it only me compensate or the proteintes? training descalar. Real or provide hard line which a concept detector is applied to video sources unseen in training, it seen referable to automatically bootstrap detection from web video and then perform ght weight manual refinement on the target domain, for example using relevant edback RL03

-DISCUSSION

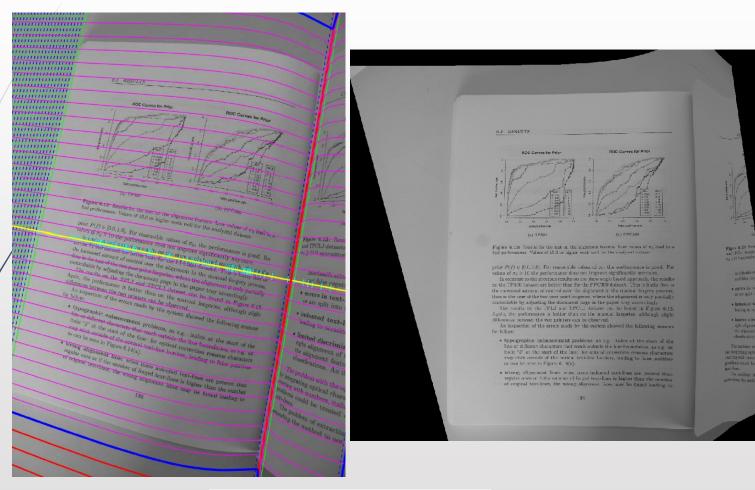
3.7. DISCUSSION

However, the situation was found to be different when generalizing to domains unseen in training. Here, significant overfitting was a key problem for all systems, and surprisingly detectors trained on web video performed about as well as the oness trained on strongly annotated data. Also, detection rates could be improved in this situation by supplementing conventional training sets with YouTube content.

Overall, these results demonstrate that web video is a highly interesting data source for concept detector training. With large-scale readily annotated data offered by services like YouTube, concept detection systems can be trained under less supervision, can scale up to more concepts, and thus provide better support for video search. Compared to the proposed web-based concept learning, a manual annotation of training sets may not really be worth the effort, as it only gives improvements on the restricted training domain. For a practical application in which a concept detector is applied to video sources unseen in training, it seems preferable to automatically bootstrap detection from web video and then perform a light-weight manual refinement on the target domain, for example using relevance feedback [RL03].

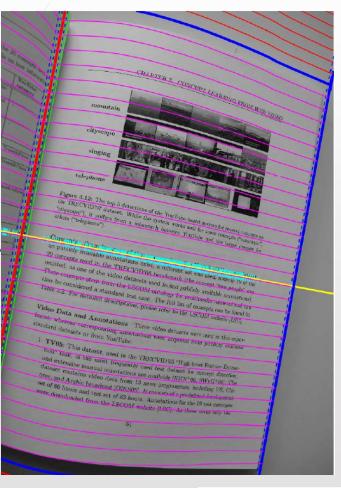


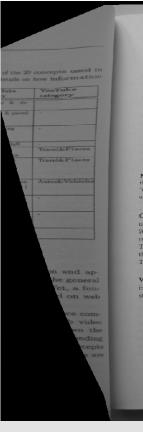




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CHAPTER 3 CONCEPT LEARNING FROM WEB VIDEO



Figure 3.12: The top 5 detections of the YouTube-based system for several concepts on the TERCVID of dataset. While the system works well for some concepts ("mountain", "rinywape"), it suffices from a mismatch between YouTube and the target domain for others ("texphone").

Concepts Since for some of size manylis from the *Yostals-28/Concepts* classest no publicly would be unsued by the *Yostals-28/Concepts* classest and the 20 curvepts and in the TRECVID 08 head mark (the concept "two-people" was critized, as one of the video datasets and headed publicly available annotational). These consepts stars from the *ISCOM* outdoor for multimedia petrolesis and can thus be considered a standard tost asset. The full list of concepts can be found in Table 3.2. For dotable development for the *ISCOM* websine [ISS].

