Teaching Computer Vision and its Societal Effects: A Look at Privacy and Security Issues from the Students' Perspective

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Abstract

In this paper, we look at the societal effects of computer vision technologies from the perspective of the future minds in computer vision: senior year engineering students. Engineering education has traditionally focused on technical skills and knowledge. Nowadays, the need for educating engineers in socio-technical skills and reflective thinking, especially on the bright and dark sides of the technology they develop, is being recognized. We advocate for the integration of social awareness modules into computer vision courses so that the societal effects of technology can be studied together with the technology itself, as opposed to the often more generic 'impact of technology on society' courses. Such modules provide a venue for students to reflect on the real-world consequences of technology in concrete, practical contexts. In this paper, we present qualitative results of an observational study analyzing essays of senior year engineering students, who wrote about societal impacts of computer vision technologies of their choice. Privacy and security issues ranked as the top impact topics discussed by students among 50 topics. Similar social awareness modules would apply well to other advanced technical courses of the engineering curriculum where privacy and security are a major concern, such as big data courses. We believe that such modules are highly likely to enhance the reflective abilities of engineering graduates regarding societal impacts of novel technologies.

1. Introduction

Computer vision, which aims to make useful decisions about real physical objects and scenes based on sensed images [1], now permeates a vast range of everyday life activities. With this permeation comes societal impact, particularly on people's privacy and security. If we look back at its study and development, in the early stages in the 1970s, computer vision was viewed as the visual perception component of an ambitious agenda to mimic human intelligence and to endow robots with intelligent behavior [2]. The 1980s and 1990s saw a focus on the development of more sophisticated mathematical techniques for performing quantitative image and scene analysis [2]. It is not until the last decade or so that we see the ubiquity of computer vision-based systems and applications reaching into everyday life. Computer vision is indeed being used today in a wide variety of real-world applications, which include for instance automotive safety and control assistance (e.g. lane departure warning systems in vehicles), optical character recognition (e.g. conversion of scanned documents into readily usable machine-encoded text), motion capture (e.g. capturing human motion for computer animation in movies), medical imaging (e.g. registration of pre- and intra-operative imagery to assist surgeons in surgical operations), 3D model building (e.g. creation of 3D building models from aerial images used in systems such as Google Maps [3]), industrial inspection (e.g. defect detection for quality assurance in the textile industry), surveillance (e.g. highway traffic monitoring), face detection (e.g. for improved digital camera focusing) [2], social media (e.g. advanced image query in Facebook [4]), and natural user interface gaming (e.g. Microsoft Kinect [5] motion controller). This recent ubiquity brings about a plethora of questions regarding the social consequences of computer vision technology.

A legitimate question that needs to be explored relates to the education of the future engineers that will further contribute to the development and permeation of computer vision technologies. Education in engineering has traditionally focused on the development of technical skills and knowledge. Socio-technical skills enabling engineers to integrate thinking, feeling and behavior while pursuing industrial goals and societal interests have attracted more attention only recently [6]. One of the traditional barriers to the integration of reflective thinking into engineering courses has been the perception or stereotype that this is an activity only suited for humanities courses [7]. However, engineering program accreditation bodies from around the world have articulated the need for a broader education and the inclusion of complementary studies into the engineering curriculum that look at economic, environmental, societal, and global impacts of engineering innovations. The development of accountable disciplinary knowledge

2160-7516/17 $31.00 © 2017 IEEE
DOI 10.1109/CVPRW.2017.180

represents only one dimension of the multi-faceted process of becoming an engineer [8]. In his book on the culture of technology, Pacey [9] distinguishes two ways in which the word technology is used: 1) in a restricted sense identified entirely with its technical aspects, with cultural values and organizational factors regarded as external; 2) in a general sense, which is not value-free and politically-neutral, and offers a contextualized perspective through the preferred term 'technology-practice'. He defines technology-practice as the application of scientific and other knowledge to practical tasks by systems that involve people and organizations, living things and machines, and incorporates technical, organizational, and cultural (such as values and ethical codes, awareness) aspects [9]. This definition is in line with our main objective, which is to integrate the development of socio-technical skills and reflecting thinking abilities for the contextualization of technology to the engineering curriculum, in parallel to technical skills, within engineering technical courses such as computer vision courses, via social awareness modules.

