NSAM Naval Shipbuilding & Advanced Manufacturing Center

# Safe Employment of Augmented Reality in a Production Environment

# Gap Analysis

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## *Purpose*

The purpose of this document is to assess the current and future state of augmented reality (AR) as they apply to training, hardware, software, safety, security, and user interface functions as it relates to the implementation in a production environment. The document identifies gaps in the current environment and what actions to take to move from the current assessment to a future state for safe deployment.

## *Introduction*

The Office of Naval Research, Navy Manufacturing Technology (ONR Navy ManTech) program and its Naval Shipbuilding and Advanced Manufacturing Center of Excellence (NSAM) seek to collaborate with a cross-functional team of US Defense Contractors to perform a technology baseline study on the state of Augmented Reality (AR) technologies. The study will also determine the leading technology providers in the following technical areas:

- Wearables & Mobile Devices for Augmented Reality
- Wearables & Mobile Devices for Mixed Reality
- Safety Requirements
- Security Considerations
- User Interfaces

The Safe Employment of Augmented Reality in a Production Environment project will investigate each of these technology areas. This research will determine the current state of the market and determine how the technology fits within the context of production facilities in the Defense industry. The outcome of this analysis is to provide market research, hardware and software requirements, infrastructure assessment, and identify gaps between as-is and to-be.

This analysis will also provide an implementation roadmap and identify the best practices to safely implement this technology and identify where this technology can potentially save cost and provide benefits to the Defense industry.

# 1. User Interface (Lead: Newport News Shipbuilding)

## Background

Market research on current off the shelf Augmented Reality (AR) user interfaces was conducted and uncovered 2 main types of augmented reality and mixed reality devices: Head worn displays (smart helmets and smart glasses) and handhelds (tablets and smart phones). Head worn displays can use a monocular or a stereoscopic display. For the purposes of understanding the state of maturity of AR implementation in production, only stereoscopic displays were considered because monocular displays due not provide the necessary spatial relevant information to create an augmented reality user interface. During research, current user interface interactions were noted as well including: a physical controller, eye or head tracking, gestures, and speech. The ability for the user to input information in a variety of ways is ideal when looking at feasible devices for a shipyard environment. Specific system interaction outputs were also noted such as various Graphical User Interface (GUI) elements and audio feedback. Products were also assessed on their ability for shared experiences and user workload assessments.

After uncovering the state of the current market, an assessment was done on the maturity of industry partners and their utilization of these user interfaces. A summary of this can be seen under the section “Infrastructure Assessment.” Industry partners are mainly implementing tablet based AR solutions following standards set forth for touch screen interactions. Research for viable use in production is focused on various aspects of head worn displays such as gestures, eye tracking, and shared experiences. A gap analysis was then performed to identify current shipyard/ aircraft production environment gaps and AR technology gaps that are present for the implementation of AR user interfaces in production.

## Infrastructure Assessment

Each industry partner was asked to fill out the below maturity matrix to gain a better understanding of the state of AR User Interfaces within their organization. Definitions for each column within the matrix include:

- Researching: Researching user interface feasibility in production environment
- Prototyping: User interface element is being tested in simulated environment.
- Piloting: User interface element is out in control portions of productions.
- Implementing: User interface element is out in production.
- N/A: Not currently investigating or implementing this aspect of AR User Interfaces.

The industry partners were then asked, to the extent possible, to provide details around the types of user interfaces they are working with. The results of this are summarized under each category.

| | Researching | Prototyping | Piloting | Implementing | N/A |
|---|---|---|---|---|---|
| **Inputs** | | | | | |
| Speech | B | | NNS | B | |
| Gesture | B | BIW | NNS | B | |
| Head Tracking | | BIW | NNS | | |
| Eye Tracking | NNS | BIW | | | |
| 6 DOF Controller | | BIW, NNS | | | B |
| **Outputs** | | | | | |
| Audio | | | | BIW, NNS | B |
| GUI Element | B | | | B, BIW, NNS | |
| Haptic | BIW, NNS | | | | B |
| Shared Experience | | BIW | NNS | | B |
| User Workload Assessment | BIW, NNS | | | | |

NNS: Newport News Shipbuilding
BIW: Bath Iron Works Shipbuilding
B: Boeing

## Inputs

- Speech: Across industry partners surveyed, speech inputs are being implemented in AR devices in production. Speech inputs are limited to basic commands for User Interface (UI) control and audio capture for note taking. Errors have been found for this input method due to environmental noise and for users where English is a second language.  Some industry partners track user feedback through surveys.
- Gestures:  Industry partners are either prototyping applications that utilize gestures or implementing applications with gestures for basic commands. This is most often done with the Microsoft HoloLens 1. When implementing applications utilizing gesture commands, basic training is given. Users are also able to use speech or gestures during interaction. Research has shown that the amount of practice and training necessary is variable across users. User surveys during implementation has also shown that repeated errors resulting from gesture commands are annoying to some users.
- Eye Tracking: Some industry partners are currently testing the available eye tracking technology for viable use and while have not begun investigating this form of user input.
- ((6 Degree of Freedom) 6 DOF Controllers:  Industry partners are testing 6 DOF controller technology for viable use in the shipyard. Testing has revealed

some shipyard gaps in the implementation of this technology (seen under the gap analysis section) including internal security requirements around Bluetooth devices and conflicts between magnetic sensors and metal shipbuilding materials.

### Outputs

- Audio outputs: Use of audio outputs varies across industry partners. Some partners are utilizing these for note taking and to provide information back to the user while other partners are not currently utilizing. Prototyping for voice outputs has shown that the quality of the voice (robotic vs. human like) influences user reactions. Users tend to dislike monotonous robotic voices.
- GUI Elements: Industry partners are implementing and prototyping different ways of displaying GUI elements to users. Control for placement of GUI objects such as menus is generally given to the user. Industry partner's use overlay methods for 3D models as well as pinning artifacts to the side to support the task. The amount of visual information is limited due to safety concerns that arise from occluding the user's field of view of the work space. Partners are exploring how to display other artifacts such as word documents and pop up text boxes that support the current task. Prototyping efforts are also ongoing for the display of hazards in the environment while utilizing Inertial Measurement Unit (IMU) driven scripts.  Given the lack of standards for 3D interfaces in industry, research efforts in this area are ongoing and continually evolving.

### Shared Experiences

Audio outputs: Use of audio outputs varies across industry partners. Some partners are utilizing these for note taking and to provide information back to the user while other partners are not currently utilizing. Prototyping for voice outputs has shown that the quality of the voice (robotic vs. human like) influences user reactions. Users tend to dislike monotonous robotic voices.

### Workload Assessments

Industry partners are currently researching how to better understand user workload and methods for assessing this such as interactive work orders. While user workload is not currently being assessed in implementation, some partners have safety regulations surrounding the duration of use to address potential fatigue.

