Computer Vision: A Sectoral Composition Approach

Technology Series

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1. Introduction: Projected Computer Vision Industry Growth

Computer vision, an offshoot of AI and machine learning, has found secure industry support due to the variety of applications it yields for civilian use. As a field, computer vision includes science and technologies that incorporate advanced analytic capabilities, including AI, machine learning, and neural networks, in order to enable computers to see videos and images. In this case, "seeing" the videos and images means that the computers are able to scan the media with the purpose of distilling certain pieces of information -- a complicated task despite the fact that it is innate to humans and most living species. The fields for which the computer vision industry is finding market interest are diverse and varied, including transportation, education, research, government, defense, security, business, finance, and agriculture.

Recently published market research projects that the computer vision market may grow by nearly 10% in the next five years (increasing from USD $12 Billion to USD $19 Billion).[1] Many of the activities which are now receiving heightened attention and support due to COVID-19 involve computer vision capabilities, including remote education, virtual healthcare provision, and public health governance. Furthermore, computer vision technologies are benefiting from the continued improvement in foundational analytic technologies, such as AI and machine learning.[2]

2. Security Implications

Given the projected growth of the computer vision market, and thus the likely expansion of the computer vision production base, the security implications of computer vision development (and wider public dispersion) must also be considered. The two primary security implications for a growing computer vision market include 1) data availability and privacy concerns and 2) augmentation of strategic military technologies.

1 "Computer Vision Market Research Report by Component, by Application - Global Forecast to 2025 - Cumulative Impact of Covid-19," Markets Insider, July 30, 2020, <https://markets.businessinsider.com/news/stocks/computer-vision-market-research-report-by-component-by-application-global-forecast-to-2025-cumulative-impact-of-covid-19-1029453298#>.

2 Kim Martineau, "Toward a Machine Learning Model that can Reason about Everyday Actions," *MIT News*, August 31, 2020, <https://news.mit.edu/2020/toward-machine-learning-that-can-reason-about-everyday-actions-0831>.

With regard to data accumulation, personally identifiable information (PII) and military-sensitive information may be more easily acquired through computer vision, both through enhancing quality of current vision systems and enhancing the ability to continuously collect data with limited human assistance.[3,4] This data may then be used for nefarious purposes through better identifying targets and methods to achieve objectives. Accumulated data may also be used to manipulate military or civilian groups through disinformation.

Computer vision also promises to increase the threat of other strategic technologies. Missiles, drones, and other types of military playforms, when augmented with powerful computer vision systems, will likely experience improved performance and capabilities with respect to targeting as well as maintaining a continuous state of readiness.[5]

Additionally, and with a more tangential relation to national security, there are economic impacts of unrestrained computer vision transfer. The ability to capture a significant portion of the computer vision market may lead to large economic returns, as well as monopolization of data storage and collection, resulting in an economic/technological leadership. As noted in the quantum computing section, although this consideration deviates from standard dual-use delineation into a more politically motivated realm, it still may be a driver of future trade controls. Distinguishing between the true motives for a given control will be necessary in order to argue the direct benefits of the control.

Potential Use of Trade Controls

Due to concerns over the dual-use nature of computer vision technologies and the data accumulated using computer vision technologies, trade controls may offer a viable method to constrain widespread dispersion of either the technologies or the associated data, depending on the security concerns identified and the ability to limit impact on civilian-purposed technology markets. Computer vision was specified by the United States Department of Commerce as a subset of AI technologies that may be deemed subject to export controls for national security purposes.[6] Because computer vision is an application of AI, it is worth noting that export

3 Chris Ciabarra, "AI Vs. Privacy: Does Computer Vision Violate Your Right to Privacy?" *Forbes Technology Council*, December 18, 2019, <https://www.forbes.com/sites/forbestechcouncil/2019/12/18/ai-vs-privacy-does-computer-vision-violate-your-right-to-privacy/#1535d7571327>.

4 Christopher Chyba, "New Technologies and Strategic Stability," *Daedulus*, 2020. [Note, Chyba discusses 'persistent overhead surveillance' which is enabled through computer vision technologies].

5 Rand Waltzman and Thomas Szayna, "First, Manage Security Threats to Machine Learning," *War on the Rocks*, November 4, 2019, <https://warontherocks.com/2019/11/first-manage-security-threats-to-machine-learning/>.

6 Justin Doubleday, "Commerce Considering Emerging Technologies, Including AI, for Export Controls," *Inside Defense*,

controls on AI may ultimately act as computer vision software restrictions.

