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Augmented Reality's Impact On Modular Robot Design

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ABSTRACT: Augmented Reality (AR) outputs computer-generated information using head-mounted displays (HMDs). A visual field such as AR can enhance other disciplines due to its ability to display information. Modular Robotics (MR) could apply AR's visual prowess to make it easier to understand. Modular Robots are formed with modules to perform a variety of tasks, such as picking and placing an object. AR can magnify MR visualization through its already established methods. Such MR methods include FEA and CAD, and AR can improve these MR designs. It can visualize and expand areas where FEA and CAD excel. MR's versatility is highlighted in its types, where many perform unique functions and have distinctive, convoluted designs. AR can enable MR designers to decipher aspects of the design process, such as the robot's design and how it will react to certain behaviors.

KEYWORDS: Engineering, Robotics, Modular Robotics (MR), Augmented Reality (AR), AR-Finite Element Analysis, SAR, AR Computed Aided Design, and HMD.

Introduction

Augmented Reality's (AR) visual uniqueness (due to it being the only field to display computerized information in the real world) gives it a variety of applications. Many devices use AR, such as Apple's Vision Pro[1] or Meta's Ray-Ban Meta.[2] While these are for entertainment, they both highlight recent advancements in this discipline, particularly the Ray-Ban Meta's glass-like structure, unlike Apple's Vision Pro headset. There are other examples of AR HMDs, including Magic Leap 1 and Microsoft's HoloLens 2, which are used for robotic applications.[3]

Modular Robots (MR) have a lot of depth for their small size. Each module can be challenging to interpret and understand. AR can be a key aspect in improving design by allowing more visualization during the design process, since this enables better interaction with the design to detect issues.[4] The development of it has given it a uniquely strong identity compared to other sectors. While most fields are physical and can interact with the real world, AR superimposes visual computerized data to project it into the real world; it can't interact with the physical world.[5]

While AR has been around for a long time, its history isn't well-known. The head-mounted display (HMD) was created in 1968 by Ivan E. Sutherland, and with this invention, both AR and virtual reality were established.[5] While the HMD was nowhere near as advanced as it is today, it still had major impacts in marking the start of a new field. Even before then, the concept of 'visual glasses' was explored. In 1957, Morton Heilig (a cinematographer and visionary) proposed the idea to transmit details, such as smell and vibrations, in movies.[5] AR can display anything the user wants that is computer-generated, which allows for unprecedented flexibility. This flexibility is highlighted in its usage in papers, as shown in Figure 1.[6] AR enhances other disciplines, but it isn't often that a breakthrough occurs. Because it is a visual field, the main breakthroughs for it specifically rely on new HMDs and optimizing how the computerized data is displayed.

The modular robot's unique history provides insight into how they function. John von Neumann established the concept of modular robotics in the twentieth century, where he discussed the terms self-reproductive automata and complication.[7] He applied nature to a new concept. Later, in 1988, CEBOT was created,[7] taking inspiration from Neumann's ideas. The 1st modular robot prototype was made using distinct, but similar, parts, which at the time were called cells. These cells were based on how animals function in nature. Then any cooperation learned in nature is applied to modular robotics. It is based on nature, which gives it the most inspiration; nature is everywhere. Each module is parallel to the components of animals.

Modular robots are a more refined version of robotics. Instead of one large robot, there are multiple smaller robots called modules that can change their orientation.[8] This makes it smaller and challenging to create due to the need for the modules to work in tandem. These modules enable diverse tasks and many configurations, especially when many modules are used together.[9] A benefit of modular robots over regular robots is their added degrees of freedom (DOF); however, this increased DOF comes with mechanical and computational challenges.[10] AR can mitigate these challenges by enabling improved visuals of the robot, both in its design and execution.

MR flexibility allows it to perform a variety of tasks. This flexibility, in part, comes from its design. The use of modules, some of which are self-reconfigurable, highlights their unique benefits, especially in unstructured and unpredictable terrain.[11] This makes it a very versatile field that includes many modular robots, such as the SMORES-EP[12] or the Anibot[13], as shown in Figures 2 and 3, respectively. While both are modular robots, they have very different uses, highlighting the flexibility and versatility of this field.

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MR and AR are both very versatile sectors, and when combined, MR can improve its design to be better in the real world. The design can be improved by being visualized to improve comprehension and collaboration. MR is important in various applications. This includes medicine,[14] manufacturing,[15] natural disaster rescue,[16] and reconnaissance.[17] It must improve due to its reach in other areas and its significance in them.