1.1. Related work

Early efforts reported in the literature to address the integration of societal impacts of technology into the engineering curriculum include the works by Vanderburg and Khan [10], who asked 1) how much do we teach students about the influence technology has on human life, society and the natural ecology? and 2) to what extent is this knowledge used in a negative feedback mode to adjust engineering methods and approaches to achieve a greater compatibility between technology and its contexts? They examined the extent to which students learn to incorporate an understanding of how technology affects human life, society and the biosphere into engineering theory and design in order to ensure a greater compatibility between technology and its contexts; the study showed cause for deep concern at the time. Installé [11] reported early efforts at the University of Louvain on a seminar on ethics, technology, society and environment. According to him, traditional engineering education, which allows engineers to perform very skillfully in the realm of technical problems, does not prepare them to consider the socio-economical and environmental dimensions of their activities. Given the impacts of technology on the socio-economic and natural environments, better preparation of student engineers to integrate such dimensions into their future professional decision-making processes should receive a very high priority within the engineering school's curricula [11]. One approach to improve the preparation of engineering school students to take into consideration socio-economic as well as environmental aspects in their future profession, tried at the University of Louvain, was that within each course, a lecture be organized that would be given by a person from another department or faculty (i.e. sociology, biology, etc.), who would present their point of view on the subject of the course [11].

A historical perspective has also been utilized to engage engineering students in societal aspects of technology. Dick and Stimpson [12] presented details on a course in technology and society for engineering students at the University of Manitoba that incorporates historical, current and future perspectives. The authors argue for the importance of engineering students to have a sense of the origins of their chosen profession in conjunction with present-day societal issues.

Several works can be found in the literature that report engineering education initiatives focusing on existing social issues that are addressed by technology, rather than the social impacts of technology. Examples include the work of Slivovski et al. [7] who reported on the Engineering Projects in Community Service (EPICS) Program in the School of Electrical and Computer Engineering at Purdue University, which has been adopted by many universities. The EPICS Program matches teams of engineering undergraduates with community service agencies that request technical assistance; the long-term projects ensuing from the matching allow students to learn lessons on the significant impact that their engineering skills can have on their community. The program also includes specific modules for guided reflection. One of these modules is the social context module, in which students are invited to reflect on their projects as more than just technical problems but as existing within a larger constellation of economic, political, and cultural interactions [7]. DiBiasio et al. [13] discussed another example of engineering education initiative focused on the development of technology that takes existing social and cultural issues into consideration. They reported the results of an introductory sophomore-year engineering course that aims to increase social, cultural, global, and diversity awareness. They found that most students were able to address appropriate cultural issues while demonstrating competency in the technical aspects, but longer term retention was problematic. Targeting the development of global skills for engineering students, Alpay et al. [14] reported various cross-departmental initiatives at the Imperial College London. The initiatives were set up to broaden the inter-professional and skills-focused development of engineering students, and to emphasize engineering in its context of societal priorities. The initiatives included the Engineering Impact series of lectures, flexible timetabling for shared option-courses across departments, a common framework for engineering ethics engagement, and the establishment of a new academic role for the support of student-led projects, which illustrate a range of methods that go beyond the discipline boundaries [14].