However, computer vision hardware, including sensors, lenses and processors, may also be deemed the subject of export controls if a specific chokepoint piece of hardware is found that offers a strategic military advantage with national security implications. Finally, specific types of data collection, transfer, or use may also be designated as controllable due to security implications, which could impact the broader computer vision field. Data regulations were noted in ANPRM comments as an area that could benefit from more robust export controls.[7]

Given the fact that certain computer vision technologies are already widely dispersed (as will be surveyed by this report), the most viable options for trade controls are emerging hardware components with large augmentation power, data accumulation and transfer, and controls on specific applications/uses. However, in determining appropriate controls, it will also be necessary to consider potential technology limitations that could arise from barring access to different countries and types of technology transfers.[8]

3. Technology Overview

Computer vision is a subset of AI technologies and most often is associated with deep learning and machine learning. The overarching goal of computer vision is to enable computers to analyze images and videos in order to ascertain certain kinds of information from various types of media. While this may be a simple task for humans, it has historically been challenging for computers, as it requires complex algorithms and software platforms capable of analyzing the numeric basis of images and videos (pigment counts, color coding, etc.) in order to "see" the image. Improvements in AI techniques, including deep learning, machine learning, and convolutional neural networks, have catalyzed dramatic improvements in computer vision capabilities.[9] Currently, computer vision systems are able to perform a large number of tasks (3D imaging, 2D image analysis, facial recognition, augmented reality, etc.) using a handful of hardware technologies (optical vision, laser scanning, infrared and ultraviolet vision, etc.)

November 21, 2018, <https://insidedefense.com/insider/commerce-considering-emerging-technologies-including-ai-export-control>.

7 "Comment for the Department of Commerce ANPRM on 'Review of Controls on Certain Emerging Technologies'," Amir Husain, Founder and CEO of SparkCognition, Inc., <https://www.regulations.gov/document?D=BIS-2018-0024-0096>.

8 Will Knight, "Export Controls Threaten the Future of AI Outposts in China" *Wired*, January 1, 2020, <https://www.wired.com/story/export-controls-threaten-ai-outposts-china/>.

9 Ben Dickson, "What is Computer Vision?" *PC Magazine*, February 9, 2020, <https://www.pcmag.com/news/what-is-computer-vision>.

and software techniques (object/pattern recognition/detection, image classification, object tracking, semantic segmentation, instance segmentation, etc.). This section will outline the different hardware bases, the software techniques, and the general applications. Finally, this section will discuss current policies and regulations over computer vision applications.

Technical Background

Computer vision is typically understood as a subcategory or application of AI that deals with image analysis.[10] A widely accepted definition for computer vision is: "the science and technology of machines that see, where seeing in this case means that the machine is able to extract information from an image that is necessary to solve some task."[11] Computer vision research began as early as the 1970s with basic image processing and has continued to improve to the point of achieving machine learning through computer vision. This has been enabled largely through advances in tangential software fields such as AI, neural networks, and deep learning.[12] The technology's growing applicability and popularity has even earned it a spot among the top AI technology trends for 2020.[13]

Given that computer vision has grown to be such an expansive field, different variations of the technology can be distinguished along a number of key axes, including: software versus hardware; 2D versus 3D vision, optical vision versus non-optical sensing, and the main techniques programmed for a given application. These different axes will be briefly reviewed below, although should not be considered exhaustive in enumerating the distinguishing characteristics of unique computer vision systems.

1. **Software and Hardware:** In computer vision, the required hardware includes a type of sensor and a processor to run software analyses. Typically a camera serves as the sensor, but some computer vision systems use other types of sensors, such as a laser, radar or thermal scanner. Recent hardware processor advances include newer graphical processing units (GPUs) and field-programmable gate arrays (FPGAs).[14] Software includes the program

10 Mark Sturdevant, "Introduction to Computer Vision," *IBM Developer Series*, July 12, 2019, <https://developer.ibm.com/technologies/artificial-intelligence/articles/introduction-computer-vision/>.

11 Sota Yoshida., ed., *Computer Vision*, *Computer Science, Technology and Applications* (N.Y.: Nova Science Publishers, 2011), p. Vii.

12 Richard Szeliski, *Computer Vision: Algorithms and Applications* (London: Springer, 2011), pp. 10-16.

13 Bernard Marr, "The Seven Biggest Technology Trends in 2020 Everyone Must Get Ready for Now," *Forbes*, September 30, 2019, <https://www.forbes.com/sites/bernardmarr/2019/09/30/the-7-biggest-technology-trends-in-2020-everyone-must-get-ready-for-now/#309411362261>.