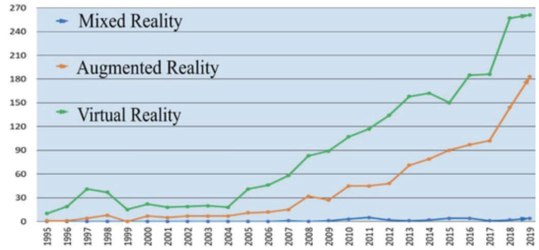

Figure 1: A graph showing the number of papers written about mixed reality, virtual reality, and AR. The X-axis is the year, and the Y-axis is the number of papers published.[6]

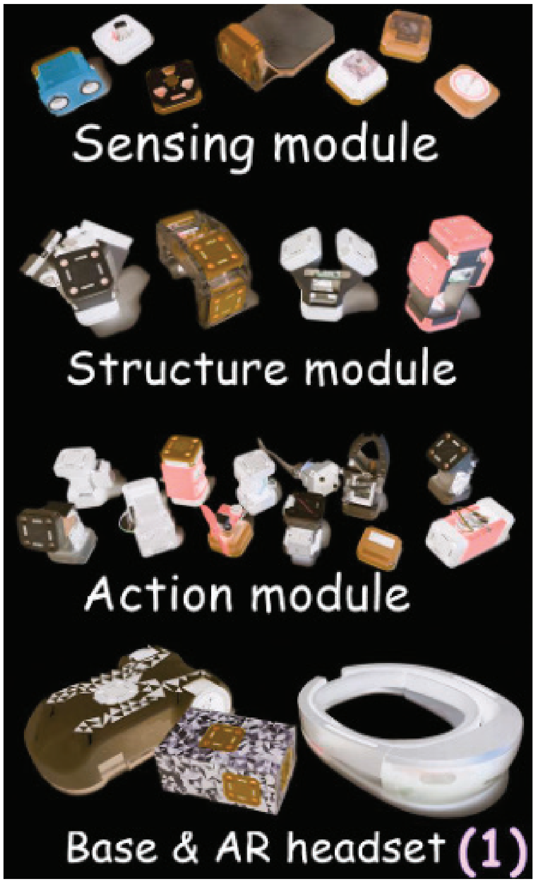

Figure 2: A depiction of an SMORES-EP module.[12]

Figure 3: Anibot modules visual. Combined, this module functions as a flexible modular robot.[13]

Modular robotics is a field that, similar to AI, has the potential to be the future. Their complex, miniature design makes them versatile, especially for their size. If MR were to improve its design, then it would facilitate interdisciplinary collaboration and even create new disciplines.

AR can be used with MR to support its design for real-world challenges. In the first section of this paper, some examples of modular robot applications are provided to highlight their versatility and flexibility. Next, the second section will depict AR applications to demonstrate how AR's visual capabilities enhance other disciplines. Finally, the third section will combine MR and AR to improve the design of modular robots. With over 40 manuscripts, the case for MR enhanced with AR will be presented.

■ Modular Robotics Application

MR has unique applications, highlighting its usefulness for many areas. It can be applied to practical areas, such as surgeries, reconnaissance, and rescue. There are different usages for modular robots in everyday fields. While some uses of MR enhance a field, other times, it can create entirely new professions and specializations.

Medicine:

In medicine, modular robots support precise surgeries in areas that require extreme precision. Nanobots are being used to detect cancer using cell-specific antibodies and create a near-infrared release of doxorubicin payload.[18] Including cancer applications, it can also be used for surgeries. Nanobots can be used with a different method. Nanorobots with chemical biosensors and transferrin, a type of protein, can detect cancerous tumors.[14] Along with detecting them, the nanorobots can also treat tumors using chemotherapy tools, such as lasers, microwaves, or ultrasonic waves.[14] Both methods with nanorobots are useful to treat cancer from inside the body.

Natural Disaster Rescue:

Utilizing modular robots for natural disaster rescue can enhance efficiency. Using a robot with multiple degrees of freedom (DOF) can enable it to change its shape to fit through tight gaps where humans can't see people stuck in need of help.[10] Equipping a camera on modular robots can permit them to explore where humans can't normally investigate. For flood disaster rescues, there are different modular robots for flood rescue. For underwater search, the Fathom One can capture High-Definition (HD) videos of submarine exploration.[19] This allows rescue workers to explore underwater for longer time periods. MR shouldn't take over the role of humans since they don't have the strength to remove rubble. Instead, they should be used to enhance rescue by allowing rescue teams to search for people affected by the disaster.