Video Data and Annotations. Three video datasets were used in this experiment, whereas conceptualing a motations were acquired from publicity available standard datasets or from YotTybe:

1. TV05: The dataset, used in the THEOVID'05 "High-load Fourture Extraction" tark, in the most irrequently used tool induced for concept detection, and extensive mental annual likelike [REW 106, SWC4756]. The dataset matrix video data from 13 rever programmes, including US, Chinaca, and Archick branches. OIKS05", it remains a for predefined development set of 85 neuro end year only the ESCOM website [LSC). As these specerously the test exceeded from the LSCOM website [LSC). As these specerously the spectrum.

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N August 2003, Mars came within 56 million et " Using more-sensitive cameras and deteckilometers of our home planet, its closest tors, they examined the Martian atmosphere antenachin neuro 50 000 years. On the astron and space environment and even discovered dy in our backyard, much to the delight of pole

sky watchers from its surface, and others from orbit. What equipped with highly advanced instrument

Surveying the Red Planet at Mars in 1997. It discovered that Mars once earlier, had a strong magnetic field. The orbiter also accurately manned the topography of Mars.

tance from the lowest spot on the surface of the planet to the highest exceeds 29 kilometers, compared with just over 19 kilometers for the earth."

Hellas basin, which was evidently formed by the ampace of a gipantic asteroid. The highest point is the summit of the immense, silometer-righ volcano Olympus Mons A camera photoard Surveyor also recorded boulders that appeared to be more than 18 meters across, as well as large shifting licks of send area as the dry land on earth, so it provide:

press, and the Mars Reconneissance Orbiter continued shear surveillance of the set plan

14 Awake! February 2005

nomical scale, that put the red planet practi- and mapped abundant ice at the planet's north This ice is a focus of the Phoenix Mars By bory 2004, a number of spectrari nad Lander which dropped down flawless on the converged on Mars Some studied the planet red planet on May 25, 2008. The Lander is

Dars UP CLOSE

have these missions tenehr as about our plan. to analyze both the atmosphere and the perlearn whether the icy soil has ever supported microbial life. However, the search for life-or The orbiter Mars Global Surveyor arrived at least conditions favorable to it-had been

> The Rovers Spirit and Opportunity nmera-of t

Opportunity, arrived on Mars in Januany 2004, their landing sites chosen on the Color-enh basis of data acquired from earlier mistions. The tovers- each about the r the arm. In 6 lowest sout on Mars is in the vast allys busin, which was evidently formed Martian atmosphere by using heat shields. parachutes, and rockets. When landing, they counced on the su face, encased in a cocoon of air bags in much the same way as their smaller prodecessor, Mars Patinnioer, had in

The surface of Mars has about the same dures and treatly carved pillies. Another many area as the dry and on each, so a contract the abroad scope for robotic exploration. The . which so a broad scope for robotic exploration is a broad scope for robotic exploration is site chosen for the rover Opportunity was Me maned an ul mission Although in November 2006 communication rocks containing the iron-rich mineral her ridiani Planum, a plateau of ancient layered sess the his automation of contrast, execution inter-tion with Mars Global Surveyor was lost three. the Spirit landed on the other side of Mars orbites, the 2001 Mars Odyssey, the Mars Fr., to explore the centrs of the ginnt Gasey effe le to life." When Spiril

* The 2001 Mars Odysney and the Mars Reconstatistance Or ⁴ Nueven with meters represents the distance from the heat. Morini traction (NASA), are the Mars Eveness was familied by the European Seate Agency.

Marsupclose

kilometers of our home planet, its closest ters, they examined the Martian atmosphere approach in nearly 60,000 years. On the astro- and space environment and even discovered nomical scale, that put the red planet macti- and mapped abundant ice at the planet's northcally in our backyard, much to the delight of pole. sky watchers.

By carly 2004, a number of spacecraft had converged on Mars. Some studied the planet from its surface, and others from orbit. What equipped with highly advanced instruments have these missions taught us about our plancrary neighbor?