### Touch Screen Interface

Touch screen interfaces are being implementing and prototyped by industry partners. Implemented AR applications utilize standards for swiping and touching for controls and input. This includes the manipulation of 3D models and other virtual objects using textured meshes within AR scenes for task execution.

### Testing Techniques

Testing for AR User Interfaces has been limited to qualitative usability testing. This includes questionnaires, observations, and surveys. Some form of quantitative testing occurs with numeric scales, however given the state of AR implementation and piloting, there are not enough participants to perform proper quantitative usability testing.

## Gap Analysis

### Speech Inputs

*AR Technology Gaps*

- Industry partners have notated two AR gaps when utilizing speech inputs for AR interfaces. The first gap in AR technology is the degree of accuracy of input. The technology makes errors in interpreting differing inputs as a result of between and within user variants. For example, a particular issue noted were errors occurring when the user's second language was English. The technology also has difficulty discriminating user input from ambient noise which is particularly problematic in loud shipbuilding or airplane construction environments.

- Currently all speech input commands must be preprogrammed and then the user must be trained on acceptable inputs. This can lead to memorability and usability issues particularly for novice and intermittent users placing a heavy cognitive burden on the user. Preprogrammed inputs lack discoverability and violate recognition over recall design principles. AR technology is currently unable to overcome these usability concerns (termed out of grammar inputs) because the devices lack the processing power needed to implement the necessary machine learning.

*Shipyard Gaps*

- When using speech inputs for AR applications, security considerations need to be in place such that sensitive information is not overheard by those without a need to know.

- Shipyard production occurs in an often noisy environment. This ambient noise can lead to false alarms on behalf of the application or an inability for the application to understand the user. Difficulty discriminating ambient noise is a problem also seen in aircraft production environments.

### Gesture Inputs

*AR Technology Gaps*

- Currently developed gestures libraries face the same issues as preprogrammed speech inputs with training and memorability issues.

While good design standards are in place for developing a gesture based system, not all preprogrammed gesture libraries follow these standards. For example, HoloLens 1 falls back on 2D metaphors such as the point and click to resemble a mouse. Good design recommendations state that 2D interface metaphors should be avoided. Currently, no industry partners voiced working towards developing a novel gesture library and applications are limited to off the shelf gesture libraries.

- Motion capture technology lacks the ability to capture extremely finite hand movements in turn placing a heavier burden on the user for accuracy with less tolerance for deviation.

*Shipyard Gaps*

- Ship yard work can occur in tight cramped spaces limiting a user’s ability to interact with the AR application using gestures. The hardware requires the user’s hands to be visible by the device which may not be possible in all environments.
- Ship yard use cases such as equipment maintenance or installation require the worker to remain hands free. A craftsman cannot utilize a necessary tool and perform a hand gesture at the same time.

### 6 DOF Controllers

*AR Technology Gaps*

- Due to metal materials inherent in shipyard production, 6 DOF controllers that utilize magnetic sensors like the Magic Leap One, are not able to be used in a production environment.
- Ship yard use cases such as equipment maintenance or installation require the worker to remain hands free. A craftsman cannot utilize a necessary tool and a controller at the same time.

*Shipyard Gaps*

- Internal security requirements for some production environments restrict the use of these devices if Bluetooth is utilized.

### Audio Outputs

*AR Technology Gaps*

- The AR industry currently lacks standards regarding different aspects for the quality of the voice. Research should also be done on the use of auditory alarms in AR applications such as when they are task or use case appropriate.

*Shipyard Gaps*

- Safety equipment requirements such as hearing protection limit the use of auditory outputs in noisy production environments.

**GUI Element**

*AR Technology Gaps*

- While this information is well documented for 2D interfaces, the AR industry lacks a set of comprehensive standards for how to display UI elements and design all interactions. Specifically for shipbuilding, use cases often involve text heavy manuals, procedures, and data. The industry lacks research backed best practices for displaying this type of information. Industry partners are continually researching and testing how to best do this in practice.
- Current 3D GUI element designs have yet to move away from 2D UI metaphors. For example, scroll bars, canvases to display 2D UI, etc. are still widely used in 3D UI design. The industry has not found an inventive and intuitive method for users to interact in a 3D AR environment.
- Depth of field effects for gaze are currently rudimentary and in the proof of concept phase for AR technology. The result for the user interface is a jumpy visual and object display experience.

*Shipyard Gaps*

- Connectivity for large models: In ship production environments, as the ship becomes larger and larger, the metal material attenuates the WIFI signal in inner ship compartments. In some of the outer areas of the hull, Long Term Evolution (LTE) is available to an extent. However, 5 GHz signals cannot effectively penetrate the hull wirelessly. Therefore, connectivity will continue to pose a problem for downloading 3D models in certain areas of the production environment. The recommended work around for industry partners is to download models to the device while in areas with WIFI signal however, this requires sufficient storage on the device. Connectivity will not be an issue in many areas of the shipyard given WIFI enhancement projects going on that should provide adequate access points to account for the number of users.

- Efforts to provide wireless communications in the inner ship compartments are ongoing, but to date, there are no standard solutions

- Sensitivity of models: There is currently no environment that can handle NNPI sensitive data and go to the cloud. Therefore, applications utilizing sensitive models will have to remain on an internal secure network without cloud architecture.

### Shared Experiences

*AR Technology Gaps*

- The remote expert use case for true telepresence in shipbuilding requires the display of the avatar on the interface which is not currently available in present technology.
- Similar to the lack of standards notated under the GUI section there also exists a lack of standards for how to display model manipulations done by remote users.
- Shared world anchors currently have set up usability issues, lack accuracy, and depending on size of shared content a 5G network can be necessary (currently non-existent). Specific connectivity issues can be seen under GUI Shipyard Gaps. Inaccurate shared world anchors leads to an inaccurate shared experience. Remote users may annotate or interact on the screen or the 3D model for the onsite user, however the onsite user would not see this annotation accurately in 3D space. This could lead to performance decrements and errors. The remote user would also see a UI where annotations are inaccurately located in 3D space.

*Shipyard Gaps*

- Connectivity as discussed under the GUI section, is another gap seen for implementing a remote expert use case in the Hull of the ship. Without connectivity, remote devices cannot connect.
- Security issues exist when using video feed and cameras particularly when this information is being transported to a remote user. Considerations need to be taken on how to control this information, need to know, and clearances.

### User Workload Assessment

*AR Technology Gaps*

- Built in eye tracking software in current off the shelf technology has issues with accuracy. This software captures XY coordinates for where the eyes are looking but no other metrics such as pupil diameter that are necessary for diagnostic eye tracking.
- To truly understand the user's cognitive state, convergent biometric measures are not currently implemented in off the shelf products without extra hardware.

*Shipyard Gaps*

- Shipyard requires Personal Protection Equipment (PPE) including safety glasses with Head Worn Displays (HWD). Eye tracking accuracy can be interfered with depending upon the reflection of the safety glass material as well as any dirt or scratches present. Poor eye tracking accuracy can lead to user frustration while attempting to interact with the application.

