A SURVEY OF MOBILE AUGMENTED REALITY TECHNOLOGIES FOR COMBAT IDENTIFICATION APPLICATIONS

BY

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DEDICATION

This essay is dedicated to Sergeant Marc Léger, Corporal Ainsworth Dyer, Private Richard Green and Private Nathan Smith of Alpha Company, 3rd Battalion Princess Patricia's Canadian Light Infantry. On 18 April 2002, while conducting a night firing exercise near Kandahar, Afghanistan, these four soldiers were mistakenly killed by a laser-guided 500 lb bomb dropped from a friendly U.S. Air National Guard F-16 fighter jet. It is my hope that continued improvement and introduction of new Combat Identification technologies will lead to a reduction of similar fratricide incidents. We will remember them.
ABSTRACT

Fratricide continues to be a very real threat on today's battlefields. To counter the rising fratricide rates of recent conflicts, Western militaries have put much effort in the development of Combat Identification (CID) technologies to improve soldiers’ ability to accurately identify and target the enemy. Due to the asymmetric nature of recent conflicts, CID systems increasingly use context-aware mobile devices to best provide the capability. In the commercial realm, Augmented Reality (AR) systems have finally leave the research laboratory and can now provide the common user with immersive and innovative tools thanks to the impressive capabilities of the smartphone. The purpose of this essay is to examine existing, commercially-available mobile AR technologies and consider their use to improve CID. Literature reviews were performed to determine the current state of two separate technology areas: mobile AR and military CID. A great number of be benefits and best practices were recognized when considering military use of mobile devices and introduction of AR tools. Similarly, a number of challenges were identified in adapting mobile and AR technology for military use, including: reliance on fixed infrastructure, information reliability, security, environmental impacts, power requirements, information overload, and equipment burden. While there would be benefits introducing mobile AR technologies into military CID tools, additional work would be required to adapt the commercial AR systems to support military networks as well more careful design of how information is presented to the user. Further study is warranted in the areas of human-computer interfaces for AR systems and use of CID systems to support all four stages of a combat mission.
ACKNOWLEDGMENTS

I would like to thank the following individuals for their support and contributions during the development of this essay: my wife for her unwavering support and tolerance; my sons for their inspiration and patience; and my essay supervisor, Dr. Mahmoud Abaza, for his guidance.
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CHAPTER I
INTRODUCTION

Statement of the Purpose

This paper will examine existing mobile Augmented Reality (AR) technologies and consider their use to improve Combat Identification (CID).

Research Problem

Fratricide is a very real threat on the battlefield. Fratricide is the term given to any unforeseen and unintentional deaths or injury to friendly forces resulting from the use of weapons intended to kill or destroy one’s enemy [1] [2] [3]. When fratricide incidents are investigated, normally there are a number of cause factors: improper tactics, inadequate group communication and even technical problems. Despite this, the most common cause factors are linked to human errors associated with CID; a soldiers’ ability to effectively perform CID tasks greatly affects the rate of fratricide incidents. Fratricide incidents not only decrease soldiers’ morale and their combat effectiveness, but they have a devastating affect on the victim’s family and can instigate public recrimination. These dramatic costs highlight the need to find the causes of fratricide and to develop possible countermeasures [2]. Hence, any tools that can be provided to soldiers to improve CID will likely lead to fewer friendly fire deaths.

Although AR technologies have been researched for two decades longer than those of CID [4] [5], AR has only recently begun to be introduced to the general public. Only in the past five years have the computational and video capture capabilities of smartphones reached the point where AR has become feasible on the mobile device [6]. Navigation, advertising,
travel, entertainment, real estate, and even news businesses are now using mobile AR to provide services. At its heart, most of the commercially available mobile AR services improve the user’s Situational Awareness (SA): finding the closest coffee shop, learning that a clothing store has a sale on pants, or determining the best lighting conditions for nature photography. Since SA is a major component of CID [3], it is logical to suggest that if mobile AR services can be used to improve the SA of a civilian then it can also be used to improve the SA of a soldier, and further reduce the risk of fratricide. With the growing success in the commercial realm and the lowering of the barriers of entry, thanks to relatively low-cost smartphones, the conditions are right to add mobile AR capabilities to CID systems for a maximum return on investment.

As historical data indicates that 46% of fratricide incidents solely involve ground units [2], the content of this paper has been more heavily weighted towards the use of CID for ground units. Furthermore, greater emphasis was put on the CID requirements of the dismounted soldier as currently CID devices are primarily found mounted within vehicles [1]. To best accomplish this dismounted soldier focus, the Canadian Army was used as a reasonable representation for typical ground troops. The Canadian Army was chosen to be the reference due to the prevalence of CID and digitization studies made available by Defence Research and Development Canada through the Soldier Information Requirements Technology Demonstration (SIREQ TD) project [7].

**Definition of Terms**
<table>
<thead>
<tr>
<th>Term</th>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Augmented Reality</td>
<td>AR</td>
<td>The overlay of spatially-registered computer graphics over a live image of the real-world [8].</td>
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<tr>
<td>Blue Force Tracking</td>
<td>BFT</td>
<td>Systems that seek to mitigate the risk of fratricide by supplying positional information regarding friendly units to enhance SA [1].</td>
</tr>
<tr>
<td>Command and Control</td>
<td>C2</td>
<td>The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission [9].</td>
</tr>
<tr>
<td>Combat Identification</td>
<td>CID</td>
<td>The process of rapidly and accurately identify friendly, enemy and neutral forces; manage and control the battlefield; optimally employ weapons and forces; and minimize the risk of fratricide [1] [2] [7].</td>
</tr>
<tr>
<td>Commercial Off the Shelf</td>
<td>COTS</td>
<td>Goods available in the commercial marketplace that can be procured by the government in the same precise form as available to the general public.</td>
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<tr>
<td>Fratricide</td>
<td></td>
<td>The employment of friendly weapons and munitions with the intent to kill the enemy or destroy his equipment or facilities, which results in unforeseen and unintentional deaths or injury to friendly personnel [2] [3]. Fratricide is synonymous with the terms “friendly fire” or “blue on blue.”</td>
</tr>
<tr>
<td>Information Warfare</td>
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<td>To corrupt, deny, degrade and exploit an adversary’s information and information systems; while protecting the confidentiality, integrity and availability of one’s own information and the relevant information systems [10].</td>
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<tr>
<td>Term</td>
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<tr>
<td>Identification Friend or Foe</td>
<td>IFF</td>
<td>An identification system designed to interrogation and identify aircraft, vehicles or forces as friendly [11].</td>
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<tr>
<td>Location Based Services</td>
<td>LBS</td>
<td>Services that determine a user’s location, returns information spatially related to this location, and offers the user dynamic interaction with this location information [12].</td>
</tr>
<tr>
<td>Military Off the Shelf</td>
<td>MOTS</td>
<td>Goods that have been developed or customized by a commercial vendor to respond to specific military requirements.</td>
</tr>
<tr>
<td>Neutricide</td>
<td></td>
<td>The misidentification of a neutral/civilian person(s) as the enemy, leading to the injury or death of that person [1].</td>
</tr>
<tr>
<td>Tactics, Techniques, and Procedures</td>
<td>TTPs</td>
<td>The doctrinal concepts that military units apply in combat situations (tactics), the tactics for small military units used in a particular circumstances (techniques), and the courses of action describing specific military tasks (procedures) [3].</td>
</tr>
<tr>
<td>Target Identification</td>
<td>Tgt ID</td>
<td>The process of making a classification judgment (friendly, enemy, or neutral) based on the characteristics of the entity [1].</td>
</tr>
<tr>
<td>Situational Awareness</td>
<td>SA</td>
<td>The perception, understanding, and forecasting of elements within an operational environment required to act effectively within that environment [1] [3].</td>
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</tbody>
</table>

**Organization of the Remaining Chapters**

Chapter II provides a review of CID-related literature, both to situate the necessity for CID and to better understand what CID capabilities exist at this time. In the following chapter, the literature review focuses on mobile computing and AR. In Chapter IV various
military-specific requirements and challenges are discussed related to the use of mobile devices. In the final chapter, a number of conclusions are presented along with suggestions of potential avenues of future mobile AR and CID research.
CHAPTER II
REVIEW OF CID RELATED LITERATURE

Fratricide

Increased Risk of Fratricide. While the First and Second World Wars’ fratricide rate have been estimated between 10% and 15%, it has been suggested that more recent conflicts have had higher rates. Nearly 80% of casualties suffered by the United Kingdom in the 1991 Iraq War have been attributed to fratricide. In the same conflict, the United States estimated a fratricide rate of 17%. While much lower than that of the UK, this is a significant increase from previous conflicts [1] [2] [5][13]. Since the end of the Iraq War many efforts have been made to reduce fratricide, with most focus put on the equipping of vehicles with Identification Friend or Foe (IFF) or Blue Force Tracking (BFT) systems. IFF devices provide indication when a shooter has targeted a friendly unit equipped with a transponder. BFT devices provide location information of friendly units to enhance SA [1] [5].

While the traditional causes of fratricide endure (improper tactics, inadequate group communication, technical malfunctions, human CID errors) [2], several new factors have been proposed to explain why there is a greater risk of fratricide on the modern battlefield:

- Weapons now have much longer ranges. Use of longer range weapons demand that targets may be engaged before positive identification is possible. As one’s enemy is likely to have long range weapons, forces must weight the risks of engaging a potential enemy without complete identification or being fired upon themselves. To overcome this challenge, remote sensors are more often being employed to assist in
target identification tasks, although these sensors often can only provide partial cues to identity [1].