14 Computer Vision Algorithms and Hardware Implementations: A Survey," *Integration*, the VLSI Journal, 2019, pp. 309-320.

language, algorithms, and mathematical techniques used to convert the image produced by the sensor into meaningful information.

2. **2D and 3D Analysis**: Within the field of computer vision, there is another key distinction between whether a specific technology performs two dimensional (2D) analysis or three dimensional (3D) analysis. Traditional computer vision, or 2D analysis, involves the analysis of a single image in order to identify specific characteristics and gain relevant information. However, more recently, the field of 3D computer vision has emerged.[15] Requiring multiple photos or a video, 3D computer vision allows for the determination of factors that vary spatially and/or temporally. It may also allow for the reconstruction of a 3D process or object through the use of a point cloud which measures different aspects of an object or process.[16]

3. **Optical and Non-Optical Vision:** Another distinction is whether traditional optical vision cameras are serving as the sensors/initial data producers or if other methods of imaging are used such as thermal vision, infrared or ultraviolet light, or laser scanners. (Here, optical is referring to visible imaging; while lasers may fall under the scientific field of optics, when applied in computer vision they are used to track motion and non-visible phenomenon).

4. **Main Techniques**: Finally, more narrow distinctions among computer vision software depend on the type of technique applied by a given system to accomplish a specific task. The main technique types applied include:[17]

   - ☐ Object/pattern recognition/detection identifies the objects or patterns that appear in an image;[18]

   - ☐ Object/image classification identifies broader categories that the objects or patterns appearing in an image belong to, or potentially classifies the image as a whole;[19]

   - ☐ Motion sensing/object tracking follows the motion of a single object as it changes

15 Mariya Yao, "What are Important AI & Machine Learning Trends for 2020?" *Forbes*, January 22, 2020, <https://www.forbes.com/sites/mariyayao/2020/01/22/what-are--important-ai--machine-learning-trends-for-2020/#79f53c232391>.

16 Boguslaw Cyganek and J. Paul Siebert, *An Introduction to 3D Computer Vision Techniques and Algorithms* (Wiley, 2009).

17 Jason Brownlee, "A Gentle Introduction to Computer Vision," Deep Learning For Computer Vision, March 19, 2019, <https://machinelearningmastery.com/what-is-computer-vision/>.

18 Mark Sturdevant, "Introduction to Computer Vision," *IBM Developer Series*, July 12, 2019, <https://developer.ibm.com/technologies/artificial-intelligence/articles/introduction-computer-vision/>.

19 Ibid.

form or position between frames;[20]

- Semantic segmentation classifies or predicts labels for all pixels in a given image based on the object they belong to, and thus is similar to image classification but more comprehensive and granular;[21]

- Instance segmentation extends beyond semantic segmentation by labeling instances of objects within the same class;[22]

- Facial recognition specifically identifies a person through recognizing a face based on features and shape.

4. Policy Background

Because computer vision is a subcategory of AI, many current policies that are strictly related to AI, by nature of the relationship between the two technologies, include computer vision. U.S. policy regarding AI has been numerous in recent years. In 2019, the Executive Order on Maintaining American Leadership in Artificial Intelligence was issued.[23] In January 2020, BIS issued a new control on AI, which incidentally impacts the computer vision industry.[24] The control covers software designed to automate geospatial imagery analysis, which could be included under the category of computer vision technologies, even if not explicitly stated in the ruling.[25] Interestingly, and potentially worthy of note, the difficulty of finding policies explicitly focused on computer vision highlights the challenges of broad national strategies on AI as a whole, rather than national strategies or policies towards specific AI subcategories.

20 Ibid.

21 "Semantic Segmentation Using Deep Learning," MathWorks Documentation, <https://www.mathworks.com/help/vision/examples/semantic-segmentation-using-deep-learning.html>.

22 Abdul Mueed Hafiz and Ghulam Mohiuddin Bhat, "A Survey on Instance Segmentation: State of the art," *Journal of Multimedia Information Retrieval* (2020):1-19, <https://arxiv.org/abs/2007.00047>.

23 "Executive Order on Maintaining American Leadership in Artificial Intelligence," United States White House Archive, February 11, 2019, <https://www.whitehouse.gov/presidential-actions/executive-order-maintaining-american-leadership-artificial-intelligence/>.

24 Burke et. al., "Bureau of Industry and Security Issues First "Emerging Technology" Control on Artificial Intelligence-Based Geospatial Imagery Software," White and Case - Publications, February 7, 2020, https://www.whitecase.com/publications/alert/bureau-industry-and-security-issues-first-emerging-technology-control-artificial#:~:text=On%20January%206%2C%20 2020%2C%20the,geospatial%20imagery%20and%20point%20clouds.