- Eye tracking software that is capable of being used with tablets, phones, or non- head worn displays is called remote or mounted eye tracking software. Shipyard work requires movement by the craftsman while this type of software is only suitable for stationary seated tasks.

**Tablets**

*AR Technology Gaps*

- Tablet based AR applications such as those using information overlay for part maintenance require the user to hold the device steady in one position which can lead to muscle fatigue and strain. This also limits the ability for the worker to view task relevant information while working. NNS has explored different mounts to overcome these safety considerations however, these mounts create additional unacceptable usability concerns particularly for target based applications.
- Ship yard use cases such as equipment maintenance or installation require the worker to remain hands free. A craftsman cannot utilize a necessary tool and a controller at the same time.

*Shipyard Gaps*

- Other than connectivity issues notated above no other gaps were found. After an infrastructure assessment tablet based AR applications appear to be the most widely implemented solution.

### Conclusion

The analysis identified several technology gaps. The industry lacks a set of standards for both the display of information in a 3D user interface as well as interactions between the user and the device. Several research opportunities exist to further understand the best placement for virtual objects, menus, etc. Research opportunities also exist for understanding which input methods are best for specific shipyard use cases with eye tracking in particular being in its infancy.

## 2. Safety Requirements (Lead: Boeing)

### Background

Infrastructure to ensure safe deployment of AR in manufacturing is paramount. Our summarized results reflect current pilot and production states which are evolving into a cohesive safety strategy. A safety strategy addresses “safety” built into software, hardware and processes to preserve the health and well-being of the end users.

Since augmented reality is a relatively new field, we are continually assessing feedback from users to improve the experience and maintain an environment free of injury. In parallel, technical improvements are continually made to the software to enhance the delivery of the experience and at the same time mitigate potential hazards in the work space.

In our technology document, we reviewed different functional categories in augmented reality across two industries – Aerospace Manufacturing and Shipbuilding. Through a series of tailored questions crafted in collaboration with ergonomic and human factor specialists, we captured safety gaps in augmented reality in four specific areas: hardware, software, safety training and safety materials. Each category was used to assess the level of safety maturity in augmented reality. The enclosed matrix is a snap shot in time, of the progress made by NSS and Boeing. It was compiled from the technology document responses.

| | **Researching** | **Prototyping** | **Piloting** | **Implementing** | **N/A** |
|---|---|---|---|---|---|
| **Inputs** | | | | | |
| Safety professional role | | | | NNS, B | |
| Safety training on device | B | | | NNS | |
| Safety procedures / business instructions | | | | NNS, B | |
| Safety survey collected on job | | | | B | NNS |
| Safety components built in software | NNS | B | | | |
| Safety built in hardware device | NNS | B | | | |
| **Outputs** | | | | | |
| Safety metrics collected | NNS, B | | | NNS | |
| Safety courses online | B | | | | NNS |
| Safety | | | B | NNS | |
| Head movements | NNS, B | | | | |
| Shared Experiences | NNS | | B | | |
| User Workload Assessment | B | | | | NNS |

The “Gap document” takes the assessment level by category and suggests opportunities to consider for migrating to “future state” of deployment.

Compiled assessment by Category: Hardware, Software, Training and Safety materials (from technology document)

Researching: Evaluating options
Prototyping: Testing functionality in simulated production environment
Piloting: Selective implementation under controlled conditions
Implementing: Production utilization

NNS: Newport News Shipbuilding
B: Boeing

## Hardware Technology Gaps

Safety built in hardware device to close the gap:

- Large field of view for better situational awareness.
- Wide, unobstructed peripheral vision to come with each new piece of hardware as it evolves and matures.
- Head rests that are comfortable and adjustable for all size individuals.
- Clips and secured devices on head worn displays are replaceable and can be adjusted by user.
- User’s range of motion is not restricted.
- Sensors to monitor the user’s range of motion and collect data on human motion and eye detection/tracking.
- Upgraded sensors and optics to leverage software capability of data collection.

## Software Technology Gaps

Safety built in hardware device to close the gap:

- Features that shut off/lock/blank the device display if the user is idle for a predetermined about of time.
- Rest break prompts in user interface to warn user when device use has exceeded acceptable time parameters based on guidelines.
- Biometric feedback for safety and risk assessment with use of AR devices.
- Use of eye tracking software for interacting with the system – reducing gesturing.
- Menus that have preselected defaults, minimizing menu actions.
- UI designs that promote minimal movement by the user to interact with menus.
- Alerts for identification of hazards in field of view such as protruding objects and uneven platforms, greater peripheral vision with device on head.
- Real time notifications of reach and posture hazards that exceed a normal status.
- Effective voice and gesture recognition for users of different backgrounds and ethnicities, minimizing miscommunication.
- Effective noise cancelation, optimized for manufacturing environments (riveting, drilling etc.)
- Data collection (sensors feedback) for reporting for process improvement.
- UI on a 3D display with good situational awareness for human.
- Display of hazards in the environment and warning indicators.
- Register employee movement out of field of view.

## User Safety Training Gaps

Formal safety training by product line to close the gap:

- Tailored training for each product line highlighting safety hazards discussed in a hands-on session and documented training manual.
- Training developed for different levels of expertise using applications on head worn displays.
- Hands on discussion for internal and external impact of safety with the head worn displays to include inside visual work area safety precautionary measures.
- Discussion on benefits of AR use in work space and how to use the hardware to optimize data collection of drawings, notes and task execution in a safe working space. Importance of the end user ALWAYS being aware of where he/she is in their space and not preoccupied with visual screens.
- Test questions to work in the hands-on session to reinforce safety and by product line. This is to ensure sufficient competency level of understanding by the mechanics.
- Survey and follow-up questions every quarter for feedback by employees.
- Physical training environments for semi- closed space where obstruction may occur with headset on employee and fall hazards.

## Gaps in Safety Related Feedback Material

Safety metrics should be standardized and feedback should be collected every quarter. Upon completion of training, surveys should be released for data collection and process improvements. One Boeing survey is weighted from 1-5 and also has a section for comments. They can be completed on-line or in-person with a human factors representative. Added questions reflect hardware and software gaps to address once the software and hardware components have been added.

- Survey questions that include training, hardware, software, and ergonomics.
- Safety questions on training received
    - Written materials, class room hands-on discussion and videos provided
    - Instructions on device use and handling of head worn display devices was given for use and storage
    - Example questions:
        - “Do you understand how to properly use and secure positioning of the head worn display on the head and holding device so it is not dropped?”
        - “Are you proficient using the device in a safe manner?”
        - “I can easily see the rendered images in all areas of my work space” (Y/N)
        - “I have no difficulty with voice commands” (Y/N)
        - “I have no difficulty with gesture commands” (Y/N)
        - “The device is safe and easy to use” (Y/N)
- Survey questions on ergonomic impacts:

  - Users should note physical awareness after use of head worn AR devices, (side effects, discomfort etc.)
  - Example questions:
    - “Does your task require awkward positions?” (Y/N)
    - “When you use a head worn display, does your posture change?” (Y/N)

Surveys should be collected, reviewed and feedback distributed to appropriate committees and improvements made.