- More precise weapons and surveillance allows all combat actions, to include fratricides and neutricides, to be more easily observed and accurately attributed. When friendly forces seem to have an overwhelming advantage, there is a trend that a Western nation’s public is much less tolerant of fratricide or neutricide incidents [1] [13].

- There is greater variance in friendly forces due to the highly mobile, joint, and coalition-based operations. It is becoming more difficult to identify even friendly forces. Relatedly, most fratricide events happen at the “boundaries” of forces. These boundaries can be between friendly and enemy forces, between two coalition forces, or even between operating environments (e.g. In coastal regions between naval and land operations) [13].

- Deemed as the most significant factor working against CID on the modern battlefield is the increasingly asymmetric nature of conflict. This includes the fact that modern battlefields have significantly more civil activity than previously met with [1] [7] [13].

**Asymmetric Warfare.** Western powers have begun to find themselves increasingly participating in high tempo, non-linear operations with enemies who forgo traditional uniforms and employ diverse equipment. In some cases, the equipment used by the enemy is similar or the same as used by friendly forces. In these types of highly mobile counter-insurgency operations, the tactical situation can change very quickly and it becomes
increasing difficult to effectively communicate a “mental map” of the situation through the
chain of command or to an adjacent unit. The presence of civilians and various Non-
Governmental Organizations within an area of operations further complicates the
circumstances. This factor is best exemplified in the asymmetric nature of conflicts such as
Iraq or Afghanistan [7] [8] [13]. The death of Private Mark Anthony Graham by two friendly
USAF A-10 Thunderbolts in September 2006 and the killing of eight Iraqi soldiers in a US
Army airstrike in February 2007 are just two tragic examples [2].

Combat Identification

At its core, the purpose of CID is to attain maximal combat effectiveness for a particular
situation and environment, to include minimizing any losses caused by enemy or friendly
fire. CID is a key element of combat effectiveness as the soldier uses CID systems to ensure
that weapons are fired at appropriate targets. Therefore, CID systems must quickly and
accurately identifying the allegiance of any detected contacts (e.g., friend, enemy, neutral)
based on the available sources of data. Failure to identify a target quickly or accurately can
lead to fratricide, neutricide, and injury or death to oneself. These CID failures carry
significant operational and, in some cases, national concern [1] [7].

While this paper deals primarily with technological aspects of CID, it is important to
realize that CID is inherently a cognitive process that is supported by technology. A series of
Defence Research and Development Canada (DRDC) studies [7] have clearly shown that
CID is not a simple “stimulus-response” task but is a much more involved mental task
involving information fusion.
Most militaries break down CID into three contributing elements: Target Identification (Tgt ID), Situational Awareness (SA) and Tactics, Techniques and Procedures (TTPs) [1] [3] [7]. All three elements are not required for CID but they all have a close relationship. Failure in any of the elements will significantly weaken the performance of CID and increases the difficulty to effectively conduct the remaining elements. For example, a soldier that does not fully understand his assigned TTPs will have difficulty building SA and properly interpret Tgt ID cues [7].

To assist in the comparison with AR technology progress, a general timeline of recent major conflicts and CID-related developments is provided in Appendix A.

Situational Awareness.

SA refers to the perception, understanding, and forecasting of elements within an operational environment required to act effectively within that environment. SA is often referred to as the “mental map” that has been created by the fusion of relevant historical and environmental factors taken from various sources. The fusion of information deals with the need for the information to be organized, processed, and integrated to provide a single coherent “operating picture.” To effectively complete CID tasks, SA is required as a precursor to the classification of entities as friendly, hostile, or neutral (or Tgt ID) [1] [7] [8].

Therefore, SA systems ensure timely dissemination of the “operating picture” to the various dispersed military units across the battlefield. SA systems are typically designed as a “system of systems” to incorporate the other CID elements. A variety of Tgt ID technologies can be integrated through TTPs and the resulting SA “operating picture” is provided to users in a usable format. Most SA systems chose to display their near real-time Tgt ID and
command and control information superimposed onto a digital map. A key operational
difference between SA systems and Tgt ID technologies deals with information latency. Tgt
ID technologies typically provides near real-time feedback while SA systems typically
display position or status information with several minutes of latency [3].

Blue-Force Tracking. Blue-Force Tracking (BFT) systems attempt to reduce the risk of
fratricide through the provision of timely and accurate friendly force positional information
to enhance situation awareness. BFT involves communicating SA and Command and Control
(C2) information among highly dispersed battlefield units in a dynamic environment [1] [14].
Benefits and weakness of BFT systems are outline in Table 1.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Weaknesses</th>
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<tr>
<td>Communication of SA and C2 information allows BFT to enhance the interoperability between separate military services (joint operations) and with allied militaries (combined operations).</td>
<td>Capability depends on network connectivity to distribute the integrated picture. Battlefield conditions (e.g., adverse weather, harsh environments) often lead to network failures that leave units without this SA tool.</td>
</tr>
<tr>
<td>Friendly position data can be fused with tactical data.</td>
<td>If positional data is not updated regularly it loses value or becomes of negative value as assets can move quickly (i.e. the longer the update delay, the less reliable it is). Current systems have several minutes of latency.</td>
</tr>
<tr>
<td>GPS technology can easily be leveraged to provide cost effective and highly accurate position data.</td>
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</table>
The research efforts for BFT began after the Gulf War to improve battlefield SA. During the Gulf War, military units experienced significant navigation difficulties thanks to the featureless desert environment. By 1995, the US Department of Defense made their first BFT systems available through the US Tactical Internet. Later that decade, improved software and satellite connectivity enabled military commanders in the Balkans to know precisely the position of their troops and vehicles [15]. BFT was used extensively during Operation Iraqi Freedom for the coordination of joint and combined military operations. BFT has grown so much that the US Army [14] estimated that their BFT bandwidth requirement in 2015 would be about 2 Mbps and therefore would not be supportable by existing space-segment data rates of a mere 2.4 kbps. The use of BFT systems are credited with the reduction of causalities in that operation due to the enhanced SA of participating military forces. BFT has become a critical capability for the modern military [14].

**Target Identification**

Tgt ID is the process of making a classification judgment (friendly, enemy, or neutral) based on the characteristics of the entity. In its simplest form, Tgt ID can be the visual identification of friendly/enemy forces based on their uniform. Visual Tgt ID was used in the Gulf War to prevent ground-to-ground or air-to-ground fratricide include the painting of allied vehicles with fluorescent orange panels and use of high-powered infrared beacons on the roof of vehicles [1]. When considering non-visual technologies, Tgt ID systems provide real-time feedback from detected friendly, enemy, or neutral entities. These types of Tgt ID systems can only provide ambiguous identification as they only provide a “do not shoot” indication rather than a clear friendly/enemy/neutral identification [3].
Identification Friend or Foe. The most common Tgt ID methodology is Identification Friend or Foe (IFF). IFF systems employ transponders attached to friendly entities that return a coded signal if they are targeted by a particular kind of transmission (e.g., infrared, radar, laser). Friendly forces with the correct signal transmitter and receiver can interrogate potential targets and identify a targeted unit as a friend, provided that they have a functioning transponder (see Fig. 1).

Before the invention of IFF, a squadron of British Blenheims light bombers returning from a mission was misidentified as hostile and radar controlled anti-aircraft guns tried to shoot them down over the River Thames in September 1939. While all bombers landed safely, the incident made it evident that a system for identifying friendly aircraft was required. The first operational IFF sets were patented by Watson-Watt and introduced before the end of 1939. The sets contained super regenerative receivers, which detected signals from
the ground stations and replied with more powerful coded signal on the same frequency [11].

Benefits and weaknesses of IFF systems are outlined in Table 2.

### Table 2. Benefits and weakness of IFF systems [1].

<table>
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<tr>
<th>Benefits</th>
<th>Weaknesses</th>
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<tr>
<td>IFF is not dependent on networked communications. Thus it can be used when under radio silence procedures or during network outages.</td>
<td>IFF requires a direct line of sight between interrogator and target. Thus IFF is subject to terrain screening or masking limitations as well as range limitations.</td>
</tr>
<tr>
<td></td>
<td>IFF is adversely affected by environmental factors such as dust and humidity as they disrupt signals.</td>
</tr>
<tr>
<td></td>
<td>IFF requires interrogator and target be equipped with functioning and interoperable transponder/receiver units.</td>
</tr>
<tr>
<td></td>
<td>IFF provides no negative feedback. Non-positive targets may be an enemy, neutral party, or a friendly without a transponder (or nonfunctioning transponder).</td>
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</table>

IFF systems are common place in all military aircraft. Adoption of IFF systems for ground vehicles is less common but, as an example, Tgt ID systems are currently installed on the US Army’s M2A2 Bradley Infantry Fighting Vehicle. This system uses two colour codes to make its indication: flashing red light for friendly targets and a constant yellow light for unknown target [2]. IFF adoption for ground vehicles is lower due to an inherent system limitations: the requirement for line of sight. Manufacturers claim their IFF system can
correctly identify up to 97.5% of friendly targets within 1100 m. Of course these tests are conducted in controlled environments and not in real-world battlefield conditions [2].

As many contemporary conflicts have been asymmetric in nature, which often requires dismounted infantry, more focus has been put on delivering IFF to the individual soldier. Individual IFF systems work the same as traditional vehicle-based systems: the interrogator is mounted on the soldiers weapon and the transponder is mounted either on the helmet or tactical vest. IFF systems have been difficult to produce for military ground units due to system cost, size, weight, and ground line-of-sight interference caused by the cluttered ground environment. Also, the use of IFF systems in asymmetric conflicts becomes very challenging as system feedback is unable to distinguish between hostile and neutral entities, which are in close proximity [1] [2].