Many efforts that relate to the ethical aspects of technology and their integration into the engineering curriculum as a reflection skill development have been reported in the literature. While they may slightly differ topically speaking from the societal impacts of technology, a parallel can drawn between ethics and societal impacts with regard to the way they are embedded in an otherwise technical engineering curriculum. Drake et al. [15] noted that many engineering departments are dealing with the issue of how to incorporate engineering ethics into their already crowded curriculum without simultaneously increasing resource requirements, an issue that is also relevant to societal impacts of technology. In a study conducted at Georgia Tech, their findings suggested that a limited module is not sufficient for improving moral reasoning skills of engineering students, while a full course on ethics did not make a significant increase in moral reasoning either (when compared to a control group). They concluded that engineering ethics must be integrative, delivered at multiple points in the curriculum, and incorporate discipline specific context [15]. O'Neill-Carrillo et al. [16] presented the efforts at the College of Engineering of the University of Puerto Rico in Mayagüez on integrating ethics and educating socially responsible engineers through the Ethics Across the Curriculum (EAC) strategy, part of the Social, Ethical and Global Issues (SEGI) in Engineering program. EAC is based on the combination of faculty development workshops, a stand-alone course in ethics, and ethics learning modules integrated at various levels of the engineering curriculum, and was expanded soon after its inception to include social and global issues in engineering. Also part of the SEGI program of the University of Puerto Rico in Mayagüez, the Interdisciplinary Group on Philosophy, Engineering and Technology was formed to provide space and opportunity for the critical discussion of technology and its implications for human life [17]. From the students' feedback on topic-specific forums organized by the group, Castro-Sitiriche et al. concluded that interest in the non-technical issues related to technology is high [17].

1.2. Contributions

De Vries [18] proposed several relevant questions for educational research purposes that relate to technology as part of our human nature: are students aware of the human and social aspects of technology? do they recognize both the positive and the negative possible impacts of technology? are they aware of the non-neutral character of technology or do they have an instrumental view on it? Using these questions as guides, we explore in this paper the educational value of a non-technical essay assignment in the context of a senior year technical course in computer vision. The essays were part of a social awareness module in a course on computer vision, aiming to weave the development of contextual thinking skills into the fabric of the technical course, an exercise in understanding the potential threats and opportunities of computer vision. The rationale for including such an assignment into the advanced level technical course is akin to the conclusions put forward by Drake et al. for integrative ethics (societal impacts in our case) delivered at multiple points in the curriculum and incorporating discipline specific context [15]. Courses dedicated to exploring the relationship between technology and society typically examine socio-cultural impacts from a generic viewpoint; modules in technical courses, as proposed here, allow for detailed examinations of specific technologies that are of interest to the students. In this paper, we present the fruits of our social awareness module via an observational study analyzing student essays, designed to provide insights into the awareness and level of thinking of senior year engineering students regarding the societal effects of computer vision technology.

The paper makes the following contributions. From an educational point of view, we propose to integrate the study of societal impacts of technology into technical courses such as computer vision courses, so that these impacts can be studied alongside the technology itself. From a practical point of view, the paper provides new insights on the societal impacts of computer vision technology from the perspective of senior year students from several cohorts, especially on privacy and security issues, and new insights on the students' strengths and weaknesses relating to their reflective thinking abilities about the societal impacts of computer vision, as expressed in written essays.

The remainder of the paper is structured in the following way. Section 2 describes our proposed approach. Section 3 discusses our findings on the students' essays. Section 4 presents concluding remarks and possible future works.

2. Proposed approach

This section presents our approach to the study of senior year computer engineering students' essays on the societal effects of computer vision technology. We first describe the assignment given to students, then explain the coding-based qualitative research methodology and other approaches used to analyze the students' essays.

2.1. Computer vision course and essay assignment

The computer vision course is a senior year technical elective course offered to students in computer and electrical engineering programs, and has a consistently high undergraduate enrolment. The course objective is to provide students with the basic skills needed to analyze, formalize, and solve computer vision problems. Its syllabus covers the following: overview of the main concepts and methods in computer vision; geometry and physics of imaging, as related to image formation and representation; image pre-processing for feature extraction; image segmentation; binary shape analysis; texture analysis; motion analysis; feature selection and pattern recognition; in-class and on-line discussions on the social, economical, and cultural impact of various modern computer vision technologies. The learning outcomes are: understand basic concepts, mathematical tools, and algorithms for manipulation of digital images; implement an algorithm to solve a specific computer vision problem; evaluate the performance of the algorithm using quantitative evaluation methods; assess the social/economical/cultural impact of novel computer vision technologies. The last element of the syllabus and its corresponding learning outcome are of interest here.

