UNITED STATES DISTRICT COURT
FOR THE WESTERN DISTRICT OF WASHINGTON
AT SEATTLE

REALD SPARK, LLC, Plaintiff, v. MICROSOFT CORPORATION, Defendant.	NO. **COMPLAINT FOR BREACH OF CONTRACT, THEFT OF TRADE SECRETS, AND PATENT INFRINGEMENT** **JURY DEMANDED**

Plaintiff RealD Spark, LLC ("RealD" or "Plaintiff") files this Original Complaint against Defendant Microsoft Corporation ("Microsoft" or "Defendant") and hereby alleges as follows:

I. SUMMARY OF THE ACTION

1. This is a breach of contract, theft of trade secrets, and patent infringement suit relating to Microsoft's unauthorized and unlicensed use of patented and/or proprietary RealD technology in its products. Microsoft's accused devices ("the Accused Products") include the Microsoft Surface product line, including the Microsoft Surface Pro X, certain Windows 10 (Build 20175 and later) and Windows 11 products, and any other Microsoft products that incorporate its "Eye contact" correction feature.

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II. PARTIES

Plaintiff RealD Spark, LLC

2. Plaintiff RealD Spark, LLC ("RealD") is a private company incorporated in Delaware with its principal place of business at 1930 Central Avenue, Suite A-2, Boulder, Colorado 80301.

3. In October 2016, RealD spun out of RealD Inc. to focus on consumer display technology. For almost two decades, RealD Inc. has been the creator of three-dimensional ("3D") imaging technologies for premium theater experiences. These technologies include both new equipment—3D glasses, projectors, and screens necessary for optimum 3D viewing—as well as new software that helps filmmakers create the immersive, 3D storytelling watched by moviegoers around the world. See https://www.reald.com/realdcinema (last visited July 5, 2022); https://variety.com/2019/film/news/reald-premium-cinema-options-1203372287/ (last visited July 5, 2022). RealD Inc.'s partnerships with AMC Theatres and Cinemark have made its technology a staple of 3D cinema, with more than 30,000 installed screens in 75 countries. https://www.reald.com/news/reald-and-cinemark-renew-3d-agreement-through-2022 (last visited July 5, 2022). Over two billion people have watched a RealD Inc. 3D movie.

4. RealD Inc.'s efforts to create revolutionary visual experiences are not limited to its cinematic origins. For instance, NASA used RealD Inc.'s 3D technologies to pilot the Mars Rover. https://www.businesswire.com/news/home/20110215005554/en/Oakley-3D-Glasses-Gain-RealD%C2%AE-Certification (last visited July 5, 2022). RealD took this imaging expertise and expanded into the fields of advanced directional displays and gaze correction. RealD's developments in these fields are used in laptops, computers, and mobile phones, as well as in the automotive/infotainment and point-of-sale sectors. For example, RealD's display technology is incorporated into many Hewlett Packard laptop computers. See

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https://www.prnewswire.com/news-releases/reald-me-and-hp-partner-to-launch-reflective-privacy-technology-on-notebooks-with-sure-view-reflect-300982045.html (last visited July 5, 2022). With years of experience, RealD continues to shape the digital world today.

Defendant Microsoft

5. On information and belief, Defendant Microsoft is a Washington corporation with its principal place of business at One Microsoft Way, Redmond, Washington 98052. Microsoft is a multinational technology company that produces computer software and consumer electronics. Microsoft also owns and operates social media and video conferencing applications such as LinkedIn and Skype.

6. On information and belief, Microsoft (including its subsidiaries) directly and/or indirectly develops, designs, manufactures, uses, distributes, markets, offers to sell, and/or sells the Accused Products in the United States, including in this District, and otherwise purposefully directs infringing activities to this District in connection with its software and devices.

III. JURISDICTION AND VENUE

7. This is an action containing claims for patent infringement arising under the patent laws of the United States, Title 35, U.S.C. § 271. This Court has exclusive subject matter jurisdiction over those claims pursuant to 28 U.S.C. §§ 1331, 1367, and/or 1338.

8. This action further arises under the laws of the United States, namely the Defend Trade Secrets Act ("DTSA") codified at 18 U.S.C. § 1836 et seq. This Court therefore has subject matter jurisdiction of those claims pursuant to 28 U.S.C. § 1331.

9. This action also arises under the laws of the State of Washington, namely the Washington Uniform Trade Secrets Act. This Court has subject matter jurisdiction pursuant to 28 U.S.C. § 1367 because the actions giving rise to those claims under applicable state law are the same and/or related to the actions giving rise to the asserted claims under federal law. As

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such, the claims are so related that they form part of the same case or controversy under Article III of the United States Constitution.

10. The Court has personal jurisdiction over Defendant because it either currently resides in the State of Washington, has a regular and established place of business within the State of Washington, has had minimum contacts with the State of Washington sufficient to confer the Court with general personal jurisdiction, or has committed acts within the State of Washington giving rise to the claims asserted herein. Defendant, in a Non-Disclosure Agreement entered into with RealD Inc. and its affiliates, agreed that jurisdiction and venue are proper in the state of Washington.

11. Venue is proper in the Western District of Washington under 28 U.S.C. § 1400(b) as Microsoft resides and has a regular and established place of business in this judicial district, and this judicial district is where Microsoft has committed acts of infringement.

IV. FACTUAL ALLEGATIONS

REALD'S HISTORY OF INNOVATION

12. RealD Inc. has spent almost twenty years developing cutting-edge imaging and visual experiences for the digital age. From revolutionary light-efficient laser projectors and filmmaking software to transformational privacy displays, RealD Inc. and RealD have been, and remain, at the forefront of imaging industry.

13. In 2003, RealD Inc. developed its core polarization management technologies that permeate both its cinematic and display product offerings. Over the coming years, RealD Inc. implemented its new technologies on the big screens of theaters and the small screens of computers, laptops, and mobile devices. RealD also adapted the technology to provide privacy on these small screens by adjusting luminance, polarization, backlighting, and reflectivity to prevent others from viewing the screens of other computer users. In 2018, RealD unveiled its

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"Privacy Guard" product in Lenovo laptops. And in 2020, RealD provided an enhanced privacy product called "SureView Reflect" in HP's Dragonfly laptops, which later expanded to multiple HP PCs, laptops, and chromebooks in multiple screen sizes. Currently, RealD is exploring the application of these ideas into vehicle infotainment systems and point-of-sale kiosks.

REALD AND MICROSOFT

14. As part of RealD's mission to create the ultimate visual experience across all consumer electronics, RealD set its sights on video conferencing. More specifically, RealD set out to develop imaging technology that adjusts the gaze of video conference participants so that it appears the participants are looking directly into the camera instead of at the device screen. RealD refers to this innovative technology as "SocialEyes" (a play on words of "Socialize").

15. RealD worked tirelessly to research, develop, and refine SocialEyes. During the development process, RealD invested significant time and resources into creating the proprietary formulas, algorithms, methodologies, and products that underlie SocialEyes. For example, RealD collected and analyzed large quantities of data through costly and time-consuming in-person tests focused on image recognition. These development efforts were led by Eric Sommerlade, Vice President of Software & Computer Vision at RealD, who oversaw the team of employees that designed, developed, and deployed SocialEyes.

16. After developing SocialEyes, RealD contacted Microsoft to see if it was interested in including SocialEyes in its products. Microsoft was enthusiastic about the prospect and sought to learn more about the technology. Before engaging in any detailed discussions about SocialEyes, RealD Inc. and its affiliates and Microsoft and its affiliates entered into a Non-Disclosure Agreement ("NDA") (attached as Exhibit A), which was executed on July 20, 2016.

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17. The NDA offers protections for both parties' confidential information. In particular, the NDA specifies that the parties can "use and disclose the other's confidential information only for purposes of our business relationship with each other." Ex. A at 2. "Confidential Information" is defined in the NDA as "non-public information, know-how and trade secrets in any form that: [(1)] Are designated as 'confidential'; or [(2)] A reasonable person knows or reasonably should understand to be confidential." Id. at 1–2.

18. Relying on the protections of the NDA and the parties' mutual understanding that each party's confidential information was protected from unauthorized use or disclosure, RealD shared confidential information about SocialEyes with Microsoft including, without limitation, the following high-level groups of trade secrets:

- Image recognition algorithms for different types of faces, lighting, eye color, and eyeglasses;
- Datasets to support SocialEyes' image recognition methods;
- Know-how resulting from RealD's lengthy and costly R&D process used to develop SocialEyes and its corresponding datasets;
- Negative know-how that resulted from RealD's lengthy and costly R&D process that was used to develop SocialEyes and its corresponding datasets; and
- Source code that contained and implemented the aforementioned trade secrets.

19. RealD's trade secrets and intellectual property made its vision to improve the video conferencing experience a reality. SocialEyes adjusts the apparent gaze of video conference participants, so that it appears they are looking directly into the camera instead of at the device screen. Since eye contact can be realistically maintained with this innovative technology, the technology makes the video conference experience more vivid, engaging, and personal for all parties concerned. In addition, the technology substantially mitigates various psychological issues that often accompany prolonged or repeated video conferences. For

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example, studies show that "Zoom Fatigue" results from video participants having to pay closer attention to non-verbal cues as compared to an in-person conversation. This fatigue results in participants expending increased mental and cognitive energy, which exhausts the participant more quickly and can cause headaches, migraines, eye strain, and other physical and emotional symptoms.

20. Recognizing the potential for SocialEyes, RealD took steps to keep its proprietary technology confidential. For example, RealD team members were under obligations not to disclose RealD's trade secrets or other confidential information. In addition, RealD limited access to its trade secrets and disclosed its confidential information only to those employees working on development of the technology. RealD also employed secure information-management and both physical and digital security protocols. Lastly, RealD required its employees, contractors, clients, and vendors to enter into confidentiality agreements, and RealD did not disclose confidential information to third parties except under the protections of confidentiality agreements.

21. Beginning in late 2016, RealD began demonstrating SocialEyes to Microsoft under the protection of the NDA and with the hope that Microsoft would ultimately license or acquire RealD's technology. Over the next several months, RealD spoke with Microsoft personnel about SocialEyes and shared confidential information with them related to the technology. RealD shared this information with Microsoft so that Microsoft could evaluate RealD's technology. At all times, RealD's disclosure of confidential information was protected by the executed NDA.

22. During the parties' discussions, Microsoft repeatedly voiced its interest in SocialEyes. After several months of communicating about the technology and its benefits, Microsoft asked RealD to install SocialEyes on one of its products. Encouraged by the promise

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of securing a license with such a large and important business partner, RealD obliged, and SocialEyes demonstration software was installed on a Surface Pro 4 tablet.

23. In March 2019, despite all of the interest Microsoft previously voiced about SocialEyes, Microsoft cut off talks with RealD.

24. RealD eventually became aware that Microsoft had hired several former RealD employees that worked on SocialEyes, including the SocialEyes team leader, former Vice President of Software & Computer Vision, Eric Sommerlade.

25. Upon learning that Dr. Sommerlade was employed by Microsoft, RealD contacted Microsoft to (i) ask about resuming licensing negotiations, and (ii) to alert Microsoft that it risked misappropriating RealD's intellectual property. Microsoft declined to resume negotiations and instead told RealD that it "ha[d] instead opted to evaluate a different technology altogether." Microsoft also informed RealD that it was taking "steps to protect [RealD's] IP[.]" For example, Microsoft reassured RealD that it "made clear to Dr. Sommerlade that he [was] not permitted to use any RealD intellectual property in the course of his work, absent an express license from RealD." Microsoft also told RealD that it instructed the employees on Dr. Sommerlade's team "not to solicit any advice or information regarding RealD's SocialEyes product." In light of Microsoft's representations, RealD reasonably understood that Microsoft was proactively taking steps to ensure that RealD's trade secrets remained confidential and were not used or disclosed absent an express license from RealD.

26. However, upon information and belief, it now appears that Microsoft did not follow through with its promises. Microsoft's patent applications indicate that its "competing" product is actually an unauthorized implementation of both RealD's patented technology and its underlying trade secrets and confidential information.

27. More specifically, on information and belief, in or around October 2019, Microsoft misappropriated RealD's confidential information by incorporating SocialEyes into

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Microsoft's Surface product line, including the Surface Pro X—a product within the same family of products as the Surface Pro 4 in which the SocialEyes demonstration software was installed months earlier. See, e.g., https://www.youtube.com/watch?v=dmaioTs0NH8 (at 50:00–53:25, Microsoft Surface Pro X Launch Event, Oct. 2, 2019) (demonstrating the Surface Pro X's "Eye Contact" gaze correction feature) (last visited July 5, 2022). Around this time, Microsoft also filed a patent application directed to RealD's SocialEyes technology, and it listed ex-RealD employees Eric Sommerlade and Alexandros Neophytou as inventors.

28. Since October 2019, Microsoft has expanded its unauthorized and unlicensed use of RealD's patented and/or proprietary technology. See, e.g., https://www.youtube.com/watch?v=0vsh1KZ1yws (at 1:05–1:18, Microsoft Windows powers the future of hybrid work, April 5, 2022) (demonstrating the Windows 11 "Eye Contact" gaze correction feature) (last visited July 5, 2022); https://www.microsoft.com/en-us/microsoft-365/blog/2022/04/05/new-experiences-in-windows-11-and-windows-365-empower-new-ways-of-working/ (last visited July 5, 2022); https://blogs.windows.com/windowsexperience/2022/04/05/windows-powers-the-future-of-hybrid-work/ (last visited July 5, 2022).

V. MICROSOFT HARMED REALD

29. Microsoft's theft of RealD's trade secrets have damaged RealD's ongoing business and its ability to win new customers going forward. On information and belief, at the most basic level, Microsoft's misappropriation of SocialEyes has deprived RealD of the licensing fees that Microsoft or others would have paid to license the SocialEyes technology. On information and belief, RealD was the only company that developed a marketable version of SocialEyes and thus it should have enjoyed a competitive advantage for licensing its technology in the marketplace. On information and belief, Microsoft's misappropriation of

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SocialEyes has vastly reduced RealD's competitive advantage for licensing the SocialEyes technology to Microsoft and others.

30. Microsoft's further dissemination of RealD's trade secrets has caused and will continue to cause irreparable harm to RealD. As a result of its misappropriation, Microsoft has been able to release products, including the Accused Products, that incorporate RealD's proprietary SocialEyes technology. Microsoft will continue to benefit from the sale of these products, including the Accused Products that incorporate RealD's technology. Microsoft cannot be allowed to continue to use RealD's trade secrets to sell its products and services in a global market without compensating RealD.

COUNT ONE: BREACH OF CONTRACT

31. Plaintiff realleges and incorporates by reference the allegations of paragraphs 1–30 of this Complaint.

32. The NDA was a valid and binding contract between Microsoft and RealD Inc. and its affiliates. RealD is an affiliate of RealD Inc.

33. RealD has performed in accordance with all material obligations, terms, and conditions of the NDA.

34. In section 3 of the NDA, Microsoft represented that it would use and disclose RealD's confidential information only for purposes of the parties' "business relationship with each other." Ex. A at 2. Microsoft also represented that it would not disclose RealD's confidential information to any third parties.

35. The confidential information that RealD disclosed to Microsoft over the course of their relationship constitutes "Confidential Information" under the NDA.

36. Microsoft breached the NDA by using or disclosing RealD's confidential information, including, without limitation, RealD's trade secrets related to SocialEyes. For

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example, upon information and belief, Microsoft used or disclosed RealD's confidential information in order to develop its own products, including the Microsoft Surface Pro X.

37. Microsoft's breach of the NDA has damaged RealD in an amount in excess of $1,000,000.

COUNT TWO: VIOLATION OF THE DEFEND TRADE SECRETS ACT (DTSA) 18 U.S.C. §§ 1836, ET SEQ.

38. Plaintiff realleges and incorporates by reference the allegations of paragraphs 1–37 of this Complaint.

39. Before entering into discussions with Microsoft, RealD developed several categories of trade secrets ("RealD Trade Secrets") related to its SocialEyes technology, including but not limited to: (1) image recognition algorithms for different types of faces, lighting, eye color, and eyeglasses; (2) datasets to support SocialEyes' image recognition methods; (3) know-how resulting from RealD's lengthy and costly R&D process used to develop SocialEyes and its corresponding datasets; (4) negative know-how that resulted from RealD's lengthy and costly R&D process that was used to develop SocialEyes and its corresponding datasets; and (5) source code that contained and implemented the aforementioned trade secrets.

40. The RealD Trade Secrets were used for the design, development, testing, evaluation, and refinement of RealD's SocialEyes technology. This information constitutes financial, business, scientific, technical, economic, and/or engineering information.

41. The RealD Trade Secrets relate to products and services used, sold, shipped and ordered in, or intended to be used, sold, shipped and/or ordered in, interstate and foreign commerce.

42. RealD took reasonable measures to keep the RealD Trade Secrets secret as described above and including, without limitation, subjecting all employees to confidentiality

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agreements in conjunction with RealD's corporate policies and practices that instruct personnel to safeguard RealD's proprietary information. RealD also took steps to ensure that the RealD Trade Secrets were clearly marked as proprietary and confidential, and were subject to restrictions on further use and dissemination. Moreover, RealD physically restricted access in its facilities to properly-credentialed individuals, and virtually restricted electronic access to the RealD Trade Secrets to properly-credentialed personnel. RealD shared the RealD Trade Secrets with Microsoft only after the parties signed a NDA that also required the parties to keep that information confidential.

43. The RealD Trade Secrets derive independent economic value from not being generally known, and not being readily ascertainable through proper means to another person who is able to obtain economic value from the disclosure or use of the information. For example, RealD expended years of time and substantial resources (including employee time and salaries; the collection, analysis, and storage of the datasets noted above; and the creation of algorithms, know-how, and factors considered for realistic gaze correction) to creating the RealD Trade Secrets. They underlie the basis of RealD's SocialEyes product, which it attempted to bring to market through, among others, Microsoft. For Microsoft to create a competing product without the RealD Trade Secrets would have taken many man hours and years of research and development. Microsoft incorporated the SocialEyes technology into the Accused Products in record time and, as such, the RealD Trade Secrets have been of immense value to Microsoft in its efforts to quickly commercialize the Accused Products. On information and belief, Microsoft misappropriated the RealD Trade Secrets for that reason and have also obtained economic value through the sale of the Accused Products. For these same reasons, the RealD Trade Secrets are novel, i.e., they are not readily ascertainable from another source.

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44. In violation of RealD's rights under the Defend Trade Secrets Act, 18 U.S.C. § 1836, on or after the execution of the NDA on July 20, 2016, Microsoft misappropriated the RealD Trade Secrets in an improper and unlawful manner as alleged above and herein. In addition to the foregoing, and upon further information and belief as detailed below, Microsoft has misappropriated the RealD Trade Secrets under federal law because it acquired them knowing or having reason to know that they were acquired by improper means. Additionally, Microsoft misappropriated the RealD Trade Secrets because at the time it obtained and/or used them without RealD's permission, Microsoft knew or had reason to know its knowledge of the RealD Trade Secrets was derived from or through a person who had utilized improper means to acquire them, acquired them under circumstances giving rise to a duty to maintain their secrecy or limit their use, or derived them from or through a person who owed a duty to RealD to maintain their secrecy or limit their use. Alternatively, Microsoft misappropriated the RealD Trade Secrets by using them without permission, knowing or having reason to know that the information constituted trade secrets acquired by accident or mistake.

45. Microsoft engaged in talks with RealD to discuss licensing or acquiring RealD's SocialEyes technology. During those discussions, Microsoft asked RealD to install SocialEyes in one of its products, RealD obliged, and thus SocialEyes demonstration software was installed on a Surface Pro 4. That product included RealD Trade Secrets. The licensing discussions between the parties also resulted in disclosure of the RealD Trade Secrets to Microsoft under circumstances that made it clear that RealD was sharing them solely for the purpose of Microsoft evaluating taking a license to or acquiring the SocialEyes technology, which incorporates the RealD Trade Secrets. In turn, Microsoft knew it lacked permission to incorporate the RealD Trade Secrets into its commercial products.

46. On information and belief, after initial discussions with RealD, Microsoft began the targeted recruiting of former RealD personnel who had experience in designing,

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developing, testing, and refining RealD's SocialEyes technology. This personnel also had information regarding the RealD Trade Secrets. On information and belief, Microsoft recruited these individuals to assist in the design, development, and implementation of SocialEyes and the RealD Trade Secrets in Microsoft's products. Upon further information and belief, Microsoft sought to hire former RealD personnel with the intention of using the new recruits to solicit and incorporate the RealD Trade Secrets in Microsoft's products.

47. On information and belief, Microsoft's misappropriation of the RealD Trade Secrets is also evidenced by the fact that shortly after former RealD personnel began working for Microsoft, Microsoft brought a Surface Pro X to market that incorporated the SocialEyes technology, which is based on or incorporates the RealD Trade Secrets.

48. On information and belief, the SocialEyes technology in Microsoft's Surface Pro X, and the other Accused Products, was and is based in whole or in part on the Microsoft product that was installed with the SocialEyes demonstration software, which contained RealD Trade Secrets.

49. On information and belief, the SocialEyes technology in the Microsoft Surface Pro X, and the other Accused Products, is based in whole or in part on the RealD Trade Secrets that Eric Sommerlade and his team developed at RealD and later brought to Microsoft.

50. On further information and belief, Microsoft knew or should have known that the Accused Products, including the Surface Pro X, incorporate the RealD Trade Secrets because of the aforementioned circumstances leading up to and surrounding Microsoft's introduction of products that include RealD's SocialEyes technology.

51. In addition to Microsoft misappropriating the RealD Trade Secrets in a corporate capacity, Microsoft is liable for trade secret misappropriation due to the conduct of its employees within the scope of their employment with and for the benefit of Microsoft. Specifically, upon information and belief, Microsoft employees, including RealD's former

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employees Eric Sommerlade, Alexandros Neophytou, Brian Hawkins, and Andrew Yu, knowingly obtained, used, and/or disseminated at least portions of the RealD Trade Secrets identified above, and each did so within the scope of their employment with, and for the benefit of, Microsoft to advance development and deployment of SocialEyes in Microsoft's products.