25 "Addition of Software Specially Designed To Automate the Analysis of Geospatial Imagery to the Export Control Classification Number 0Y521 Series," U.S. Department of Commerce, Federal Register, Vol. 85, No. 3, January 6, 2020, pgs. 459-462, <https://www.govinfo.gov/content/pkg/FR-2020-01-06/pdf/2019-27649.pdf>.

One area of computer vision that has received a significant amount of attention among policymakers is facial recognition. Many governmental agencies have expressed interest in applying facial recognition to their activities, particularly organizations under the Department of Homeland Security, including Customs and Border Patrol and the Transportation Security Agency.[26] However, other members in the government, and even in the private sector, have expressed concern over certain applications, calling for federal protections on facial recognition use and associated data sets.[27]

5. Mapping Analysis

Overview

This mapping analysis found that the computer vision industry has largely surpassed the research and development stage of technology production. Private industry interest in computer vision has fostered a robust, global manufacturing base. Because the technology is no longer in the early research and development stage, many of the partnerships that exist for younger technology areas, like quantum computing, do not exist. Instead, firms are staking their claim for certain applications of computer vision and producing patented computer vision technologies. There is also significantly less government and academia involvement. Thus, although computer vision was listed as a potential target for export controls, this research shows that computer vision technologies are already widely available. However, export controls on certain byproducts of computer vision technologies, such as data libraries and training data sets, may be desirable. Additionally, specific, high-resolution or high-performance computer vision sensors and cameras may still be controllable, if a security relevance is identified.

Selection of Organizations

Organizations were selected for the computer vision mapping analysis if they are actively developing computer vision hardware or software technologies. This includes companies that use computer vision as a subcomponent of some larger technology (for example, drones),

26 "Facial Recognition: CBP and TSA are Taking Steps to Implement Programs, but CBP Should Address Privacy and System Performance Issues," United States Government Accountability Office: Report to Congressional Requesters, September 2020, https://www.gao.gov/assets/710/709107.pdf.

27 Tom Simonite, "A Bill in Congress Would Limit Uses of Facial Recognition," *Wired*, June 12, 2020, https://www.wired.com/story/bill-congress-limit-uses-facial-recognition/.

companies that have included computer vision technologies in a larger portfolio, and companies that work exclusively on computer vision. In some cases, a distinction had to be made between machine vision and computer vision because the former falls outside of the scope of this mapping analysis. For these cases, an assessment was made based on the

description provided by the company about the type of programming used and the actions performed by the computer vision system. Computer vision systems based on non-optical sensors, such as lasers, radars, and heat sensors were also included in the database.

In total, this analysis identified 200 computer vision firms. This likely only represents a fraction of the industry, given the wide dispersal and large manufacturing base. For reference, a survey conducted in August 2020 on start-up companies alone found 529 companies labeled under the category of computer vision on an investment platform.[28] However, because the firms were chosen through a number of different manners (including business database searches and computer vision libraries), the authors hope to have captured a representative piece of the computer vision industry. It also must be noted that although the computer vision industry is not in a nascent stage of development, there have still been organizations that have ceased operation or have been acquired since the beginning of data collection. In these cases, the mapping data has been updated as much as possible to account for changes.

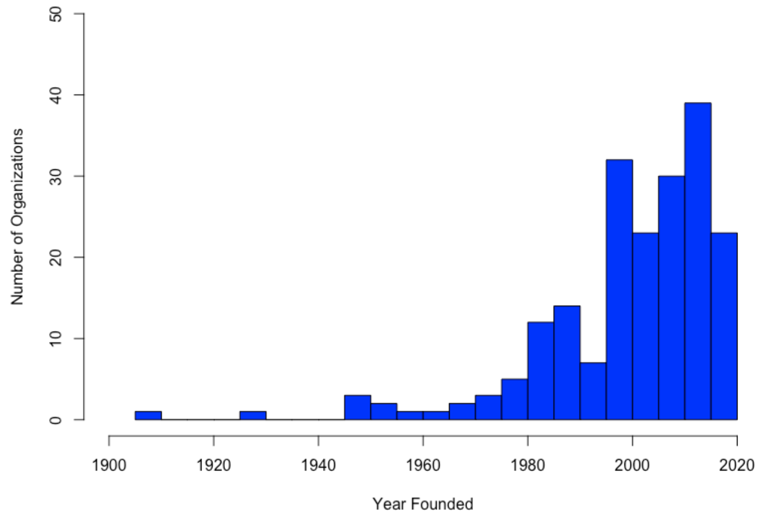
Findings

1. Organization Age and Type

Based on this analysis, the computer vision manufacturing base may have already seen its peak organization establishment period. As shown in Figure 9, the large surge in computer vision entity development began in the 1990s and continued through the early 2000s. However, given that the average ages for the organizations focused on hardware, software, or both are 37, 13, and 25 years, respectively, it is likely that the peak for hardware company development occurred much earlier, and thus the increase in growth in the manufacturing base in the 2000s can be attributed to computer vision software companies.