As part of the social awareness module of the course, the students were asked to write a 750 to 1000 word essay (worth 5% of the final course mark) conducting an investigation on the socio-cultural implications of novel computer vision-based technologies. The students were asked to select a computer vision technology (program/app, consumer product, etc.) which has a significant socio-cultural impact, briefly describe the selected technology, and discuss its socio-cultural implications, backing up their arguments with references.

2.2. Essay analysis

The essay analysis constitutes an observational study; we attempt to gain insight into the awareness of senior year computer engineering students about the societal impacts of computer vision technology, and into their level of thinking. Research questions of interest include: what topics are addressed by students? what place do privacy and security issues take? what level/depth of analysis are students able to perform? In order to analyze the students' essays, which constitute a qualitative dataset, we use a coding-based qualitative research methodology, along with a rubric for rating the students' critical and integrative thinking.

According to Saldana [19], coding is the transitional process between data collection and more extensive data analysis. A code, in qualitative inquiry, is most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data [19]. There are several dozens of coding methods reported in the literature. In this paper, we adopt the technique of descriptive coding. Descriptive coding summarizes in a word or short phrase, most often as a noun, the basic topic of a passage of qualitative data [19]. Passages of the students' essays dealing with the impacts of the selected technology are therefore coded to capture the various topics (we use the terms 'code' and 'topic' interchangeably in the remainder of the paper). Coding was performed by the lead author, then verified by the co-author.

We may then analyze the code frequencies among the essays and discover trends. Namey et al. [20] suggest determining code frequencies on the basis of the number of individual participants who mention a particular topic, rather than the total number of times a topic appears in the text. They base their recommendation on the assumption that the number of individuals independently expressing the same idea is a better indicator of overall thematic importance than the absolute number of times a topic is expressed and coded. We thus compile code frequencies according to the number of essays in which they are found. We also study the topic prevalence by technology. These essay- and technology-centric analyses allow us to figure out how much privacy and security issues, as societal impacts, are addressed by the students.

Another relevant aspect that we want to analyze from the students' essays relates to the associations between topics, i.e. their proximity. What topics are found together in the students' essays? What does this tell us about how the students explored the societal impacts of computer vision? We thus analyze associations between topics by looking at the proximity of the codes, i.e. codes that appear together in the same essay. We compile, for each possible pair of codes, in how many essays the pair is found. These statistics are akin to an incidence matrix that shows the relationships between two classes of objects A and B, with the number of rows and columns dictated by the number of elements in A and B, respectively. Each row represents the first code of a pair, and each column the second code of a pair. The value of a particular cell indicates the number of essays that include the specific pair ($code_A$, $code_B$). As these 'absolute' statistics, i.e. computed in terms of the total number of essays that contain each pair, might be biased towards the most frequent topics, we utilize a more objective way to look at the proximity between topics by computing instead the relative occurrence of each pair: in what proportion is each code in the pair found with the other code? The relative incidence matrix can be computed from the absolute incidence matrix, by dividing the total number of essays that include the specific pair ($AbsOcc_{AB}$) by the total frequency of $code_A$ ($Freq_A$), which is assigned to row $code_A$ column $code_B$, and also by the total frequency of $code_B$ ($Freq_B$), assigned to row $code_B$ column $code_A$. The relative occurrence of a pair is thus an asymmetrical relation, as the relative occurrence of $code_A$ with respect to $code_B$ ($RelOcc_{AB}$) is computed using a different denominator than the relative occurrence of $code_B$ with respect to $code_A$ ($RelOcc_{BA}$):