52. Dr. Sommerlade, Mr. Neophytou, Mr. Hawkins, and Dr. Yu also knew or had reason to know that the RealD Trade Secrets were improperly obtained, particularly because each was aware during their employment with RealD that they had an ongoing duty to maintain confidentiality of the RealD Trade Secrets even following their departure from RealD. Their use of the RealD Trade Secrets to further Microsoft's development and incorporation of SocialEyes in Microsoft's products, including the Surface Pro X, contravened these ongoing obligations of confidentiality and constitute acquisition, distribution, and use of the RealD Trade Secrets by improper means. Under these circumstances, in accordance with the doctrine of respondeat superior, Microsoft is liable for the improper actions—and in this case the trade secret misappropriation—by those individuals.

53. Microsoft's conduct as described herein was intentional, knowing, willful, malicious, fraudulent, and oppressive.

54. As a direct and proximate result of Microsoft's conduct, RealD has suffered and will continue to suffer irreparable financial loss, loss of goodwill, and loss of the confidentiality of the RealD Trade Secrets, for which there is no adequate remedy at law.

55. RealD has also suffered substantial damages as a direct and proximate cause of Microsoft's conduct in an amount to be proven at trial.

56. Microsoft has also been unjustly enriched by its misappropriation of the RealD Trade Secrets in an amount to be proven at trial.

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COUNT THREE: VIOLATION OF THE WASHINGTON UNIFORM TRADE SECRETS ACT (WUTSA), RCW 19.108.010 ET SEQ.

57. Plaintiff realleges and incorporates by reference the allegations of paragraphs 1-56 of this Complaint.

58. As explained above, RealD has developed, owns, and possesses the RealD Trade Secrets, including but not limited to: (1) image recognition algorithms for different types of faces, lighting, eye color, and eyeglasses; (2) datasets to support SocialEyes' image recognition methods; (3) know-how resulting from RealD's lengthy and costly R&D process used to develop SocialEyes and its corresponding datasets; (4) negative know-how that resulted from RealD's lengthy and costly R&D process that was used to develop SocialEyes and its corresponding datasets; and (5) source code that contained and implemented the aforementioned trade secrets.

59. The RealD Trade Secrets are information, including a formula, pattern compilation, program, device, method, technique, or process, that (a) derives independent economic value, actual or potential, from not being generally known to, and not being readily ascertainable by proper means by, other persons who can obtain economic value from its disclosure or use, and (b) is the subject of efforts that are reasonable under the circumstances to maintain its secrecy.

60. RealD took reasonable measures to keep the RealD Trade Secrets secret as described above and including, without limitation, subjecting all employees to confidentiality agreements in conjunction with RealD's corporate policies and practices that instruct personnel to safeguard RealD's proprietary information. RealD also took steps to ensure that the RealD Trade Secrets were clearly marked as proprietary and confidential, and were subject to restrictions on further use and dissemination. Moreover, RealD physically restricted access in its facilities to properly-credentialed individuals, and virtually restricted electronic access to the

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RealD Trade Secrets to properly-credentialed personnel. RealD only shared the RealD Trade Secrets with Microsoft after the parties signed a NDA that also required the parties to keep that information confidential.

61. The RealD Trade Secrets derive independent economic value, actual or potential, from not being generally known to, and not being readily ascertainable through proper means to another person who is able to obtain economic value from the disclosure or use of the information. For example, RealD expended years of time and substantial resources (including employee time and salaries; the collection, analysis, and storage of the datasets noted above; and the creation of algorithms, know-how, and factors considered for realistic gaze correction) to creating the RealD Trade Secrets. They underlie the basis of RealD's SocialEyes product, which it attempted to bring to market through, among others, Microsoft. For Microsoft to create a competing product without the RealD Trade Secrets would have taken many man hours and years of research and development. Microsoft incorporated the SocialEyes technology into the Accused Products in record time and, as such, the RealD Trade Secrets have been of immense value to Microsoft in its efforts to quickly commercialize the Accused Products. On information and belief, Microsoft misappropriated the RealD Trade Secrets for that reason and have also obtained economic value through the sale of the Accused Products. For these same reasons, the RealD Trade Secrets are novel, i.e., they are not readily ascertainable from another source.

62. In violation of RealD's rights under the WUTSA, RCW 19.108.10 et seq., on or after the execution of the NDA on July 20, 2016, Microsoft misappropriated the RealD Trade Secrets in an improper and unlawful manner as alleged above and herein. In addition to the foregoing, and upon further information and belief as detailed below, Microsoft has misappropriated the RealD Trade Secrets under state law because it acquired them knowing or having reason to know that they were acquired by improper means. Additionally, Microsoft

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misappropriated the RealD Trade Secrets because Microsoft used improper means to acquire knowledge of the RealD Trade Secrets and/or at the time Microsoft disclosed and/or used the RealD Trade Secrets without RealD's permission, Microsoft knew or had reason to know its knowledge of the RealD Trade Secrets was derived from or through a person who had utilized improper means to acquire them, acquired them under circumstances giving rise to a duty to maintain their secrecy or limit their use, or derived them from or through a person who owed a duty to RealD to maintain their secrecy or limit their use. Alternatively, Microsoft misappropriated the RealD Trade Secrets by disclosing or using them without permission, knowing or having reason to know that the information constituted trade secrets acquired by accident or mistake.

63. Microsoft engaged in talks with RealD to discuss licensing or acquiring RealD's SocialEyes technology. During those discussions, Microsoft asked RealD to install SocialEyes in one of its products, RealD obliged, and thus SocialEyes demonstration software was installed on a Surface Pro 4. That product included RealD Trade Secrets. The licensing discussions between the parties also resulted in disclosure of the RealD Trade Secrets to Microsoft under circumstances that made it clear that RealD was sharing them solely for the purpose of Microsoft evaluating taking a license to or acquiring the SocialEyes technology, which incorporates the RealD Trade Secrets. In turn, Microsoft knew it lacked permission to incorporate the RealD Trade Secrets into its commercial products.

64. On information and belief, after initial discussions with RealD, Microsoft began the targeted recruiting of former RealD personnel who had experience in designing, developing, testing, and refining RealD's SocialEyes technology. This personnel also had information regarding the RealD Trade Secrets. On information and belief, Microsoft recruited these individuals to assist in the design, development, and implementation of SocialEyes and the RealD Trade Secrets in Microsoft's products. Upon further information and belief,

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Microsoft sought to hire former RealD personnel with the intention of using the new recruits to solicit and incorporate the RealD Trade Secrets in Microsoft's products.

65. On information and belief, Microsoft's misappropriation of the RealD Trade Secrets is also evidenced by the fact that shortly after former RealD personnel began working for Microsoft, Microsoft brought a Surface Pro X to market that incorporated the SocialEyes technology, which is based on or incorporates the RealD Trade Secrets.

66. On information and belief, the SocialEyes technology in Microsoft's Surface Pro X, and the other Accused Products, was and is based in whole or in part on the Microsoft product that was installed with SocialEyes demonstration software, which contained RealD Trade Secrets.

67. On information and belief, the SocialEyes technology in the Microsoft Surface Pro X, and the other Accused Products, is based in whole or in part on the RealD Trade Secrets that Dr. Sommerlade and his team developed at RealD and later brought to Microsoft.

68. On further information and belief, Microsoft knew or should have known that the Accused Products, including the Surface Pro X, incorporate the RealD Trade Secrets because of the aforementioned circumstances leading up to and surrounding Microsoft's introduction of products that include RealD's SocialEyes technology.

69. In addition to Microsoft misappropriating the RealD Trade Secrets in a corporate capacity, Microsoft is liable for trade secret misappropriation due to the conduct of its employees within the scope of their employment with and for the benefit of Microsoft. Specifically, upon information and belief, Microsoft employees, including RealD's former employees Eric Sommerlade, Alexandros Neophytou, Brian Hawkins, and Andrew Yu, knowingly obtained, used, and/or disseminated at least portions of the RealD Trade Secrets identified above, and each did so within the scope of their employment with, and for the benefit of, Microsoft to advance development and deployment of SocialEyes in Microsoft's products.

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70. Dr. Sommerlade, Mr. Neophytou, Mr. Hawkins, and Dr. Yu also knew or had reason to know that the RealD Trade Secrets were improperly obtained, particularly because each was aware during their employment with RealD that they had an ongoing duty to maintain confidentiality of the RealD Trade Secrets even following their departure from RealD. Their use of the RealD Trade Secrets to further Microsoft's development and incorporation of SocialEyes in Microsoft's products, including the Surface Pro X, contravened these ongoing obligations of confidentiality and constitute acquisition, distribution, and use of the RealD Trade Secrets by improper means. Under these circumstances, in accordance with the doctrine of respondeat superior, Microsoft is liable for the improper actions—and in this case the trade secret misappropriation—by those individuals.

71. Microsoft's conduct as described herein was intentional, knowing, willful, malicious, fraudulent, and oppressive.

72. As a direct and proximate result of Microsoft's conduct, RealD has suffered and will continue to suffer irreparable financial loss, loss of goodwill, and loss of the confidentiality of the RealD Trade Secrets, for which there is no adequate remedy at law.

73. RealD has also suffered substantial damages as a direct and proximate cause of Microsoft's conduct in an amount to be proven at trial.

74. Microsoft has also been unjustly enriched by its misappropriation of the RealD Trade Secrets in an amount to be proven at trial.

COUNT FOUR: INFRINGEMENT OF U.S. PATENT NO. 10,740,985

75. Plaintiff realleges and incorporates by reference the allegations of paragraphs 1–74 of this Complaint.

76. U.S. Patent No. 10,740,985 ("'985 Patent") is valid and enforceable under United States Patent Laws.

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77. RealD owns, by assignment, all right, title, and interest in and to the ’985 Patent, including the right to collect for past damages.

78. A copy of the ’985 Patent is attached as Exhibit B.

VI. THE ’985 PATENT

79. The ’985 Patent describes, among other things, a method and apparatus for adjusting a digital representation of a head region, particularly by adjusting target features, such as correcting a perceived gaze direction of eyes or modifying the texture and/or shape of features such as the nose, mouth, chin or neck. Ex. B at 1:6–13.

80. By 2018, RealD recognized that when “a user whose head is imaged is observing a display in the same device as a camera system and the camera system is offset above (or below) that display . . . the gaze in the displayed images will be perceived to be downwards (or upwards),” and that these “[e]rrors in the perceived gaze are disconcerting.” Id. at 1:35–43.

81. To address these issues, in one embodiment, the ’985 Patent uses “processing techniques (e.g. image processing techniques) for adjusting digital representations (e.g. images)” of the person’s head, particularly the person’s face, so the receiver, the person at the other end of the video conference, perceives their conversational partner as making eye contact with them instead of looking down, even when both parties are looking at the screen. Id. at 1:46–50.

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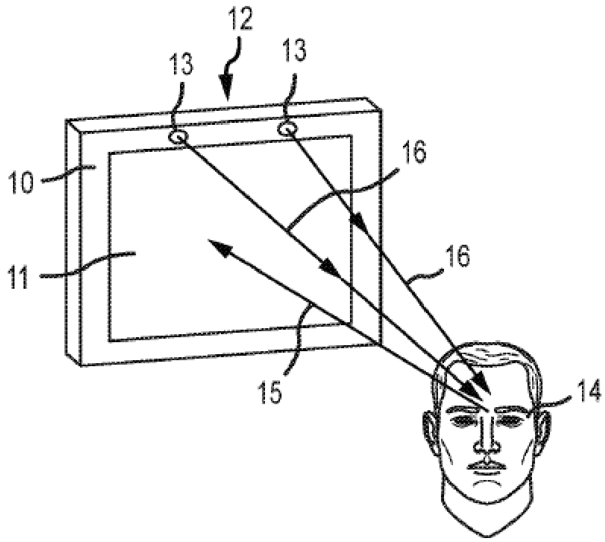

Id. at Fig. 1.

82. The invention of the '985 Patent works, for example, by "generating reference data for adjusting a digital representation of a head region," and "adjusting the digital representation of a head region." Id. at Abstract.

83. The '985 Patent describes a "method of generating" this "reference data for adjusting a digital representation of a head region." Id. at 1:60–61.

84. In one embodiment, this method consists of "receiv[ing] training data comprising: a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch." Id. at 1:62–66. The training data also consists of "a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region." Id. at 1:67–2:4. The method also uses "a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital representations of the head region." Id. at 2:4–8. The method further uses "a second machine learning algorithm to generate second reference data using the same training data as the first

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machine learning algorithm and the first reference data generated by the first machine learning algorithm." Id. at 2:8–12. The second reference data comprises "editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region." Id. at 2:12–16.

’985 PATENT ALLEGATIONS

85. Microsoft designed, implemented, and currently performs one or more methods for generating reference data for adjusting a digital representation of a head region. See https://blogs.windows.com/devices/2020/08/20/make-a-more-personal-connection-with-eye-contact-now-generally-available/ ("[p]owered by Artificial Intelligence and the onboard Neural Network accelerator," the "Eye Contact" feature of the Microsoft Surface X "helps to adjust your gaze on video calls and recordings, so you appear to be looking directly in the camera."). Because Microsoft "wanted any application on Surface Pro X to have access to Eye Contact without needing extra work on part of the app developers," Microsoft "made a conscious choice to integrate it as feature of the camera – in principle, just like how your camera can be adjusted for focus, resolution or brightness, we wanted it capable for Eye Contact." Id.

86. On information and belief, Microsoft’s U.S. Provisional Patent Application 62/908,363 (the ’363 Application), filed on September 30, 2019, relates to and describes the operation of Microsoft’s Surface Pro X "Eye Contact" feature. This is evidenced by at least the following facts: (1) the ’363 Application was filed two days prior to the first public demonstration of the Eye Contact feature (at a Microsoft Surface launch event on October 2, 2019) and (2) the ’363 Application lists three inventors—Eric Sommerlade, Alexandros Neophytou, and Sunando Sengupta—each of whom works in the ~60-person Microsoft Applied Sciences team responsible for the Eye Contact feature. See https://www.microsoft.com/applied-sciences/people; https://www.microsoft.com/applied-sciences/news (listing the "eye gaze tech" feature under "some of the stuff [the Microsoft

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Applied Sciences team has] been working on"). Eric Sommerlade and Alexandros Neophytou were RealD employees prior to joining Microsoft, and are also named inventors on the '985 Patent.

87. The '363 Application claims "receiving a digital input image depicting a human eye; generating a gaze adjusted image from the digital input image . . . generating a detail-enhanced image from the gaze-adjusted image . . . outputting the detail-enhanced image." See U.S. Provisional Patent Application No. 62/908,363 claim 1.

88. On information and belief after reasonable investigation, the Accused Products, including the Surface Pro X and Microsoft's Windows 11 products with the Eye Contact feature, infringe at least claim 18 of the '985 Patent. See, e.g., https://www.youtube.com/watch?v=dmaioTs0NH8 (at 50:00–53:25 Microsoft Surface Pro X Launch Event, Oct. 2, 2019) (demonstrating the Surface Pro X's "Eye Contact" gaze correction feature) (last visited July 5, 2022); see also https://www.youtube.com/watch?v=0vsh1KZ1yws (at 1:05–1:18 Microsoft Windows powers the future of hybrid work, April 5, 2022) (demonstrating the Windows 11 "Eye Contact" gaze correction feature) (last visited July 5, 2022).

89. For example, Microsoft's Accused Products operate a method for generating reference data for adjusting a digital representation of a head region. See, e.g., https://blogs.windows.com/devices/2020/08/20/make-a-more-personal-connection-with-eye-contact-now-generally-available/ ("Eye Contact helps to adjust your gaze on video calls and recordings, so you appear to be looking directly in the camera.").

90. Microsoft's Accused Products receive training data comprising: a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch. For instance, Microsoft's Accused Products process images of a

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head by identifying image patches containing different target features of the head, identifying the left and right eyes of the head, respectively. See https://www.youtube.com/watch?v=dmaioTs0NH8 (at 51:08–53:25 Microsoft Surface Pro X Launch Event, Oct. 2, 2019). As another example, Microsoft also trains its Puppets AI system by using "thousands of images and videos of people making different expressions to track and record facial movements;" Puppets then uses "facial anchors such as the corner of the eyes" and transfers "those tracked human facial expressions and head motions to the Puppet in real-time." See Ex. C at 2. As a further example, the '363 Application states the computing device is provided with an original set of images where the human subject is looking away from the camera. See U.S. Provisional Patent Application No. 62/908,363 para. [0017] and Fig. 2.

91. Microsoft's Accused Products receive training data comprising a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region. For instance, Microsoft's Accused Products, including the Surface Pro X, are configured to adjust images of a head to correct gaze via the "Eye Contact" feature. See https://news.thewindowsclub.com/eye-contact-feature-in-microsoft-teams-uses-ai-to-help-you-gaze-at-the-camera-102439/. In this example, the user's eyes are adjusted to look as if the user is gazing at the camera. As another example, Microsoft's Puppets AI system uses "facial anchors such as the corner of the eyes" and transfers "those tracked human facial expressions and head motions to the Puppet in real-time." See Ex. C at 2. As another example, in the '363 Application, the original images are respectively paired with a set of corresponding gaze-adjusted target images. See U.S. Provisional Patent Application No. 62/908,363 para. [0017] and Fig. 2. "The target images are captured while the human subjects are looking into the camera." Id.

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92. Microsoft's Accused Products use a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region. For instance, for at least the Surface Pro X devices, Microsoft "ensure[s] the AI algorithm maintains people's identity and intention when communicating." https://blogs.windows.com/devices/2020/08/20/make-a-more-personal-connection-with-eye-contact-now-generally-available/. As another example, Microsoft's "Puppets" feature uses "advanced deep neural network systems to allow users to create animal characters that mimic their facial expressions and head movements." https://www.thurrott.com/microsoft/209813/microsoft-copied-the-iphones-animoji-and-made-it-more-accessible. As a further example, in the '363 Application, "pairs including original and target images may be used as the basis for training a gaze adjustment machine learning model, which may then apply gaze adjustment to new test images." U.S. Provisional Patent Application No. 62/908,363 para. [0017]. These AI algorithms, neural networks, and machine learning models generate reference data editing instructions that adjust the digital representation of the head region for a range of possible digital representations of the head region. As one example, the Accused Products, including the Surface Pro X, generate reference data editing instructions to adjust images of a head via the "Eye Contact" feature. See https://news.thewindowsclub.com/eye-contact-feature-in-microsoft-teams-uses-ai-to-help-you-gaze-at-the-camera-102439/. Similarly, the "Puppets" feature generates reference data editing instructions to adjust "human facial expressions and head motions." See Ex. C at 2. And the '363 Application states "the computing device uses a gaze adjustment machine learning model to generate [a] two-dimensional displacement vector field, which is applied to the test image. This results in a gaze-adjusted image, in which the pupils of the eyes are shifted to the approximate centers of the eyes." Id. at [0020] and Fig. 1.

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93. Microsoft's Accused Products use a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data generated by the first machine learning algorithm, the second reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region. For instance, Microsoft's Surface Pro X uses AI algorithms to constantly "adjust where our eyes are looking in a video call or chat to make sure that you always appear to be making eye contact with the camera." https://www.theverge.com/2020/7/22/21334622/microsoft-eye-contact-surface-pro-x-video-chat-ai-correction-feature-rolling-out; see https://www.microsoft.com/en-th/surface/devices/surface-pro-x?activetab=overview (explaining Microsoft's "New Eye Contact automatically adjusts your gaze on video calls."). As another example, Microsoft's "Puppets" feature uses "advanced deep neural network systems to allow users to create animal characters that mimic their facial expressions and head movements." https://www.thurrott.com/microsoft/209813/microsoft-copied-the-iphones-animoji-and-made-it-more-accessible. As yet another example, the '363 Application states the "computing device may apply a detail enhancement machine learning model to an image of human eyes to add, supplement, or replace details in the eyes." See U.S. Provisional Patent Application No. 62/908,363 para. [0023] and Fig. 5. Further, "the detail enhancement machine learning model may be trained in any suitable way." Id.

94. Microsoft's Accused Products target an eye region comprising at least part of an eye and the adjustment of the digital representation of the head region comprises a gaze direction. For instance, Microsoft's Accused Products, including the Surface Pro X, are configured to adjust images of a head to correct gaze via the "Eye Contact" feature. See, e.g., https://news.thewindowsclub.com/eye-contact-feature-in-microsoft-teams-uses-ai-to-help-you-

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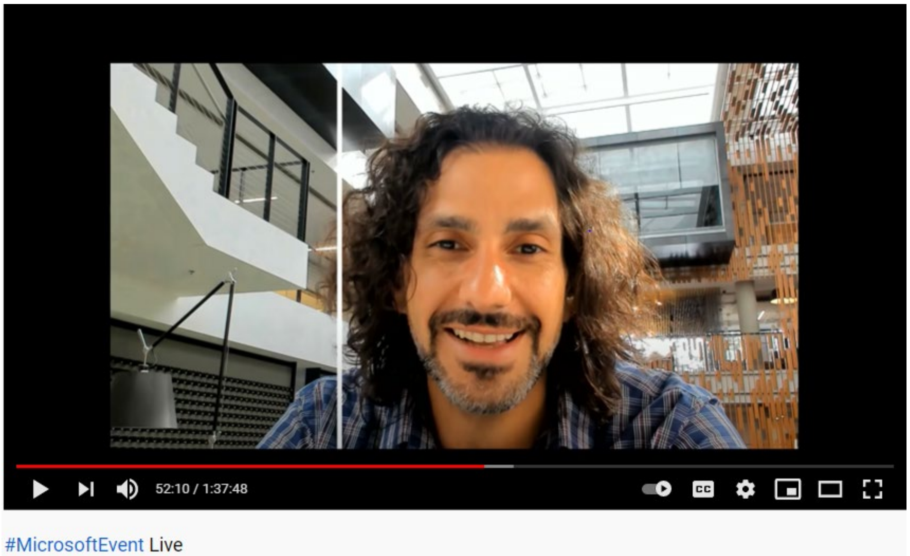
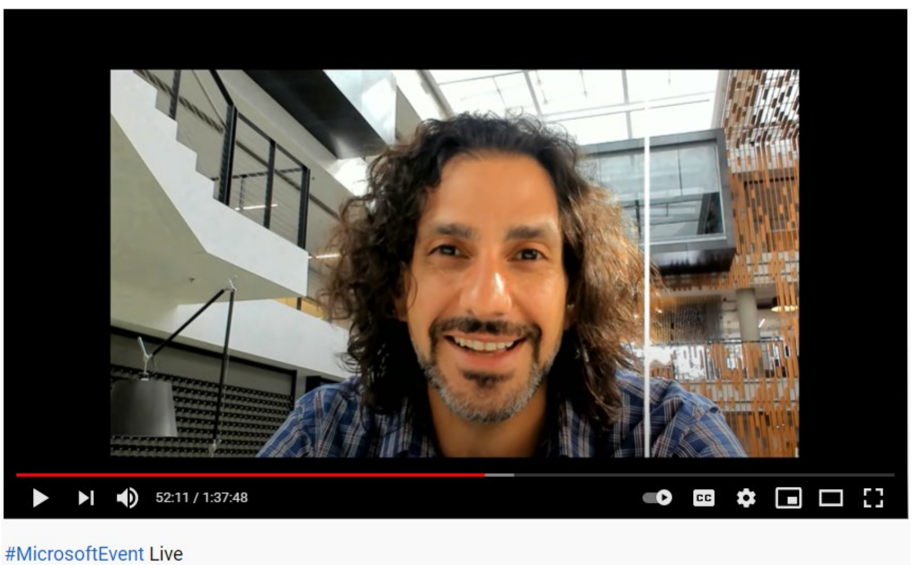
gaze-at-the-camera-102439/. The screenshots below demonstrate the adjustment of the digital representation of the head region comprises adjusting a gaze direction.



https://www.youtube.com/watch?v=dmaioTs0NH8 (at 52:10–52:11 Microsoft Surface Pro X Launch Event, Oct. 2, 2019) (without "Eye Contact" feature).