## Survey in Practice

Below is a survey given to NNS, by Boeing, to perform an infrastructure assessment on the category of safety.

1. How do we ensure deployment and use is safe?
   - UI warnings to be aware of surroundings and check for hazards/tripping concerns
   - Usability testing and piloting to understand user interaction in the environment
   - All users of AR devices are required to wear PPE while on the job. Safety is monitored while testing and piloting for HWD using the Simulator Sickness Questionnaire and the Motion Sickness Susceptibility Questionnaire.
2. Do we use AR to make work safer/training?
   - NNS develops AR training applications, which are primarily used within the classroom, to improve knowledge retention and on the job performance. NNS has participated in joint efforts with NSRP to create applications with the goal of improving training of both skills and safety information. Applications teach the craftsman safety information as well as the necessary steps to take when equipment or the environment has been determined to be unsafe.
   - NNS uses AR applications to show the internals of various equipment and spaces to reduce rework. Compartment visualization is also used to increase the safety of craftsman through improved situation awareness.
3. Health diagnostic measures?
   - During usability testing for HMD’s, NNS uses the Simulator Sickness Questionnaire (modified) and the Motion Sickness Susceptibility Questionnaire to assess for simulator sickness symptoms as a result of the application. The participant is also assessed for normal or corrected to normal vision.
     - Higher scores for the SSQ have been found for participants who did not have normal vision but also did not have their glasses or contacts with them. These symptoms were generally eye strain and headache. In general these symptoms appear to dissipate after 15 minutes.
4. Usability testing

- NNS includes safety related questions including user discomfort from the device and the users understanding of elements outside of their FOV.
    - Design considerations for the placement of UI such that extraneous head movement is limited have been shown to reduce reported user discomfort including symptoms of neck strain and headache. The weight of handheld devices is also considered by NNS particularly when the application includes overlay information. The overlay of information requires the user to hold the device steady in one position which can lead to muscle fatigue and strain. NNS has explored different mounts to overcome these safety considerations however, these mounts create additional unacceptable usability concerns.
    - Testing has shown that participants do not always explore their environment especially with novel technology. Safety related information should be placed with in the users FOV or UI elements should be utilized to guide the user to explore for safety relevant information.

### Summary of Gaps Discuss

Identification of the safety “gaps’ provides the opportunity to build into AR strategy the supports resources and funds to bridge the gap and move towards a future state of optimized safety.

Having a standard workflow process introduces consistency and standardization across product lines and business units. Standardized surveys are a part of the continuous feedback loop to gather data and identify the process improvements.  Through the continuous process flow of user feedback, we can continually mature our safety lifecycle.

The suggested actions addressed in this document articulate the specific steps to take and products to build into the four categories to mature a safe state of execution for augmented reality end delivery devices.

## 3. Shipbuilding Collaboration on Gap Analysis

### Background

The Wearable & Mobile Devices Augmented Reality (AR), Wearable & Mobile Devices Mixed Reality (MR), Security Consideration, and User Interface team was tasked to identify the differences between the “As-is” conditions (Infrastructure Assessment) and

“To-be” state (Market Research). The teams agreed to clarify the definition of the task to identify the gaps between the Desired State and current capabilities of:

A. The state of the AR Market
B. The state of readiness of shipyard infrastructures to enable AR technologies.

The Desired State is defined as broad and substantial use of AR technologies to improve the quality, efficiency and safety of naval ship construction.

The team consists of four private shipyards; Newport News Shipbuilding, Ingalls Shipbuilding, General Dynamics Electric Boat and General Dynamics Bath Iron Works.

AR Gap Analysis Table.xlsx

## AR Gap Analysis Table Structure

The attached Excel spreadsheet “AR Gap Analysis Table” is organized by layers of the Augmented Reality Technology Stack: User Interface, Applications, Software Development Kits, Development Environments, Device Operating System, Communications, Sensor Suite and Delivery Device. In the following sections the scope of the stack layers is defined and a summary description of technology gaps and industry infrastructure gaps from the table are summarized.

## User Interface

### Layer Definition

The interface layer is the set of functions on the AR devices that address the means by which the user engages and controls an Augmented Reality session. Primary functions under consideration at the User Interface layer are device registration and localization initiation, augmentation initiation and control, reality capture and navigation, and application interaction (data input, output and transformation). The modes of user interaction and application utilization can be substantially different depending on the form factor of the AR Device, primarily handhelds (tablets or phones) or head mounted displays (headsets or glasses). All modes of user interaction need to be considered including hand gestures, screen swiping, voice commands and potentially eye tracking.

### AR Technology Gap Summary

In general, a lack of User Interface standards was identified as a gap for widespread use in shipbuilding (and other industries). It was noted that AR UI elements are still incorporating 2D interface metaphors such as the use of scroll bars. More specifically, AR technology gaps were identified in the areas of Navigation, Gestures and Commands, Display Lighting, Object Display and Data Display. See Attachment “AR Gap Analysis Table” for specific gaps identified.

### Industry Infrastructure Gap Summary

No gaps were attributed to shipyard infrastructure for the User Interface layer. This layer of the AR technology stack is entirely the purview of the AR technology suppliers.

## Applications

### Layer Definition

The Application layer is the focused software on the AR device that provides the functionality to input, display, transform and output data to accomplish specific use cases.  Ideally, the application layer is populated by purchased, turnkey software that can be configured for specific uses.  In these early days of AR adoption, however, we see a great deal of custom applications developed by end user organizations.

### AR Technology Gap Summary

Two general gaps were identified in available AR technology for the Application layer.  Firstly, it was noted that many AR applications are cloud-based and require a more robust security schema for use with Navy Technical Data, NOFORN data and classified data.  Either more applications will have to capable of being hosted on premises or more secure “gov” clouds will have to be utilized.  The second general gap is most applicable to Remote Expert type Use Cases where it was noted that shared world anchoring functionality is still not accurate or reliable.  Additional, specific gaps in available the AR Application layer were noted with Work Order Authoring applications and Remote Expert applications with Shared World Anchoring, Distributed Holograms and Remote Telepresence functionality.  See Attachment “AR Gap Analysis Table” for specific gaps identified.