28 Irina Peregud and Anastasiya Zharovskikh, "Computer Vision Applications Examples Across Different Industries," InData Labs, August 19, 2020, <https://indatalabs.com/blog/applications-computer-vision-across-industries>.

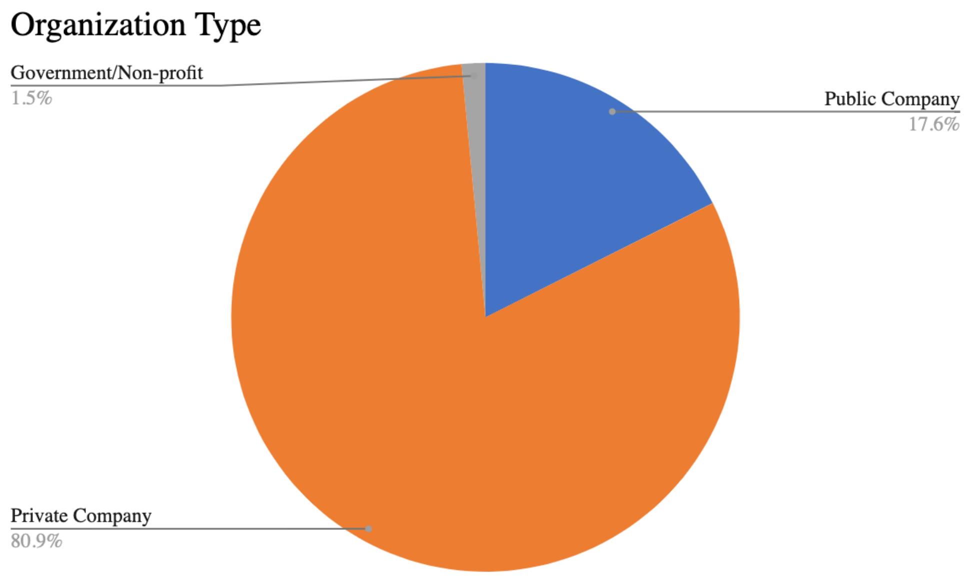
Figure 1. Computer Vision Founding Years, 1900-2000



A large majority of the computer vision manufacturing base is composed of private or public companies. As shown in Figure 10, private companies make up 80.9% of the manufacturing base and public companies make up 17.6%, leaving just 1.5% of the organizations analyzed to be government or non-profit firms. This further supports the hypothesis that the field of computer vision technologies is no longer in the research and development stage.

Computer vision has a larger percentage of public-for-profit organizations (17.6%) than PNT (9%) or quantum computing (12%). This is likely due to the fact that computer vision is already marketable and distributable. This means that computer vision products are already able to be profitable and therefore public companies are more willing to acquire private companies that produce computer vision capabilities or are more willing to create their own line of computer vision products so that they can capitalize on computer vision sales.

Figure 2. Computer Vision Industry by Entity Type



2. Global Dispersion

The global dispersion of the computer vision manufacturing base was analyzed using both a mapping visualization of the headquarters locations of the organizations and through quantitative analysis of multinational operations. As Map 4 shows, computer vision organizations are spread out globally, though maintain large presences in North America, Europe, and Asia. A smaller hub of organizations also exists in the Middle East (largely concentrated in Israel).

Map 5 specifically shows the geographical distribution of organizations based on whether they produce hardware, software, or both. Due to the fact that the hardware manufacturing base is smaller, it might be more directly susceptible to trade controls. However, because the organizations that distribute hardware technologies tend to be large firms with distribution and manufacturing facilities in multiple countries, the utility of the mapping visualization may be limited, especially compared to manufacturing bases where firms do not have multiple locations and are predominantly located at their headquarters' country.