Reconnaissance:

Modular robots for reconnaissance allow combatants to gain new information. Using modular robots, such as drones, to get real-time information. Drone reconnaissance is easier than human reconnaissance. The risk of sending a human with a camera to enemy terrain is higher than sending a drone. Using swarm drones, for example, enables information gathering over a large area in conjunction with recognizing people or cars.[20] Modular robots can detect traps on the field, such as mines, which can reduce the number of deaths related to mine explosions. The Remote Environmental Monitoring Unit (REMUS) is used in waters to detect the location of underwater mines and relay it to ships so they avoid them, as mines have contributed to a large number of deaths.[21]

Education:

MR can be used to teach students a variety of topics. One of these topics includes coding. The I-BLOCKS are Lego-like pieces that can connect to complete different functions. These blocks enable students to learn Java, a coding language, at an introductory level, allowing them to understand slowly; learning coding is learning a new language.[22] However, sometimes MR doesn't have to teach a specific concept; it can be a skill. One modular robot, the CreaCube, teaches students problem-solving. It provides a vague goal that allows students to engage in creative problem-solving skills for cognitive flexibility.[23]

Augmented Reality Application

Augmented reality provides visualization in many fields that lack it. Using AR in fields can make real-world interpretation easier with visualization.

Medicine:

Similar to MR, AR can enhance the performance of surgeries. Using AR in surgeries provides virtual transparency, highlighting the patient's anatomy.[24] This visual clarity enables surgeons to view the surgical site. Another way AR impacts surgeries is in spinal surgery. AR overlays the distance between the surgical instrument and the patient's spine.[25] This allows the surgery to run smoothly and with reduced risk for the patient.

Education:

Due to AR being used to visualize objects, it can help students understand difficult concepts. For example, in 2009, AR allowed students to visualize the digestion process.[26] While it is easy to explain, AR can improve this ease by displaying where the food is in real time. Another example of teaching concepts with AR is the Specialist Schools and Academies Trust (SSAT), which depicts organs on an individual level.[27] Figure 4 illustrates how the organs' structure is presented to students. Viewing individual organs empowers students to gain knowledge of the organs and their structures. This enables them to recognize them based on their structures.

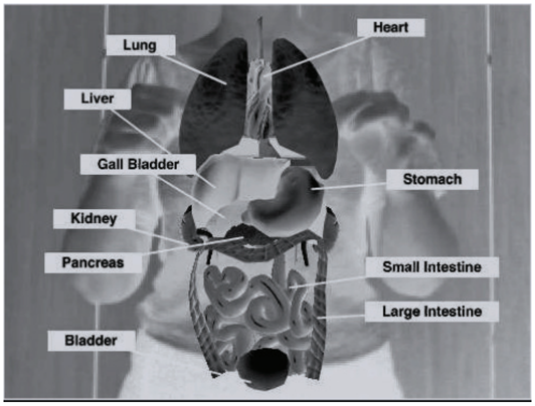

Figure 4: Shows how the organs look using AR.[27]

Architecture:

A problem with architecture is the difficulty of visualizing buildings during the construction process, and this can be mitigated with AR. During urban planning, this process can be challenging due to the presence of established buildings. However, AR systems such as the ARTHUR project can support construction in urban environments. The ARTHUR project utilizes a first-person perspective to create a virtual scale design that emulates the scale required for construction.[28] Another way to expand construction with AR is to overlay holographs of the finished building. A holograph enables visuals of the finished product and adds on-site information, allowing the construction to run smoothly.[29]

Tourism:

Tourism and navigation can be confusing for tourists. Using AR can help mitigate this confusion. Mobile AR (MRA) allows users to drive or walk with fewer distractions from changing focus from walking or driving with navigation.[30] This enables pedestrians to be more alert while walking, and for drivers to have reduced distractions, leading to fewer car accidents. For tourism in particular, tour guides can optimize AR using information about tour locations, such as historical areas or artwork.[31] This provides more information for tourists, enabling them to remember landmarks. They will have more information and be more immersed in their environment.

Modular Robotics and Augmented Reality

Both MR and AR have many applications, more than listed here; however, these applications show the diversity and flexibility of both fields. Both are versatile, but combining them allows for the best of both disciplines. As shown in Figure 5, both MR and AR have fields where they have different applications, but contain similarities in which they thrive.