**Tactics, Techniques and Procedures**

Tactics, Techniques and Procedures (TTPs) deal with the application of doctrine and tactics in particular combat situations. While SA provides data about battlefield objects, TTPs provides the knowledge needed by soldiers to interpret that SA data and therefore guide the human decision-making process for CID [1] [3]. Rules of Engagement (ROE) are often considered a component of TTPs.

Following the Gulf War, the US DoD examined changing TTPs and ROEs in order to reduce the escalating incidents of fratricide. It was discovered that while tightening the ROEs would result in a reduction of fratricide incidents, it also resulted in increased casualties caused by the enemy. When ROEs are tightened, additional time is required confirm the identification of the potential enemy target. This additional time allows the enemy a chance
to react [5]. A US Defense Science Board report regarding CID later drew the conclusion that minimum overall casualties does not necessarily mean minimum fratricide [13]. Fig. 2 visually explains this concept.

![Figure 2. Relationship between Rules of Engagement and Friendly Causalities levels [13].](image)

While TTPs are not discussed further in the essay, as TTPs focus on how CID is conducted rather than the technology used, it is important to understand that TTPs can dramatically affect what aspects of the battlefield are monitored and what CID cues will be used by soldiers [1].

**Digitization**

Previously SA on the ever-changing battlefield only meant reporting position or other tactical information by voice via the radio either up or down the Chain of Command. Today,
radios require data capacity to support computer-based applications that send and receive friendly and enemy positions reports from anyone on the radio network [16]. In parallel to the development of CID technologies, has been the digitization of today’s modern militaries. Extensive research, trials and delivery of digital tools for the soldier has taken place over the past decade. The intent of military digitization efforts is to replace antiquated tools or processes with modern computerized tools as well as to introduce new military capabilities based on new digital technologies. The research efforts of digitizing the Canadian Army has largely been headed by DRDC [7] [17].

One such research effort was the DRDC sponsored field trial to evaluate the overall mission effectiveness of digitization for infantry soldiers. Location-aware digital maps, video, and text messaging were the three digital tools used for this study. Compared to non-digital baseline trials, the results were supportive of the use of digital tools [17]:

• SA was enhanced. Digital tools provided faster more indications of one’s own unit position, the position of other friendly units, key terrain features, and known enemy positions.
• Soldiers were able to better respond to tactical opportunities or adapt to unexpected mission changes thanks to their improved SA.
• Units were able to maintain greater tactical separation as each unit was aware of the other’s location. If necessary, units were able to quickly manoeuvre to support one other. The increased tactical separation of digitally-enabled units made them less detectable by the enemy.
• Soldiers reached their objectives faster and more reliably using the provided digitally-enabled tools. At night, soldiers could navigate through the same terrain at daytime speeds without error.

• The digitally-enabled units were better able to receive and transmit information with digital messaging and intra-section radios.

Besides the objective results of this study, the participating soldiers strongly endorsed the use of digitally-enabled tools and concluded that these tools contributed greatly to mission success [17]. It was noted in this study, and in other DRDC studies, that soldiers were aware that existing TTPs would need to evolve with the introduction of digital technologies on the battlefield. Many benefits of digitization would likely remain unknown until new tactics could be developed [18]. These promising results led to further studies of battlefield digitization focus on particular soldier tasks:

Navigation. Following a field trial of digital orienteering tools [19], participants indicated that digital maps were extremely valuable in coordinating movement at the objective and for the initial unit mission briefing as tablet displays could clearly indicate positions, routes, and the status of other sub-units. It was also remarked that the digital map display provided all sub-units with improved SA of the battle while being able to maintain stealth and unit separation. Knowing their own location, the location of other sub-units, and estimates of arrival times at various mission waypoints; participants were able to take up the most advantageous positions before an assault. As the position information was updated in near real-time, radio messages could be shorter and conveyed more quickly. Overall fewer radio messages were exchanged.
**Target Designation.** In a target designation field trial, infantry soldiers were tasked to identify the position of selected targets using three target designation methods and then report the locations. Performance results revealed that soldiers were much faster and more than twice as accurate at designating targets using a laser rangefinder integrated with a GPS-based digital map as compared to the use of current equipment (paper map, compass, and binoculars). Use of these digital tools also allow for targets positions to be more easily transmitted to other friendly units while also reducing the risk of transmission errors [20].

**Off-Bore Weapon Sighting.** A popular research area for battlefield digitization as been the use of off-bore weapon sighting systems. Off-bore sighting is the use of a video camera, which is bore-sighted to the soldier’s rifle barrel, to provide a remote the sight image to a video display or Helmet Mounted Display (HMD). A soldier using an off-bore weapons sighting system is able to reduce the duration and/or extent of his exposure to enemy fire as he can safely remain behind cover while observing his field of fire through the remote video sight. Apart from the use of off-bore weapons sighting systems in conjunction with remotely operated armed robotic vehicles, most studies have not yet yielded positive results. Soldiers most often complain that their overall SA is compromised when using the off-bore systems [21].

**Mission Planning.** A number of DRDC studies have studied the use of digital tools in small unit mission planning activities [22] [23]. When it comes to mission planning, digitization was found by study participants to be most acceptable in the initial stages of mission planning to view aerial photographs or 3D maps and to prepare and deliver orders. [22]. Participants recommended that these digital tools be deliver in a personal digital assistant
(PDA) form factor that integrates reference material together to include the following tools [1] [23]:

- **Reference information**: Access to relevant multimedia reference materials.
- **File storage**: Storage of mission plans for future retrieval and reference.
- **Auto formatting**: Incoming information automatically placed in an appropriate and common format.
- **Awareness**: User should be alerted of pertinent situational information (i.e. Low ammunition, weather warnings).
- **Customized interface**: User should be able to customize the interface so it is made more relevant to their role and type of operation.
- **Filters**: All information display should have customizable filters to allow users to choose information display that is relevant to their role and type of operation.
- **Sharing**: Information, including positional information, should automatically be shared with higher or lower command levels.
- **Cut and paste**: This functionality would allow cut and paste of desired information from higher level orders, or other reference materials, into the user’s plan.
- **Time-stamping**: All information should include time-stamping metadata ensure accuracy of information.
- **Security of information**: The device must have security features to prevent the enemy from disrupting, imitating, or accessing information.

When considering hardware for a battlefield PDA device, the following components were listed as important by study participants [23]:
• Overall the device must be durable and lightweight.
• The display must be readable in all lighting conditions.
• Laser range finder.
• Wireless communication for both transmit and receive.
• A choice of input devices, such as: a touch screen, physical joystick, and speech-to-text input
• A video camera capable of still photography. If detachable or separate from PDA device, the camera could be used in a remote sensing role.
• Global Positioning System (GPS) receiver with electronic compass.
• Heart rate monitor.

Examples of CID Systems

The most significant development of CID technology began in 1996, led by the US DoD [5]. DRDC reported in 2008 [2] that more than 25 technologies have been proposed and/or developed to aid soldiers in the CID process. The following section provides an example of some of these CID technologies that have seen active use.

Geographical Based Situational Awareness (GBSA). The Royal Netherlands Army’s GBSA provides a BFT capability using existing VHF vehicle radios. While the initial concept of GBSA was to quickly disseminate all immediate geographical related information (position updates, enemy information, Improvised Explosive Devices, status of minefields, roadblocks, etc), GBSA project requirements were simplified to reduce the complexity and timeline of the project. GBSA now provides only position update information, via VHF radios, to all vehicles in the immediate vicinity. Position reports are automatically transmitted
as many times as possible. A major advantage of GBSA is that distribution of position information is provided based on vicinity rather than on unit hierarchy; GBSA is considered to provide a radar view of all vehicles in reach [16].

**Force XXI Battle Command Brigade and Below—Blue Force Tracking (FBCB2–BFT).** FBCB2–BFT is the US Army CID system that links communication devices, sensors, vehicles, rotary-wing aircraft, and weapon platforms via the US DoD Tactical Internet to provide SA. FBCB2–BFT is able to generate and distribute battlefield SA with ground vehicles, rotary-wing aircraft, command posts, and command centres. When planning for the rapid deployment of units for combat in Afghanistan and Iraq, Northrop Grumman updated the system to provide satellite-based connectivity to augment the existing, less robust line-of-sight on-the-move digital communications network [24].

**TacNet Tracker.** TacNet Tracker is a lightweight wearable low-cost device, developed by Sandia National Laboratories, that provides secure real-time tracking and self-forming connectivity using commercial off-the-shelf hardware components and customized software. TacNet Tracker, a multifunctional device, is able to support various security and logistic applications. As TacNet Tracker has the option of communicating via a mesh network, it can provide SA to users without the need for fixed infrastructure. TacNet Tracker attempts to maximize its value by building-in a great number of features: low-power computing, multiple communication options (802.11, Bluetooth, Ethernet, USB, and JTAG), and voice-over internet protocol [25].

**Augmented Reality Visualization of the Common Operation Picture (ARVCOP).** ARVCOP was first developed for small ships involved in coastal counter-mine operations.
ARVCOP provides navigational and tactical capabilities. The AR component of ARVCOP overlays the navigational and tactical information onto live video feed to increase the SA and reduce the workload of the user. ARVCOP is an integrated and ruggedized system made up of the following hardware components: multiple displays, a user interface, a core server, thermal camera, night-vision camera, and GPS receiver. In addition, satellite or airborne sensor data can be fed into the system. The system has been redesigned to allow for installation on watercraft or land vehicles. An Apple iPhone and RIM Blackberry variant is planned for release [26].