Map 1. Computer Vision Global Dispersion

Map 2. Computer Vision Global Dispersion by Technology Focus

In order to determine the extent to which the headquarters mapping visualization utility is limited, and to gain a better understanding of the global presence of the manufacturing base, international transaction mechanisms were also analyzed. The results of this analysis are presented below in Table 5. In this research, the overarching designation of whether or not an organization is “Multinational” was coded on the basis that an organization engages in an international research partnership, has international manufacturing or distribution bases, has international headquarters, or has received international investment. The analysis found that 70.85% of computer vision organizations have multinational presences, with large drivers being international manufacturing and distribution facilities (36% and 58%, respectively) and international investment (30%). The high percent of organizations with international distribution facilities, relative to quantum computing and PNT technologies, supports the hypothesis that the computer vision industry has progressed much further than the other emerging technologies analyzed in this report and has reached a stage where the technology is marketable to consumers. Finally, the significant international investment found in this analysis can be attributed to the large presence of public companies and smaller start-up firms developing highly specialized computer vision application packages.

Table 1. Key Traits of Computer Vision Organizations

Category	Percent of Computer Vision Sector
Government Involvement	20%
Academia Ties	8%
Multinational – Umbrella Category	71%
International Partnership	16%
International Manufacturing	36%
International Distribution	58%
International Headquarters	8%
International Investment	30%
Explicitly Dual-Use	16%

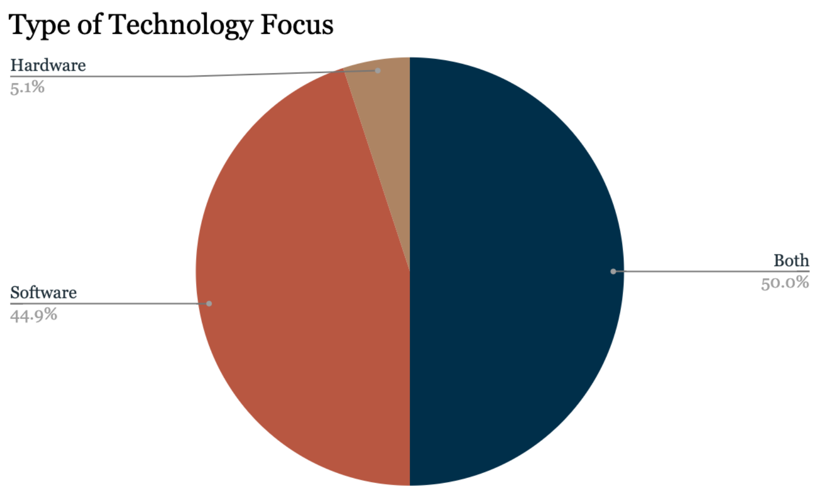
3. Partnerships with Academia and Government

Table 5 also provides the results for the analysis of government and academia interactions with the computer vision industry. Government involvement is at 19.6%, which is relatively low compared to the government involvement with the other technologies analyzed in this research project. This is likely due to the sheer size of private interest in computer vision, compared to that of governmental interest. Largely, the 20% portion of government interest can be attributed to defense projects supporting computer vision companies for drone and surveillance purposes and city and national governance projects utilizing computer vision capabilities for security, surveillance, and automation purposes. There is a fairly low tie to academia, with only 8% of organizations having academic affiliations or partnerships. Again, this supports the hypothesis that the computer vision field has surpassed the basic research stage. Interestingly though, the lower presence of academia engagement could increase the viability of trade controls, because academia serves as a mechanism for technology and knowledge exchange that is particularly difficult to control.

4. Technology Trends

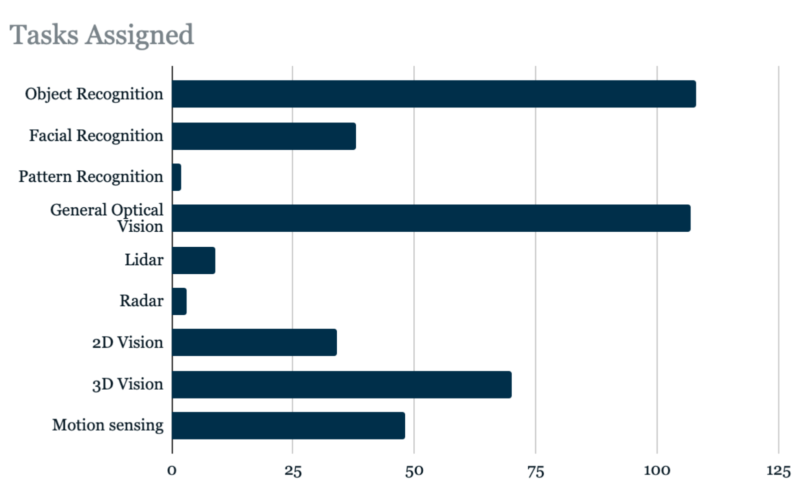
Given the wider dispersion and later stage in development of the computer vision industry, this research attempted to categorize the composition of the manufacturing base in terms of the types of technologies that are being prioritized and the tasks these technologies are performing. As shown below in Figure 11, this research found a significant fraction of organizations working specifically on software, at 44.9%, and a large fraction working on both hardware and software, at 50%, with only a small fraction, 5.1%, working exclusively on hardware. This distribution can be attributed to the fact that computer vision hardware knowledge is fairly dispersed, meaning that having unique computer vision technologies is not a high priority for many companies, who instead focus on how to apply quantum computing hardware through customized software. Additionally, although few in number, the hardware-only firms tend to be large and have widespread manufacturing and distribution bases, meaning that fewer organizations are able to supply a larger portion of the industry with hardware.