### Industry Infrastructure Gap Summary

One of the general gaps in AR Technology, cloud based application security, was also noted in shipyard infrastructure capabilities as a shared responsibility.  As in the above, additional, specific gaps in the shipyard’s Application layer were noted with Work Order Authoring applications and Remote Expert applications with Shared World Anchoring, Distributed Holograms and Remote Telepresence functionality.  Some of the recurring challenges that were identified include gaps in the fidelity and completeness of legacy program product models, as well as limited wireless network connectivity in some of the shipyard facilities.  See Attachment “AR Gap Analysis Table” for specific gaps identified.

## Software Development Kits

### Layer Definition

The SDK layer is populated by both independent, third party and operating system unique tool sets that facilitate the performance of AR functions on devices, as well as the development of custom applications.  Although third party SDKs can enhance device performance, the AR capabilities of each type of device is largely determined by the sophistication of the embedded operating system SDK:  ARKit for iOS devices, ARCore for Android devices and Windows Mixed Reality SDK for devices running Windows OS.

### AR Technology Gap Summary

No general gaps were identified in the capability of currently available AR SDKs, but a wide variety of specific gaps were uncovered in the following functional areas:  2D and 3D Recognition, Cloud Recognition, Geo-Location, Simultaneous Localization And Mapping, Plane Detection, Mesh Creation, Advanced Lighting, Object Occlusion and Shared Spaces.  See Attachment "AR Gap Analysis Table" for more information on specific gaps that were identified.

### Industry Infrastructure Gap Summary

Relatively few Industry infrastructure gaps were identified.  As with the User Interface layer, the SDK layer of the AR technology stack is within the purview of the AR technology suppliers, not the end users.  The few gaps that were identified were also identified elsewhere, namely data security issues related to cloud-based software and the limited availability of wireless network connectivity in some of the shipyards.

## Development Environments

### Layer Definition

The Development Environment layer is a device operating system independent domain for the development, publishing and management of AR applications. Although there are many AR development environment, this layer is currently dominated by two popular gaming engines: Unity and Unreal.

### AR Technology Gap Summary

No gaps were identified.  Currently available AR Development Environments are suitable for AR use in shipyard environments.

### Industry Infrastructure Gap Summary

No gaps were identified.  Typical shipyard infrastructures are compatible with AR Development Environments.

## Device Operating System

### Layer Definition

The Operating System is of course essential to the core functions of the mobile AR device, but also has direct influence on its AR capabilities through the embedded SDK.  Selection of a mobility infrastructure operating system standard determines the opportunities for AR application in any enterprise.  The absence of Windows Mixed Reality based phones, for example, is a notable gap for an AR implementation strategy based on small form factor, inexpensive devices.

### AR Technology Gap Summary

No gaps were identified. AR capable mobile operating systems are suitable for AR use in shipyard environments.

### Industry Infrastructure Gap Summary

Only a generic gap was identified related to mobile device operating systems. AR development tends to be OS focused (there are OS-agnostic applications, they are not common). The potential gap was noted as “If they haven't already, shipyards have to commit to building out a secure mobile network based on one of the three major AR capable operating systems: iOS, Android or Windows Mixed Reality”. It is likely that the shipyards in question have already standardized on a mobile OS. If they have not, widespread AR implementation will force them to.

## Communications

### Layer Definition

The Communications layer is critically important to a robust AR implementation in shipbuilding. Many AR use cases require live connectivity with low latency, broadband wireless access throughout the shipyard. In many cases dense, streaming data will be utilized from enterprise data sources. These streams will assuredly include sensitive data that must comply with DOD cyber hardening requirements.

### AR Technology Gap Summary

One general gap was identified with available AR technology at the Communications layer. Voice communications and commands will play an increasingly important role in the utilization of AR. Particularly in the production environment, AR enabled mobile devices must support high fidelity audio, voice recognition and sophisticated noise suppression.

### Industry Infrastructure Gap Summary

Three general gaps were identified with regard to shipyard infrastructure readiness on the Communications layer.

- As noted previously, many AR applications are cloud-based. More robust security around communications channels for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds.
- Broad band wireless with yard wide coverage is required to ensure live communications for Remote Expert use cases.

- Access to product and process master data to enable AR is required for the more sophisticated AR use cases. This includes access to core PLM, ERP and MES data.

## Sensor Suite

### Layer Definition

Although embedded in all devices, the Sensor Suite layer is separated from the Device layer because the option exists to add non-organic sensors to a device to enhance performance. Combined with an SDK that can interpret the incoming data, sensor performance is a critical factor in the AR capability of any device.

### AR Technology Gap Summary

One general, potential gap was identified with state of the market AR technology at the sensor level. Noting the numerous gaps identified with AR device performance related virtual object placement at the SDK layer, the path forward may require more information harvested by sensors. Introduction of more accurate, supplemental depth sensing may be required to achieve the fidelity levels required in shipbuilding.

### Industry Infrastructure Gap Summary

No gaps were identified. The performance of the sensor suite is an issue that is limited to the delivery devices and has not direct impact on the shipyard's infrastructure.

## AR Delivery Device

### Layer Definition

Most of the AR capabilities of the Device are addressed in the higher levels of the Technology Stack. As a mobile device, the form factor of the device itself creates opportunities and gaps in widespread adoption of AR in shipbuilding. Several fundamental gaps were identified in the areas of device ergonomics, safety and industrial hardening.

### AR Technology Gap Summary

Two general gaps were identified at the mobile AR delivery device layer.

- Hand held devices can be hardened and ergonomically acceptable, but fully capable head mounted displays are not shipyard ready, yet. Ergonomics need to be improved with tethered form factors to get heat generation and weight off the users head. Safety needs to be improved with broader field of vision. Battery life needs to be extended.
- Over-heating of the device can pose an issue. Improve ergonomics of non-tethered devices.

### Industry Infrastructure Gap Summary

One general gap in shipyard infrastructure readiness was identified. Care, protection and management of mobile devices in the workforce needs to be enhanced for the harsh shipbuilding environment.