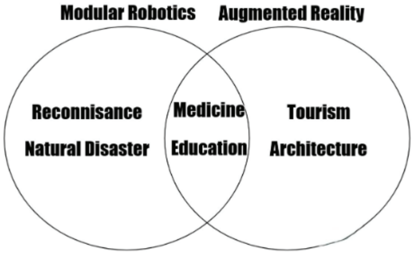

Figure 5: Showing the similarities and differences of MR and AR.

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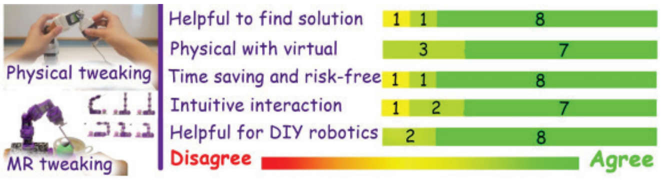

Figure 6: The answers provided when asked about changing the design physically vs with Mixed reality.[13]

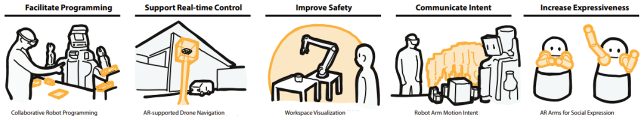

Figure 7: Depicting the many benefits of using AR.[33]

AR can be used to build modular robots. For example, if the modular robot needs to be placed a certain way, an AR tool can be used to assemble and orient the modules correctly.[32] This allows modular robots to be crafted with ease by having a separate tool that ensures the module is formed properly. When asked to determine a fix for design aspects in a modular robot, people preferred to use mixed reality (a type of augmented reality) to make changes to it.[13] Figure 6 illustrates the preferences when improving the design.

AR has many effects on MR. The visualization is a key benefit; however, it's not the only benefit. Other benefits include improved control, safety, and communication.[33] Figure 7 depicts these benefits. These key benefits provide a case for AR in MR. All of these benefits make MR easier to control. This enables testing and designing robots more easily.

In industrial robots, AR is used for path planning, spatial programming, and trajectory planning.[13] These aspects can also be applied to MR. Path planning can test how the modular robot will react when sent on a given path.

Augmented Reality-Finite Element Analysis:

Augmented Reality-Finite Element Analysis (AR-FEA) is based on FEA, which is used to test modular robots' behaviors, such as how much pressure they can handle. FEA tests certain structures that are fragile and depicts modifications to the overall structure.[34] A mesh allows MR designers to determine how pressure affects the tested object. A limitation with FEA, however, is that it can't display in 3D when the test objects are usually 3D objects.[35] AR can be used with FEA for 3D visualization. This leads to enhanced interpretation and visualization of tested objects.

AR-FEA works by overlaying a computer-generated FEA image onto a 3D plane. Then, a server sends the physical model and transforms it into an FEA model, which allows the user to use AR to visualize the FEA model in 3D.[36] This enables collaboration between different people, which can occur remotely.[37] Once designers identify a change in the FEA model, they can interact with the nodes individually to conform to the criteria.[36]

While AR-FEA is more unproven than FEA, some experts prefer AR-FEA over FEA. When students proficient in FEA software were asked about their opinion regarding AR-FEA. Their responses to the questionnaire were all positive. Figure 8 highlights their responses.[38] Using this figure, it is possible to determine the effects of AR-FEA. It can provide a better understanding by providing the FEA model, allowing for more interaction with the FEA mesh and better testing of the design. The AR aspect of AR-FEA, by design, allows for more collaboration.

AR-FEA can highlight specific areas where the design needs improvement. This is useful for modular robotics because it enables designers to pinpoint a particular node where there is strain and change the design to ensure there isn't too much strain. FEA covers multiple configurations for MR, while it doesn't in conventional robots. This means it is important for refined visualization to interpret each possible configuration.