$$RelOcc_{AB} = AbsOcc_{AB}/Freq_A \tag{1}$$

$$RelOcc_{BA} = AbsOcc_{AB}/Freq_B \tag{2}$$

Finally, we look at the students' level of thinking based on the discussion of positive and negative impacts if applicable and on the inclusion of personal thoughts/analysis. These clues are based on the Critical and Integrative Thinking (CIT) rubric, a tool developed by the Center for Teaching, Learning, and Technology at Washington State University (WSU) [21] to guide the rating of students' critical and integrative thinking. With this tool, each assessment criterion is marked using a score ranging from 0 (absent) to 6 (mastering), with 4 (competent) representing competency for a student graduating from WSU. The two CIT criteria that apply in our case are "integrates diverse relevant perspectives" and "develops, presents, and communicates own perspective, hypothesis or position". Several researchers have reported using this tool in the literature (e.g. [22]).

We use RQDA [23] as our computer-assisted qualitative data analysis software (CAQDAS), which is based on R, a free software environment for statistical computing and graphics. Many studies have successfully used RQDA for qualitative and quantitative analyses in various fields such as perception of medical care, expert evaluation of enterprise resource planning systems, or student and faculty outcomes for capstone projects (e.g. [22]).

3. Results

This section presents our findings in relation to the senior year computer engineering students' essays on the societal effects of computer vision technology. We first present the data, then we provide essay- and technology-centric analyses of the topics (codes) that are found in the students' essays, investigate the associations between topics, and finally analyze the students' level of thinking, with a special focus on privacy and security issues.

3.1. Data description

The data include all the essays for which consent to be used for this research project was obtained from the student. They consist of 13 essays for the year 2012, 17 essays for the year 2013, and 15 essays for the year 2014, (45 total). The essays cover various computer vision technologies and applications (total of 17, table 1). There is one essay that covers simultaneously two technologies or applications in the list above. There are eight essays from female students, and 37 essays from male students.

Table 1. Computer vision technologies and applications covered by the students' essays.

Technology/Application	# of Essays
3D modeling/virtual tour	2
ambient intelligence	5
augmented reality	5
autonomous cars	5
autonomous military robots	2
brain-computer interfaces	1
casino monitoring	1
computer aided diagnosis	2
content-aware image/video processing and filtering	3
driving assistance	3
drowning detection	2
emotion recognition	2
food/drug safety inspection	1
gaming	5
sports refereeing	1
traffic monitoring/management	4
visually impaired assistance	2

3.2. Privacy, security, and topic analysis

A total of 50 topics were used as codes in the process of coding the students' essays for societal impacts of technology. Table 2 presents the overall frequencies or prevalence of the topics (codes) with respect to the number of students' essays in which they are found. Interestingly, 'safety/security' comes in first place among the most prevalent topics identified as a societal impact of a computer vision technology, with a frequency of 29 (64.4%). 'Privacy/anonymity' comes in second place, alongside 'legislation/legality/policy making', with both a frequency of 22 (48.9%). Among all topics, only 'safety/security' was mentioned by a majority of students. Data security is included in 'safety/security'. Table 3 presents the prevalence of topics (codes) with respect to the number of technologies and applications (see table 1) for which they were discussed. Again, 'safety/security' constitutes the most prevalent topic, present in 14 technologies (82.4%), while 'privacy/anonymity' makes the top six with 8 technologies (47.1%). Privacy issues were discussed in 100% of the essays related to 3D modeling/virtual tour, ambient intelligence, drowning detection, and emotion recognition technologies, while security issues were discussed in 100% of the essays related to ambient intelligence, autonomous cars, casino monitoring, driving assistance, drowning detection, food/drug safety inspection, and traffic monitoring/ management technologies.