|  |  | AR Technology Gaps |  |  |  |  | Shipyard Infrastructure Gaps |  |  |
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| **ARWBS** | **AR Technology Stack Requirement** | **Gap A** | **Gap B** | **Gap C** | **Gap D** | **Gap E** | **Gap F** | **Gap G** | **Gap H** |
| 1 | **User Interface:** For the Work Instruction use case, the Augmented Reality user interface has a particularly broad set of requirements. In shipbuilding the shop floor and deck plate work environment can be exceedingly challenging. The AR device user interface must enhance tradesman safety by increasing situational awareness and minimizing distractions, in addition to providing complete and clear work instruction. 1. User Interface: For the Work Instruction use case, the Augmented Reality user interface has a particularly broad set of requirements. In shipbuilding the shop floor and deck plate work environment can be exceedingly challenging. The AR device user interface must enhance tradesman safety by increasing situational awareness and minimizing distractions, in addition to providing complete and clear work instruction. | Lack of standards such as those that already exist for 2D interfaces. | UI elements are still incorporating 2D UI metaphors (ie: scroll bars) |  |  |  |  |  |  |
| 1.1 | **Navigation, Gestures and Commands:** Given the near ubiquitous use of gloves in the shipbuilding work environment, the reliance on hand gestures for user input is problematic. Ideally, the majority of user interaction should be voice activated. However, background noise in the work environment demands the employment of high fidelity microphones and superior noise suppression algorithms. | More intuitive and precise control over virtual objects using hand motions (for HMDs and glasses) or screen interactions (handheld devices). | Broader library of audio commands to supplement gestures and screen interactions. | Quantified test data on audio command capabilities (noise suppression and command recognition) in shipbuilding environment. | Cramped Shipboard spaces limit the ability to utilize gesture interactions. | Due to materials necessary for shipbuilding, considerations are necessary for input devices. For example, the Magic Leap One utilizes a magnetic 6DOF that will not working in shipyard production environment. |  |  |  |
| 1.2 | **Display Lighting:** Lighting conditions in the workplace can vary widely from dark inner bottoms to the bright sunshine of the weather deck. Display lighting must automatically adjust for ambient light to ensure spatial awareness is not lost. | Quantified test data on best ranges of lighting for registration and tracking performance. | Devices or device holders with controllable, supplemental lighting. | Production work can occur outside in bright sun and extreme outdoor temperatures. |  |  |  |  |  |
| 1.3 | **Object Lighting:** Good Light Estimation capabilities of both AR applications and the user interface are required to ensure virtual images are shown with same light intensity as the real scene. The ability to manage lighting of virtual objects creates the necessary degree of realism that clarifies the information delivered by the Work Instruction, and allows the tradesman end user to use his intuition in making decisions. In addition to aiding tradesman understanding, display realism and accuracy are also key to workplace safety through complete spatial awareness. | Adequate performance - no gaps. |  |  |  |  |  |  |  |
| 1.4 | **Object Display:** In addition to realistic lighting, special effects should be available to enhance the realism of the scene, as well as highlight the subjects of the work instruction. For example, proper occlusion of virtual and real objects is necessary to clarify graphical depiction of the instruction. Similarly, translucence of virtual objects and other graphical enhancements are often necessary to allow the tradesman to clearly see installation details, such as mounting holes or system connections. | More effective occlusion of virtual objects to simulate line of sight. ARKit 3 from Apple needs to expand "people occlusion" capability to all objects. | Depth of field effects for gaze (example: Magic Leap One) are currently rudimentary and in the proof of concept state. | Ship building production environment is ever changing with material and structures constantly moving locations. |  |  |  |  |  |
| 1.5 | **Data Display:** Typical shipbuilding work instruction provides a large amount of textual and referential data to enhance guidance, such as method mounting details and additional views. The AR user interface should be able to manage and arrange supplemental data in the field of view in a manner that is not distracting or limits the user’s spatial awareness. | The same problem seen for the User Interface category- there is no standardization in 3D spatial computing for how to display large quantities of text or data. |  |  |  |  |  |  |  |
| 2 | **Applications:** For the Work Instruction Use Case, relevant applications must function in three broad roles: Work Order Authoring, Work Order Publishing (and Configuration Management) and Work Order Delivery. | Many AR applications are cloud-based. More robust security for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds. | Remote Expert Use Case: Shared world anchoring is still not accurate or reliable. | Keeping applications patched and updated and ensuring there are no vulnerabilities |  |  | Many AR applications are cloud-based. More robust security for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds. |  |  |
| 2.1 | **Work Order Authoring:** The end users for authoring functions are typically Planners who assemble product design details, material details and production details into a sequenced set of work instructions that is in accordance with the master plan. Based on Task 2.1 Market Research findings and shipbuilder experience, shipbuilding work instructions are typically quite different than the paradigm that COTS AR systems assume. Shipbuilding work instruction normally covers a broader scope of work than the prototypical COTS use case, and they rarely provide the step-wise, detailed instructions seen in market offerings (the exception is when Special Installation Instructions are used in critical or difficult installations). It is reasonable to expect COTS authoring systems to be capable of producing typical shipbuilding style work instruction, but that remains to be proven. An “expert capture” function that is offered by some of the COTS systems is, however, a good basis for efficiently capturing best practices and poorly documented “tribal knowledge”. An example is a current offering in the PTC Vuforia suite, Expert Capture, which records the actions of master tradesman as a basis of work instruction authoring. | Many AR applications are cloud-based. More robust security for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds. | Work order authoring capabilities that are more construction oriented and have direct feeds from planning models and operations simulations. | Needs to be compliant with NIST 800-144 |  |  | Many AR applications are cloud-based. More robust security for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds. | For DDG 51 class implementation, expand footprint of validated product models beyond DDG 51 Flight III. | For DDG 51 class implementation, improved access to legacy work order data sources (CAD, PDM, MRP). |
| 2.2 | **Work Order Publishing:** There are several necessary components to publishing work orders in an AR environment. Once authored, the instruction needs to be published in a format and location that is accessible to the AR Delivery system, or the AR device. Additionally, the Planning department must have the ability to queue up work orders for release in the proper sequence and at the proper time as dictated by the master schedules. Further, the publishing system has to offer configuration management capabilities that permit revisioning of work orders in a controlled and traceable manner. | Many AR applications are cloud-based. More robust security for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds. | Needs to be compliant with NIST 800-144 |  |  |  | Many AR applications are cloud-based. More robust security for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds. |  |  |
| 2.3 | **Work Order Delivery:** The delivery system is the “final mile” of the AR work order utilization process by presenting the end user, the fabricating or installing tradesman, with work instruction in an AR device. The presentation application must faithfully deliver the work order contents in compliance with the technology requirements identified in the above User Interface section. | Many AR applications are cloud-based. More robust security for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds. | Needs to be compliant with NIST 800-144 |  |  |  | Many AR applications are cloud-based. More robust security for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds. |  |  |