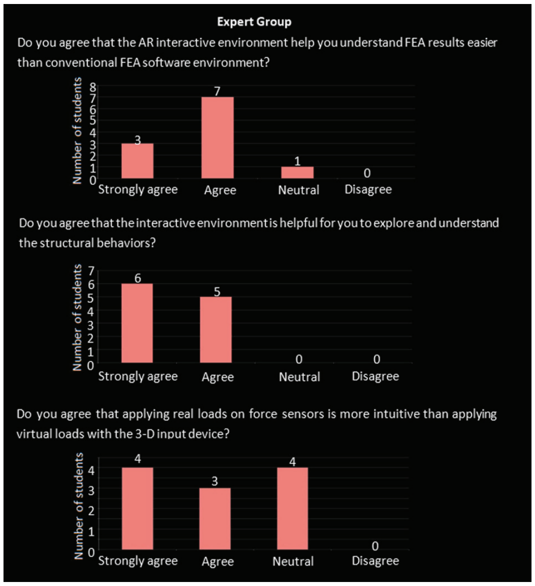

Figure 8: A questionnaire asking expert students about their opinions of AR-FEA and ranking them on a scale of 1-5.[38]

Spatial Augmented Reality:

Spatial AR (SAR) displays virtual content onto physical objects. It tests the robot's actions and how it will react to its environment, providing insight into how the modular robot will behave with its given code.[39] While there are no papers for SAR with MR, using papers from different fields presents a case for how it can be used with MR.

SAR can be used to create a model of an object.[40] This enables designers to visualize how the object will look in a real-world environment. Using it provides insight into the modular robot's intention when faced with a problem, forcing it to modify itself (such as a change in elevation).[39] SAR provides a 3D visualization of simulations to determine how the modular robot would operate in the real world. An example of this is a modular robot tasked with picking trash. Another instance of SAR involves the MARS robot. When testing this modular robot, AR markers are used to experiment with the modular robot's mobility.[41] Figure 9 shows how the robot moves to the markers.

Figure 9: The MARS robot moving towards the AR markers.[41]

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SAR can have a variety of benefits for modular robotics. Some of these benefits include easy assembly, flexible environmental parameters, and a capturing system.[42] Another benefit is improved safety, by highlighting a physical safety area.[43] This allows for modular robots to be tested with ease due to the simplicity of setting up an SAR system for experimentation. The capturing system analyzes by frame and detects information about the modular robot, including position and velocity, which is displayed to the users.[42] This analytical ability allows designers to view the robot in each frame to ensure it consistently functions.

This visualization and testing of modular robots enables modular robotic designers to determine how the robot will perform with its given code, environment, and task. All of this determines how the modular robot will react in the real world and visualize any errors the robot and design may contain.

SAR can be used to determine the pathing of the robots.[44] This has a larger impact on modular robotics than conventional robotics because of the orientations of the modular robots. Conventional robots normally don't change shape; however, modular robots are more prone to reconfigurability. SAR can help visualize the pathing of the robot, which would include when the modular robot needs to change its orientation to complete an objective.

Augmented Reality Computer-Aided Design:

Visualizing Computer-Assisted Design (CAD) can be confusing due to the small details involved in CAD. However, AR can support MR by helping visualize the CAD. Sony has experience with AR CAD to analyze their CAD, such as for the AIBO robot.[45] CAD works by using computer hardware to design. However, the implementation of rotating CAD in 3D instead of 2D has led to classes, such as descriptive geometry, manual drafting, and sketching, being eliminated, which has decreased visualization skills among engineering students.[45] AR can help rectify this decreased visualization skill by helping with visualization.

AR CAD functions uniquely from regular CAD. It works by capturing real-world video to convert it into a binary image. Then, AR software uses the binary image to calculate the orientation of the camera used to capture the real-world video. Finally, it outputs markers (square patterns displayed to the camera)[47] of the CAD in an HMD to project the CAD in the real world.[46] This conversion allows better visualization by seeing the CAD in a 3D space instead of a 2D screen. Figure 10 depicts the process mentioned above.

AR CAD allows users to easily view their design in 3D, review their model, and detect errors.[47] Doing this enhances comprehension of their model, efficiency, collaboration, reduces errors, and places their CAD in the real world.[47] This unique visualization can allow better interpretation of the design. A 3D visual is simpler than managing a 3D object on a 2D plane.