Typical excerpts from the students' essays that are associated with privacy and security issues include:

- 'safety/security':

  [Autonomous cars]: "Traffic accidents occur everyday around the world; some are deadly and some are just fender-benders. Autonomous vehicles are much more consistent in safety characteristics and faster reaction to changes in road situations; therefore, making the road safer by cutting down or eliminating from deadly crashes to daily fender-benders."

  [Ambient intelligence]: "The system would provide a sense of safety for elderly people in the home, knowing that the fall monitoring and motion tracking system is in place."

  [Ambient intelligence]:"This technology can increase security and help better protect people."

  [Augmented reality]: "The potential effects of malware on such devices is a huge unknown factor.

Table 2. Prevalence of topics (codes) related to societal impacts of computer vision in the students' essays.

Topic (Code)	# of Essays
safety/security	29
privacy/anonymity	22
legislation/legality/policy making	22
productivity/efficiency	15
expenses/cost reduction/increase	13
reliability of technology	11
law enforcement/abidance	11
assistance	10
job loss/job shift	9
friendship/social relations	9
stress/mental health	9
liability	8
quality of life	8
behavior change	8
autonomy/independence	7
revenue loss/gain	7
commuting/transportation	7
advertisement/marketing	7
medical care accessibility	6
self-image	5
medical care quality	4
fuel/energy efficiency/consumption	4
popularity	4
authenticity/integrity	4
morality/ethics	4
physical discomfort/injury	4
carbon emissions	3
human abilities/skills	3
resource/staff management	3
abuse/violence/exploitation	3
dehumanization	3
looks of consumer products	2
exercising	2
education	2
addiction/dependence	2
destruction/human casualty	2
identity theft/fraud	2
warfare	2
communications	1
family time	1
healthy lifestyle	1
social etiquette	1
film industry	1
sports enjoyment	1
unfairness	1
social advancement	1
medical consent	1
media coverage	1
international monitoring/spying	1
global warming	1

Table 3. Prevalence of topics (codes) related to societal impacts of computer vision by technology (or application).

Topic (Code)	# of Technologies
safety/security	14
legislation/legality/policy making	12
expenses/cost reduction/increase	9
productivity/efficiency	9
reliability of technology	9
privacy/anonymity	8
behavior change	8
job loss/job shift	7
law enforcement/abidance	7
quality of life	7
stress/mental health	7
assistance	6
friendship/social relations	5
liability	5
medical care accessibility	5
revenue loss/gain	5
advertisement/marketing	4
morality/ethics	4
physical discomfort/injury	4
popularity	4
resource/staff management	4
abuse/violence/exploitation	3
authenticity/integrity	3
autonomy/independence	3
commuting/transportation	3
human abilities/skills	3
medical care quality	3
self-image	3
addiction/dependence	2
carbon emissions	2
dehumanization	2
fuel/energy efficiency/consumption	2
looks of consumer products	2
warfare	2
communications	1
destruction/human casualty	1
education	1
exercising	1
family time	1
film industry	1
global warming	1
healthy lifestyle	1
identity theft/fraud	1
international monitoring/spying	1
media coverage	1
medical consent	1
social advancement	1
social etiquette	1
sports enjoyment	1
unfairness	1

For example, potential exploits could use the camera of the device to record images when the user is unaware, capturing any amount of important and sensitive data."

[Driving assistance]: "False positives would not just annoy the driver but a sudden stop can cause other drivers to react with panic which can also cause an accident where none should happen in the first place. However, with false negatives the probability of an accident is much higher."

- 'privacy/anonymity':

  [Augmented reality]: "The fact that it is an opt-out program and that someone can take your photo without your consent infringes on personal privacy."

  [Ambient intelligence]: "With regards to invasion of personal privacy, satellite imagery has been around

Table 4. Top 20 proximity relationships between pairs of topics (codes) in terms of relative occurrence of the first topic ($code_A$) with the second topic ($code_B$), related to societal impacts of computer vision.