Id. (with "Eye Contact" feature). Similarly, the "Puppets" feature generates reference data editing instructions to adjust "human facial expressions and head motions." *See* Ex. C at 2.

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95. Microsoft's Accused Products also target a nose region comprising at least a part of a nose and the adjustment of the digital representation of the head region comprises adjusting a shape and/or texture of the nose. For instance, Microsoft's Puppets feature targets the user's nose, then allows the user to adjust the nose shape to mimic that of a selected character. See, e.g., https://www.youtube.com/watch?v=31YAemod-HI (at 51:08–53:25 Microsoft Surface Pro X Launch Event, Oct. 2, 2019).

96. Microsoft's Accused Products target the chin region comprising at least part of a chin and the adjustment of the digital representation of the head comprises adjusting a shape and/or texture of the chin. For example, Microsoft's Puppets feature targets the user's chin, then allows the user to adjust the chin shape to mimic that of a selected character. See, e.g., https://www.youtube.com/watch?v=31YAemod-HI (at 51:08–53:25 Microsoft Surface Pro X Launch Event, Oct. 2, 2019).

97. Microsoft's Accused Products target a neck region comprising at least part of a neck and the adjustment of the digital representation of the head region comprises adjusting a shape and/or texture of the neck. Microsoft's Puppets feature targets the user's neck, then allows the user to adjust the chin shape to mimic that of a selected character. See, e.g., https://www.youtube.com/watch?v=31YAemod-HI (at 51:08–53:25 Microsoft Surface Pro X Launch Event, Oct. 2, 2019).

98. Microsoft's Accused Products target a hair region comprising hair and the adjustment of the digital representation of the head region comprises adjusting a color of the hair. For example, Microsoft's Puppets feature targets the user's hair, then allows the user to adjust the hair shape and color to mimic that of a selected character. See, e.g., https://www.youtube.com/watch?v=31YAemod-HI (at 51:08–53:25 Microsoft Surface Pro X Launch Event, Oct. 2, 2019).

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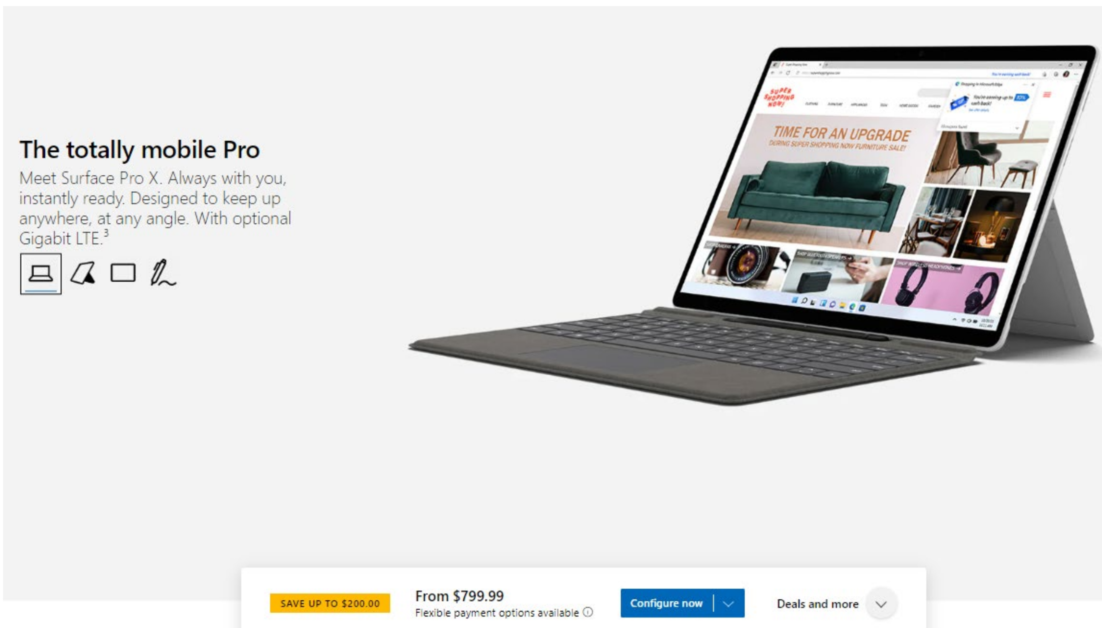
99. Microsoft has infringed and is infringing, individually and/or jointly, either literally or under the doctrine of equivalents, at least claim 18 of the '985 Patent in violation of 35 U.S.C. §§ 271, et seq., directly and/or indirectly, by making, using, offering for sale, selling, offering for lease, leasing in the United States, and/or importing into the United States without authority or license, the Accused Products. See https://www.microsoft.com/en-us/d/surface-pro-x/8xtmb6c575md?activetab=pivot%3aoverviewtab; see also https://www.bestbuy.com/site/surface-pro-x-13-touch-screen-microsoft-sq1-8gb-memory-128gb-ssd-wifi-4g-lte-device-only-matte-black/6375623.p?skuId=6375623.



https://www.microsoft.com/en-us/d/surface-pro-x/8xtmb6c575md?activetab=pivot:overviewtab

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https://www.bestbuy.com/site/surface-pro-x-13-touch-screen-microsoft-sq1-8gb-memory-128gb-ssd-wifi-4g-lte-device-only-matte-black/6375623.p?skuId=6375623.

100. Microsoft has been, and currently is, an active inducer of infringement of one or more claims of the ’985 Patent under 35 U.S.C. § 271(b). On information and belief, one or more of the Accused Products directly and/or indirectly infringe (by induced infringement) at least claim 18 of the ’985 Patent, literally and/or under the doctrine of equivalents.

101. Microsoft had knowledge of the ’985 Patent based on the licensing negotiations between the parties. Microsoft also knew of the ’985 Patent because RealD showed Microsoft the software under a NDA. Furthermore, Microsoft’s knowledge of the ’985 Patent is demonstrated by the fact that the ’985 Patent’s inventors are now employees of Microsoft. Finally, should Microsoft contend that it did not have knowledge of the ’985 Patent, this Complaint will serve as notice.

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102. Microsoft intentionally encourages and aids at least its users to directly infringe the ’985 Patent.

103. Microsoft provides the Accused Products and instructions to its users such that they will use the Accused Products in a directly infringing manner. Microsoft markets the Accused Products to its users and provides instructions to its users on how to use the functionality of the ’985 Patent on its website and elsewhere. See, e.g., https://blogs.windows.com/devices/2020/08/20/make-a-more-personal-connection-with-eye-contact-now-generally-available/ (stating “[y]ou can access Eye Contact by opening the Surface app on your Pro X. It will work on video calling applications like Microsoft Teams, Skype, and others.”).

104. Microsoft users directly infringe by using the Accused Products in their intended manner. Microsoft induces such infringement by providing the Accused Products and instructions to enable and facilitate infringement. On information and belief, Microsoft specifically intends that its actions will result in infringement of the ’985 Patent or has taken deliberate actions to avoid learning of infringement.

105. Additional allegations of Microsoft’s knowledge of the ’985 Patent and willful infringement will likely have additional evidentiary support after a reasonable opportunity for discovery.

106. Microsoft’s infringement of the ’985 Patent is willful and deliberate, entitling RealD to enhanced damages and attorneys’ fees.

107. Microsoft’s infringement of the ’985 Patent is exceptional and entitles RealD to attorneys’ fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

108. RealD has been damaged by Microsoft’s infringement of the ’985 Patent and will continue to be damaged unless Microsoft is enjoined by this Court. RealD has suffered and

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continues to suffer irreparable injury for which there is no adequate remedy at law. The balance of hardships favors RealD, and public interest is not disserved by an injunction.

109. RealD is entitled to recover from Microsoft all damages that RealD has sustained as a result of Microsoft's infringement of the '985 Patent, including without limitation, lost profits and/or not less than a reasonable royalty.

VII. JURY DEMAND

Plaintiff hereby demands a trial by jury as to all issues so triable.

VIII. PRAYER FOR RELIEF

110. WHEREFORE, RealD respectfully requests that this Court enter judgment in its favor and against Microsoft and respectfully requests the following relief:

111. A judgment and order requiring Microsoft to pay RealD's monetary damages that were caused by Microsoft's breaches of contract and theft of trade secrets;

112. Disgorgement of all profits Microsoft has made through the unauthorized use of RealD's trade secrets;

113. A judgment and order of injunction to prevent future violations of the Defend Trade Secrets Act and Washington Uniform Trade Secrets Act by Microsoft through use of RealD's trade secrets;

114. A judgment that Microsoft infringed and continues to infringe the '985 Patent;

115. A judgment and order requiring Microsoft to pay RealD's monetary damages sufficient to compensate RealD for Microsoft's infringement of the '985 Patent, but in no event less than a reasonable royalty under 35 U.S.C. § 284;

116. An award of enhanced damages pursuant to 35 U.S.C. § 284;

117. An award of treble damages for willful infringement;

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118. A judgment and order requiring Microsoft to pay RealD's pre-judgment and post-judgment interest on the damages awarded, to the full extent allowed under the law, as well as its costs;

119. A judgment and order finding this to be an exceptional case under 35 U.S.C. § 285 and requiring Microsoft to pay costs of this action and attorneys' fees;

120. A permanent injunction against all Microsoft products found to infringe the '985 Patent;

121. In lieu of an injunction, an award of a compulsory forward royalty;

122. An order for an accounting of damages; and

123. An award of such further relief as the Court may deem appropriate and just under the circumstances.

DATED this 7th day of July, 2022.

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Attorneys for Plaintiff RealD Spark, LLC

Exhibit A

Microsoft

Non-Disclosure Agreement

This Non-Disclosure Agreement ("agreement") is between the parties signing below. "We," "us" and "our" refer to both of the parties signing below and our respective affiliates.

COMPANY AND ITS AFFILIATES or INDIVIDUAL: RealD, Inc	**MICROSOFT CORPORATION AND ITS AFFILIATES**
Address: 100 North Crescent Dr., Suite 200 Beverly Hills, CA 90210 United States	One Microsoft Way Redmond, WA 98052-6399 USA
Sign: DocuSigned by: [signature] 0903182AB16A49E...	[signature]
Print Name: Leo Bannon	Lucy Bassli (LCA)
Print Title: Executive Vice President	Assistant General Counsel
Signature Date: 07/20/2016	19-Jul-16

For information about this agreement, contact the Microsoft Contact, Tracy Belyea (CBRE, Inc).

1. The purpose of this agreement.

This agreement allows us to disclose confidential information to each other, to our own affiliates and to the other's affiliates, under the following terms. An "affiliate" is any legal entity that one of us owns, that owns one of us or that is under common control with one of us. "Control" and "own" mean possessing a 50% or greater interest in an entity or the right to direct the management of the entity.

2. Confidential information.

a. **What is included.** "Confidential information" is non-public information, know-how and trade secrets in any form that:

- Are designated as "confidential"; or
- A reasonable person knows or reasonably should understand to be confidential.

b. **What is not included**. The following types of information, however marked, are not confidential information. Information that:

- Is, or becomes, publicly available without a breach of this agreement;
- Was lawfully known to the receiver of the information without an obligation to keep it confidential;
- Is received from another source who can disclose it lawfully and without an obligation to keep it confidential;
- Is independently developed; or
- Is a comment or suggestion one of us volunteers about the other's business, products or services.

3. Treatment of confidential information.

a. **In general.** Subject to the other terms of this agreement, each of us agrees:

- We will not disclose the other's confidential information to third parties; and
- We will use and disclose the other's confidential information only for purposes of our business relationship with each other.

b. **Security precautions**. Each of us agrees:

- To take reasonable steps to protect the other's confidential information. These steps must be at least as protective as those we take to protect our own confidential information;
- To notify the other promptly upon discovery of any unauthorized use or disclosure of confidential information; and
- To cooperate with the other to help regain control of the confidential information and prevent further unauthorized use or disclosure of it.

c. **Sharing confidential information with affiliates and representatives.**

- A "representative" is an employee, contractor, advisor or consultant of one of us or one of our respective affiliates.
- Each of us may disclose the other's confidential information to our representatives (who may then disclose that confidential information to other of our representatives) only if those representatives have a need to know about it for purposes of our business relationship with each other. Before doing so, each of us must:
  - ensure that affiliates and representatives are required to protect the confidential information on terms consistent with this agreement; and
  - accept responsibility for each representative's use of confidential information.
- Neither of us is required to restrict work assignments of representatives who have had access to confidential information. Neither of us can control the incoming information the other will disclose to us in the course of working together, or what our representatives will remember, even without notes or other aids. We agree that use of information in representatives' unaided memories in the development or deployment of our respective products or services does not create liability under this agreement or trade secret law, and we agree to limit what we disclose to the other accordingly.

d. **Disclosing confidential information if required to by law.** Each of us may disclose the other's confidential information if required to comply with a court order or other government demand that has the force of law. Before doing so, each of us must seek the highest level of protection available and, when possible, give the other enough prior notice to provide a reasonable chance to seek a protective order.

4. Length of confidential information obligations.

a. **Termination.** This agreement continues in effect until one of us terminates it. Either of us may terminate this agreement for any reason by providing the other with 30 days' advance written notice. Termination of this agreement will not change any of the rights and duties made while this agreement is in effect.

b. **No other use or disclosure of confidential information**. Except as permitted above, neither of us will use or disclose the other's confidential information for five years after we receive it. The five-year time period does not apply if applicable law requires a longer period.

5. General rights and obligations.

a. **Law that applies; jurisdiction and venue.** The laws of the State of Washington govern this agreement. If federal jurisdiction exists, we each consent to exclusive jurisdiction and venue in the federal courts in King County, Washington. If not, we each consent to exclusive jurisdiction and venue in the Superior Court of King County, Washington.

b. **Compliance with law.** Each of us will comply with all export laws that apply to confidential information.

c. **Waiver.** Any delay or failure of either of us to exercise a right or remedy will not result in a waiver of that, or any other, right or remedy.

d. **Money damages insufficient.** Each of us acknowledges that money damages may not be sufficient compensation for a breach of this agreement. Each of us agrees that the other may seek court orders to stop confidential information from becoming public in breach of this agreement.

e. **Attorneys' fees.** In any dispute relating to this agreement the prevailing party will be entitled to recover reasonable attorneys' fees and costs.

f. **Transfers of this agreement.** If one of us transfers this agreement, we will not disclose the other's confidential information to the transferee without the other's consent.

g. **Enforceability.** If any provision of this agreement is unenforceable, the parties (or, if we cannot agree, a court) will revise it so that it can be enforced. Even if no revision is possible, the rest of this agreement will remain in place.

h. **Entire agreement.** This agreement does not grant any implied intellectual property licenses to confidential information, except as stated above. We may have contracts with each other covering other specific aspects of our relationship ("other contracts"). The other contract may include commitments about confidential information, either within it or by referencing another non-disclosure agreement. If so, those obligations remain in place for purposes of that other contract. With this exception, this is the entire agreement between us regarding confidential information. It replaces all other agreements and understandings regarding confidential information. We can only change this agreement with a signed document that states that it is changing this agreement.

Exhibit B

US010740985B2

(12) **United States Patent**
Sommerlade et al.

(10) **Patent No.: US 10,740,985 B2**
(45) **Date of Patent: Aug. 11, 2020**

(54) **ADJUSTING A DIGITAL REPRESENTATION OF A HEAD REGION**

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(72) Inventors: **Eric Sommerlade**, Oxford (GB); **Alexandros Neophytou**, Oxford (GB)

(73) Assignee: **RealD Spark, LLC**, Beverly Hills, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(22) Filed: **Aug. 7, 2018**

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Related U.S. Application Data

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(51) **Int. Cl.**

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G06T 7/33	(2017.01)
G06N 3/04	(2006.01)
G06N 3/08	(2006.01)

(52) **U.S. Cl.**

CPC ***G06T 19/20*** (2013.01); ***G06N 3/0454*** (2013.01); ***G06N 3/08*** (2013.01); ***G06T 7/337*** (2017.01); *G06T 2207/20081* (2013.01); *G06T 2219/2004* (2013.01); *G06T 2219/2012* (2013.01); *G06T 2219/2021* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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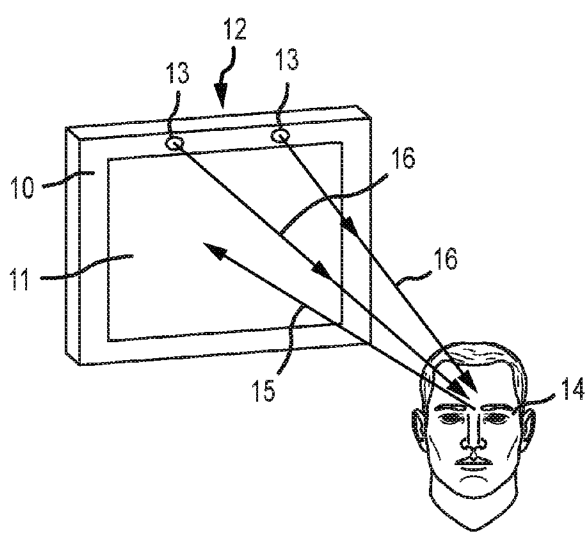
(57) **ABSTRACT**

Methods and devices for generating reference data for adjusting a digital representation of a head region, and methods and devices for adjusting the digital representation of a head region are disclosed. In some arrangements, training data are received. A first machine learning algorithm generates first reference data using the training data. A second machine learning algorithm generates second reference data using the same training data and the first reference data generated by the first machine learning algorithm.

19 Claims, 12 Drawing Sheets



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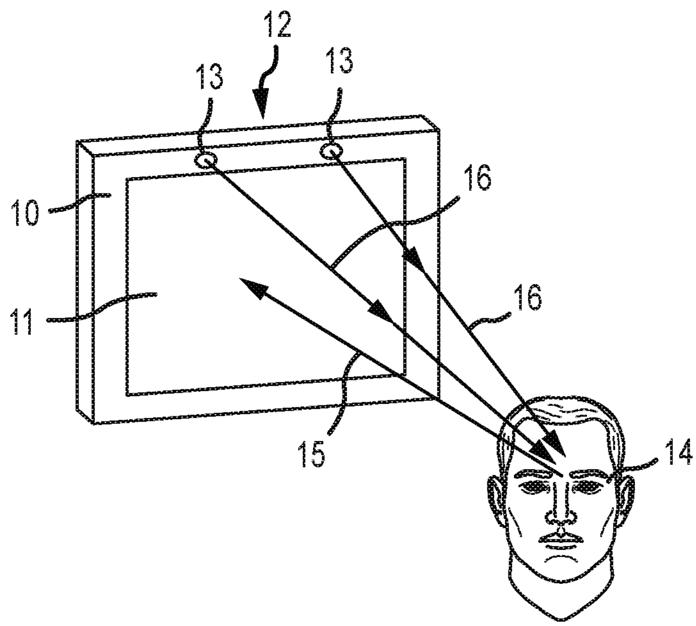