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| 2.4 | **Supplemental Capabilities:** In addition to clear presentation of work instruction in an AR scene, several supplemental functions will enable improved tradesman performance. Reality capture through photo and video recording will help the mechanic communicate with other work crews for support from other trades or other shifts. Similarly, if barriers are encountered in the execution of the work order, reality capture will help tradesmen communicate the problems to supervision and remote experts (Field Liaison and Engineering, for example). Annotation of the reality capture with audio or mark-up capabilities will allow the end user to clarify issues and improve communications, further. Finally, these communications can be made live if the Work Order Delivery system and device support secure, wireless communications. | Many AR applications are cloud-based. More robust security for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds. | Security gap in identifying where the data is securely stored | Security gap in identifying who has permission to access data | | | Many AR applications are cloud-based. More robust security for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds. | Thorough wireless coverage is required to ensure live communications for Remote Expert use cases. | Expanded AR implementation, especially for communications intensive use cases like Remote Expert will tax existing network bandwidth. |
| 2.6 | **Remote Expert:** Anchored Remote | Shared world anchors currently have set up usability issues and lack UI standards. | | | | | Security issues using video and cameras as well as controlling need to know information and clearances. | Connectivity issues in work location and network signal strength. | Remote Expert Use Case: The technology may be lacking a model to augment. |
| 2.7 | **Remote Expert:** Distributed Holograms | Lack of UI standards | | | | | Security issues using video and cameras as well as controlling need to know information and clearances. | Connectivity issues in work location and network signal strength. | Remote Expert Use Case: The technology may be lacking a model to augment. |
| 2.8 | **Remote Expert:** Remote Telepresence | Shared world anchors currently have set up usability issues, lack of accuracy, and depending on size of shared content a 5G network can be necessary (currently non-existent). | | | | | Security issues using video and cameras as well as controlling need to know information and clearances. | Connectivity issues in work location and network signal strength. | Remote Expert Use Case: The technology may be lacking a model to augment. |
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| 3 | **Software Development Kit:** All three AR industry leading mobile operating systems offer native AR software Development Kits (iOS ARKit, Android ARCore and Windows Mixed Reality). In addition, there is a growing universe of 3rd party, often OS agnostic SDKs that claim to add functionality to the native solutions. In any case these SDKs must enable the core functionality that the higher levels of the Augmented Reality Technology Stack (User Interface and Applications) demand. In the Work Instruction use case where accuracy of scene registration, virtual object placement, and persistence of this data is critically important, the technology requirements of the SDK can be stringent. | Security gap in making sure that code is properly patched and not vulnerable | | | | | Safety and quality control of code if we develop in-house. Software assurance: the software is doing what it's supposed to be doing. No more or no less. | | |
| 3.1 | **Reality Capture:** In conjunction with the AR Delivery System device sensor suite, the SDK must offer software that supports recording of reality as well as reality augmented with virtual images and objects. Reality Capture capabilities are used to gather simplified point clouds or meshes to enable localization of the device to its current environment, as well as provide a basis for proper augmentation occlusion. It can also be used to create a textured mesh representation of the real world to support many use cases. It is also a useful capability to support communications, especially in cases where the Work Instruction use case leads to a Remote Expert use case to resolve deck plate issues. | Reality Capture performance of current AR technology offerings is not sufficient for targetless placement of virtual objects within shipbuilding tolerances. | Industrial security issue that captures could inadvertently perform a foreign export. EAR/ITAR compliance | | | | Security issues as noted in Remote Expert Use case. Emerging technology surpasses current security policies. | | |
| 3.2 | **2D and 3D Recognition:** For most use cases the SDK must support the recognition of real objects in an AR scene beyond simple plane detection. The capability is required for good placement of intelligent overlay of virtual objects and can support improved fidelity of virtual object placement and reduction of object drift. | ARKit and ARCore need to broaden 2D and 3D recognition beyond orthogonal plane detection for targetless object placement within shipbuilding tolerances. | With a fiducial marker, while roll and position are highly accurate, pitch and yaw are still inaccurate (this inaccuracy compounds over distances). | 3D recognition requires too much pre-baking and the outcome is inconsistent. Lighting poses a problem with 3D recognition because of the shadows created. | | | Security issues as previously noted and models can be sensitive. | | |
| 3.3 | **Cloud Recognition:** The ability of the SDK to utilize cloud storage for harvested images expands the data set available to the AR device to feed 2D and 3D Recognition algorithms and increase AR accuracy. | More robust security for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds. | Needs to be compliant with NIST 800-144 | | | | Connectivity issues occurring in the shipyard environment. | | |
| 3.4 | **Geo-Location:** This capability enables an AR app to understand where the host device is in geographic coordinate system vs a local coordinate system. Although useful in many use cases, it is not considered essential to a manufacturing use case, particularly Work Instruction. | GPS coordinates not accurate enough nor accessible for shipbuilding. | Lack of connectivity inside buildings. | Large metal objects throw off even Differential GPS. | Security gap on the dependency of whether or not the device can do geofencing | | | | |
| 3.5 | **Simultaneous Localization And Mapping:** Simultaneous Localization and Modeling is a localization methodology used by all spatially aware SDK's. The resolution from SLAM algorithms interpreting and improving information from optical sensor and IMU data will have to improve to support the Work Instruction use case. It is possible that a re-introduction of depth sensors to supplement optical sensors will provide necessary reality capture fidelity. | SLAM performance of current AR technology offerings is not sufficient for tracking that is accurate enough to eliminate virtual object location drift . | Repetitively manufactured items such as stiffeners can confuse SLAM technology for pose initialization. | SLAM is too computational heavy for consumer/commercial mobile processors. | | | | | |
| 3.6 | **Plane Detection:** The ability to detect planar surfaces in the scene. As of this writing both horizontal and vertical surfaces are typically tracked, but future SDK upgrades will have to provide planar surface tracking at any angle. | ARKit and ARCore need to broaden plane detection beyond orthogonal axes for targetless object placement within shipbuilding tolerances. | Mat be too computational heavy for consumer/commercial mobile processors | In a shipyard environment, hull surfaces are not flat. | Cloud storage requirements | EAR/ITAR compliance and capturing technology encryption | | | |
| 3.7 | **Mesh Creation:** Although not essential, the ability of an Augmented Reality SDK to generate a textured mesh from point cloud data would be useful to increase accuracy as well as recording the existing session as a 3D scan. | Faster conversion of point clouds to textured meshes will be required for realistic object occlusion. | There are limitations in large mesh creations. | Resolution is too poor for realistic object occlusion. | The shipyard production environment includes large compartments requiring mesh creation. | | | | |
| 3.8 | **Advanced Lighting:** Management and enhancement of object lighting is required to render AR elements to appear real. It is enabled by realistic physically-based materials, environment reflections, grounding shadows, cameras noise, motion blur & realistic lighting and shadows derived from current ambient light in the scene. | Adequate performance - no gaps. | | | | | | | |