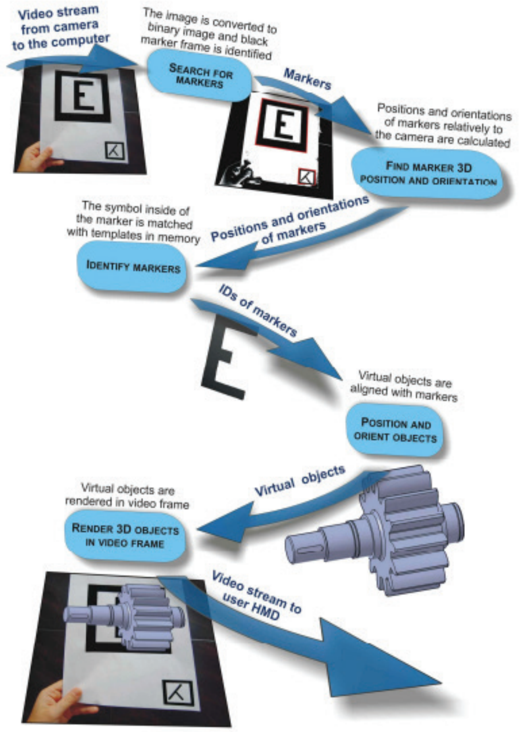

Figure 10: A visualization of how CAD can be converted to be displayed in the real world with an HMD.[46]

AR CAD enables the robot's design to be more streamlined. This is achieved by using a plug-in mixed with CAD software, AutoCAD, to input the design into the real world.[48] This makes the switch from CAD to AR CAD easier due to no delay being present between the computer model and the displayed model. AR CAD, similar to CAD, also highlights where the design may intersect itself and cause damage. Figure 11 illustrates how this may look in AR CAD.[48] This is useful for modular robots due to their size. Their miniature size means there could be scenarios similar to the one shown in the figure. This provides improved visuals of where the design may intersect, especially with a zoom function.[48]

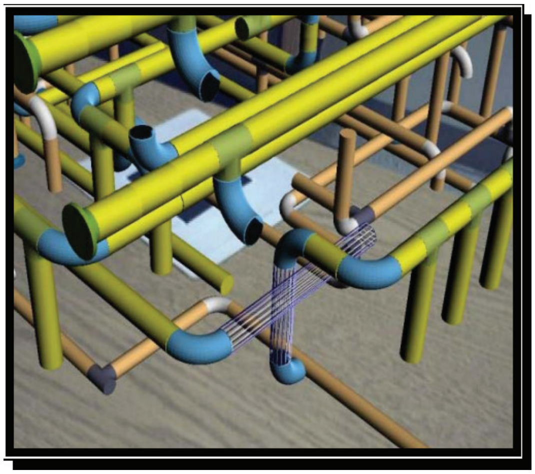

Figure 11: The purple wires highlight where the design intersects itself.[48]

While AR CAD can be useful for both modular robots and conventional robots, modular robots can better take advantage of it. Modular robots are usually small, which makes their design more difficult to view. AR CAD enables designers to view it with ease by having the design immersed in the real world, providing an easier 3D view. AR CAD can also depict a modular robot's reconfigurability. This ensures each designed configuration doesn't have a similar intersection problem, as shown in Figure 11. AR CAD has automatic interface detection, which decreases errors by highlighting mistakes.[49]

Conclusion

Both AR and MR have different and similar applications, but when combined, MR design can be improved. Using AR for visualization and collaboration can provide insight into how the design can be improved. Both have applications for different uses. MR is focused on the physical world and interacting with its physical environment. AR is focused on displaying computerized visuals in the physical world. Both of these are very different, but have a large reach and impact on various other disciplines, such as medicine and education.

There are many unique ways MR and AR can be used in tandem, including AR-FEA, SAR, and AR CAD. AR-FEA can be used to test how modular robots react to different strains (such as weight) in the real world. SAR can be used to simulate how modular robots operate by simulating their reaction to objects and their surroundings. AR CAD is especially important for modular robot designs. It visualizes how modular robots will look in the real world on a true 3D scale.

While all of these design processes can be optimized, especially the HMD, since that is essential for most AR applications, all of these design elements can be pivotal in improving modular robots' capabilities and preparing them for real-world impact.

SAR has the potential to visualize how modular robots will react to their surroundings. However, due to the lack of papers, SAR is important for research since there is limited information proposing its use for MR. SAR has many benefits for MR (as explored above) and can be beneficial. Another issue is the disproportionately low number of research papers in medicine with either AR or MR. Both topics had few papers. Nanobots can be used for many things other than cancer treatment. However, cancer treatment was the main topic mentioned.

While writing this paper, the problems AR and MR currently have were not calculated. For example, a problem with AR is that the HMD is large and isn't commonly accepted (in areas such as tourism). This paper assumes that issues such as these can be solved, and they won't impact either discipline.

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