FIG.1

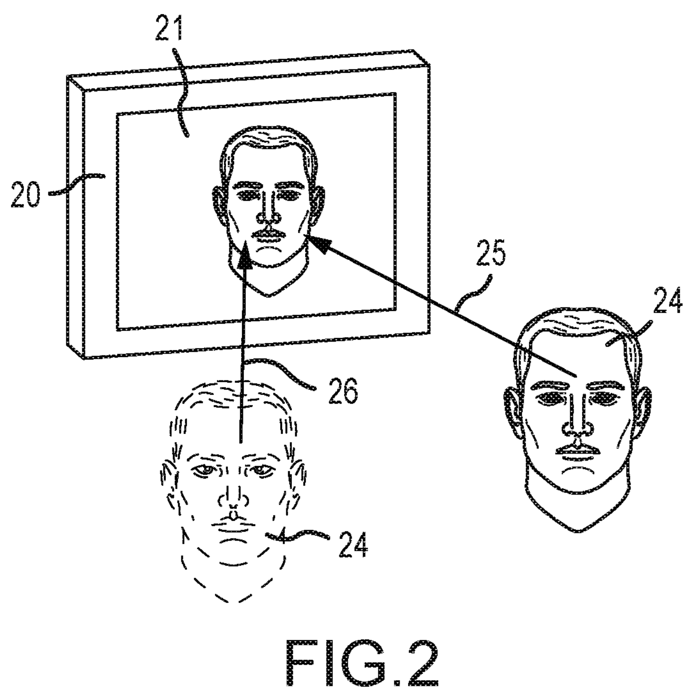


FIG.2

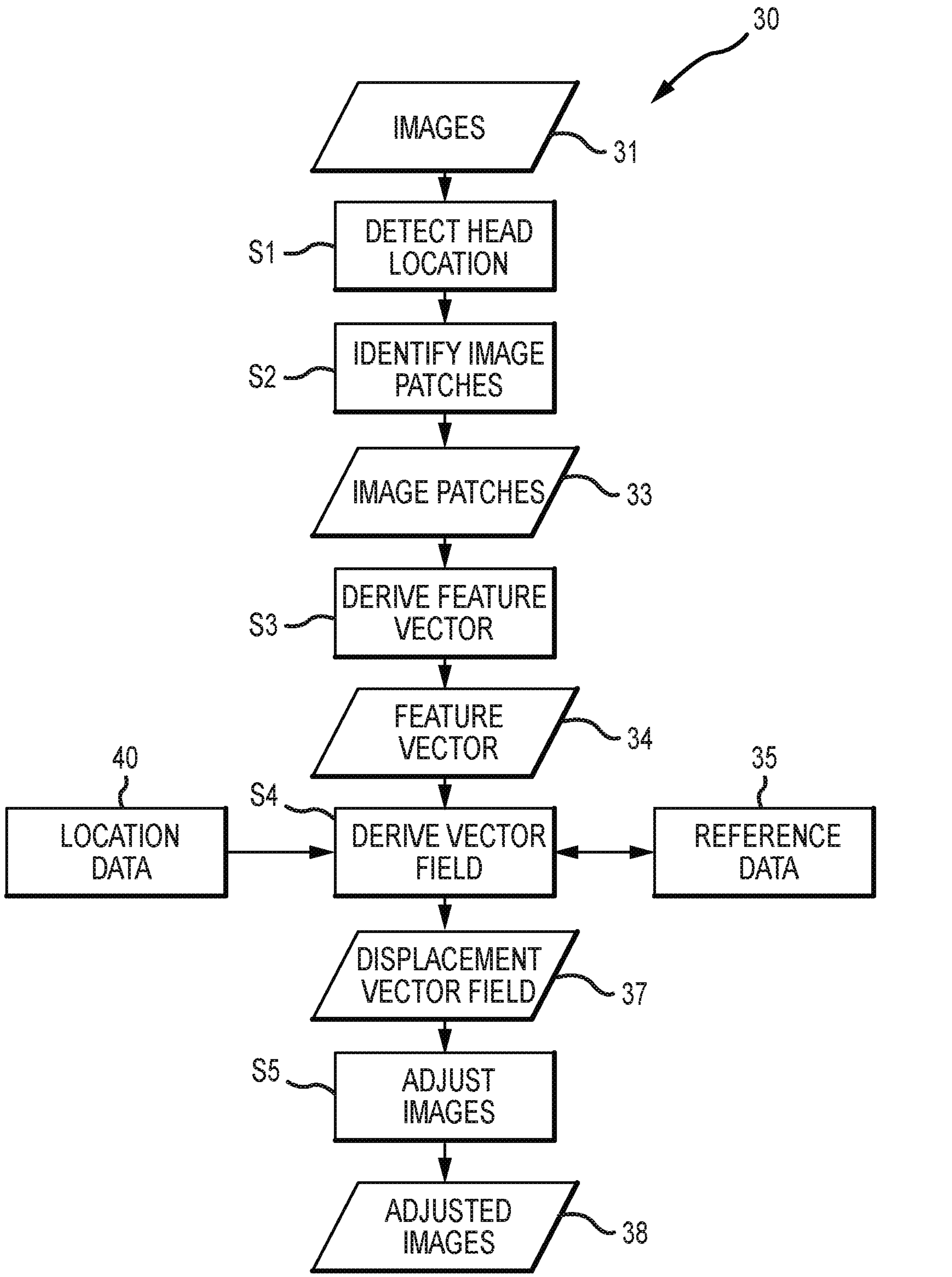

30
IMAGES
31
S1
DETECT HEAD LOCATION
S2
IDENTIFY IMAGE PATCHES
IMAGE PATCHES
33
S3
DERIVE FEATURE VECTOR
FEATURE VECTOR
34
40
LOCATION DATA
S4
DERIVE VECTOR FIELD
35
REFERENCE DATA
DISPLACEMENT VECTOR FIELD
37
S5
ADJUST IMAGES
ADJUSTED IMAGES
38

FIG.3

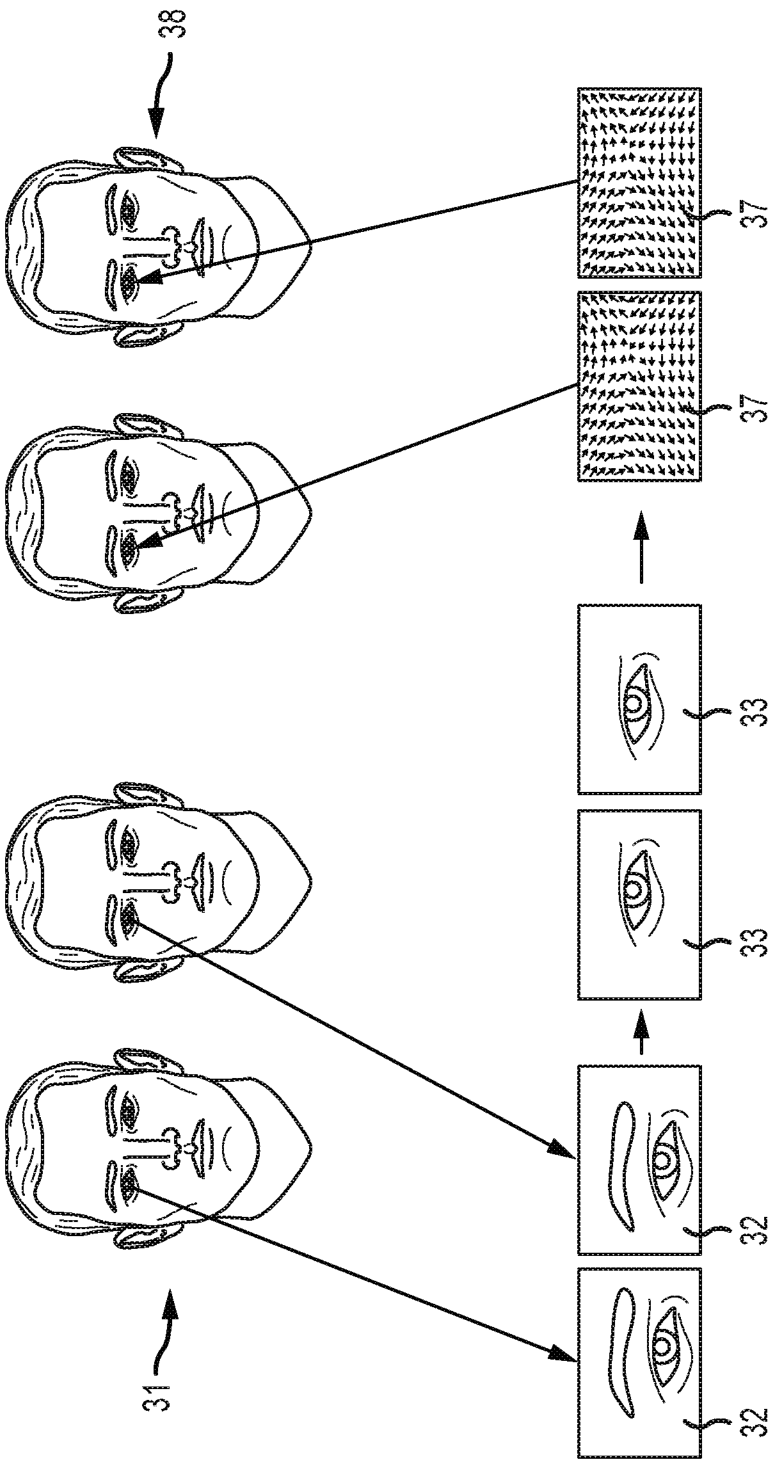


FIG.4

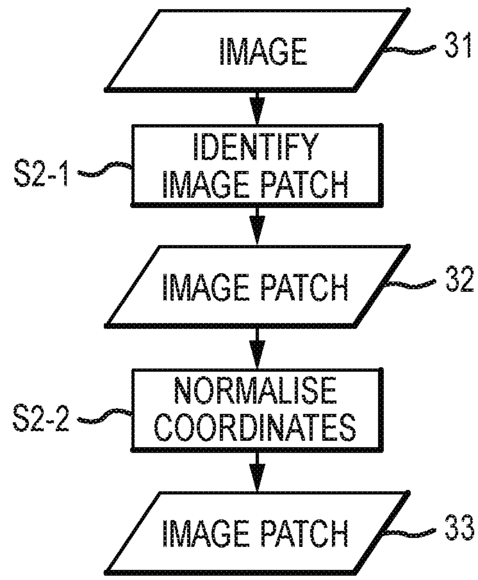


IMAGE
31
S2-1
IDENTIFY IMAGE PATCH
IMAGE PATCH
32
S2-2
NORMALISE COORDINATES
IMAGE PATCH
33

FIG.5

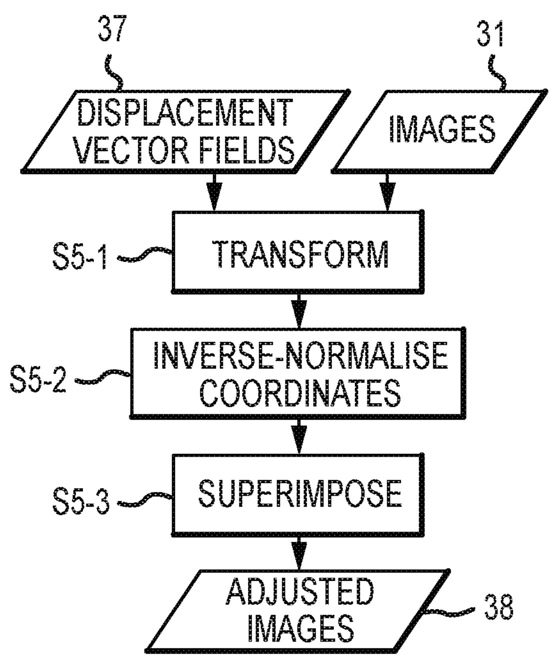

37
31
DISPLACEMENT VECTOR FIELDS
IMAGES
S5-1
TRANSFORM
S5-2
INVERSE-NORMALISE COORDINATES
S5-3
SUPERIMPOSE
ADJUSTED IMAGES
38

FIG.6

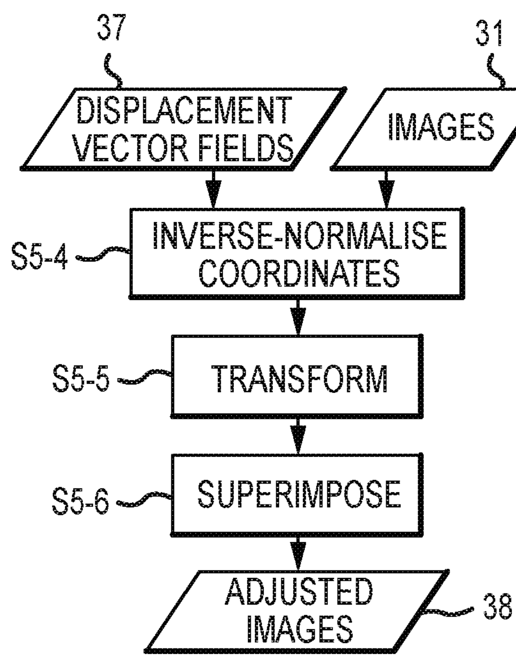

37
31
DISPLACEMENT VECTOR FIELDS
IMAGES
S5-4
INVERSE-NORMALISE COORDINATES
S5-5
TRANSFORM
S5-6
SUPERIMPOSE
ADJUSTED IMAGES
38

FIG.7

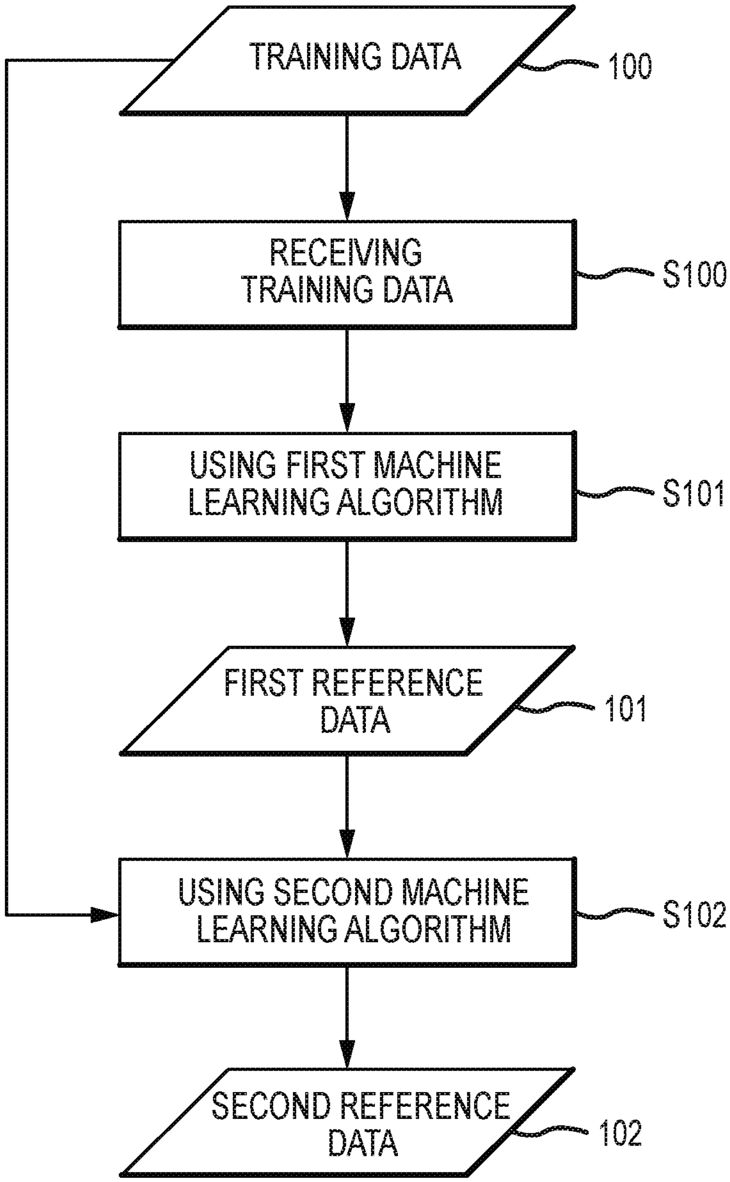

TRAINING DATA
100
RECEIVING TRAINING DATA
S100
USING FIRST MACHINE LEARNING ALGORITHM
S101
FIRST REFERENCE DATA
101
USING SECOND MACHINE LEARNING ALGORITHM
S102
SECOND REFERENCE DATA
102

FIG.8

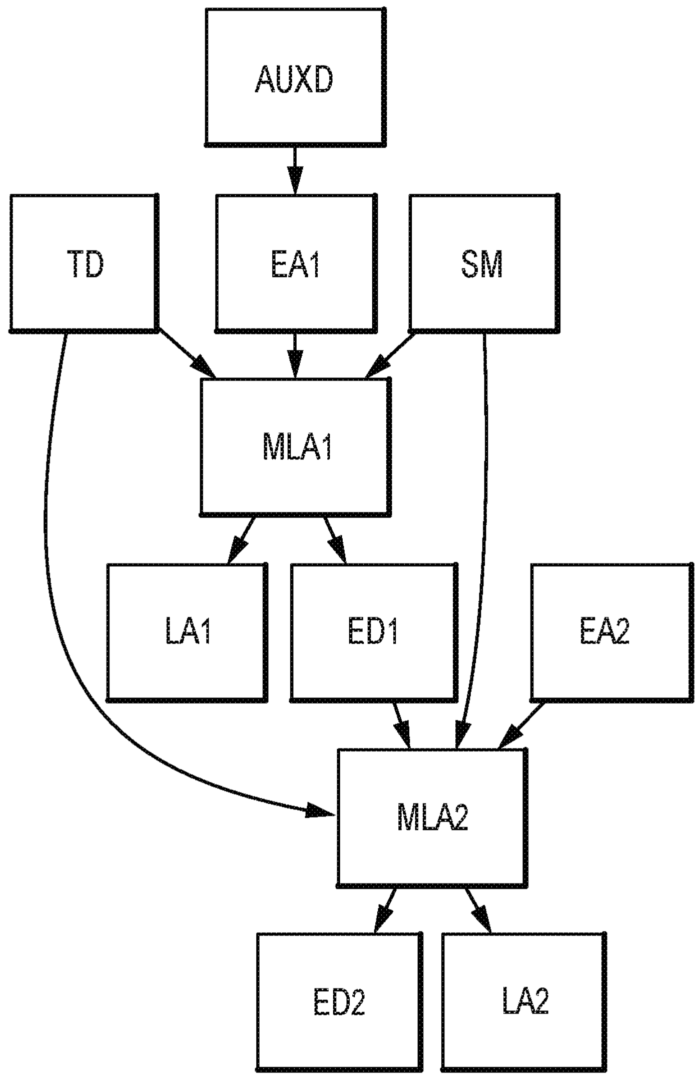


FIG.9

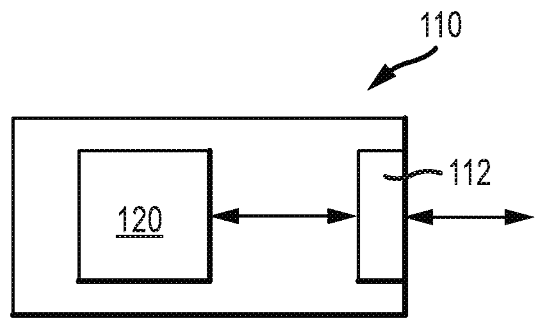

110
120
112

FIG. 10

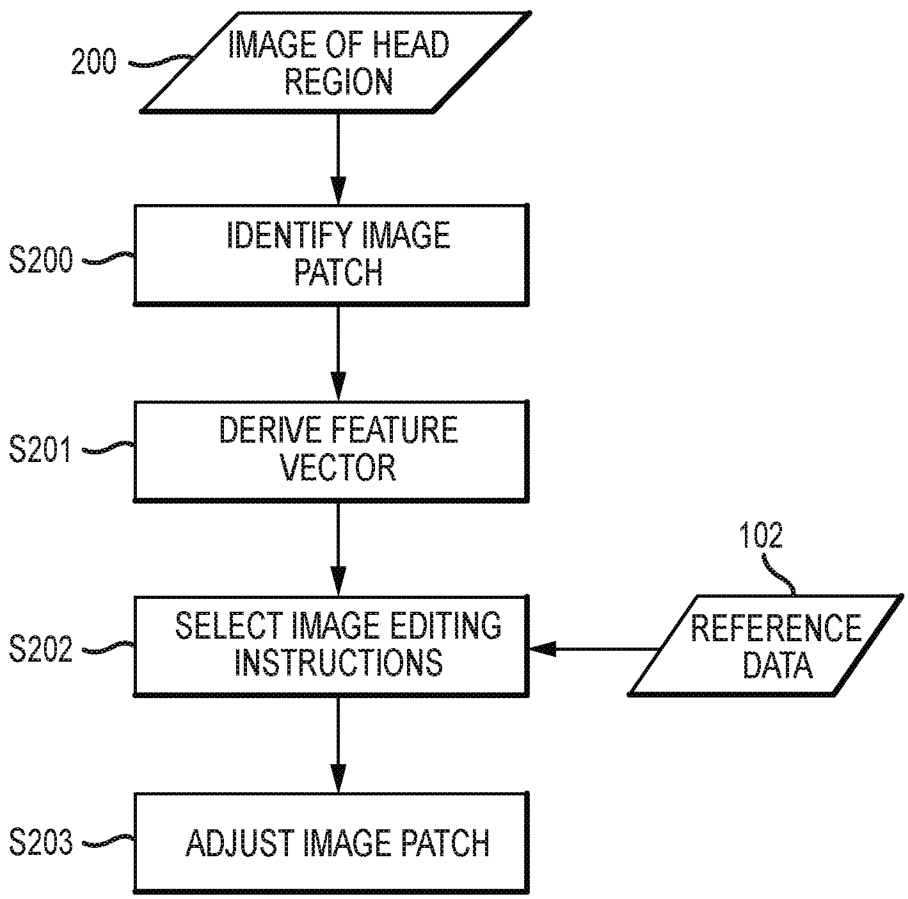

200
IMAGE OF HEAD REGION
S200
IDENTIFY IMAGE PATCH
S201
DERIVE FEATURE VECTOR
S202
SELECT IMAGE EDITING INSTRUCTIONS
102
REFERENCE DATA
S203
ADJUST IMAGE PATCH