**Battlefield Target Identification Device (BTID).** BTID is a IFF and BFT hybrid system being developed under NATO Standardization Agreement 4579. Development under a NATO Standardization Agreement ensures that interoperability can be achieved when operating in a Coalition environment, hence it is considered Canada’s favoured CID solution. BTID encompasses a family of CID solutions to cover off Tgt ID and SA requirements for the ground, air, and land environments. While components of BTID have been tested at various BOLD QUEST military exercises over the past seven years, it is not yet available as an integrated system [7].
CHAPTER III
REVIEW OF MOBILE AR RELATED LITERATURE

Augmented Reality

AR is a technique for overlaying a spatially-registered virtual scene onto a real-world scene. Simply the overlay of information is not enough to qualify for AR. The overlaid information must behave as if it has its own location within the scene and thus the overlaid information will move as the view changes. Hence, when properly implemented, AR provides the user with an immersive experience and allows for interaction between the virtual and real-world [8] [27]. Azuma [28] put constraints on the definition of AR with the addition of three criteria: combine the real and the virtual, interactive in real time, and they are registered and aligned in three dimensions. For the purposes of this essay, Azuma’s definition for AR is not considered due to the restrictiveness of the second criteria.

AR is part of a field of technologies usually described as Mixed Reality, which is described as a continuum of real and virtual information [29] [30]. The term Mixed Reality was selected to best capture the conceptual ideas of blending and merging of different realities. This continuum is visual represented in Fig. 3.

![Mixed Reality Continuum](image)

Figure 3. The Mixed Reality continuum [29].
The concept of Mixed Reality is nothing new to military. The common infantry soldier has long used a reticle, or cross-hairs, to predicted his bullet impact when aiming a rifle [29].

**AR Methods.** AR systems can be classified as either optical or video overlay:

The optical AR method uses optics to combine the real-world scene with the virtual scene. Optical AR is considered less complicated and cheaper than video overlay and is traditionally the method used for head-mounted displays (HMD), whether the display is providing AR or static information [8] [29] [31] [32]. There are a number of drawbacks of the optical method [29] [33]:

- The optical AR method makes the real-world scene darker than actual, as the optics cannot capture all the light from real-world scene.
- The virtual projection cannot completely obscure the real world image and thus all virtual projections are transparent.
- Placement of the virtual projection in relation to the surroundings is difficult as semi-transparent objects provide no depth clues to the viewer.

The video overlay AR method uses a video camera to first capture the real-world scene and then the AR information is overlaid. This method forces the alignment between the real-world and virtual scenes and allows for image enhancement, improved sensor fusion, and simulation applications [8] [29] [32] [33]. The video overlay AR method is popular as it does not require any special devices apart from a camera. Combined with simple markers, graphic overlay can be used to bring AR tools online quickly and built more robustly [27]. Disadvantages include [29]:

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• The video resolution of the camera and display sets the limit for what the user perceives.

• Field of view that is very limited compared to natural vision.

• There is an eye offset distortion as the camera cannot be positioned exactly where the eyes are located. The resulting difference between perceived bodily and visual movement can effect the user experience, in some cases causing motion sickness.

Mobile Computing

Advancement of Mobile Computing. With the continued miniaturization of digital components and the vast technological development of the past years, the personal computer is now a mobile devices rather than the desktop computer [29] [34]. Unlike the desktop computer, mobile computing is able to fully support Location-Based Services (LBS) to users. While they first debuted commercially in the mid-1990s, thanks to the US government mandated Enhanced 911 services, it took another decade for LBS to become mainstream. GPS-capable mobile devices, Web 2.0, and the rollout of 3G wireless services are credited with setting the stage for LBS to be successful [35].

Military Use of Commercial Mobile Computing. In 2010, the Canadian Forces conducted an assessment of various hand-held mobile geographic information systems (GIS) that included both commercial off-the-shelf (COTS) products (including some smartphones) and Military off-the-shelf (MOTS) [36]. The mobile GIS devices were reviewed based on their specifications and capabilities. Twenty-six units were selected for further investigation and potential acquisition. Six were smartphones, 10 COTS systems and 10 MOTS systems. Commentary in the report made mention to the fact that the smartphone devices were also
able to perform additional functions outside of GIS whereas the other COTS and MOTS systems were GIS specific devices.

DRDC funded a small research project [37] to develop a reporting and return application for the Apple iPhone to demonstrate that a soldier with smartphone loaded with the reports and returns application could simplify and accelerate the process of creating and sending reports compared to the current process of handwriting and verbal transmission. The driving force behind the project was the growing recognition of the capability inherent in modern smartphones as a result of their computing power and many embedded smartphone sensors. Additional functionality can be added with the use of self-contained sensor modules that can be connected to the smartphone wirelessly via WiFi or Bluetooth. This type of work shows that smartphone devices could easily function as communication hubs to transmit position reports, ammunition consumption rates, or a variety of useful information gathered from attached sensors.

In the summer of 2011, the US DoD directed that work on the US Army’s long-standing Nett Warrior project be halted until it could be reviewed [38]. Nett Warrior project was a wearable computing project that was set to deliver an average of eight pounds of computing gear to a typical soldier. The review was the result of a suggestion to use lighter, less bulky, cheaper, and more capable smartphones to accomplish the work of a wearable computing ensemble. Following the review, the US Army has changed the Nett Warrior project to now use “repackaged smartphone technology” to deliver enhanced mission planning, monitoring, communication and SA tools.
Mobile AR. As outlined in the paragraphs above, the last decade has seen a rapid advancement of the computational capability of mobile devices. This advancement has also brought us to a point that mobile AR is now commercially feasible [6]. That said, using mobile devices for AR purposes has benefits and limitations.

Due to the small form factor and fact that cameras have become a standard feature, the cellular phone is a convenient AR platform. AR applications also benefit from the plethora of additional sensors (e.g. accelerometers) as they can be leveraged to further improve the quality of the AR experience [6].

Despite the many advances in mobile computing device technology, mobile devices still have reduced computing power and therefore their performance for real-time imaging can be limited. Many non-mobile AR systems benefit from the availability of specialized high-quality graphics hardware; mobile devices do not share this benefit [6] [39]. Further limitations are bound to the basic characteristics of the mobile devices: small screens, limited input options, and the need to hold the device away from the body to view. These form-factor limitations have challenged researchers in their development of usable interfaces and can cause problems when using a device in locations without much body space (e.g. within crowds, small spaces) [31].

A common approach to overcome the computational and visual rendering limitations of mobile devices is to accomplish the push the computational and rendering work onto a powerful remote server via a network connection and then simply display the results on the mobile device, potentially as a video stream. While this approach bypasses the low computational power problem of mobile devices, this method has to deal with the potential of
bandwidth limitations and requires additional power consumption due to increased data communication [6].

Examples of existing commercial mobile AR applications include [31]:

- Sekai Camera. An application for Apple iPhone that allows users to virtual labelling of general locations.
- Wikitude. The first mobile AR web browser, available for Android, iPhone, Blackberry, Windows Mobile, Symbian and Bada.
- NearestTube. One of the original Apple iPhone AR applications. Provides users with location of the nearest London tube station.
- Layar. An AR platform that allows developers to create and publish geolocated or vision-based AR information. Available for both iPhone and Android.

A general timeline of major milestones concerning mobile computing and AR is provided in Appendix A.

Positioning

The most important and often most troublesome aspect of location-aware computing and mobile AR is the determination of physical location. Researchers continue to create and use various location-sensing methods, tailored to their own requirements, that offer different levels of accuracy, coverage, frequency of location updates, and cost of infrastructure. These various approaches tend to fall into one of two groups: pose computation and object recognition. Object recognition has been the most popular approach to provide information about the recognizable objects within the field of view. This approach however limits the use of the AR system as augmentation of the scene is only possible if it can see, and recognize,
specific known objects (marker or markerless). The pose computation approach overcomes this limitation as scene augmentation is based on the understanding of the 6 degrees of freedom (DOF) pose of the camera. Once the pose is known for the AR camera, the virtual objects can be projected anywhere in the environment based on their location/pose that is stored in a database [6] [40].

Object Recognition

**Marker.** In AR systems visual markers are commonly used in positioning. Visual markers will typically identify real objects in the environment and permit camera pose calculation in relation to the real object(s). There are instances that markers are also used to determine localization but this is an undesirable solution for large scale projects as real objects must be marked before they can be localized. The fact that an environment must be carefully prepared and often system calibrations are required are major drawbacks of marker-based AR and often limits its use to indoor applications. Regardless, markers are still popular in the AR community due to the low computation power required and marker robustness [6] [34][41].