Figure 3. Computer Vision Industry by Technology Focus



Given the sizable presence of organizations working on computer vision software, the tasks that software systems were created to perform may provide insight into those organizations' priorities and the extent to which specialization is occurring. As Figure 12 shows, many companies are focused on fairly general tasks, including object recognition, general optical vision, and 3D vision. This means that very few firms are focusing on specialized tasks, such as LIDAR-based or radar-based computer vision, pattern recognition, and even 2D vision. This could also be explained by the fact that the majority of areas which have received less focus among the computer vision industry require highly specialized components, including hardware such as laser and radar sensors, and software such as data libraries in order to train computer vision systems on pattern recognition.

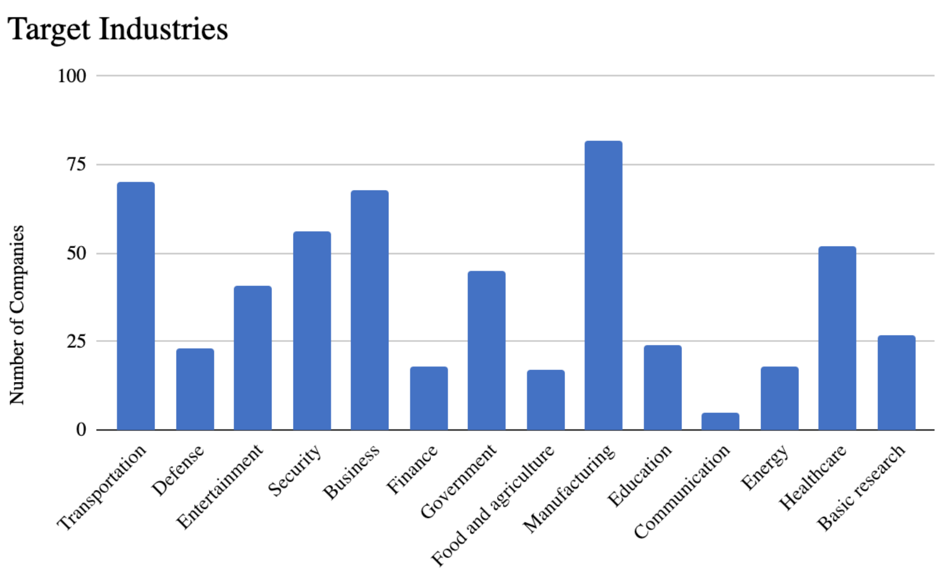
Figure 4. Computer Vision Industry by Task Assigned



5. Target Industries

The “target industries” for each firm were also recorded in order to understand which industries are most responsible for driving the computer vision manufacturing base. The results of this analysis are shown in Figure 13. Computer vision firms advertise to a large number of industries, but manufacturing, transportation, business, and security are of particular interest, with each being targeted by over 25% of the manufacturing bases (here security is taken to mean civilian security, such as home or office surveillance). Healthcare, government, and entertainment are also popular targets for the computer vision manufacturing base. Defense, finance, education, communication, energy, government, basic research, and food and agriculture are also often targeted, though not found to be leading industries.

Figure 5. Computer Vision Target Industries



With respect to the defense industry, and thus dual-use interest, over 20 organizations identified the defense community as potential consumers, which is over 10% of the organizations surveyed. Of those organizations that identify the defense industry as consumers, automation and surveillance are major fields indicated as suitable for computer vision implementation. Facial recognition may also be a task that surfaces dual-use concerns, depending on the scope of the definition of security and is rapidly being applied by governmental agencies.[29]

29 “Facial Recognition: CBP and TSA are Taking Steps to Implement Programs, but CBP Should Address Privacy and System Performance Issues,” United States Government Accountability Office: Report to Congressional Requesters, September 2020,

However, not all facial recognition organizations identified the defense industry as primary consumers.