FIG. 11

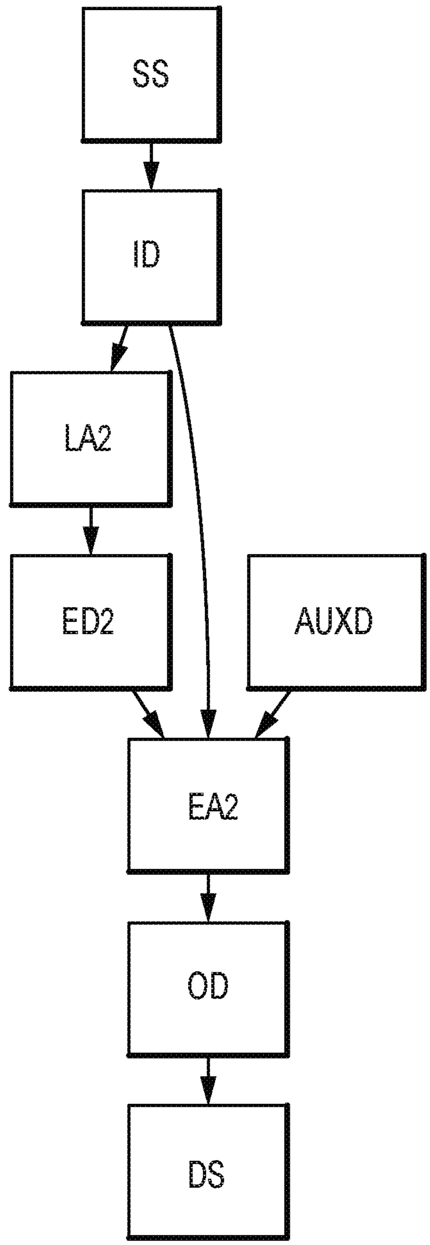


FIG.12

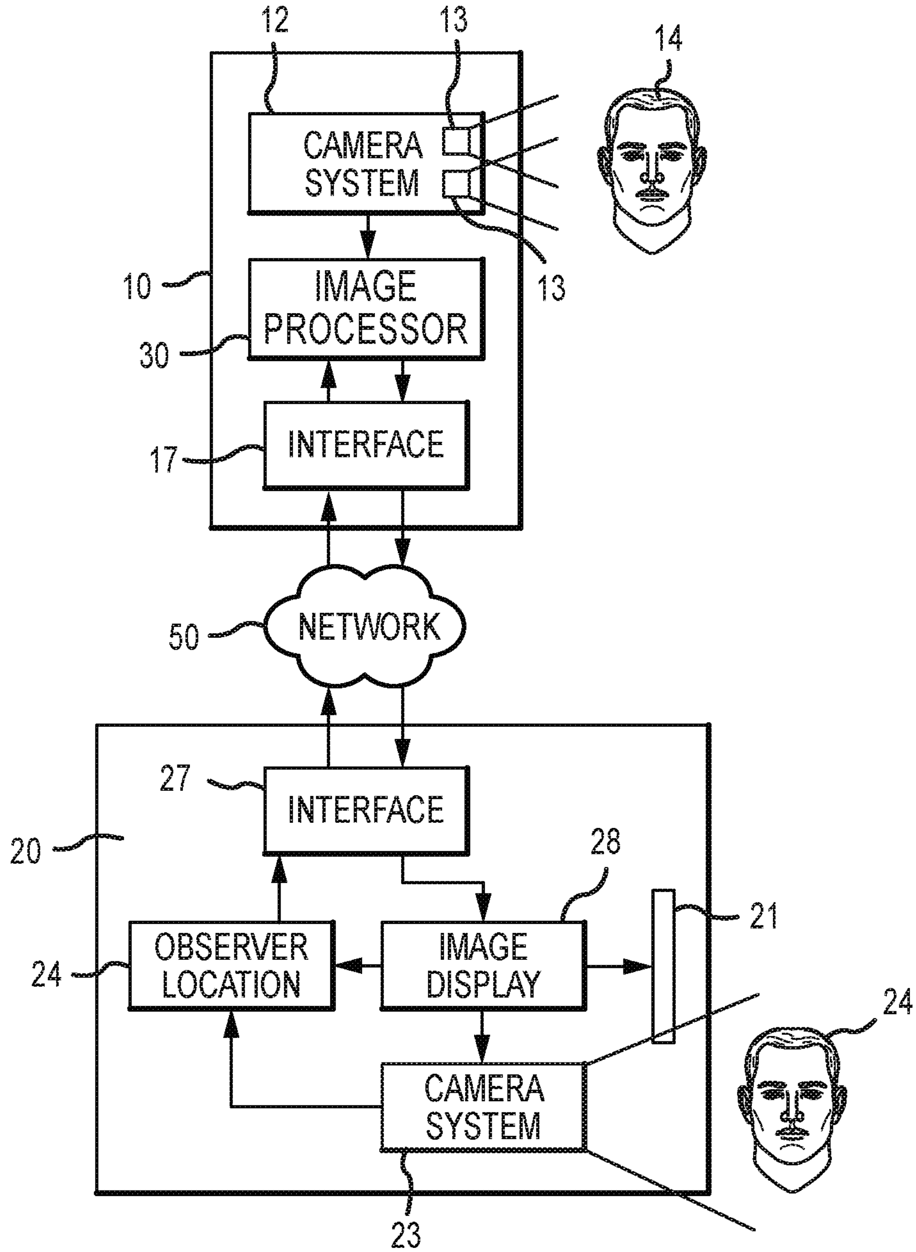

12
13
14
CAMERA SYSTEM
13
10
IMAGE PROCESSOR
30
INTERFACE
17
NETWORK
50
27
INTERFACE
20
28
21
OBSERVER LOCATION
24
IMAGE DISPLAY
24
CAMERA SYSTEM
23

FIG.13

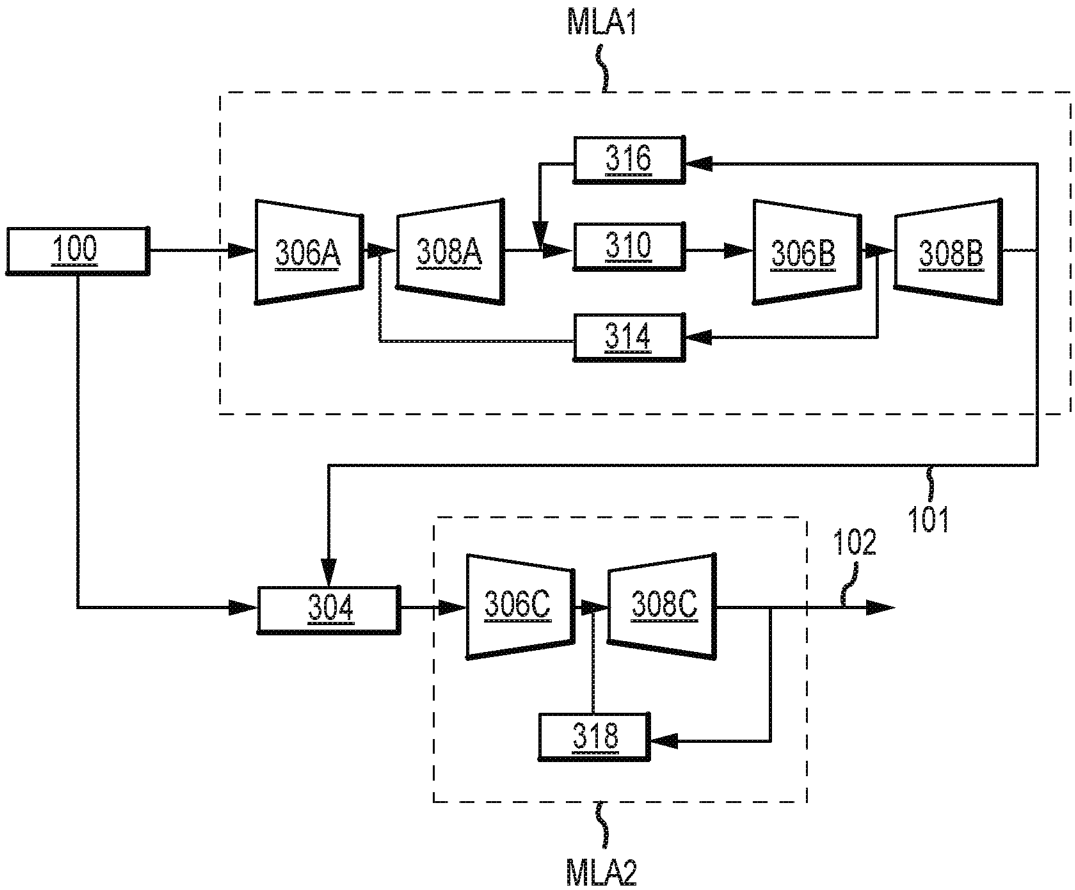

MLA1
316
100
306A
308A
310
306B
308B
314
101
102
304
306C
308C
318
MLA2

FIG. 14

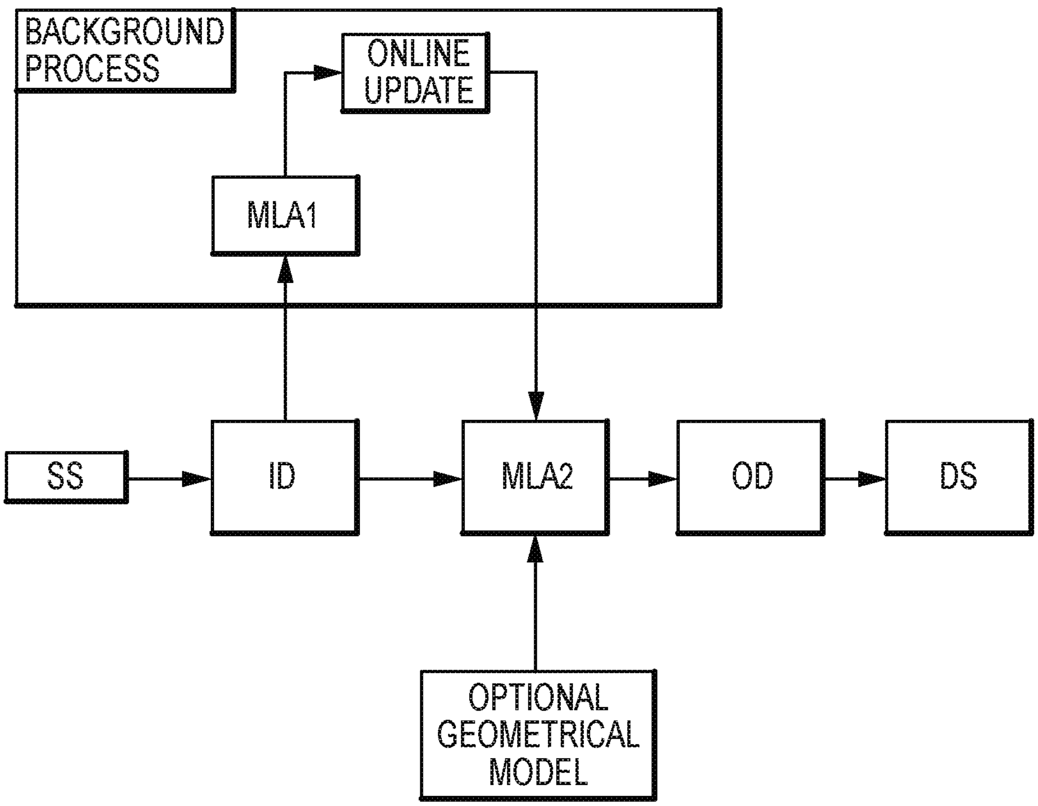

BACKGROUND PROCESS
ONLINE UPDATE
MLA1
SS
ID
MLA2
OD
DS
OPTIONAL GEOMETRICAL MODEL

FIG.15

ADJUSTING A DIGITAL REPRESENTATION OF A HEAD REGION

TECHNICAL FIELD

This application relates to adjusting a digital representation, such as an image or a three-dimensional geometrical representation, of a head region, particularly a facial and/or neck region. The application relates particularly to adjusting target features of the digital representation of the head region, for example to correct a perceived gaze direction of eyes, or to modify the texture and/or shape of features such as the nose, mouth, chin or neck.

BACKGROUND

In many systems, images of a head, which may comprise single images at different times, or stereoscopic pairs of images or other multi-view images, may be captured in one device and displayed on a different device for viewing by an observer. One non-limitative example is a system for performing teleconferencing between two telecommunications devices. In that case, each device may capture images of the observer of that device and transmit them to the other device over a telecommunications network for display and viewing by the observer of the other device. Digital representations other than images and/or complementary to images may also be captured, for example using depth measurements (e.g. using a time-of-flight camera).

When an image or other digital representation of a head is captured and displayed, the gaze of the head may not be directed at the observer. This may be caused for example by the gaze of the head not being directed at the sensing system (e.g. camera system) used to capture the digital representation (e.g. image), for example because a user whose head is imaged is observing a display in the same device as a camera system and the camera system is offset above (or below) that display. In that case, the gaze in the displayed images will be perceived to be downwards (or upwards). The human visual system has evolved high sensitivity to gaze during social interaction, using cues gained from the relative position of the iris and white sclera of other observers. Errors in the perceived gaze are disconcerting. For example in a system for performing teleconferencing, errors in the perceived gaze can create unnatural interactions between the users.

The present disclosure is concerned with processing techniques (e.g. image processing techniques) for adjusting digital representations (e.g. images) of a head region to correct the perceived gaze and/or to improve other aspects of a computer-generated display of the head region. The present disclosure is particularly concerned with implementing such processing techniques with minimal demands on computer hardware and/or power such that they provide results at or near input data frame rate or user feedback requirements.

BRIEF SUMMARY

According to a first aspect of the present disclosure, there is provided a method of generating reference data for adjusting a digital representation of a head region, the method comprising: receiving training data comprising: a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region; using a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region; and using a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data generated by the first machine learning algorithm, the second reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region.

The described use of two machine learning algorithms allows an improved balance to be achieved between accuracy of the adjustment process and speed of execution. The first machine learning algorithm can be configured to provide highly detailed first reference data, which provides high accuracy. Use of this first reference data directly in a processing technique (e.g. image processing technique) to adjust a digital representation (e.g. image or three-dimensional geometrical representation) of a head region would be relatively expensive in terms of computational resources because of the high level of detail. By arranging instead for the first reference data to be provided to a second machine learning algorithm, which provides, based on the first reference data and the original training data, the reference data (the second reference data) that is to be used for the adjustment of the digital representation of the head region, it is possible to benefit to an extent from the high accuracy of the first machine learning algorithm whilst also providing reference data that is less detailed and thus easier to process efficiently when performing the adjustment of the digital representation of the head region. The quality of the reference data provided by the second machine learning algorithm is found to be significantly improved when the second machine learning algorithm is provided with both the first reference data and the training data in comparison to when the second machine learning algorithm is provided only with the training data.

In an embodiment, efficiency is further improved by providing editing instructions (e.g. image editing instructions) in the second reference data in a compressed representation. The use of a compressed representation reduces data storage and bandwidth requirements during use of the editing instructions to perform adjustment of a digital representation of a head region.

According to a second aspect of the present disclosure, there is provided a device configured to perform a similar method to the first aspect of the invention.

According to a third aspect of the present disclosure, there is provided a method of adjusting a digital representation of a head region, the method comprising: identifying a target patch in the digital representation of the head region, the target patch comprising a target feature of the digital representation of the head region; deriving a feature vector from plural local descriptors of the target patch; using the feature vector to select editing instructions from reference data, the reference data comprising editing instructions for a range of possible values of the feature vector; and applying the selected editing instructions to the target patch to adjust the digital representation of the head region, wherein the editing instructions in the reference data are provided in a compressed representation.

According to a fourth aspect of the present disclosure, there is provided a device configured to perform a similar method of the third aspect of the invention.

The use of a compressed representation reduces data storage and bandwidth requirements.

According to a fifth aspect of the present disclosure, there is provided a method of training a machine learning algorithm to adjust a digital representation of a head region, comprising: receiving training data comprising: a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and first reference data generated by a pre-trained first machine learning algorithm, the first reference data comprising a set of editing instructions in one-to-one correspondence with the input patches, each editing instruction being for adjusting the digital representation of the head region; updating a pre-trained second machine learning algorithm trained to generate second reference data, where the input for the updating comprises the training data and the generated first reference data, the second reference data comprising editing instructions for adjusting the digital representation of the head region.

According to a sixth aspect of the present disclosure, there is provided a method of training a machine learning algorithm to adjust a digital representation of a head region, the method comprising: receiving training data comprising a set of input digital representations of a head region; training a first machine learning algorithm using the training data to perform an adjustment of a digital representation of a head region; using the trained first machine learning algorithm to generate first reference data, the first reference data comprising an adjusted digital representation of the head region for each of at least a subset of the input digital representations, each adjusted digital representation being obtained by performed the adjustment that the first machine learning algorithm was trained to perform; and training a second machine learning algorithm using at least a subset of the training data used to train the first machine learning algorithm and the first reference data to perform the same adjustment of a digital representation of a head region as the first machine learning algorithm.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limitative embodiments are illustrated by way of example in the accompanying figures, in which like reference numbers indicate similar parts, and in which:

FIG. **1** is a schematic perspective view of a device that captures a stereoscopic pair of images;

FIG. **2** is a schematic perspective view of a device that displays the stereoscopic pair of images;

FIG. **3** is a flow chart of a method of adjusting a stereoscopic pair of images;

FIG. **4** is a diagram illustrating the processing of the stereoscopic pair of images in the method of FIG. **3**;

FIG. **5** is a flow chart of a step of extracting an image patch;

FIG. **6** and FIG. **7** are flow charts of two alternatives for a step of adjusting an image;

FIG. **8** is flow chart of a method of generating reference data;

FIG. **9** schematically depicts data flow in an example method of generating reference data;

FIG. **10** depicts a device for generating reference data;

FIG. **11** is a flow chart of a method of adjusting an image of a head region;

FIG. **12** schematically depicts data flow in an example of a method of adjusting an image of a head region;

FIG. **13** is a diagram of a telecommunications system in which the method may be implemented;

FIG. **14** schematically depicts data flow in an example method of generating reference data for converting a two-dimensional digital representation of a head region to a three-dimensional digital representation of a head region; and

FIG. **15** schematically depicts data flow in an example of a method of adjusting a digital representation of a head region in which a second machine learning algorithm is updated online.

DETAILED DESCRIPTION

FIG. **1** and FIG. **2** illustrate how incorrect gaze is perceived when a stereoscopic pair of images of a head is captured by the device **10** shown in FIG. **1** which will be referred to as the source device **10**, and displayed on a different device **20** shown in FIG. **2** which will be referred to as the destination device **20**. Capturing of a stereoscopic pair of images is shown as an example. A similar effect can occur when a monocular image is captured and when more than two views of the head are captured. A similar effect can also occur when alternative or additional sensing techniques are used to build a digital representation of the head (e.g. where a depth sensor such as a time-of-flight camera is used to obtain three-dimensional geometrical information about positions on the surface of the head).

In the embodiment shown, the capture device **10** includes a display **11** and a camera system **12**. In this particular example, the camera system comprises two cameras **13** in order to capture the stereoscopic pair of images of the head of a source observer **14**. In a monocular implementation a single camera may be provided instead of the two cameras **13**. In other implementations a depth sensor is alternatively or additionally provided. The source observer **14** views the display **11**, along line **15**. The cameras **13** (optionally including one or more depth sensors) of the camera system **12** are offset from the display **11**, in this case being above the display **11**. Thus, the cameras **13** effectively look down on the source observer **14** along line **16**.

The display device **20** includes a display **21**, which in this example can be a stereoscopic display of any known type, for example an autostereoscopic display of any known type. The display **21** displays the stereoscopic pair of images as captured by the capture device **10**. A destination observer **24** views the display **21**. If the destination observer **24** is located in a normal viewing position perpendicular to the center of the display **21**, as shown by the hard outline of the destination observer **24**, then the gaze of the source observer **14** is perceived by the destination observer **24** to be downwards, rather than looking at the destination observer **24**, because the cameras **13** of the source device **10** look down on the source observer **14**.

Although the cameras **13** are above the display **11** in this example, the cameras **13** could in general could be in any location adjacent the display **11**, and the gaze of the source observer **14** perceived by the destination observer **24** would be correspondingly incorrect.

If the destination observer **24** is located in an offset viewing position, as shown by the dotted outline of the destination observer **24** so that the destination observer **24** views the display **21** along line **26**, then the offset of the destination observer **24** creates an additional error in the gaze of the source observer **14** perceived by the destination observer **24**. A similar additional error in the perceived gaze of the source observer **14** occurs if the destination observer **24** is located in the normal viewing position along line **25**, but the displayed image (or stereoscopic pair of images in this example) is displayed on the display **25** in a position offset from the center of the display **25**.

A stereoscopic pair of images is an example of multi-view images where there are two images. Although FIG. **1** illustrates an example where the camera system **12** includes two cameras **13** that capture a stereoscopic pair of images, alternatively the camera system may include more than two cameras **13** that capture more than two multi-view images, in which case similar issues of incorrect perceived gaze exist on display. The camera system may alternatively include only one camera and/or one or more depth sensors.

FIG. **3** illustrates a method of adjusting multi-view images to correct such errors in the perceived gaze. The method of FIG. **3** is a specific example of a method of adjusting digital representations of a head region in a case where the digital representations comprise images of the head region and where the images comprise one or more multi-view images of the head region. For simplicity, this method will be described with respect to the adjustment of multi-view images comprising a stereoscopic pair of images. The method may be generalized to multi-view images comprising more than two images, simply by performing similar processing on a larger number of images. The method may also be generalized to the case where single view (monocular) images of the head region are used and to the case where information from other sensing modalities, such as depth measurements, is included within the digital representations of the head region.

The method may be performed in an image processor **30** (or other processor). The image processor **30** may be implemented by a processor executing a suitable computer program or by dedicated hardware or by some combination of software and hardware. Where a computer program is used, the computer program may comprise instructions in any suitable language and may be stored on a computer readable storage medium, which may be of any type, for example: a recording medium which is insertable into a drive of the computing system and which may store information magnetically, optically or opto-magnetically; a fixed recording medium of the computer system such as a hard drive; or a computer memory.

The image processor **30** (or other processor) may be provided in the source device **10**, the destination device **10** or in any other device, for example a server on a telecommunications network, which may be suitable in the case that the source device **10** and the destination device **10** communicate over such a telecommunications network.

In this example, a stereoscopic pair of images **31** are captured by the camera system **12**. Although the camera systems **12** is illustrated in FIG. **1** as including two cameras **13**, this is not limitative and more generally the camera system **13** may have the following properties.

The camera system comprises a set of one or more cameras **13**, with at least two cameras **13** in the case where multi-view images are processed. Where two cameras are provided, the cameras are typically spaced apart by a distance less than the average human intrapupilar distance. In the alternative that the method is applied to more than two multi-view images, then there are more than two cameras **13**, that is one camera **13** per image. In some embodiments, a depth sensor is provided for obtaining three-dimensional geometrical information about a surface of the head region, optionally in addition to one or more other cameras (e.g. optical cameras). The depth sensor may comprise a time-of-flight camera.

Where plural cameras **13** are provided, the cameras **13** may be spatially related to each other and the display **11**. The spatial relationship between the cameras **13** themselves and between the cameras **13** and the display **11** is known in advance. Known methods for finding the spatial relationship may be applied, for example a calibration method using a reference image, or specification a priori.

The camera or cameras **13** face in the same direction as the display **11**. Thus, when the source observer **14** is viewing the display **11**, then the camera or cameras **13** face the source observer **14** and the captured information, such as depth information, image or images (e.g. stereoscopic pair of images) are digital representations (e.g. images and/or three-dimensional geometrical representations) of the head of the source observer **14**. Different cameras in the camera system can have different fields of view.

The camera system **12** may include cameras **13** having different sensing modalities, including but not limited to visible light, infrared, and time-of-flight (depth).

In some embodiments, the main output of the camera system **13** is images **31** which are typically video images output at a video rate. The output of the camera system **13** may also include data representing the spatial relationship between the cameras **13** and the display **11**, the nature of the sensing modalities and internal parameters of the cameras **13** (for example focal length, optical axis) which may be used for angular localization, as well as three-dimensional geometrical information, for example from depth measurements.

An example of the method performed on a digital representation of a head region comprising a stereoscopic pair of images **31**, for the case of adjustment of eye regions, is as follows. To illustrate this example method, reference is also made to FIG. **4** which shows an example of the stereoscopic pair of images **31** at various stages of the method.

In step S**1**, the stereoscopic pair of images **31** are analyzed to detect the location of the head and in particular the eyes of the source observer **14** within the stereoscopic pair of images **31**. This is performed by detecting presence of a head, tracking the head, and localizing the eyes of the head. Step S**1** may be performed using a variety of techniques that are known in the art.