While initially markers were simple in nature, today markers often use two dimensional codes such as the Quick Response (QR) code. Two dimensional codes are popular as they can contain a large amount of data in a fixed amount of space. For example, QR codes require only 10 percent of the space that traditional one dimensional bar code required to provide the same information. When used for AR purposes, two dimensional codes can now provide location information which can be used to locate the user in both outdoor and indoor environments [31]. QR codes became the ISO international standard, ISO/IEC 18004, in 2000 [42]. A simple example of a QR code is provided in Fig. 4.
ARToolkit is an extremely popular AR creation tool used to implementing online AR applications. ARToolkit uses planar square markers where the pattern inside the square is used to decide which virtual object should be displayed and the square is used to determine the camera position and pose. To accomplish this, the video image is first converted into black and white and ARToolKit searches for all squares within the binary image. If the found squares match a marker within the database, ARToolKit uses the known square size and pattern orientation to calculate the pose of the camera relative to the marker. Knowing the camera pose, the virtual object is then displayed by overlaying the marker [8] [27] [31]. ARTag, MXRToolKit and stbTracker are other examples of AR libraries that use a similar two step technique [41]. A sample marker, such as used with ARToolKit, is provided in Fig. 5.
If only one marker is used in an AR application, the camera's field of view becomes limited as the camera must be able to see the marker for augmentation to be possible. Additionally, marker recognition is limited by visibility. Markers obscured by other objects, viewed at oblique angles, or position too far away simply cannot be recognized. The use of multiple markers is a popular way to overcome these limitations [27].

**Markerless.** Considering some of the limitations of marker-based AR, researchers are developing markerless AR to move AR outside of indoor environments plastered with markers. Markerless AR aims to recognize, track and then augment real-world 3D objects [43] [44]. Finding the camera pose is based on finding landmarks the camera image, rather than fiduciary markers, and then matching them to previously cached landmarks within the database. Once sufficient landmarks are matched, the markerless AR system can precisely compute the camera pose. Combined with GPS positioning methods and other data from
embedded sensors found in smartphones, markerless AR can further improve on the position and orientation accuracy when outdoors. This improvement in tracking precision allows for virtual objects to be overlaid onto the scene with much greater precision [6] [45] [46].

On the downside, markerless AR methods are computationally intensive, require prior knowledge of the environment to build a landmark database, cluttered or low contrast environments make for landmark detection difficult, and performance can be hampered in poor lighting conditions, mostly due to shadows [8] [31] [43] [47]. Since markerless technology requires significant processing power to recognize landmarks, there is a significant power requirements for mobile devices that already limited battery life. To overcome this processing and power issue, markerless AR developers have begun to partner with mobile chipset manufacturer, ARM, to build mobile CPU chipsets designed to support markerless AR applications [44].

Markerless AR is still in the early stages of development and commercially viable products are a long way off. There are considerable efforts being taken to develop techniques so that unknown 3D landmarks can be registered and then added to the reference landmark database as the system operates. This would allow markerless AR systems to function in environments without previous knowledge. [43]. Also research is being done to use markerless AR to augment people, even when they are not directly facing the camera [44].

Pose Computation. For applications in open, outdoor areas, the Global Positioning System (GPS) is a common choice to determine position. A GPS receiver determines its position by measuring satellite signals’ time difference of arrival, using a process called trilateration. GPS position accuracy, for straightforward mobile applications, can be 5 to 10
meters. Although GPS offers near-worldwide coverage, its performance degrades indoors and in high-density urban areas, and receivers have a relatively long start-up time [31] [40] [48] [49].

It is important to note that GPS provides only position information, thus orientation information must be obtained using other methods in order to determine a camera’s pose for use in AR applications. Luckily, present-day mobile devices are equipped with digital compasses and accelerometers that can be used to determine orientation [31] [40] [48].

Alternate global navigation satellite systems include Russia’s GLONASS (Global Orbiting Navigation Satellite System) and Europe’s GALILEO system. The GALILEO system is not expected to be fully operational until 2019. With more reliable service available from multiple global navigation satellite systems, various smartphone vendors have begun to integrate support for both GPS and GLONASS. Vendors include: Sony Ericsson, Samsung, Apple, Motorola and Nokia. In some cases, the addition of GLONASS support includes the ability to determine position using both systems simultaneously to increase position accuracy [12] [50].

Besides the popular use of global navigation satellite systems, basic location information can also be determined using various radio frequency (RF) infrastructures including that from the cellular phone network or even over-the-air television broadcasts. Many of these methods can be deployed over a wide area with relative ease as they simply leverage existing long range RF infrastructure. Considering the previous two examples, accuracies of 20 meters are possible using cellular phone infrastructure while digital TV signals can allow for accuracies down to 3 meters. WLAN-based location can be sufficiently accurate with 30 to 50 meters
but the required registered wireless hotspot may only be found in urban centres. Of course all of these RF positioning methods require sufficient preexisting infrastructure to deliver adequate results. Fig. 6 gives a general comparison of different location-sensing technologies.

Figure 6. A general comparison of different location-sensing technologies [40] [49].

There are researchers working on techniques to fuse location data gathered from multiple sensors and even use location data from one sensor to improve the operation of other sensors (e.g. Assisted GPS). The combined use of GPS, WLAN, and cellular technologies to
determine location is a standard feature in today’s smartphones. If wireless hotspots or cellular coverage is good, an initial yet imprecise position can be found quite quickly. Greater location accuracy can then be determined using the onboard GPS receiver. While for some applications a rough estimate is sufficient (gathered via WLAN or Cellular), others may require more accurate information (gathered via GPS). While location accuracy of 500 m is often sufficient to identify an object in rural areas, it would be far too inaccurate to find such an object in an urban areas. In urban areas, accuracies of 100 m or less are required. Hence, it is important to understand that position accuracy requirements can be relative to one’s surrounding as well as the function being performed [40] [49].

It is becoming necessary for all mobile devices to support location determination using a hybrid of location technologies to ensure that the most appropriate location technology is used based on the context of the user. When there are large amount of information or the location data is contradictory for these different location-sensing technologies, sensor fusion can be an arduous task. Learning from the field of robotics, location researchers most often use the Bayesian inferencing method to processing data from disparate location sensors. Using Kalman filters, hidden Markov models, and dynamic Bayes nets, researchers have developed methods of effectively incorporating the uncertainty of the sensors as well as accommodating for errors due to speed and travel paths [12] [40].

Context-Aware

The idea of context-aware computing was pioneered by researchers at Olivetti Research Ltd. and Xerox PARC Laboratory in the early 1990s. Context-aware computing is the idea that an application can adapt it’s behaviour based on a change in context. To accomplish this
the device first needs to be able to sense context changes. Context is best defined as environmental states or settings, such as: location, orientation, time, neighbouring objects or people, ambient light level, noise, and temperature. An original concern was that the addition of sensors to a mobile device to assess changes in context would reduce the mobility of the device, require too much user attention, and reduce battery life to unusable levels. As we now see with current smartphones, vendors were able to developed small and unobtrusive sensors requiring little or no interaction with the user which have allowed context-aware mobile computing to flourish [51].

Location Based Services (LBS). A subset of context-aware computing, LBS can be defined as services that determine a user’s location, returns information spatially related to this location, and offers the user dynamic interaction with this location information. LBS applications require four common components: mobile device, content provider, communication network, and positioning. The origins of LBS are closely linked to the development of the Geographical Information Systems (GIS), the digital evolution of cartography. GIS use was pioneered in 1962 by the Federal Department of Forestry and Rural Development for the Canada Land Inventory. GIS has subsequently allowed for the digitization of paper-based maps to allow for the improved computer analysis of the data [12].

A central problem in providing LBS has been the location determination of the device/user based on the specific requirements of the service. Both industry and academia have developed numerous methods to determine the mobile device’s location based on different various operating parameters: location accuracy, coverage area, frequency of position
updates, and cost of infrastructure [40]. Further accuracy discussions are provided in Chapter IV.

Augmented Paper

Using AR to augment traditional paper-based items offers a number of compelling advantages: users are already familiar with the items, the tactile qualities of paper can be retained, and the already useful information is simply enhanced with digital information [46]. Technically speaking, augmented paper is consider a Tangible User Interface; an interface where the use interacts with digital information via the physical environment [52]. There exists research projects that are using AR methods to embed additional content or enable interactivity with existing books, and other paper-based items. One of these projects, aimed more towards using AR as an artistic tool, uses augmentation to make words suddenly appear, spin and dance off the page [53].

Cartography. Maps are a great example of a traditional paper-based item that can provide very complex location information in a tight space: high resolution printing allows the display of vast amount of information, contour lines describe topography, and simple symbols are used to represent complex locale features. A typical map user can gather the necessary location awareness after only a quick glance at a map or can gather detailed information after close inspection. A map is also an excellent common frame of reference between multiple users that can be directly manipulated and annotated [41] [46]. It may seem that the map requires little further improvement yet AR is being used to leverage the benefits of traditional cartography and provide even greater utility.
A limitation of paper-based maps is that they can present only static information. Virtual augmentations can be overlaid to complement the existing properties of the map while introducing interactive, dynamic and geographically embedded information. One method to accomplish map augmentation is to spread a map onto a table with a camera and projector mounted above [41] [46] [54]. The camera is used to recognize the map (via visual markers), track its location on the table, and register any interaction devices added into the field of view. The projector provides the augmentation overlay onto the maps. With such a augmented map system, symbols can dynamically indicate the location of various mobile entities and even change their appearance to indicate status or a change in state. They also move to correctly present the location of non-stationary objects. For example, vehicles or pedestrians can be visualised in the context of the map. Lines, curves, and shaded areas can be used to indicate paths of travel, changing borders of interest, or the extent of flood plains. All of these augmentations can be easily changed to study historical happenings or forecast future situations [46].

A mobile augmented map solution is MapLens. MapLens was built for Nokia smartphones to augment paper-based maps with real-time information. The system uses the smartphones camera to recognize and track the map while the phone’s screen, referred to as the “magic lens,” displays the virtual overlays onto the real-time view of the map. Rather than using visual makers, MapLens uses predetermined map data files to recognize and register the visible area of the map [55].