6. Comments on Data

Due to the more advanced stage of the development in the computer vision manufacturing base, one of the key concerns regarding the data analyzed in this report is the extent to which it accurately represents the manufacturing base as a whole. Again, as with other emerging technologies, data omitted due to lack of publicly available information is a limitation. Data omission may occur due to privacy concerns, either arising through threat of IP theft or persuasion by government agendas or policies of opacity. This may lead either to entire companies being omitted from the analysis or specific applications/technologies developed by the company to be omitted. In general though, the data included in this report is not attempting to extend to the entire computer vision manufacturing base, instead it is just representing a subsection of the industry to the extent that the companies were able to be identified through publicly available methods and were able to be identified when the data was collected. However, the data collected does cover a diverse array of companies in the manufacturing base, including global, technical, and organizational variety.

Another central concern with the data and analysis is the designation of "dual-use" applicability. Companies were coded as developing "dual-use" technology only if defense (or defense-related activities) were openly identified by the company as potential applications. This means that the dual-use category may be undercounted, if there are organizations pursuing deals with defense industries but excluding this information from their publications and/or if the technologies may still have dual-use implications despite not being marketed toward the defense industry.

The extent to which computer vision capabilities translate to meaningful security threats is also a source of uncertainty, as the sheer application to the defense industry are sometimes not immediately clear. Furthermore, the extent to which "government application" in comparison to "defense application" translates to dual-use capability is somewhat nebulous. Recent sanctions on surveillance firms related to Uighur populations in Xinjiang, China, are an example of how surveillance technologies attract dual-use attention, despite not necessarily

<https://www.gao.gov/assets/710/709107.pdf>.

being direct military hardware.[30] Computer vision algorithms may not appear as dual-use initially, but they may have dual-use applications depending on how they are manipulated later, which differs from some physical dual-use hardware.

7. Conclusions and Trade Control Implications

Technology Conclusions

The results of this analysis demonstrate that the computer vision manufacturing base has evolved beyond a research-oriented industry and has established a relatively global distribution reach. However, this analysis also indicates that hardware development is concentrated in a relatively small number of larger firms. This hardware is used by a larger number of smaller private organizations that incorporate their own software technologies for specific applications. Among these organizations, there are relatively few research partnerships with governments, academia, or other industry members. Despite the lack of research partnerships, there is a relatively high number of organizations identified as engaged in multinational activities, largely driven by a wide distributional reach.

Implications for Trade Controls

The trends identified in this report offer insight into chokepoint technologies and suitable targets for trade controls. Although these findings illustrate an already expansive computer vision manufacturing base, the security concerns regarding certain computer vision byproducts and applications merit consideration of potential trade control options. Indeed, the U.S. private sector, in addition to flagging this issue in ANPRM comments, has begun to lobby policymakers to adopt responsible controls to evade misuse of the technology. In September 2020, IBM submitted specific recommendations to the U.S. Department of Commerce for limiting the export of facial recognition systems in specific cases.[31] IBM's CEO explained the reasoning behind its assertiveness, stating that,

30 "U.S. Sanctions 8 China Tech Companies Over Role in Xinjiang Abuses," Nikkei Asian Review, October 8, 2019, <https://asia.nikkei.com/Economy/Trade-war/US-sanctions-8-China-tech-companies-over-role-in-Xinjiang-abuses>.

31 IBM, "A Precision Regulation Approach to Controlling Facial Recognition Technology Exports, September 11, 2020, <https://www.ibm.com/blogs/policy/facial-recognition-export-controls/>.

> *"IBM firmly opposes and will not condone uses of any technology, including facial recognition technology offered by other vendors, for mass surveillance, racial profiling, violations of basic human rights and freedoms, or any purpose which is not consistent with our values and Principles of Trust and Transparency."*

The mapping data and analysis support the potential use of trade controls to mitigate these risks. In light of the identified trends, hardware-specific trade controls focused on security-relevant sensor technology and software-specific trade controls focused on data accumulation and transfer or end-use application all could be viable trade control options. Because hardware development, and specifically non-optical sensor technology development, is consolidated into a relatively tight circle of organizations, trade and investment controls restricting the transfer of high-power, non-optical sensors may be a feasible option. Furthermore, non-optical sensors, including laser, radar, and thermal sensors, make up a smaller percentage of the private industry interest. This means that, should they be identified as having security implications, their production and trade could be restricted without creating a notable impediment to potential private industry profits.

Software technologies, which have already been identified as potentially problematic in terms of restrictability through trade controls, may require more finesse. Because software technologies are what ultimately connect computer vision hardware to specific industry use cases, software-specific trade controls must be highly targeted, either through restricting their application to certain activities or through restricting specific types of data incorporation, accumulation, or transfer.