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| 3.9 | **Occlusion:** Another capability that is important to creating a convincing and clear display of virtual data in a real scene is occlusion, the correct obscuring of virtual and real objects in accordance with their placement relative to the viewer. Correct occlusion is essential to a clear display of work instruction and the ability of the tool to engage the user’s intuition. As with many of the technology requirements of mobile devices, proper occlusion is constantly shifting based on the movement and perspective of the device. A clear display of the work from any vantage point is critical to successfully supporting the Work Instruction use case. | Occlusion of virtual objects with real objects will have to be improved to include all relevant objects and all lines of sight. Fidelity and speed of mapping will have to be increased. | Ship building production environment is ever changing with material and structures constantly moving locations. | | | | | | |
| 3.10 | **Shared Spaces:** Many Work Instruction use cases in the shipbuilding industry require crews of tradesmen. The SDKs should be capable of supporting shared AR work scenes so that teams can see the same superimposed images and text simultaneously through separate devices. Although not essential to this use case, it would also be useful for the SDK to have the capability to display the entire AR scene to a remote participant. This capability is essential to the Remote Expert use case, below. | Some SDKs provide impressive capability for shared spaces. Availability of this function will have to expand. | Shared world anchors currently have set up usability issues, lack of accuracy, and depending on size of shared content a 5G network can be necessary (currently non-existent). | | | | There can be limited connectivity in the shipyard production environment. | | |
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| 4 | **Development Environment:** Since the Work Instruction use case type is one of the more technologically demanding, it is likely that it will require some custom development utilizing one of the AR development environments. The optimal development environment for AR will provide a solid framework for building accurate and realistic experiences. It is important that the environment is easy to use and provides both a large selection of input formats as well as output formats. Platforms such as Unity and Unreal work with many import and export formats, as well as large selection of SDK's. Both Unity and Unreal support all major operating system platforms as well. For the Work Instruction use case the development environment will need to be able to process a number of CAD import formats and be able to export to a number of device operating systems. Unity has AR Foundation that supports basic AR functionality within the development environment. This flexibility is important for keeping investments productive in the rapidly evolving field of AR technology. | Adequate performance - no gaps. | There's a gap in the ease of use of the SDK's. Content creation needs to be more automated and user-friendly. | | | | | | |
| **5** | **Device Operating System:** The power of a cooperating operating system to support AR is crucial. Both Apple (iOS) and Android are building rapidly increasing AR capability into both their basic OS framework as well as into their supported hardware devices. A good example of this is the A12 Bionic chip that Apple has incorporated into in their latest generation phones. This chip is designed to support AR core capabilities such as planar recognition, advanced lighting, 3D object recognition, occlusion, motion tracking and much more. With the amount of money and intellectual capital that Apple, Google and Microsoft are investing into AR, the underlying operating systems are going to increase the organic capability of all current and future devices. | Adequate performance - no gaps. | Keeping operating system patched and updated and ensuring that there are no vulnerabilities | | | | If they haven't already, shipyards have to commit to building out a secure mobile network based on one of the three major AR capable operating systems: iOS, Android or Windows Mixed Reality. | | |
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| **6** | **Communications:** In addition to live communications with colleagues as described in Supplemental Capabilities in the Applications section, above, integration with enterprise systems is essential to the Work Instruction use case. In particular, work instruction utilizes data from the Material Resource Planning (MRP), Computer Aided Design (CAD), and Product Data Management/Product Lifecycle Management (PDM/PLM) systems. The ability to integrate with these systems directly, or through associated data warehouses is a critical enabler to the core AR functionality for the use case. | Voice communications and commands will play an increasingly important role in AR. Devices must support high fidelity audio, voice recognition and sophisticated noise suppression. | Must be EAR/ITAR and FIPS 140.2 compliant | | | | Many AR applications are cloud-based. More robust security for Navy Technical Data, NOFORN data and classified data is needed either through on-prem solutions or secure clouds. | Broad band wireless with yard wide coverage is required to ensure live communications for Remote Expert use cases. | Access to product and process master data to enable AR is required. This includes access to core PLM, ERP and MES data. |
| **6.1** | **Network:** The assumption that must be made is that a ubiquitous wireless network is available in all spaces that AR/VR will be used. This poses a special difficulty for shipyard environments due to rampant signal attenuation by the vast quantities of metal being used. Another complexity is that large metal structures are being moved frequently. | Encryption of data should not degrade network performance | | | | | Identifying security vulnerabilites for software and operating systems | Must have wireless network connectivity in every environment even when large metal structures are present | |
| **6.2** | **Hardware Encryption:** Strong encryption is required to secure data at rest and in motion. The devices that are utilized for AR/VR need to provide this functionality to ensure the protection of data. | Does the device encrypt its data streams | | | | | | | |
| **6.3** | **Authentication:** A method to authenticate to the network is needed. Two-factor authentication is preferable. | How is the authentication process performed on these devices | Near seamless authentication process for the end user | | | | | | |
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| 7 | **Sensor Suite:** A foundation of Augmented Reality, specifically as it relates to the work instruction use case, is the device's ability to understand the world around it. Data acquisition of the device to localize to physical reality and continue to track its position is accomplished by the internal hardware referred to as the sensor suite. On some devices such as the Microsoft HoloLens the sensor site is extensive; there are over 11 sensors:<br>• Inertial Measurement Unit<br>• 4 environmental understanding cameras<br>• 1 depth camera<br>• 1 2MP photo / HD video camera<br>• Mixed reality capture<br>• 4 microphones<br>• 1 ambient light sensor<br><br>Each of these sensors provides input from the real world that is fed to the SDK and Development Environment running on top of the device operating system. In a target-less registration mode where dependence on the sensor suite is the greatest, current capabilities seem to provide a consistent accuracy around 1 - 2 inches. With the next generation of depth sensors or stereo optical sensors, and improved algorithms to interpret the data, accuracy will increase to the point that it will support the Work Instruction use case. Some solutions have provided a probe sensor that enables the device to provide more accurate registration and understanding of the real world.<br><br>In addition to sensors organic to the AR device, supplemental sensors may be required to achieve shipbuilding tolerance accuracy for the Work Instruction use cases. Since the retirement of the Tango Software Development Kit by Google, the phone and tablet based AR solutions rely upon optical sensors, only. Supplemental, 3rd party sensor suites like Occipital's Bridge may be required to create a more data rich environment for improved accuracy. These supplemental sensors would likely simulate current head mounted display sensor suites with the addition of depth sensors and additional optical sensors. | Introduction of accurate, supplemental depth sensing may be required to achieve accuracy requirements of shipbuilding. | The process of collecting data must be EAR/ITAR compliant | | | | | | |
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| 8 | **Delivery Device:** Although many AR use cases can be satisfied with less expensive phone and tablet based solutions, the Work Instruction Use Case demands hands free operation for the tradesman. The most useful form factor is a head mounted display. Current offerings will have to address fundamental workplace requirements including ergonomic, safety and physical hardening. It is expected that the recent improvements in ergonomics demonstrated on the second generation HoloLens will continue through Microsoft's development of combat ready devices under contract with the US Army. We speculate that the dominant architecture for head mounted displays will evolve to a lighter headset (more Google Glass-like) with a tether to belt-mounted CPU and batteries. For phone/tablet applications we expect IMU-driven safety features that force the user to navigate the work site without staring at the device screen. | Hand held devices can be hardened and ergonomically acceptable, but fully capable head mounted displays are not shipyard ready, yet. Ergonomics need to be improved with tethered form factors to get heat generation and weight off the users head. Safety needs to be improved with broader field of vision. Battery life needs to be extended. | Over heating of the device can pose an issue. Improve ergonomics of non-tethered devices | | | | Care, protection and management of mobile devices in the workforce needs to be enhanced for the harsh shipbuilding environment. | | |