Militaries typically make extensive use of paper maps for planning, rehearsals, and active operations. A common 3D tool is the “sand table”: a miniature model made of sand that
provides a small-scale representation of the actual terrain relative to a particular operation [8] [56]. Military forces employ paper maps and sand tables as they are efficient, space-saving, and inexpensive. A common limitation when using paper maps or sand tables for military planning is that simple symbols or markers do a poor job of representing complicated physical objects or organizations. Also, airborne or subsurface equipment (e.g. aircraft, satellites, or submarines) cannot be easily represented. These types of limitations may cause poor battlefield decisions to be made as these tools are often used as decision support tools. Despite these consequences, a number of studies have remarked that there is a considerable discomfort factor for military users surrounding the abandonment of traditional paper maps or sand tables. The use of AR maps both overcomes the limitations while retaining the military user’s comfort with them. Some proof of concept AR systems have been developed to provide “virtual tactical maps” that augment either paper maps or sand tables [41] [56] [57]. These initial systems have only been designed to support military training and planning activities and do not seem to have been integrated into battlefield SA systems to date.

**Human Computer Interface**

The blending of the virtual with the real offers new possibilities for interfaces to simplify and improve interaction [34]. One of the altruistic concepts of AR is that it can be used to provide a more natural and intuitive interface when interacting with computer systems. It is the hope that AR-infused interfaces can assist in the realization of ubiquitous computing [58]. While most AR interfaces are still in the research phase, and most often simply use visual markers as switches [41], there have been significant interface developments in the mobile computing realm as smartphones and tablets have matured in the marketplace.
A significant DRDC study was completed [59] that evaluated the usability of a number of alternative input devices for mobile devices by soldiers in the field. This study looked at touchscreens, smart stylus, keyboard alternatives, and speech recognition interfaces. In most evaluated areas, the touchscreen keyboard dominated. The touchscreen keyboard has a reduced form factor, is lightweight, higher resolution displays allow for more effective use at night, and can combine multiple functions in the same device (e.g. text entry, tabbing, and pointing). Subjectively, soldiers in the study expressed a unique dislike for the external miniature keyboard and recommended the touchscreen keyboard [59].

Along with studies related to system input, DRDC has also investigated alternate feedback interfaces for use in navigation tasks [57]. One such study compared three systems that interfaced with a GPS receiver: an AR visual HMD, a 3D audio system using tone pitch and frequency cues, and an eight-tactor chest-distributed tactile system. The AR visual HMD was preferred by study participants and qualitative results also indicated that it performed better in wayfinding accuracy and time trials. The only drawback to the AR visual HMD found was that it reduced the soldier’s immediate situation awareness resulting in soldiers tripping on low ground obstacles.

Display

While we have learnt that users can navigate more effectively in urban areas using reference 3D models rather than traditional 2D maps [39], the challenge now comes how to best present those 3D models to the user. What is the most effective method of displaying AR tools to a user without hampering their efforts to accomplish a task?
In DRDC studies investigating the effectiveness of displaying AR battlefield information using different types of visual displays [19] [60] [61] [62], soldier participants selected the see-through prism HMD and the hand-held tablet displays as most suitable visual display device for digital map information. While both of these display methods were ranked equally well, participants remarked that each displays very different use cases. For example, the average infantry soldier would require systems to assist in target detection and engagement, off-bore surveillance, wayfinding, and tactical movement tasks. The HMD see-through prism displays were reported to be the best suited for these individual tasks. Soldiers in leadership positions would require a display for a greater number of tasks (i.e. route planning, on-route navigation, mission planning, and SA) and would also want a tool be able to display and share information to others. A hand-held tablet display was recommended as the more suitable for leadership tasks involving complex graphics (e.g., tactical maps), detailed text messages (e.g., orders), and for planning (e.g., freehand sketch on digital map) and briefing missions to other soldiers. An interesting common recommendation from study participants was that displays specifically designed for wayfinding tasks should be adaptable in the way they are used: weapon-mounted, head-mounted, helmet-mounted, or handheld. This adaptability would allow soldiers choose how to use the display based on the situation they find themselves in.

During these studies there was little differences between the display types when considering performance measures and they all outperformed existing methods (e.g. map and compass for navigation tasks). This led the researchers to suggest that AR information can be effectively used with variety of display formats. Considering these results, an ideal AR
display would be a see-through HMD, readable in bright lighting conditions, that could be used without soldiers needing to remove their hands from their weapon. The following general observations on the three types of displays tested during these DRDC studies [60]:

- **Hand-held tablet.** Performance results were similar to other display types. Focus group results suggested tablet display not ideal for AR purposes or wayfinding as displays could not be used while on the move without taking their hands off of their weapons.

- **Occluded HMD.** Rated the worst of the displays. The occluded HMD obscured soldier’s field of view and subsequently caused problems with depth perception, target detection and equipment compatibility. Soldiers felt that use of the occluded HMD led to a loss of SA.

- **See-through prism HMD.** The most effective display for use while moving. Most soldiers found that they could not concurrently focus on both the displayed image and the surrounding environment. The See-through prism HMD allow for much faster and easier navigation.

As AR deals with the augmentation of vision, the vast majority of wearable computing devices selected focus on the user’s eyes: Head mounted displays, glasses, and now even contact lenses.

**Athletics.** The 4iiii company has released a heads up display, called Sportiiiis, to provide athletes with real-time feedback on their performance. Sportiiiis uses a small plastic boom that attaches to glasses or sunglasses and provides information via multicoloured light
emitting diodes (LEDs) and a built-in speaker. Data to be presented can be pulled from a variety of sport sensors via the ANT+ wireless protocol [63]. This device could not be used as an AR display but simply illustrates that this type of robust display technology is readily available.

**Aviation.** The National Aeronautics and Space Administration (NASA) continues research on their Synthetic Vision program, which aims to provide commercial airline pilots with AR capable eyewear that will display flight data traditionally found on the cockpit’s dashboard. Initial systems are intended to assist pilots when landing in weather difficult situations (e.g. snow, fog, rain). In this case, the AR glasses will project an overlay of the airport's runway to help pilots safely land aircraft when airport visual conditions are poor. These AR glasses are being designed to be almost entirely autonomous from existing cockpit system so that they can be used on any aircraft and no expensive retrofit or software update is required [64].

**Contact Lenses.** Microsoft and the University of Washington are actively developing AR contact lenses that aim to display static, and then AR, overlays front of the cornea. Aimed towards the consumer market, Microsoft intends to link the lenses to their own desktop and mobile software [65].

**Military.** Eyekon is CID decision support aid that delivers Tgt ID and SA overlays onto a soldiers weapon sight. Using a variety of “smart icons,” Eyekon uses AR to naturally draw the soldiers attention to the most desirable target and highlight the locations of friendly forces within an already common display. The Eyekon system also provides a networked capability to allow the designating and assigning targets to individual soldiers within the team [66].
The US Army has recently invested into a number of AR display technologies. To better coordinate close air support missions, the US Army has contracted Vuzix, a small AR eyewear company, to provide AR glasses/goggles displays. These displays would be used by forward deployed soldiers that direct combat aircraft in close air support missions. These systems would allow the Joint Terminal Attack Controller (JTAC) to keep focused on the current combat situation rather than forced to divert their attention to consult maps and computer screens. Vuzix already manufacturers transparent monocular AR displays that can be clipped on to a pair of glasses [67] [68].

DARPA recently ordered prototype contact lenses, from the Innovega company, that will be used in conjunction with AR eyewear. The concept is that these contact lenses will allow the wearer to focus on both the information projected onto the glasses' lenses and the more distant real-world environment [69].

Applications of AR

Outside of some of the trivial uses, AR technology is starting to see serious commercial and industrial applications in the fields of civil engineering, mechanics, and even computer network management:

Civil Engineering. Field workers of utility companies are regularly engaged in outdoor tasks that deal with underground infrastructure. Redlining is the industry term for annotating either paper maps or a 2D geographic information system in the field with the actual location of underground infrastructure. Redlining requires field workers to first find the physical location of the infrastructure and then annotated the physical or digital map with the real location. This task can be difficult for even experienced users when the terrain is occluded or
inaccessible. AR tools are being tested to give users “X-ray vision” to both simplify and improve the accuracy of redlining work [70].

Mechanics. Research has been completed, with assistance from the US Army, to explore the use of AR to benefit professional mechanics while repairing vehicles. A prototype system was used by military mechanics conducting routine maintenance tasks inside an armoured vehicle turret. It was found that mechanics using the AR system were able locate items more quickly and lessened overall head movement. Interestingly, results also showed that heads-up displays displaying only static information performed much worse than an external display displaying static information [71].

Network Management. A proof-of-concept AR system was built to both visualize the operation of the network but also to control the network nodes of that network. The system used visual markers affixed to each network node that would allow the overlay of node status on the AR display (a smartphone). Furthermore, the user is also able to interact with the node to control basic settings and even control the connections between it and other nodes by simply drawing a line between two nodes on the device’s touch screen [72].
CHAPTER IV
ISSUES AND CHALLENGES

It is to be hoped that the previous two chapters have demonstrated that there are a number of opportunities to use COTS mobile AR technology to the benefit of soldiers engaged in CID tasks. While there certainly are opportunities for AR in CID, there will be a number of challenges to overcome when trying to use or adapt existing COTS systems for military use.