One possible technique for detecting the presence of the head is to use Haar feature cascades, for example as disclosed in Viola and Jones, "Rapid Object Detection using a Boosted Cascade of Simple Features", CVPR 2001, pp 1-9, which is herein incorporated by reference in its entirety.

One possible technique for tracking the head is to use the approach of Active Appearance Models to provide the position of the head of the subject, as well as the location of the eyes, for example as disclosed in Cootes et al., "Active shape models—their training and application", Computer Vision and Image Understanding, 61(1):38-59, January 1995 and in Cootes et al. "Active appearance models", IEEE Trans. Pattern Analysis and Machine Intelligence, 23(6): 681-685, 2001, both of which are herein incorporated by reference in their entireties.

In step S**1**, typically, a set of individual points ("landmarks") are set to regions of the face, typically the eyes, for example corners of the eye, upper and lower lid locations, etc., thereby localizing the eyes.

In step S**2**, patches representing portions of a digital representation of the head region, which in this example may be referred to image patches, containing the left and right eyes of the head, respectively, are identified in each image **31** of the stereoscopic pair. FIG. **4** shows the identified image patches **32** of the right eye in each image **31** (the image patches for the left eye being omitted in FIG. **4** for clarity).

Step S**2** may be performed as shown in FIG. **5**, as follows.

In step S**2-1**, image patches **32** containing the left and right eyes of the head are identified in each image **31** of the stereoscopic pair. This is done by identifying an image patch **39** in each image **31** located around the identified points ("landmarks") corresponding to features of an eye, as shown for example in FIG. **4**.

In step S**2-2**, the image patches **32** identified in step S**2-1** are transformed into a normalized coordinate system, being the same normalized coordinate system as used in the machine learning process which is described further below. The transformation is chosen to align the points ("landmarks") of the eye within the image patch that were identified in step S**1**, with predetermined locations in the normalized coordinate system. The transformation may include translation, rotation and scaling, to appropriate extents to achieve that alignment. The output of step S**2-2** is identified image patches **33** of the right eye in each image in the normalized coordinate system as shown for example in FIG. **4**.

The following steps may be performed separately (a) in respect of the image patches containing the left eyes of the head in each image **31** of the stereoscopic pair, and (b) in respect of the image patches containing the right eyes of the head in each image **31** of the stereoscopic pair (in this example). For brevity, the following description will refer merely to image patches and eyes without specifying the left or right eye, but noting the same steps are performed for both left and right eyes.

In step S**3**, a feature vector **34** is derived from plural local descriptors (representing information about a local region in a patch), which in this example may be referred to as local image descriptors, of an image patch **33** in at least one image **31** of the stereoscopic pair (in this example). Depending on the approach and as described further below, this may be an image patch in a single image **31** of the stereoscopic pair or may be both images **31** of the stereoscopic pair. Thus, the local image descriptors are local image descriptors derived in the normalized coordinate system.

The feature vectors **34** are representations of the image patches **33** that are suitable for use in looking up reference data **35** to be used for adjusting the image patches. The reference data **35** may comprise reference displacement vector fields that represent transformations of the image patch, or other representations of transformations of the image patch, including compressed representations as described below, and are associated with possible values of the feature vector.

The reference data **35** is obtained and analyzed in advance using a machine learning technique. The machine learning technique may derive the form of the feature vectors **34** and associate transformations such as the reference displacement vector fields with the possible values of the feature vector. A specific example of a machine learning technique applied in the case where it is desired to correct gaze using digital representations of a head region comprising images of the head region, will now be described before reverting to the method of FIG. **3**.

The training input to the machine learning technique is two sets of images (or image patches), which may be stereoscopic pairs of images or monoscopic images, as discussed further below. Each set may comprise images of the head of the same group of individuals but captured from cameras in different locations relative to the gaze so that the perceived gaze differs as between them (in the case where gaze is to be corrected).

The first set are input images, being images of each individual with an incorrect gaze where the error is known a priori. In particular, the images in the first set may be captured by at least one cameras in a known camera location where the gaze of the individual which is in a different known direction. For example in the case of the source device of FIG. **1**, the camera location may be the location of a camera **13** and while the gaze of the imaged individual is towards the center of the display **11**.

The second set are output images, being images of each individual with correct gaze for a predetermined observer location relative to a display location in which the image is to be displayed. In the simplest case, the observer location is a normal viewing position perpendicular to the center of the display location, for example as shown by the hard outline of the destination observer **24** in the case of the destination device **20** of FIG. **2**.

For each image in the two sets, the image is analyzed to detect the location of the head and in particular the eyes using the same technique as used in step S**1** described above, and then image patches containing the left and right eyes of the head, respectively, are identified using the same technique as used in step S**2** described above. The following steps may then be performed separately (a) in respect of the image patches containing the left eyes of the head in each image, and (b) in respect of the image patches containing the right eyes of the head in each image. For brevity, the following description will refer merely to image patches and eyes without specifying the left or right eye, but noting the same steps are performed for both left and right eyes in this embodiment.

Each image patch is transformed into the same normalized coordinate system as used in step S**2** described above. As described above, the transformation is chosen to align points ("landmarks") of the eye with predetermined locations in the normalized coordinate system. The transformation may include, for example, translation, rotation and/or scaling, to appropriate extents to achieve that alignment.

Thus, the image patches input and output images of each individual are aligned in the normalized coordinate system.

From an input and output image of each individual, there is derived a displacement vector field that represents the transformation of the image patch in the input image required to obtain the image patch of the output image, for example as follows. Defining positions in the image patches by (x,y), the displacement vector field F is given by

$$F=\{u(x,y),v(x,y)\}$$

where u and v define the horizontal and vertical components of the vector at each position (x,y).

The displacement vector field F is chosen so that the image patch of the output image O(x,y) is derived from the image patch of the input image I(x,y) as

$$O(x,y)=I(x+u(x,y),y+v(x,y))$$

For image data from more than one camera, the system delivers a displacement vector field for the input image from each camera.

The displacement vector field F for an input and output image of an individual may be derived using a process in which a trial feature vector F'={u',v'} is modified to minimize error, optionally in an iterative process, for example in accordance with:

$$\Sigma|O(x,y)-I(x+u'(x,y),y+v'(x,y))|=\min!$$

By way of non-limitative example, the displacement vector field F may be derived as disclosed in Kononenko et al., “Learning To Look Up: Realtime Monocular Gaze Correction Using Machine Learning”, Computer Vision and Pattern Recognition, 2015, pp. 4667-4675, which is herein incorporated by reference in its entirety, wherein the displacement vector field F is referred to as a “flow field”.

Another example for editing instructions, which may be referred to as image editing instructions in cases where the digital representation of the head region consists of images, which can be used additionally or as an alternative to the displacement vector field in any of the arrangements disclosed herein, is given by filter field L={k(P,x,y)}, which defines a filter kernel for a given location (x,y). This filter field L is chosen so that the image patch of the output image O(x,y) is derived from the image patch of the input image I(x,y) as O(x,y)=k(P(I,x,y)), x, y)), where P(I,x,y) is a local region around the point (x,y) in the image I, and k(P,x,y) operates on the patch P with coefficients depending on the position (x,y). For example, it could be the output of a convolution of the patch with a Gaussian filter with width depending on the position x in the image, or a brightness increase of a local pixel depending on the vertical position y.

Another example for editing instructions (e.g. image editing instructions) which can be used additionally or as an alternative to the displacement vector field in any of the arrangements disclosed herein, is given by a set of typical image components that make up the edited image area, e.g. texture showing beard stubbles. These are then blended with a factor depending on the image coordinates and local image content (i.e. a texture blending field). Other transformation fields can be used, such as a brightness adjustment field.

A machine learning technique is used to obtain a map from the displacement vector field F (or other editing instructions such as image editing instructions) of each individual to respective feature vectors derived from plural local (e.g. image) descriptors of a target patch of an input image.

The local descriptors (e.g. local image descriptors) capture relevant information of a local part of a patch (e.g. image patch) of an input digital representation of the head region (e.g. an input image) and the set of local descriptors usually form a continuous vectorial output.

The local descriptors input into the machine learning process are of types expected to provide discrimination between different individuals, although the specific image descriptors are selected and optimized by the machine learning process itself. In general, the local descriptors may be of any suitable type, some non-limitative examples which may be applied in any combination being as follows.

The local descriptors may include values of individual pixels or a linear combination thereof. Such a linear combination may be, for example, a difference between the pixels at two points, a kernel derived within a mask at an arbitrary location, or a difference between two kernels at different locations.

The local descriptors may include distances of a pixel location from the position of an eye point (“landmark”).

The local descriptors may include SIFT features (Scale-invariant feature transform features), for example as disclosed in Lowe, “Distinctive Image Features from Scale-Invariant Keypoints”, International Journal of Computer Vision 60 (2), pp 91-110, which is herein incorporated by reference in its entirety.

The local descriptors may include HOG features (Histogram of Oriented Gradients features), for example as disclosed in Dalal et al. “Histograms of Oriented Gradients for Human Detection”, Computer Vision and Pattern Recognition, 2005, pp. 886-893, which is herein incorporated by reference in its entirety.

The local descriptors may include “low level representations” from pre-classification stages in deep learning neural networks, for example as disclosed in Yang and Ramanan, “Multi-scale recognition with DAG-CNNs”, ICCV 2015, which is herein incorporated by reference in its entirety. In a classifying deep learning neural network with multiple layers applied to an input digital representation (e.g. image), for example, such low level features could be taken from a layer before the final classification layer of the network.

The derivation of the feature vector from plural local descriptors depends on the type of machine learning applied.

In a first type of machine learning technique, the feature vector may comprise features that are values derived from the local descriptors (e.g. local image descriptors) in a discrete space, being binary values or values discretized into more than two possible values. In this case, the machine learning technique associates a reference displacement vector field F derived from the training input with each possible value of the feature vector in the discrete space, so the reference data **35** may provide similar functionality to a look-up table, with the machine learning generating a machine learning parameter set that can be used to generate corresponding editing instructions. This allows a reference displacement vector field F to be simply selected from the reference data **35** on the basis of the feature vector **34** derived in step S**3**, as described below.

In the case that the feature vector comprises features that are binary values derived from the local descriptors, the feature vector has a binary representation. Such binary values may be derived in various ways from the values of descriptors, for example by comparing the value of a descriptor with a threshold, comparing the value of two descriptors, or by comparing the distance of a pixel location from the position of an eye point (“landmark”).

Alternatively, the feature vector may comprise features that are discretized values of the local descriptors. In this case, more than two discrete values of each feature are possible.

Any suitable machine learning technique may be applied, for example using a decision tree, a decision forest, a decision fern or an ensemble or combination thereof, or a neural network.

By way of example, a suitable machine learning technique using a feature vector comprising features that are binary values derived by comparing a set of individual pixels or a linear combination thereof against a threshold, is disclosed in Ozuysal et al. “Fast Keypoint Recognition in Ten Lines of Code”, Computer Vision and Pattern Recognition, 2007, pp. 1-8, which is herein incorporated by reference in its entirety.

By way of further example, a suitable machine learning technique using a distance of a pixel location with the position of an eye landmark is disclosed in Kononenko et al., “Learning To Look Up: Realtime Monocular Gaze Correction Using Machine Learning”, Computer Vision and Pattern Recognition, 2015, pp. 4667-4675, which is herein incorporated by reference in its entirety.

By way of further example, a suitable machine learning technique using a random decision forest is disclosed in Ho, "Random Decision Forests", Proceedings of the 3rd International Conference on Document Analysis and Recognition, Montreal, QC, 14-16 Aug. 1995, pp. 278-282, which is herein incorporated by reference in its entirety.

In a second type of machine learning technique, the feature vector may comprise features that are discrete values of the local descriptors (e.g. local image descriptors) in a continuous space. In this case, the machine learning technique associates a reference displacement vector field F (in this example, but other editing instructions could be used) derived from the training input with possible discrete values of the feature vector in the continuous space. This allows a displacement vector field F to be derived from the reference data **35** by interpolation from the reference displacement vector fields based on the relationship between the feature vector **34** derived in step S**3** and the values of the feature vector associated with the reference displacement vector fields.

Any suitable machine learning technique may be applied, for example using support vector regression.

By way of example, a suitable machine learning technique using support vector regression is disclosed in Drucker et al. "Support Vector Regression Machines", Advances in Neural Information Processing Systems 9, NIPS 1996, 155-161, which is herein incorporated by reference in its entirety. The output of the technique is a continuously varying set of interpolation directions that form part of the reference data **35** and are used in the interpolation.

The machine learning technique, regardless of its type, inherently also derives the form of the feature vectors **34** that is used to derive the reference displacement vector fields F (or other image editing instructions). This is the form of the feature vectors **34** that is derived in step S**3**.

The description now reverts to the method of FIG. **3**.

In step S**4**, at least one displacement vector field **37** representing a transformation of an image patch is derived by using the feature vector **34** derived in step S**3** to look up the reference data **35**. Due to the derivation of the displacement vector field **37** from the reference data **35**, the transformation represented thereby corrects the gaze that will be perceived when the stereoscopic pair of images **31** are displayed.

In the case that the feature vector **34** comprises features that are values in a discrete space and the reference displacement vector fields of the reference data **35** comprise a reference displacement vector field associated with each possible value of the feature vector in the discrete space, then the displacement vector field for the image patch is derived by selecting the reference displacement field associated with the actual value of the derived feature vector **34**.

In the case that the feature vector **34** comprises features that are discrete values of the local descriptors in a continuous space, then the displacement vector field for the image patch is derived by interpolating a displacement vector field from the reference displacement vector fields based on the relationship between the actual value of the derived feature vector **34** and the values of the feature vectors associated with the reference displacement vector fields. In the case that the machine learning technique was support vector regression, this may be done using the interpolation directions that form part of the reference data **35**.

In step S**5**, each image **31** of the stereoscopic pair is adjusted by transforming the image patches containing the left and right eyes of the head in accordance with the derived displacement vector fields **37**. This produces an adjusted stereoscopic pair of images **38** as shown in FIG. **4**, in which the gaze has been corrected. In particular, the adjustment may be performed using two alternative methods, as follows.

A first method for performing step S**5** is shown in FIG. **6** and performed as follows.

In step S**5-1**, the image patch is transformed in the normalised coordinate system in accordance with the corresponding displacement vector field **37** in respect of the same image, thereby correcting the gaze. As described above, for a displacement vector field F the transformation of the image patch of the input image I(x,y) provides the output image O(x,y) in accordance with

$$O(x,y)=I(x+u(x,y),y+v(x,y))$$

In step S**5-2**, the transformed image patch output from step S**5-1** is transformed out of the normalised coordinate system, back into the original coordinate system of the corresponding image **31**. This is done using the inverse transformation from that applied in step S**2-2**.

In step S**5-3**, the transformed image patch output from step S**5-2** is superimposed on the corresponding image **31**. This may be done with a full replacement within an eye region corresponding to the eye itself, and a smoothed transition between the transformed image patch and the original image **31** over a boundary region around the eye region. The width of the boundary region may be of fixed size or a percentage of the size of the image patch in the original image **31**.

A second method for performing step S**5** is shown in FIG. **7** and performed as follows.

In this second, alternative method, the transformation back into the coordinate system of the corresponding image **31** occurs before the transformation of the image patch in accordance with the transformed displacement vector field F.

In step S**5-4**, the displacement vector field F is transformed out of the normalised coordinate system, back into the original coordinate system of the corresponding image **31**. This is done using the inverse transformation from that applied in step S**2-2**.

In step S**5-5**, the image patch **32** in the coordinate system of the image **31** is transformed in accordance with the displacement vector field F that has been transformed into the same coordinate system in step S**5-4**. As described above, for a displacement vector field F the transformation of the image patch of the input image I(x,y) provides the output image O(x,y) in accordance with

$$O(x,y)=I(x+u(x,y),y+v(x,y))$$

but this is now performed in the coordinate system of the original image **31**.

Step S**5-6** is the same as S**5-3**. Thus, in step S**5-6**, the transformed image patch output from step S**5-5** is superimposed on the corresponding image **31**. This may be done with a full replacement within an eye region corresponding to the eye itself, and a smoothed transition between the transformed image patch and the original image **31** over a boundary region around the eye region. The width of the boundary region may be of fixed size or a percentage of the size of the image patch in the original image **31**.

FIG. **8** depicts a method of generating reference data (including reference data **37** of the type described in the specific examples discussed above) for adjusting a digital representation of a head region. In some embodiments, the digital representation of the head region comprises or consists of an image of the head region. In some embodiments, the digital representation of the head region comprises or consists of a three-dimensional digital representation (representing, for example, three-dimensional geometrical information). The three-dimensional digital representation may be obtained from depth measurements, using for example a time-of-flight camera. In an embodiment, the digital representation of the head region is usable to provide a computer generated display of the head region. In an embodiment, the adjustment of the digital representation comprises converting a two-dimensional digital representation of the head region to a three-dimensional digital representation of the head region.

In a case where the digital representation of the head region (prior to adjustment, after adjustment, or both) comprises a three-dimensional digital representation, this may be provided in any of various known ways. For example, the three-dimensional digital representation may comprise a point cloud, a particle system, or a mesh representation. The mesh representation may comprise one or more of: a polygonal surface, a multi-resolution surface, a subdivision surface. The digital representation may comprise a three-dimensional digital representation and texture information associated with the three-dimensional digital representation, e.g. via a texture map. The digital representation may comprise a three-dimensional geometrical representation and color information (e.g. obtained from an optical camera) aligned with the three-dimensional geometrical representation. Other volumetric representations such as particle system or implicit definitions such as signed distance functions may also be used.

The method comprises a step S**100** of receiving training data **100**. The training data **100** may be provided for example via a communications interface **112** (e.g. connecting to an external data connection or storage device) connected to a data processing unit **120** that is to perform the method (as depicted schematically in FIG. **10**). The training data **100** comprises a set of input patches. A patch consists of a target portion of a digital representation of a head region. In a case where the digital representation comprises an image, the patch may be referred to as an image patch. Each input patch (e.g. input image patch) comprises a target feature of the digital representation (e.g. image) of the head region prior to adjustment of the digital representation (e.g. adjustment of the image to be displayed) of the head region. The target feature is the same for each input patch. The target feature may comprise one or more of the following: an eye region comprising at least part of an eye (as in the specific examples discussed above with reference to FIG. **4** for example), a nose region comprising at least part of a nose, a mouth region comprising at least part of a mouth, a chin region comprising at least part of a chin, and a neck region comprising at least part of a neck. In an embodiment each input image patch comprises a portion of the image of the head region corresponding to the target feature, such as the above-mentioned eye region, nose region, mouth region, chin region, or neck region.

In an embodiment, the target feature comprises an eye region comprising at least part of an eye and the adjustment of the digital representation (e.g. image) of the head region comprises adjusting a gaze direction.

In an embodiment, the target feature comprises a nose region comprising at least part of a nose and the adjustment of the digital representation (e.g. image) of the head region comprises adjusting a shape and/or texture of the nose (e.g. to make nose look smaller and/or slimmer by a fixed proportion, similar to the effect of a "tele lens").

In an embodiment, the target feature comprises a chin region comprising at least part of a chin and the adjustment of the digital representation (e.g. image) of the head region comprises adjusting a shape and/or texture of the chin (e.g. to reduce or remove double chin appearance).

In an embodiment, the target feature comprises a neck region comprising at least part of a neck and the adjustment of the digital representation (e.g. image) of the head region comprises adjusting a shape and/or texture of the neck (e.g. to reduce or remove wrinkles).

In an embodiment, the target feature comprises a hair region comprising hair and the adjustment of the digital representation (e.g. image) of the head region comprises adjusting a color of the hair (e.g. by a fixed hue).

In the case where the target feature comprises an eye region, the input patches may be obtained using the methodology described above with reference to steps S**2-1** and S**2-2**, except that stereoscopic pairs of images are not necessarily required. Thus, the input patches may be obtained by using identified points ("landmarks") corresponding to features of an eye to locate the relevant region of the digital representation (e.g. image) of the head region (e.g. surrounding the eye) and/or transformation of the input patch into a normalized coordinate system, including alignment of the landmarks with predetermined locations in the normalized coordinate system using translation, rotation and/or scaling.

In some embodiments, the training data **100** further comprises a set of output patches. As described above, each patch consists of a target portion of a digital representation of a head region. In a case where the digital representation comprises an image, the patch may be referred to as an image patch. The output patches (e.g. output images patches) are in one-to-one correspondence with the input patches. Each output patch comprises the target feature of the digital representation (e.g. image) of the head region after adjustment of the digital representation (e.g. adjustment of the image to be displayed) of the head region. Thus, in the case where an image of the head region is to be adjusted to correct a gaze direction, each output patch comprises an eye region that has been adjusted so that the gaze appears to be in the desired direction (e.g. directly towards a destination observer **24**).

The method further comprises a step S**101** comprising using a first machine learning algorithm to generate first reference data **101** using the training data **100**. The first reference data **101** comprises editing instructions (e.g. image editing instructions) for adjusting the digital representation (e.g. image) of the head region for a range of possible digital representations (e.g. digital representations representing different states of the head, such as different positions and/or orientations, optionally represented as different images) of the head region.

The method further comprises a step S**102** comprising using a second machine learning algorithm to generate second reference data **102**. The second machine learning algorithm uses the same training data **100** as the first machine learning algorithm in step S**101**. The second machine learning algorithm further uses the first reference data **101** output by the first machine learning algorithm in step S**101**. The second reference data **102** comprises editing instructions (e.g. image editing instructions) for adjusting the digital representation (e.g. image) of the head region for a range of possible digital representations (e.g. different positions and/or orientations, optionally represented as different images) of the head region.

In an embodiment, the first reference data **101** comprises first editing instructions (e.g. first image editing instructions) for a range of possible configurations of the target feature (e.g. different gaze directions and/or eye morphologies in the case where the target feature comprises an eye region) and first selection instructions for selecting editing instructions (from the first editing instructions) for a particular input patch (e.g. input image patch) based on the configuration of the target feature of the input patch (e.g. the particular gaze direction and/or particular eye morphology of that input patch).

In an embodiment, the second reference data comprises second editing instructions (e.g. second image editing instructions) for a range of possible configurations of the target feature and second selection instructions for selecting editing instructions (from the second editing instructions) for a particular input patch (e.g. input image patch) based on the configuration of the target feature of the input patch.