Rank	$code_A$	$code_B$	Relative Occurrence $RelOcc_{AB}$ (%)[a]
1	commuting/transportation	**safety/security**	100.0
2	reliability of technology	**safety/security**	90.9
	law enforcement/abidance	**safety/security**	90.9
4	productivity/efficiency	**safety/security**	86.7
5	autonomy/independence	**safety/security**	85.7
	commuting/transportation	productivity/efficiency	85.7
7	self-image	friendship/social relations	80.0
8	job loss/job shift	**safety/security**	77.8
	stress/mental health	**safety/security**	77.8
	stress/mental health	productivity/efficiency	77.8
11	expenses/cost reduction/increase	**safety/security**	76.9
	expenses/cost reduction/increase	productivity/efficiency	76.9
13	liability	**safety/security**	75.0
	quality of life	**safety/security**	75.0
	liability	legislation/legality/policy making	75.0
	liability	reliability of technology	75.0
17	**privacy/anonymity**	**safety/security**	72.7
	reliability of technology	legislation/legality/policy making	72.7
	law enforcement/abidance	legislation/legality/policy making	72.7
20	revenue loss/gain	**safety/security**	71.4

Only topics that have a frequency of 5 or more are considered.
[a]The relative occurrence is that of $code_A$ with $code_B$, computed as the number of essays for the pair divided by the number of essays for $code_A$ (1).

for many years, and the issue has been present ever since the technology was introduced. In recent years however, the quality of the imagery has drastically improved to the point where the personal lives of individuals are possible to be tracked."
[Content-aware image/video processing and filtering]: "However, although PrivacyCam can afford more privacy than standard CCTV cameras, there are still many arguments against them. Since the PrivacyCam cameras perform analysis of the video, including identity detection and tracking, they are potentially worse for privacy than CCTV cameras which just provide the raw feed. Also, the issue of recording citizens remains. Many people are strongly against the idea of being recorded constantly, especially given the lack of consent. Since there is no guarantee that the owner of the camera is using it as intended, so there is no way for a citizen to tell if the processed video is actually being used instead of the raw feed."
[Drowning detection]: "The images can be used to identify swimmers and invade their privacy."
[Emotion recognition]: "Topics such as this are indicative of a trend to apply technology to intrude on the privacy of people. Much like the application of facial recognition to track people's activities, emotion recognition can be used to track a subject's emotional reaction to stimulus, allowing a dossier or emotional profile of a tracked subject to be developed. This could easily be accomplished without the knowledge of the participant, just as cameras may record activities without the knowledge of the participant, or tracking software may record online browsing habits without the knowledge of the participant, or even after permission has explicitly been denied. The precedent has long been set, with nearly all the power over a person's privacy given to the parties least interested in preserving that privacy. It is left to those being infringed upon to cope as best they can."

From tables 2 and 3, the large quantity of codes suggests that students have explored many subjects and have a variety of interests with respect to the societal effects of computer vision, which often go beyond the most obvious and mainstream topics related to a particular computer vision technology. The fact that privacy and security issues ranked in the top most frequently discussed impacts, both with respect to the number of essays and the number of technologies, within that vast range of impacts (50), reinforces the sentiment that the consequences of computer vision in real life on privacy and security are taken seriously by the students and hold a prominent place within the realm of potential threats and opportunities of computer vision.

3.3. Association between topics

Table 4 shows the top 20 topic proximity relationships in terms of the relative occurrence of $code_A$ with $code_B$ ($RelOcc_{AB}$) computed with (1), i.e. the proportion in which the essays that contain $code_A$ also contain $code_B$, for all topics that have a minimal frequency of 5. All pairs from this top 20 possess a relative occurrence of at least 70%, which constitute strong proximity relations. Interestingly, 'commuting/transportation' is found 100% of the time in proximity to 'safety/security', the only relative occurrence of 100% from all the essays, which suggests that the issue of safety and security is a primordial societal impact of commuting/transportation-related computer vision technologies (e.g. autonomous cars) to discuss from the students' viewpoint. Privacy and security issues, via the 'safety/security' and 'privacy/anonymity' codes, appear in the majority of these top proximity relationships (60%), supporting their high importance and strong connections with various other societal impacts. They appear to have a central role when it comes to understanding the potential threats and opportunities of computer vision.