Location-Based Privacy

The use of LBS raises user privacy concerns as service providers could use the location to reveal information regarding a user’s activities or interests. While it is possible for mobile devices to provide less accurate location information to LBS providers, to better protect privacy many LBS require fairly accurate user location information to function properly. In many cases, today’s users must simply trust their service providers to not misuse or provide location information to a third party. Unfortunately, even if all LBS providers have good intentions and act ethically with their client’s location information, software bugs or unauthorized access to systems can leak this valuable information. Considering this, efforts continue to be made to ensure the protection of user identity and location within cellular networks and the LBS that leverage these networks [79] [80]. Considering that CID software tools are in essence LBS, the potential of unintended disclosure of friendly force location information could easily undermine military operations and lead to the death of friendly and neutral persons. Even non-military LBS services could compromise military operations if location information is not safeguarded. As an example, a simple weather application may send a user’s location over the network to deliver a local forecast. [75].
Location anonymization is the concept of providing only a vague or “fuzzy” location information to keep user’s identification detached from the location. As suggested earlier, this method can lead to inferior quality of service from the LBS when performing functions requiring more accurate location information [80]. Another method to implement location privacy is through access control, where location information is encrypted when communicating between devices and notes using a key that is known to all authorized group members. Many protocols have been proposed to support these solutions yet the best solutions appear to be protocols using a hierarchical tree of key-encrypting keys as they allow decent LBS performance while maintaining security. These types of protocols hierarchically encrypt location information under different keys to then distribute keys only to individuals/systems with permission to see the location information with the level of accuracy associated with the key [80].

Infrastructure

To both determine location and to allow network communication, consumer mobile devices require significant amounts of infrastructure. Cellular network penetration continues to limit the use of smartphones in rural areas. While urban centres benefit from high bandwidth cellular data service (e.g. 4G or LTE), lower populated areas in Canada often have only basic cellular data services available. Significant portions of Canada’s land mass have no cellular service whatsoever. In these more remote and uninhabited regions, users predominately rely on costly satellite communications system. When considering the consumer use of mobile devices, the provision of cellular data services largely based on population density makes pure business sense. When considering even the domestic military
application of mobile devices, it quickly become evident that the existing fixed cellular infrastructure could not support the data communication required in the remote regions of Canada. Therefore, the military must be able to operate independently of a commercial cellular infrastructure for their mobile devices [37] [38].

The Mobile Ad-Hoc Network (MANET) is an infrastructureless and wireless network able to self-configure itself. The various operating systems of today’s smartphones each provide different levels of MANET capability, using their existing wireless networking capabilities, but unfortunately none of them allow the smartphone to operate as a backbone MANET node. A large number of effective MANET network protocols have been developed over the past decade using tree-based and mesh-based solutions. Protocols such as Ad hoc Multicast Routing (AMRoute), Core Assisted Mesh Protocols (CAMP), On-Demand Multicast Routing Protocol (ODMRP), Congestion-controlled Adaptive Lightweight Multicast (CALM), Reliable Adaptive Lightweight Multicast (RALM) and extensions of Multicast Ad hoc On-Demand Distance Vector (MAODV) routing now allow MANETs to be adaptable, scalable, faster, and failure-resilient [37] [73]. A special sub-set of the MANET is the Vehicular Ad-Hoc Network (VANET); a wireless network formed between vehicles. For military use, the VANET is an attractive alternate as much of the digitization effort provided vehicle-borne computer systems and the power requirements can more easily be provided from a vehicle. As with MANETs, VANETs do not require infrastructure but permanent “roadside” network nodes can be used to provide additional services such as message centres, local GIS data depositories, or network gateways. Rather than the installation of roadway
communication infrastructure, vehicle-to-vehicle communication could be used to extend the effective range of networked vehicles while reducing cost [74].

It is expected that a soldier’s mobile device will not rely on a single communication mode to connect to its network. Along with the potential use of MANETs, the device will likely need to tether to a tactical radio and be able to intelligently failover to any available communications mode available [38][37].

Reliability

For a decision support tool to be effective, the user must trust the outputs of that system. User’s trust is affected by the tool’s level of accuracy, the tool’s reliability, and the user’s ability to understand what the accuracy and reliability is of the tool. Hence, a decision support tool should provide information to the user regarding the accuracy and reliability of its outputs so that the user can appropriately adjust their trust levels. It is also worth noting that a user’s trust in the tool is based on perceived reliability; humans are vulnerable to the misuse and/or disuse of automated tools when its reliability has been perceived wrongly. Studies have consistently shown that a humans’ trust in automation is a major factor that determines their reliance on the tool [2] [7].

During the great number of CID and digitization related studies completed by DRDC, the perceived reliability of CID tools by soldiers was a constant theme:

- One study dealing specifically with IFF systems [2] concluded that there were two key attributes were crucial: acknowledgement of system activation and the reliability of the inquiry feedback.
• During a defensive monitoring trial using video cameras and remoted ground sensors, soldiers preferred the in-service ground monitoring methods over the use of video cameras and ground sensors. It was noted that soldiers felt uncomfortable trusting the data from these sensors and felt the need to monitor the ground with their own eyes [22].

• In a number of navigation trials, where AR wayfinding tools were compared to in-service map and compass methods [60], soldiers ratings stated that the map and compass were preferred over the AR displays. This preference was noted even when the performance of the soldiers was improved when using the AR wayfinding tools. Clearly these soldiers had a misperception that either the map and compass was more reliable or that the AR wayfinding tool was less reliable.

Timeliness

In one DRDC trial to evaluate the effectiveness of BFT devices [1], the impact of delays between actual movement of friendly units and the display of this movement on a soldier’s hand-held BFT display was studied. Two test conditions and two baseline test were run: a 10 second delay without warning user of lag, a 10 second delay condition where users were warned of the lag, and baseline tests with real-time update. Results showed that the addition of the delay did not significantly effect the rate in which soldiers correctly engaged enemy targets but did significantly increase the incorrect engagements of friendly forces. Soldiers exhibited a strong bias to engage targets in both delay conditions but this test also indicates that the effectiveness of BFT devices is significantly reduced when the devices cannot work in near real-time [1].
Security

Device security. While users of consumer mobile devices are becoming increasingly concerned with the security of their personal data, governments and militaries have always been very serious about the security of their information due to the potentially grave consequences if their information was liberated. As with traditional military systems, any mobile device processing or storing tactical or classified information would require the capability to be quickly destroy that information in emergency situations. In military jargon this action is referred to as “zeroing” the device. With these mobile devices being so small and highly dispersed across the battlefield, the likelihood of mobile devices falling into enemy hands is increased. To mitigate the risk of data compromise, sensitive information should be encrypted, information recipients should be limited in number, and devices should be able to be zeroed remotely [18] [23].

Later this year, smartphones will be made available to US officials, from multiple federal agencies and government contractors, that are capable of handling classified documentation via cellular networks. Until now, the US has not allowed the use of smartphones to process or send classified information as these mobile devices were unable to meet stringent security standards. Rather than engineering the hardware to provide the necessary security, as was the normal procedure in the past, the US government will be using software technologies to provide the security running on a modified version of Google's Android software. This new approach is expected to be far less expensive and will better allow for the government to more easily refresh their smartphone hardware [75].
Information Warfare. In the military context, the security of the communications infrastructure also becomes a concern. Electronic warfare aims to exploit unsecured wireless links and network warfare targets network connections and services. Of the known incidents of compromised mobile networks, the majority of compromises have been accomplished through network warfare. As the popularity of smartphones continue to increase, mobile networks and computer networks will continue to merge and provide new opportunities in the business of information warfare. As an enemy advances their capabilities in information warfare the probability of successful detection, interception and spoofing of communications increases. When facing a high-technology adversary, military forces using low-technology CID systems likely provide an easy target for information warfare [3] [10].

Within the past 18 months, North Korea has used electronic warfare methods to disrupt South Korean GPS signals on a number of occasions [76] [77] [78]. According to South Korean authorities, GPS signals near the Korean demilitarized zone have been jammed in August 2010, March 2011, and as recently as May 2012. These incidents, which most often correspond with combined US/South Korean military exercise, have caused mobile phones and military equipment to malfunction. In the most recent series of publicized disruptions, in May 2012, North Korea’s jamming of GPS signals illustrated significant vulnerabilities to two separate military systems:

- As the US Army’s Rifleman Radio is equipped with a commercial GPS technology rather than the jam-resistant military GPS technology, the US Army units utilizing these radios within the disruption zone lost their BFT capability. The US Army had
previously decided to use a commercial GPS chip to only receive and process only civil GPS signals as it would be far cheaper and GPS processing would be faster.

• An unmanned aerial vehicle (UAV) conducting surveillance crashed into its control truck resulting in the death of an engineer and the injury of two UAV pilots. It was later confirmed that the loss of the UAV’s GPS signal led to the accident. Like this particular UAV, most modern UAVs use automatic GPS waypoint navigation for the vast majority of its movements rather than being actively piloted for an entire mission.

The director of the Defense Intelligence Agency, US Army Lt. Gen. Ronald Burgess Jr., told a US Senate Armed Services Committee in 2012 that North Korea is using vehicle-mounted Russian-built GPS jamming devices that have an effective range of 30 to 60 miles. Seoul is a mere 40 miles from the border. He also stated that there is evidence that North Korea is developing its own GPS jammer with a greater effective range.

Even without specialized high-powered jamming equipment, significant degradation of service is possible with small and inexpensive GPS jammers that are widely available for purchase via the Internet. As an example, it took the US Department of Homeland Security, the Federal Communications Commission and the Federal Aviation Administration six months to locate a single truck-mounted GPS jammer that was knocking out GPS signals at the Newark, N.J., airport.