Surveying the Red Planet

at Mars in 1997. It discovered that Mars once - earlier. had a strong magnetic field. The orbiter also

accurately mapped the topography of Mars, revealing, among other things, that the distance from the fusient spot on the surface of the planet to the highes, exceeds 29 kilomoters, compared with just over 19 kilometers. for the earth. "

The lowest spot on Mars is in the vast Hellas basin, which was evidently formed parachutes, and reckets. When landing, they by the impact of a gigantic asteroid. The highest point is the summit of the immense. 21-kilometerhigh volcano Olympus Mons. A camera onboard Surveyor also recorded both 1997.2 ders that appeared to be more than 18 meters across, as well as large shifting fields of sand duncs and freshly carved gullies. Another in strument determined that most surface rocks are of volcanic origin.

tion with Mars Global Surveyor was lost, three tite. Spirit landed on the other side of Mars orbiters--the 2001 Mars Odyssev, the Mars Ux- to explore the cepths of the giant Gusev crapress, and the Mars Reconnaissance Orbitor -continued their surveillance of the red plan-

* Ninnteen kultunges a representa the discusse from the bot torn of the Mariana Treach in the Pacific Usean to the top of Mount Everest.

14 Awakel February 2009

N August 2003. Mars came within 56 million er.* Using more-sensitive curneras and detec-

This ice is a focus of the Phoenix Mars Lander, which dropped down flawlessly on the red planet on May 25, 2008. The Lander is to analyze both the atmosphere and the permairost at the polar region. Scientists hope to learn whether the icy soil has ever supported microbial life. However, the search for life-or The orbiter Mars Globa! Surveyor arrived at least conditions favorable to it-had begun

The Rovers Spirit and Opportunity

Two Mars Exploration Rovers, Spirit and Opportunity, arrived on Mars in January 2004, their landing sites claisen on the basis of data acquired from earlier missions. The rovers-each about the size of po-cart-slowed their descent through the Martian atmosphere by using heat shields, bounced on the surface, encased in a economof air bags in much the same way as their smaller predecessor. Mars Pathfinder, had in

The surface of Mars has about the same area as the dry land on earth, so it provides. a h-had scope for robotic exploration. The site chosen for the rover Opportunity was Metidiani Planum, a plateau of ancient lavered Although in November 2006 communications containing the properties mineral hema

¹ The 240, Mars Calvase, and the Mars Recontainstance Or-near zero function by the Numeral Approximiting and Space Administration (NMSA), and the Mars Equipres was humering by the European Space Agency. ² So the article 'A Richer Explores Mars,' in the June 22.

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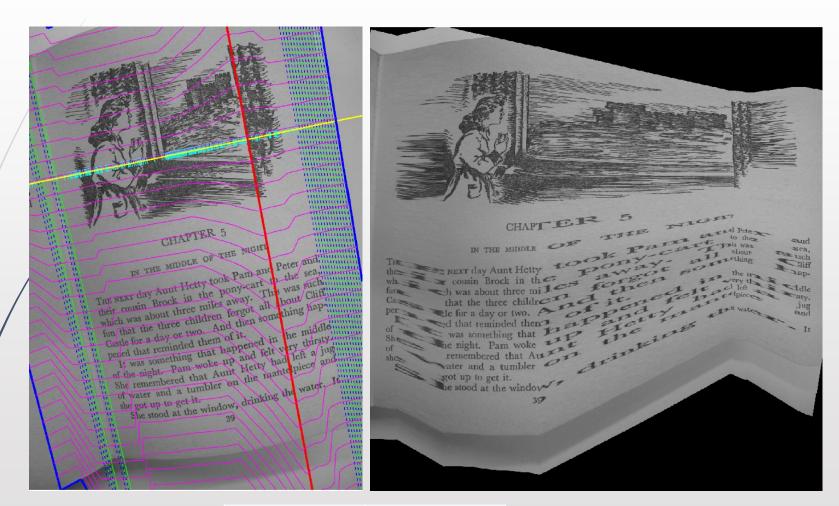
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Quantitative results

Recovered words on the IUPR ICDAR dataset

Our method	> 90%
[Takezawa 2016 & 2017]	~ 50%
[Chen et al. 2010]	~ 30%

A failure case



34 97 100



Conclusion

- Unlike many other dewarping methods ours does not require any text extraction, line segmentation or image binarization
- A generic method and interesting perspectives in areas other than document analysis