3.4. Level of thinking

Using the CIT rubric [21], we assessed the students' ability to integrate diverse perspectives, represented typically by positive and negative aspects, or contrary views, relating to the societal impacts of the computer vision. Students obtained a score of 4.1 ± 1.2 on average for the diverse perspectives criterion, with a minimum of 0 and a maximum of 6. This means that they integrated multiple viewpoints, compared ideas and perspectives, acknowledged the value of presenting multiple perspectives, but that they sometimes discussed them in a limited way. Some students favored to list and analyze positive impacts followed by negative impacts, whatever the topic of the impacts, while others opted for a topic-centric approach.

Using the same tool, we also assessed the students' ability to develop, present, and communicate their own perspective or position on the societal impacts of technology. Students obtained a score of 3.8 ± 1.3 on average for the own perspective criterion, with a minimum of 0 and a maximum of 6. According to the rubric, this means that there was generally some evidence of reflection and/or self-assessment but that the students generally remained within predictable parameters; few students demonstrated ownership for framing original questions and explored ideas that stretched conventional parameters. The slightly lower score for the own perspective criterion, compared to the diverse perspectives criterion, suggests that typically, students did present various perspectives on the societal impacts, but were less inclined to draw their own. The following excerpts from the essays illustrate some of the ways that were taken by the students to communicate their own perspective:

- Concluding with a clear position: "Large cities that are experiencing [an] increase in the number of vehicles on the road are looking for a way to optimize the flow of traffic through high traffic areas. There are several products on the market now that use computer vision technology to solve this problem. The positive social consequences drastically outweigh the negatives when it comes to real-time traffic monitoring and management."
- Including personal experience: "Automated license plate recognition systems will vastly improve the detection of drivers holding suspended or revoked licenses [...] As knowledge of the system spreads, drivers holding suspended licenses will refrain from driving if the chances of getting caught are high. From personal experience, I know of people that have driven/drive with a suspended license but have not heard of any of them getting caught."
- Making predictions: "[About a vision enhancement (augmented reality) system called 'sixth sense'] As a technology like this becomes an integral part of day-to-day life a dependence [on] it may arise. With a technology so new as this, and so foreign to how things operate in the present, it is difficult and unrealistic to predict exactly how this dependence would take shape. Likely, it would resemble one of two cases: a dependence on the technology to operate properly and a requirement of sixth sense by other technologies."

4. Conclusion

This paper presents the fruits of an observational study analyzing senior year computer engineering student essays on the societal impacts of computer vision technology, with a particular emphasis on privacy and security issues. By integrating a social awareness module into a technical computer vision course, we aim to provide a venue for students to exercise their reflective thinking skills in the context of specific technologies that are of interest to them, in contrast to the often more generic 'impact of technology on society' courses. Through descriptive coding of the essays, we showed that security issues ranked as the top impact topic discussed by students among 50 topics, with privacy issues in second place. Using a proximity-based analysis, we also showed that those issues appear to have a central role when it comes to understanding the potential threats and opportunities of vision. Our approach of integrating reflective thinking development into the technical engineering curriculum for the contextualization of technology through a social awareness module was successful in the sense that it allowed students, who were able to offer an analysis at a competent level, to effectively reflect on the societal impacts of a computer vision technology alongside learning the related technical aspects.

Future works may include the integration of similar modules to other advanced technical courses of the engineering curriculum where privacy and security are a major concern, such as big data courses, to enhance the reflective abilities of engineering graduates regarding societal impacts of technology.

Acknowledgements

This work was supported by the Learning and Teaching Center of the University of Victoria, through the Learning without Borders Initiative.

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