Environmental

As with any equipment considered for military use, environmental constraints must be seriously considered when assessing the suitability of the various CID technologies.
Vegetation, dust, humidity and other battlefield conditions may decrease or even prevent the effective operation of the CID technology or simply the devices used. In addition, environmental conditions play a role in how soldiers interpret the information displayed by the CID system [3].

**Power**

Until very recently, LBS were slow to become successful in consumer markets. One of the major attributing factors to this slow growth was that the addition of location-sensing equipment severely reduced the effective battery life of the supporting mobile device. It was a very hard task for both engineers and developers to develop hardware and software to allow the provision of LBS while still having decent battery life. That said, the location-sensing continues to be one of the major battery draining activities of the smartphone [81].

This problem is exacerbated when using mobile devices to support the soldier. On the battlefield the soldier must carry all his own supplies, including batteries, for extended durations. Power requirements are often considered as the most important constraint when deploying CID tools to soldiers due to the weight of batteries and their logistical burden. In the case of vehicle-mounted systems, the problem is eased slightly as CID systems are able to draw power from the vehicle itself [3].

**Information Overload**

It is feared by some that one benefit of AR technology may impede its own success. It is possible that the display of too much information using mobile AR technologies may cause users to become confused or overwhelmed. With other forms of computer automation, it has been a common error to believe that the introduction of the automation would replace human
operators and reduce human error. In reality, users are still required to monitor automated systems. If system engineers design the automated system without taking into account the mental workload of the users, the user monitoring task can end up being more demanding than the original non-automated work and errors can be made [2] [82].

In early digitization projects within the Canadian Forces, concerns were raised that the use of SA tools at the small unit level may distract leaders and soldiers. As a result, DRDC was charged to see if SA tools would truly distract soldiers [17] [18]. DRDC found that this was not case; soldiers did not use the devices as frequently as feared but tended to use the tools when they were stopped, unthreatened, or would simply glance at the display to confirm navigation and BFT statuses. It was also discovered that soldiers did not used the SA tools during the assault phase of a mission and remained focused on the execution of their battle drills. Soldiers stated that a huge benefits of using digital messaging, vice radio voice transmissions, was the ability to save a copy of all information for future reference and the reduced transmission time. In a different study focused on the use of AR to support navigation [60], participant soldiers remarked that using the traditional map and compass required more mental effort than the various AR tools tested.

Not all studies indicated that digital and AR tools were beneficial for use on the battlefield. While mobile device provided information was found to be very useful during mission planning stages, too much information provided during mission execution stages was deemed a problem, as sub-units leaders typically relies on TTPs during this part of the mission [22] [83]. DRDC researchers concluded that for mobile device to be useful during mission execution stages, they would have to provide information with greater accuracy,
more manageable in size and analysis, and pertain directly to the task at hand (i.e. highly context aware). In this same study, participants suggest that a dedicated “digital” signaller may be required to deal with the plethora of digital tools provided at the sub-unit level: UAV video feeds, digital navigation tools, SA/BFT tools, etc.. This soldier would complement the existing signaller, who traditionally deals with voice communications, but would operate and monitor the digital tools. Soldiers suggested this option as they felt that the incoming digital systems were more burdensome than the existing radio systems. Overall the participant noted that disadvantages of digitization was that it was time consuming to use the tools and attention now had to be split between the real-world and these digital tools [18] [22].

In today’s highly mobile military operations, the tactical situation on the battlefield changes quickly and hence it becomes difficult to effectively provide SA to a replacing military unit. This type of SA handover is currently accomplished via “ride alongs” or “data dumps”. A ride along is simply a job-shadowing activity where the incoming unit observes the outgoing unit in the conduct of routine operations. The data dump is the transfer of digital products (presentations, documents, images, video, etc.) to the incoming unit normally via physical media. These data dumps are very ineffective as the incoming unit most often receives far too much data to be reviewed and they are unable to put the information into context [8].

Considering these conflicting accounts, the conclusion that should be reached is that it is important to assess the overall cognitive workload of the user to best determine if there are limits to the amount of CID information that can be provided. A lack of information makes mobile devices less useful, while too much information could easily overload the soldier.
There must be balance between the volume of information provided and the effort required to use/monitor the information. Likely CID systems will require the ability to be customized to the individual user to best maximize information exchange and minimize cognitive strain [7] [18].

**Encumbrance**

In early experimental mobile AR systems, the user was required to wear a large backpack and a oversized helmet with a HMD and camera mounted on [39]. These size and bulk of these systems prevented the user from moving freely and the HMI was troublesome. An effective mobile AR system for military use would need to allow for free movement and a more natural HMI capability [39].

**Helmets.** When testing various HMDs in support of mobile AR systems, soldier participants indicated concern with the addition of extra weight on the head, as there is already a fair amount to weight put on the head thanks to helmet-mounted night vision and radio communications systems. It was the wish of these soldiers that these various systems could be integrated together to reduce weight and awkwardness of operation [61].

**Body worn.** When military trials dealt with IFF system components that were wore on the body [20], soldiers found that exposed system wiring and the overall bulk of the target designation system were incompatible with their clothing and equipment. Suggestions were provided that future IFF systems would need to be ruggedized, lighter and smaller, and snagging hazards eliminated.

**Displays.** While larger tablet-sized devices work well for commercial AR systems, military trials found that these display sizes were far too large and too thick. Soldiers
preferred reduced screen sizes as device were much lighter and could more easily be stored when not in use [59].

To reduce the embrace on the soldier, the following common recommendations have been made by various military mobile device studies [23] [39] [59]:

• Display size should be minimized: approximately a 10 cm diagonal screen size.
• Durable: The device should be ruggedized and waterproofed.
• Variety of mounting options: the system should allow a variety of placements so users can adjust the device location based on the task.
• Wiring should be minimized or eliminated if possible.
• System weight should be minimized.
• Battery life should be maximized and batteries interoperable with other soldier systems.
CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Just as AR tools are being chosen by industry to enhance certain business tasks [70] [71] [72], AR can clearly be used within the military to enhance operations:

- AR applications used for military learning have been shown to be more economical than real training, improve learning efficiency of students, and guarantee student safety [56].
- The use an AR display has been demonstrated to improve military vehicle operator performance by 342% while conducting multiple tasks [26].

While a great number of potential benefits were introduced in Chapters II and III related to use of mobile AR technologies for general or CID-specific military tasks, there are a number of challenges that would need to be overcome before using COTS AR technologies, particularly those that are smartphone-based, for battlefield CID. Considering the challenges and issues stated in Chapter IV, two major challenge areas are revealed: inadequacies of the supporting networks and immature design regarding the presentation of information.

Supporting Networks. The vast majority of commercial mobile AR tools use cellular networks and civil GPS signals to support their operation. Of course, these supporting networks are used due more to the host mobile platform (commonly a smartphone) rather than as a choice of the AR system. As previously identified, cellular networks and civil GPS signals are ill-suited for military use [37] [38] [78]. Apart from the limited coverage of fixed cellular infrastructure and the fact that civil GPS signals are susceptible to jamming, military
forces also require control over their own networks to best ensure security, quality of service, flexibility, and mobility. Compared to effort required to develop military-specific AR applications from scratch, the retrofit of existing AR software to support use of military-specific networks would not be an arduous task. If approached properly, such a retrofit would predominately be a software development activity.

Information Presentation. To deal with the previously identified issues of information overload, encumbrance, and reliability; study needs to put towards the use cases of the mobile AR applications. In particular, how can the required information be best presented to the user considering the task they are involved in. Unlike the consumer or industrial AR user, a soldier cannot focus all of their attention on the AR display or allow the display to degrade vision. The soldier will require that relevant and often crucial context-dependent information be provided when they need it. Figuring out “when they need it” becomes a serious context-aware challenge for the AR developer related more to how the user does their job than what technology is required [8].

Suggestions for Further Research

A soldier will conduct CID tasks in all four stages of a combat mission: preparation, monitoring, execution, and evaluation. Yet current CID technology only attempts to assist the soldier during the monitoring and execution stages. DRDC function flow analysis indicated that actions taken in the preparation stage (e.g. learning about the enemy, terrain, local culture) made the most significant contribution towards successful CID [7]. Similarly, not using CID tools to provide assistance in the evaluation stage, soldiers and their leaders are
unable to take full advantage of after-action learning. To see even greater CID success, the supporting tools must be able to support all stages of the combat mission.

There is very little academic information to be found related to user studies or HCI evaluations of AR systems. It has therefore been assumed that very little human factor research has been done in the development of AR technologies [29]. Considering that the nature of AR is to provide a better and more natural interface with users, the fact that little human factor research has been completed is troubling. It is likely that since AR is a relatively new technology that development of systems and applications has been limited by technological constraints. Particularly when planning to use AR to enable industrial or military operations, effort will soon need to focus on the actual use cases; workers or soldiers in situations where their personal safety is at risk will demand equipment that is designed for their own work and can consistently perform.

It is also important to reiterate that despite advances in CID technology, incorrect CID and fratricide incidents are rarely attributed to a unique technology failure [3]. In the Gulf War, Iraq War and in Afghanistan; aircraft equipped with state-of-the-art CID systems have been involved in actions resulting in fratricide on various occasions. Subsequent investigation into these accidents invariably identify some human factor that contributed to the failure. Further technology advancement, including the use of AR to support CID functions, can only solve part of the CID problem. Human-oriented research must continue in tandem with technology development to also allow for the improvement of TTPs [7].
REFERENCES


APPENDIX A

Comparison timeline between major Western military events and technology development of commercial mobile and AR systems [4] [35].