The configuration of the target feature of each input patch may be represented by a feature vector derived from plural local descriptors (e.g. local image descriptors) of the input patch, as described above with reference to step S**3** of FIG. **3** for the particular case where stereoscopic pairs of images containing eye regions are processed (but the method is applicable more generally than this particular case). As described above, the feature vector may take various forms but is generally adapted to be suitable for looking up editing instructions for performing adjustment of the digital representation (e.g. image) of the head region. In the present embodiment, the first and second selection instructions define how the feature vector is used to select editing instructions for the input patch. In an embodiment, the editing instructions comprise a displacement vector field defining how the input patch is to be transformed to perform the adjustment. The displacement vector field may take any of the forms discussed above. The editing instructions are not limited to displacement vector fields, however. Other editing operations may additionally or alternatively be associated with the features vectors to perform other desired adjustments of the digital representation (e.g. image) of the head region, including for example adjustments to pixel colors or intensities, or changes to underlying geometries (e.g. via a filter field, brightness adjustment field, or texture blending field).

In an embodiment, a first editing algorithm (e.g. first image editing algorithm) is used by the first machine learning algorithm to define how the first editing instructions are to be applied to an input patch to derive an output patch. A second editing algorithm (e.g. second image editing algorithm) is used by the second machine learning algorithm to define how the second editing instructions are to be applied to an input patch to derive an output patch. The first and second editing algorithms may comprise any of the methods described above for implemented step S**5** of FIG. **3**, described with reference to FIGS. **6** and **7**.

In an embodiment, the second editing instructions in the second reference data are provided in a compressed representation. The compressed representation may comprise a principle component analysis representation or a wavelet representation for example. In this case, the first and second editing algorithms may be adapted to define how to operate efficiently in this context.

In an embodiment, the second editing instructions are principle component analysis components of a principle component analysis of the first editing instructions. The second editing algorithm in this case transforms the second editing instructions into the first editing instructions by inverse principle component analysis transform.

In an alternative approach, the second editing instructions are wavelet components of the first editing instructions. The second editing algorithm in this case transforms the second editing instructions into the first editing instructions by inverse wavelet transform.

In an embodiment, the first selection instructions for the first reference data are able to select between a larger number of alternative editing instructions (e.g. image editing instructions) than the second selection instructions for the second reference data. The first machine learning algorithm may thus be described as having more input parameters than the second machine learning algorithm. The first machine learning algorithm may provide higher accuracy than the second machine learning algorithm but will typically operate considerably slower. Additionally, the first selection instructions may be significantly more complex (e.g. involving linear algebra or other relatively computer intensive operations) than the second selection instructions (where the selection instructions may resemble a computationally straightforward look-up table, a combination of a look-up table and a tree structure, or similar).

In one particular embodiment, the first machine learning algorithm comprises a neural network (known to provide relatively high accuracy, but at the expense of relatively high computational demands). In such an embodiment, and others, the second machine learning algorithm may comprises a regression forest (known to provide higher computational efficiency, but at the expense of reduced accuracy). The inventors have found that the combination of the two different machine learning algorithms provides reference data that can be used in an adjustment method with high efficiency while still achieving high adjustment accuracy. The first machine learning algorithm may alternatively comprise a support vector machine or a generative adversarial network (GAN). The second machine learning algorithm may alternatively comprise regression ferns, cluster centres, a lookup table, or separable filter banks. In one embodiment, the first machine learning algorithm comprises a first neural network and the second machine learning algorithm comprises a second neural network, wherein the second neural network comprises fewer layers and/or smaller convolution fields than the first neural network.

FIG. **9** schematically depicts data flow in a detailed example of the method of generating reference data of FIG. **8**. The first and second machine learning algorithms are respectively labelled MLA**1** and MLA**2**. The first machine learning algorithm MLA**1** receives the training data (labelled TD) and, optionally, the first editing algorithm EA**1**, and a similarity metric SM. The similarity metric SM provides a numerical value to measure similarity between an adjusted image and a desired image and can be used to control the first machine learning algorithm MLA**1** and the second machine learning algorithm MLA**2** to vary the extent to which differences are penalized according to the nature of the differences. For example, the similarity metric SM may be configured to penalize reductions in portions of images that it is desired to maintain (e.g. sclera in the case where eye regions are being adjusted) or deviations of adjusted features from a known form (e.g. deviations in the shape of an iris from an elliptical form) or from a form that is observed in training data. Alternatively or additionally, the training data may comprise an average absolute or square difference between the adjusted image and a target, or average absolute or square difference between low level representations of the adjusted image and target, such as low level features from a deep learning network (as discussed above). In the example shown, the first editing algorithm EA**1** receives auxiliary data AuxD, which defines a basis set used for providing a compressed representation of image editing instructions. The first machine learning algorithm MLA**1** outputs first selection instructions LA**1** and first editing instructions ED**1**. The second machine learning algorithm MLA**2** receives the same training data TD and, optionally, the second editing algorithm EA**2**, and the similarity metric SM. The second machine learning algorithm MLA**2** additionally receives the first editing instructions ED**1**. The second machine learning algorithm outputs second selection instructions LA**2** and second editing instructions ED**2**.

The second machine learning algorithm MLA**2** thus gets the editing instructions to match or to approximate, and does not have to infer these from the matched input images as MLA**1**.

FIG. **10** depicts a device **110** for generating the reference data. The device **110** comprises a data processing unit **120** configured to perform the method of generating the reference data according to any of the disclosed embodiments. The data processing unit **110** may be implemented by a processor executing a suitable computer program or by dedicated hardware or by some combination of software and hardware. Data input/output may be provided via a communications interface **112**. Where a computer program is used, the computer program may comprise instructions in any suitable language and may be stored on a computer readable storage medium, which may be of any type, for example: a recording medium which is insertable into a drive of the computing system and which may store information magnetically, optically or opto-magnetically; a fixed recording medium of the computer system such as a hard drive; or a computer memory.

FIG. **11** depicts a method of adjusting a digital representation of a head region. In the example shown, the digital representation comprises an image of a head region, but the method can be adapted to use any of the digital representations discussed above (e.g. to additionally or alternatively process three-dimensional digital representations). The method may use reference data generated using any of the methods of generating reference data disclosed herein or may use reference data generated using other methods.

The method comprises a step S**200** in which a target patch (in this case an image patch) is identified in an image **200** of a head region that is to be adjusted. The target patch comprises a target feature of the head region. The target feature may take any of the forms discussed above. The step S**200** may optionally comprise detecting a head and/or eye location as described above with reference to step S**1** of FIG. **3**. The step S**200** may optionally further comprise identifying image patches using the methodology described above with reference to steps S**2-1** and S**2-2** of FIG. **5**, except that the image patches do not necessarily need to be identified as stereoscopic pairs (although they may be if desired).

In step S**201**, a feature vector is derived from plural local descriptors (e.g. local image descriptors) of the target (e.g. image) patch. The feature vector may be derived using the methodology described above with reference to step S**3** of FIG. **3**. The feature vector may take any of the forms discussed above.

In step S**202**, the feature vector is used to select editing instructions (e.g. image editing instructions) from reference data **102**. The reference data **102** comprising editing instructions for a range of possible values of the feature vector

(representing for example different gaze directions and/or eye morphologies in the case where the target feature comprises an eye region).

In step S**203**, the selected editing instructions are applied to the target patch to adjust the image of the head region (e.g. to correct a gaze direction).

In an embodiment, the editing instructions (e.g. image editing instructions) are provided in a compressed representation, comprising for example one or more of the following: a principle component analysis representation; a wavelet representation; Fourier and/or discrete cosine transform components; cluster centers. The use of a compressed representation reduces data storage and bandwidth requirements during use of the image editing instructions to perform adjustment of the digital representation (e.g. image) of the head region. Alternatively or additionally, the reference data containing the editing instructions may be generated using any of the embodiments disclosed herein. The reference data may comprise the second reference data discussed above for example.

Reference to editing instructions herein is understood to encompass any data which can be used to define how a digital representation (e.g. image) of a head region should be adjusted to achieve a desired aim (e.g. gaze correction or conversion from a two-dimensional digital representation to a three-dimensional digital representation or both). The editing instructions may comprise data that can used directly to modify a digital representation (e.g. image), such as a vector field, or intermediate data such as a machine learning parameter set that can be used to generate data that can be used directly to modify the digital representation (e.g. image).

FIG. **12** schematically depicts data flow in a detailed example of a method of adjusting a digital representation of a head region in the case where the digital representation comprises an image, using reference data generated according to the detailed example of FIG. **9**. Input data ID is provided from a sensor system SS (e.g. comprising one or more cameras). The input data ID is input to the second selection instructions LA**2** to select editing instructions appropriate to the input data ID from the second editing instructions ED**2**. The selected editing instructions, which in this example are provided in a compressed representation (e.g. principle component analysis components or wavelet components) from the compressed second editing instructions ED**2**, are then used by the second editing algorithm EA**2**, in combination with the auxiliary data AuxD providing the basis set for the compressed representation, to provide output data OD. The output data OD comprises an adjusted image of the head region and is displayed via a display DS.

As described above, the method of adjusting a digital representation of a head region (e.g. an image of a head region) may be implemented in an image processor **30** provided in various different devices. By way of non-limitative example, there will now be described a particular implementation in a telecommunications system which is shown in FIG. **13** and arranged as follows.

In this implementation, the source device **10** and the destination device **10** communicate over such a telecommunications network **50**. For communication over the telecommunications network **50**, the source device **10** includes a telecommunications interface **17** and the destination device **20** includes a telecommunications interface **27**.

In this implementation, the image processor **30** is provided in the source device **10** and is provided with an image of a head region directly from a camera system **12** (in this example, a stereoscopic pair of images). The telecommunications interface **17** is arranged to transmit the adjusted images **38** over the telecommunications network **50** to the destination device **20** for display thereon.

The destination device **20** includes an image display module **28** that controls the display **26**. The adjusted images **38** are received in the destination device **20** by the telecommunications interface **27** and supplied to the image display module **28** which causes them to be displayed on the display **26**.

The following elements of the destination device **20** are optionally included in the case that the method corrects gaze for a destination observer **24** in an observer location other than a normal viewing position perpendicular to the center of the display location. In this case, the destination device **20** includes a camera system **23** and an observer location module **29**. The camera system **23** captures an image of the destination observer **24**. The observer location module **29** derives the location data **40**. The observer location module **29** includes a head tracking module that uses the output of the camera system **23** to detect the location of the destination observer **24**. Where the relative observer location also takes into account the location of the image displayed on the display **21**, the observer location module **29** obtains the location of the image displayed on the display **21** from the image display module **28**. The telecommunications interface **17** is arranged to transmit the location data **40** over the telecommunications network **50** to the source device **10** for use thereby.

Although the above description refers to a method applied to images supplied from a source device **10** to a destination device **20**, the method may equally be applied to images supplied in the opposite direction from the destination device **20** to the source device **10**, in which case the destination device **20** effectively becomes the "source device" and the source device **10** effectively becomes the "destination device". Where images are supplied bi-directionally, the labels "source" and "destination" may be applied to both devices, depending on the direction of communication being considered.

FIG. **14** depicts a further embodiment of a method of generating reference data for adjusting a digital representation of a head region using a framework of the type depicted in FIG. **8**. In this embodiment, the training data **100** received in step S**100** (FIG. **8**) comprises a set of input digital representations of a head region (e.g. input patches each consisting of a target portion of a two-dimensional digital representation of the head region, such as a captured image).

In step S**101**, a first machine learning algorithm MLA**1** is trained using the training data **100**, the training causing the first machine learning algorithm MLA**1** to become capable of performing an adjustment of a digital representation of a head region. In an embodiment, the adjustment of the digital representation comprises converting from a two-dimensional digital representation to a three-dimensional digital representation (e.g. converting from a 2D image of a portion of a head region to a 3D mesh of a portion of the head region). The trained first machine learning algorithm MLA**1** is then used to generate first reference data **101**. The first reference data **101** comprises an adjusted digital representation of the head region for each of at least a subset of the input digital representations in the training data **100**. Each adjusted digital representation is obtained by performing the adjustment that the first machine learning algorithm MLA**1** was trained to perform.

In step S**102**, a second machine learning algorithm MLA**2** is trained using at least a subset of the training data **100** used to train the first machine learning algorithm MLA**2** and the first reference data **101**. The training causes the second machine learning algorithm MLA**2** to become capable of performing the same adjustment of a digital representation of a head region as the first machine learning algorithm MLA**1**.

In the particular embodiment of FIG. **14**, the first machine learning algorithm MLA**1** comprises a first encoder **306**A and a first predictor **308**A. The training data **100** is input to the first encoder **306**A. In this embodiment, the first encoder **306**A comprises a feature extractor algorithm. The feature extractor algorithm derives informative and non-redundant values from the training data **100** (i.e. extracts meaningful features from the training data **100**). Examples of feature extractor algorithms include Convolutional Neural Networks, Principal Component Analysis, SIFT (Scale Invariant Feature Transform). An output from the first encoder **306**A is input to a first predictor **308**A. The first predictor **308**A generates an adjusted version of each input digital representation in the training data **100** based on the output of the first encoder **306**A (e.g. features extracted by the first encoder **306**A). In this embodiment, each input digital representation comprises a two-dimensional digital representation (e.g. a two-dimensional image) and the adjusted version of each input digital representation comprises a three-dimensional digital representation (e.g. a mesh). Each three-dimensional digital representation is input to a renderer **310**. The renderer **310** synthesizes one or more two-dimensional digital representations corresponding to each input three-dimensional digital representation (e.g. one or more photorealistic images of the head region defined by the three-dimensional digital representation). The output from the renderer **310** is then input to a second encoder **306**B. The second encoder **306**B may be identical to the first encoder **306**A. An output from the second encoder **306**B is input to a second predictor **308**B. The second predictor **308**B may be identical to the first predictor **308**A. A first regularizer **314** is provided that compares the output from the first encoder **306**A with the output from the second encoder **306**B and imposes one or more predetermined first constraints. A second regularizer **316** is provided that compares the output from the first predictor **308**A with the output from the second predictor **308**B and imposes one or more predetermined second constraints. The first regularizer **314** and the second regularizer **316** may use a set of semantically meaningful constraints (examples of the first constraints and second constraints) or additional information to help reach a desirable solution and to prevent overfitting. The constraints may help to ensure that generated three-dimensional digital representations are natural looking for example, by requiring high levels of natural levels of smoothness. Using this architecture, the first machine learning algorithm MLA iteratively updates properties of the first predictor **308**A and the second predictor **308**B (e.g. by adjusting parameters such as weights defining the operation of the predictor) to maximize matching between the outputs from the first and second encoders (as measured by the first regularizer **314**) subject to the first constraints and to maximize matching between the outputs from the first and second predictors (as measured by the second regularizer **316**) subject to the second constraints. In other embodiments, the first encoder **306**A and second encoder **306**B may also be iteratively updated. The training of the first machine learning algorithm MLA**1** thus comprises iteratively using a rendering process to generate a two-dimensional digital representation from a three-dimensional digital representation generated by the first machine learning algorithm MLA**1** and comparing the generated digital representation with a corresponding digital representation in the training data. Once matching has been achieved or a predetermined number of iterations have been performed, the first machine learning algorithm MLA**1** is considered trained and the resulting output from the second predictor **308**B can be used to provide the first reference data **101** (which in this embodiment comprises three-dimensional digital representations corresponding to the input two-dimensional representations in the training data **100**).

As an extension, new two-dimensional and/or three-dimensional digital representations can be generated by applying editing instructions either to two-dimensional digital representations (which are converted to three-dimensional digital representations by the trained first machine learning algorithm MLA**1**) or to three-dimensional digital representations output by the trained first machine learning algorithm MLA**1**). In this case, the first reference data **101** may include the two-dimensional digital representations and/or three-dimensional representations after modification by the editing instructions.

A set of thus generated three-dimensional digital representations output as first reference data **101** and corresponding two-dimensional digital representations (e.g. directly from the training data **100** as shown in FIG. **14**) are used to train the second machine learning algorithm MLA**2** (input at block **304**). In this embodiment, the second machine learning algorithm MLA**2** also comprises an encoder **306**C and a predictor **308**C, which may be configured as described above for the first machine learning algorithm MLA**1**. The predictor **308**C (and, optionally, the encoder **308**C) may be iteratively updated (trained) using a regularizer **318** based on the input training data **100** and first reference data **101**. Thus, the second machine learning algorithm MLA**2** learns to convert between a two-dimensional digital representation and a three-dimensional digital representation based on the mapping between two-dimensional digital representations and three-dimensional digital representations derived using the renderer **310** in the first machine learning algorithm MLA**1**. Provided the mapping derived by the first machine learning algorithm MLA**1** is reliable, the second machine learning algorithm MLA**2** will be able to provide accurate conversion between two-dimensional digital representations and three-dimensional digital representations using a simpler trained machine learning model (which can be stored and operated using fewer computing resources than the first machine learning algorithm MLA**1**).

FIG. **15** depicts data flow in an example implementation of an embodiment in which a pre-trained second machine learning algorithm MLA**2** is updated (i.e. trained further) in at or near input data frame rate (i.e. online). In embodiments of this type, a plurality of the digital representations (e.g. images) of the head region may be received as input data ID (e.g. from a sensor system SS as described above) and adjusted (e.g. as described above with reference to FIGS. **11**, **12** and **14**) to provide output data OD that is subsequently displayed via display DS (as described above with reference to FIG. **12**). The input data ID may comprise a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch. The adjustment may be performed using a pre-trained version of the second machine learning algorithm MLA**2**, optionally in combination with a geometrical model. The input data ID may comprise digital representations captured at different points in times, such as different frames in a sequence of images obtained by the sensor system SS in a video capture mode. In an embodiment, the method comprises updating

the pre-trained second machine learning algorithm MLA**2** using first reference data (e.g. editing instructions) generated by the first machine learning algorithm MLA**1** using one or more of the received digital representations (from the input data ID). The first reference data may comprise a set of editing instructions in one-to-one correspondence with the input patches, each editing instruction being for adjusting the digital representation of the head region. In the example depicted in FIG. **15**, the first reference data for the updating is generated in a background process and the second machine learning algorithm MLA**2** is updated at or near input data frame rate (i.e. online).

The updating thus uses a pre-trained version of the first machine learning algorithm MLA**1** (which, as described above, is configured to provide more highly detailed reference data at the expense of higher computational demands, relative to the second machine learning algorithm MLA**2**) to generate first reference data that is used to update the second machine learning algorithm MLA**2**. Where the first machine learning algorithm MLA**1** is slower than the second machine learning algorithm MLA**2** (which will normally be the case where the first machine learning algorithm MLA**1** is configured to provide more highly detailed reference data than the second machine learning algorithm MLA**2**), only a subset of the input data ID (comprising the received and adjusted digital representations) are used to update the second machine learning algorithm MLA**2**, thereby allowing the updating process to keep up with the adjusting of the input data ID by the second machine learning algorithm MLA**2** to provide the output data OD. Any of various known techniques may be used to perform the updating of the second machine learning algorithm MLA**2**. For example, the online updating may be performed as described in Amir Saffari, Christian Leistner, Jakob Santner, Martin Godec, and Horst Bischof, "On-line Random Forests," in 3rd IEEE ICCV Workshop on On-line Computer Vision, 2009, which is herein incorporated by reference in its entirety, or as described in Online Deep Learning: Learning Deep Neural Networks on the Fly, Doyen Sahoo, Quang Pham, Jing Lu, Steven C. H., Hoi School of Information Systems, Singapore Management University (https://arxiv.org/pdf/1711.03705.pdf), which is herein incorporated by reference in its entirety. The second machine learning algorithm MLA**2** can therefore be gradually improved during use, as more input data ID are encountered and processed by the system.

Additional embodiments of the disclosure are described in the following numbered clauses.

1. A method of generating reference data for adjusting an image of a head region, the method comprising:
   receiving training data comprising:
   - a set of input image patches, each input image patch comprising a target feature of an image of a head region prior to adjustment of the image of the head region, wherein the target feature is the same for each input image patch; and
   - a set of output image patches in one-to-one correspondence with the input image patches, each output image patch comprising the target feature of the image of the head region after adjustment of the image of the head region;

   using a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising image editing instructions for adjusting the image of the head region for a range of possible images of the head region; and using a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data generated by the first machine learning algorithm, the second reference data comprising image editing instructions for adjusting the image of the head region for a range of possible images of the head region.

2. The method of clause 1, wherein:

the first reference data comprise first image editing instructions for a range of possible configurations of the target feature and first selection instructions for selecting image editing instructions for a particular input image patch from the first image editing instructions based on the configuration of the target feature of the input image patch; and

the second reference data comprise second image editing instructions for a range of possible configurations of the target feature and second selection instructions for selecting image editing instructions for a particular input image patch from the second image editing instructions based on the configuration of the target feature of the input image patch.

3. The method of clause 2, wherein the configuration of the target feature of each input image patch is represented by a feature vector derived from plural local image descriptors of the input image patch, and the first and second selection instructions define how the feature vector is used to select image editing instructions for the input image patch.

4. The method of clause 2 or 3, wherein the image editing instructions comprise a displacement vector field defining how the input image patch is to be transformed.

5. The method of clause 2 or 3, wherein the image editing instructions comprise a filter field, a brightness adjustment field, or a texture blending field.

6. The method of any of clauses 2-5, wherein:

a first image editing algorithm is used by the first machine learning algorithm to define how the first image editing instructions are to be applied to an input image patch to derive an output image patch; and

a second image editing algorithm is used by the second machine learning algorithm to define how the second image editing instructions are to be applied to an input image patch to derive an output image patch.

7. The method of clause 6, wherein:

the second image editing instructions are principle component analysis components of a principle component analysis of the first image editing instructions; and

the second image editing algorithm is configured to transform the second image editing instructions into the first image editing instructions by inverse principle component analysis transform.

8. The method of clause 6, wherein:

the second image editing instructions are wavelet components of the first image editing instructions; and

the second image editing algorithm is configured to transform the second image editing instructions into the first image editing instructions by inverse wavelet transform.

9. The method of any of clauses 2-8, wherein the first selection instructions for the first reference data are able to select between a larger number of alternative image editing instructions than the second selection instructions for the second reference data.

10. The method of any preceding clause, wherein the first machine learning algorithm is of a different machine learning algorithm type than the second machine learning algorithm.

11. The method of any preceding clause, wherein the first machine learning algorithm comprises one or more of the following: a neural network; a support vector machine; a generative adversarial network, GAN.

12. The method of any preceding clause, wherein the second machine learning algorithm comprises one or more of the following: a regression forest; regression ferns, cluster centres, a lookup table, separable filter banks.

13. The method of any of clauses 1-10, wherein the first machine learning algorithm comprises a first neural network and the second machine learning algorithm comprises a second neural network, wherein the second neural network comprises fewer layers and/or smaller convolution fields than the first neural network.

14. The method of any preceding clause, wherein the target feature comprises one or more of the following: an eye region comprising at least part of an eye, a nose region comprising at least part of a nose, a mouth region comprising at least part of a mouth, a chin region comprising at least part of a chin, a neck region comprising at least part of a neck, and a hair region comprising hair.

15. The method of any of clauses 1-13, wherein:

the target feature comprises an eye region comprising at least part of an eye and the adjustment of the image of the head region comprises adjusting a gaze direction;

the target feature comprises a nose region comprising at least part of a nose and the adjustment of the image of the head region comprises adjusting a shape and/or texture of the nose;

the target feature comprises a chin region comprising at least part of a chin and the adjustment of the image of the head region comprises adjusting a shape and/or texture of the chin;

the target feature comprises a neck region comprising at least part of a neck and the adjustment of the image of the head region comprises adjusting a shape and/or texture of the neck; and/or

the target feature comprises a hair region comprising hair and the adjustment of the image of the head region comprises adjusting a color of the hair.

16. The method of any preceding clause, wherein the second image editing instructions in the second reference data are provided in a compressed representation.

17. The method of clause 16, wherein the compressed representation comprises one or more of the following: a principle component analysis representation; a wavelet representation; Fourier and/or discrete cosine transform components; cluster centres.

18. A method of adjusting an image of a head region, the method comprising:

identifying an image patch in the image of the head region, the image patch comprising a target feature of the image of the head region;

deriving a feature vector from plural local image descriptors of the image patch;

using the feature vector to select image editing instructions from reference data, the reference data comprising image editing instructions for a range of possible values of the feature vector; and

applying the selected image editing instructions to the image patch to adjust the image of the head region, wherein:

the reference data comprises the second reference data generated by the method of any of clauses 1-17.

19. A method of adjusting an image of a head region, the method comprising:

identifying an image patch in the image of the head region, the image patch comprising a target feature of the image of the head region;

deriving a feature vector from plural local image descriptors of the image patch;

using the feature vector to select image editing instructions from reference data, the reference data comprising image editing instructions for a range of possible values of the feature vector; and

applying the selected image editing instructions to the image patch to adjust the image of the head region, wherein:

the image editing instructions in the reference data are provided in a compressed representation.

20. The method of clause 19, wherein the compressed representation comprises one or more of the following: a principle component analysis representation; a wavelet representation; Fourier and/or discrete cosine transform components; cluster centres.

21. A computer program capable of execution by a processor and arranged on execution to cause the processor to perform a method according to any of the preceding clauses.

22. A computer readable storage medium storing a computer program according to clause 21.

23. A device for generating reference data for adjusting an image of a head region, the device comprising a data processing unit arranged to:

receive training data comprising:

a set of input image patches, each input image patch comprising information about a target feature of an image of the head region prior to adjustment of the image of the head region, wherein the target feature is the same for each input image patch; and

a set of output image patches in one-to-one correspondence with the input image patches, each output image patch comprising the target portion of the image of the head region after adjustment of the image of the head region;

use a first machine learning algorithm to generate first reference data using the training data; and

use a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data output by the first machine learning algorithm.

24. A device for adjusting an image of a head region, the device comprising an image processor arranged to process the image of the head region by:

identifying an image patch in the image of the head region, the image patch comprising information about a target feature of the image of the head region;

deriving a feature vector from plural local image descriptors of the image patch;

using the feature vector to select image editing instructions from reference data, the reference data comprising image editing instructions for a range of possible values of the feature vector; and

applying the selected image editing instructions to the image patch to adjust the image of the head region, wherein:

the image editing instructions in the reference data are provided in a compressed representation.

25. The device of clause 24, further comprising a telecommunications interface arranged to transmit the adjusted image over a telecommunications network to a destination device for display thereon.

While various embodiments in accordance with the principles disclosed herein have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of this disclosure should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with any claims and their equivalents issuing from this disclosure. Furthermore, the above advantages and features are provided in described embodiments, but shall not limit the application of such issued claims to processes and structures accomplishing any or all of the above advantages.

Additionally, the section headings herein are provided for consistency with the suggestions under 37 CFR 1.77 or otherwise to provide organizational cues. These headings shall not limit or characterize the embodiment(s) set out in any claims that may issue from this disclosure. Specifically and by way of example, although the headings refer to a "Technical Field," the claims should not be limited by the language chosen under this heading to describe the so-called field. Further, a description of a technology in the "Background" is not to be construed as an admission that certain technology is prior art to any embodiment(s) in this disclosure. Neither is the "Summary" to be considered as a characterization of the embodiment(s) set forth in issued claims. Furthermore, any reference in this disclosure to "invention" in the singular should not be used to argue that there is only a single point of novelty in this disclosure. Multiple embodiments may be set forth according to the limitations of the multiple claims issuing from this disclosure, and such claims accordingly define the embodiment(s), and their equivalents, that are protected thereby. In all instances, the scope of such claims shall be considered on their own merits in light of this disclosure, but should not be constrained by the headings set forth herein.

The invention claimed is:

1. A method of generating reference data for adjusting a digital representation of a head region, the method comprising:

receiving training data comprising:

a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region;

using a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region; and

using a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data generated by the first machine learning algorithm, the second reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region,

wherein the first reference data comprise first editing instructions for a range of possible configurations of the target feature and first selection instructions for selecting editing instructions for a particular input patch from the first editing instructions based on the configuration of the target feature of the input patch; and

wherein the second reference data comprise second editing instructions for a range of possible configurations of the target feature and second selection instructions for selecting editing instructions for a particular input patch from the second image editing instructions based on the configuration of the target feature of the input patch.

2. The method of claim **1**, wherein the configuration of the target feature of each input patch is represented by a feature vector derived from plural local descriptors of the input patch, and the first and second selection instructions define how the feature vector is used to select editing instructions for the input patch.

3. The method of claim **1**, wherein the editing instructions comprise a displacement vector field defining how the input patch is to be transformed.

4. The method of claim **1**, wherein the editing instructions comprise a filter field, a brightness adjustment field, or a texture blending field.

5. The method of claim **1**, wherein:

a first editing algorithm is used by the first machine learning algorithm to define how the first editing instructions are to be applied to an input patch to derive an output patch; and

a second editing algorithm is used by the second machine learning algorithm to define how the second editing instructions are to be applied to an input patch to derive an output patch.

6. The method of claim **5**, wherein:

the second editing instructions are principle component analysis components of a principle component analysis of the first editing instructions; and

the second image editing algorithm is configured to transform the second editing instructions into the first editing instructions by inverse principle component analysis transform.

7. The method of claim **5**, wherein:

the second editing instructions are wavelet components of the first editing instructions; and

the second editing algorithm is configured to transform the second editing instructions into the first editing instructions by inverse wavelet transform.

8. The method of claim **1**, wherein the first selection instructions for the first reference data are able to select between a larger number of alternative editing instructions than the second selection instructions for the second reference data.

9. The method of claim **1**, wherein the first machine learning algorithm is of a different machine learning algorithm type than the second machine learning algorithm.

10. The method of claim **1**, wherein the first machine learning algorithm comprises one or more of the following: a neural network; a support vector machine;

and a generative adversarial network (GAN).

11. The method of claim **1**, wherein the second machine learning algorithm comprises one or more of the following: a regression forest; regression ferns, cluster centres, a lookup table, and separable filter banks.

12. The method of claim **1**, wherein the target feature comprises one or more of the following: an eye region comprising at least part of an eye, a nose region comprising at least part of a nose, a mouth region comprising at least part of a mouth, a chin region comprising at least part of a chin, a neck region comprising at least part of a neck, and a hair region comprising hair.

13. A method of adjusting a digital representation of a head region, the method comprising

receiving a digital representation of a head region; and

using reference data comprising editing instructions to adjust the digital representation of the head region, wherein the reference data comprises the second reference data generated by the method of claim **1**.

14. A non-transitory computer readable storage medium storing a computer program capable of execution by a processor and arranged on execution to cause the processor to perform a method according to claim **1**.

15. A method of training a machine learning algorithm to adjust a digital representation of a head region, the method comprising:

receiving training data comprising a set of input digital representations of a head region;

training a first machine learning algorithm using the training data to perform an adjustment of a digital representation of a head region;

using the trained first machine learning algorithm to generate first reference data, the first reference data comprising an adjusted digital representation of the head region for each of at least a subset of the input digital representations, each adjusted digital representation being obtained by performed the adjustment that the first machine learning algorithm was trained to perform; and

training a second machine learning algorithm using at least a subset of the training data used to train the first machine learning algorithm and the first reference data to perform the same adjustment of a digital representation of a head region as the first machine learning algorithm, wherein the adjustment of the digital representation comprises converting from a two-dimensional digital representation to a three-dimensional digital representation, and wherein the training of the first machine learning algorithm comprises iteratively using a rendering process to generate a two-dimensional digital representation from a three-dimensional digital representation generated by the first machine learning algorithm and comparing the generated digital representation with a corresponding digital representation in the training data.

16. A device for generating reference data for adjusting a digital representation of a head region, the device comprising a data processing unit arranged to:

receive training data comprising:

a set of input patches, each input patch comprising information about a target feature of a digital representation of the head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target portion of the digital representation of the head region after adjustment of the digital representation of the head region;

use a first machine learning algorithm to generate first reference data using the training data; and

use a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data output by the first machine learning algorithm

wherein the first reference data comprises editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region,

wherein the second reference data comprises editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region, and

wherein the second editing instructions in the second reference data are provided in a compressed representation.

17. A method of generating reference data for adjusting a digital representation of a head region, the method comprising:

receiving training data comprising:

a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region;

using a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region; and

using a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data generated by the first machine learning algorithm, the second reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region,

wherein the first machine learning algorithm comprises a first neural network and the second machine learning algorithm comprises a second neural network, and wherein the second neural network comprises fewer layers and/or smaller convolution fields than the first neural network.

18. A method of generating reference data for adjusting a digital representation of a head region, the method comprising:

receiving training data comprising:

a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region;

using a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region; and

using a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data generated by the first machine learning algorithm, the second reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region,

wherein the target feature comprises an eye region comprising at least part of an eye and the adjustment of the digital representation of the head region comprises adjusting a gaze direction, and/or

wherein the target feature comprises a nose region comprising at least part of a nose and the adjustment of the digital representation of the head region comprises adjusting a shape and/or texture of the nose, and/or

wherein the target feature comprises a chin region comprising at least part of a chin and the adjustment of the digital representation of the head region comprises adjusting a shape and/or texture of the chin, and/or

wherein the target feature comprises a neck region comprising at least part of a neck and the adjustment of the digital representation of the head region comprises adjusting a shape and/or texture of the neck, and/or

wherein the target feature comprises a hair region comprising hair and the adjustment of the digital representation of the head region comprises adjusting a color of the hair.

19. A method of generating reference data for adjusting a digital representation of a head region, the method comprising:

receiving training data comprising:

a set of input patches, each input patch comprising a target feature of a digital representation of a head region prior to adjustment of the digital representation of the head region, wherein the target feature is the same for each input patch; and

a set of output patches in one-to-one correspondence with the input patches, each output patch comprising the target feature of the digital representation of the head region after adjustment of the digital representation of the head region;

using a first machine learning algorithm to generate first reference data using the training data, the first reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region; and

using a second machine learning algorithm to generate second reference data using the same training data as the first machine learning algorithm and the first reference data generated by the first machine learning algorithm, the second reference data comprising editing instructions for adjusting the digital representation of the head region for a range of possible digital representations of the head region,

wherein the second editing instructions in the second reference data are provided in a compressed representation, and

wherein the compressed representation comprises one or more of the following: a principle component analysis representation; a wavelet representation; Fourier and/or discrete cosine transform components; cluster centers.

* * * * *

Exhibit C

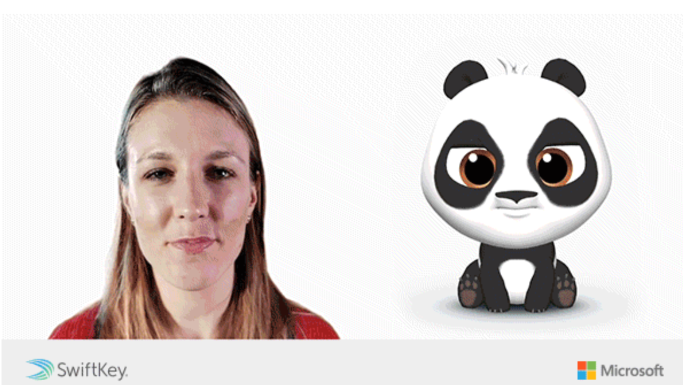
How to use Puppets with Microsoft SwiftKey Beta for Android

As of September 2020 Puppets has been removed from Microsoft SwiftKey Beta. Puppets was very much a Beta feature and a work in progress. The support content on this page is being preserved for archival purposes only.

Introducing Puppets

Puppets was an interactive and experimental feature that allowed you to control your own virtual character. There were five different animated characters: Dinosaur, Panda, Cat, Owl or Dog – and each Puppet mimicked your facial expressions and head movements.

You could also record short videos of your Puppet in action, and then share recordings to your friends and family.



How did it work?

Puppets used AI which has been trained using thousands of images and videos of people making different expressions to track and record facial movements. The feature understood everyone's unique face shape by using facial anchors such as the corner of the eyes. Puppet animation was then achieved by transferring those tracked human facial expressions and head motions to the Puppet in real-time.

How to create your Puppet

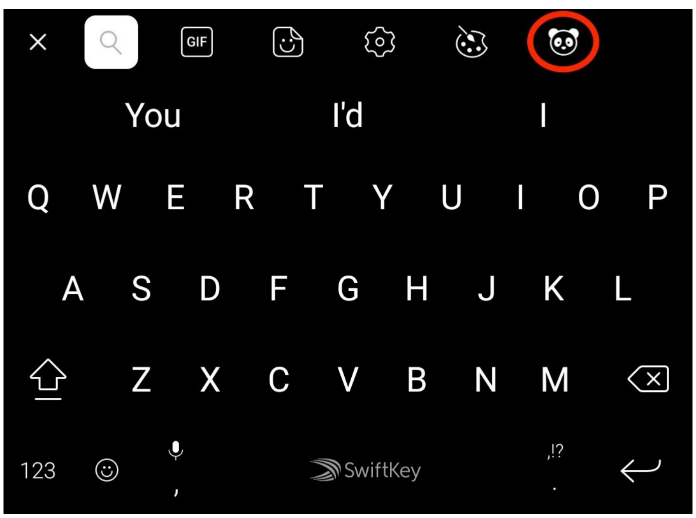
Puppets lived in your Toolbar. But you'd only see the icon if your phone satisfied the minimum system requirements:

- Your phone is running Android 9.0 (Pie)
- Your phone is equipped with a minimum of 8GB RAM. Examples include: Samsung Galaxy S10, Google Pixel 4 XL, Huawei P30 Pro, and OnePlus 7 Pro.

To open Puppets:

1. Open your Microsoft SwiftKey Beta Toolbar
2. Tap on the 'Panda' icon to launch Puppets.

On first run the Panda will be picked as default – let the camera find your face

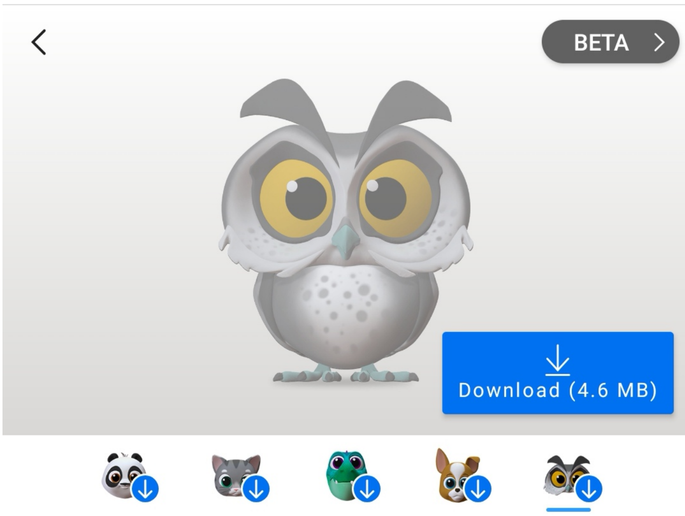


To pick another character

1. Tap on the Dinosaur, Cat, Dog or Owl icon.
2. You'll be prompted to sign into your Microsoft SwiftKey Account (if you're not signed-in already).

3. Press the ‘Download’ button. If you don’t want to use your data allowance, then make sure you connect to a Wi-Fi network first.

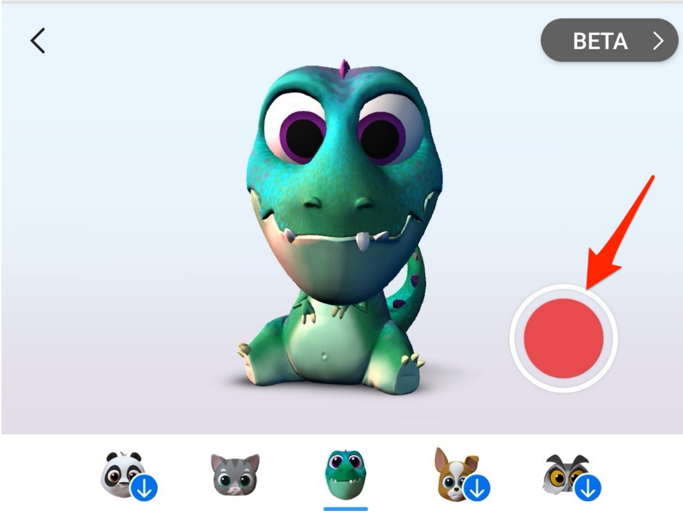
Once you've downloaded a character - just tap on its icon to switch. There's no need to repeat the other steps unless you sign out of your Microsoft SwiftKey Account, reinstall your Microsoft SwiftKey Keyboard, or use Puppets on an entirely new device.

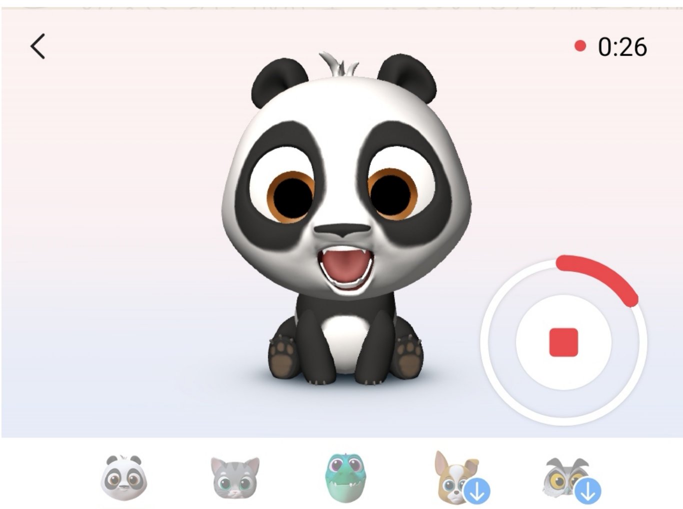


To share your Puppet

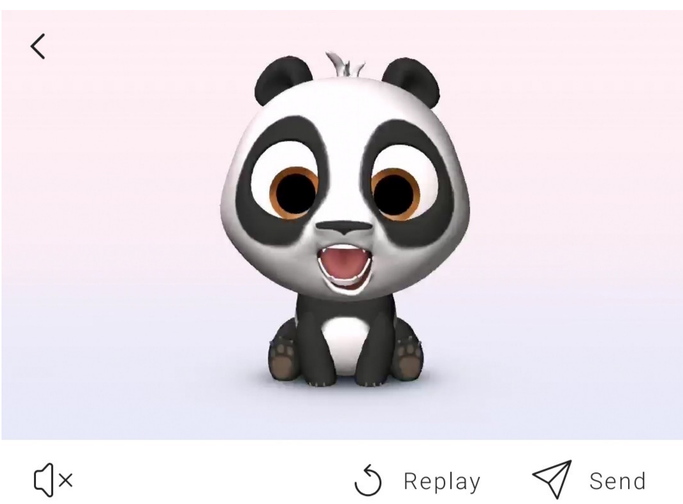
Pressing the red ‘Record’ icon will let you record short video (and audio) snippets. Each clip is limited to 30 seconds in length.

You can then share these video and audio recordings directly to your friends and family through most Android messaging and social apps.





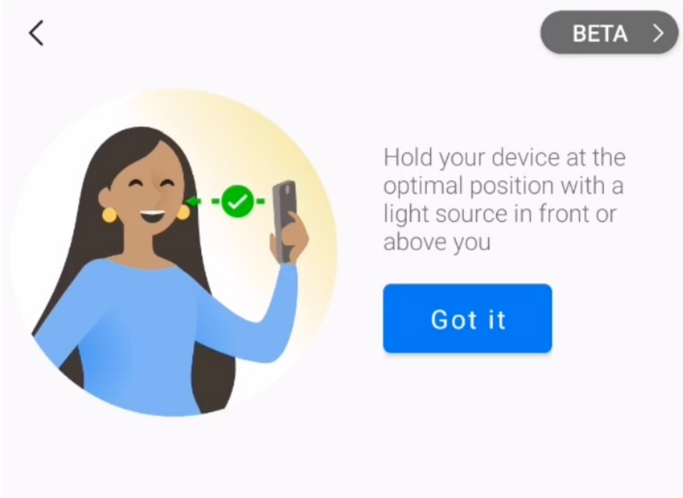
If you'd like to share your Puppet with audio just tap the 'speaker' icon to toggle this on/off.



When you're done tinkering, tap 'Send' to share your character.

Tips for an enjoyable Puppets experience

Before you use the feature for the first time, you'll see an animated graphic that shows you the best angle to hold your phone.



To ensure best performance of your virtual puppet we recommend using the feature in a brightly lit environment, and your phone's camera should have an unobstructed view of your face.

And while your Puppet should work when wearing glasses, you'll probably have less luck if used with pets!

When recording video your audio will be picked up too, so why not make your Puppet talk?

Data and Privacy

Images collected by the camera are not stored and not transmitted. They are in device memory for a few milliseconds to recognize the expression locally on device and are then discarded.

As of September 2020 Puppets has been removed from Microsoft SwiftKey Beta. Puppets was very much a Beta feature and a work in progress. The support content on this page is being preserved for archival purposes only.

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