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Enabling real-time remote diagnostics for biosecurity applications

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# 1 Executive summary

- A basic remote diagnostic microscopy system consists of a computer connected externally to a web server, a monitor and a microscope with digital camera attached. Together with suitable software, this allows biological specimens to be viewed and diagnosed by remote experts in real time.
- A wide range of currently available web-based technologies were reviewed for use in remote microscopy. Four of the most mature products were selected for detailed testing: EVO, Mirial, WebEx and Nikon Digital Sight.
- Standardised tests were designed to measure the image resolution (sharpness), colour resolution and latency (time delay) implicit in each system. These, together with actual diagnostic challenges, were tested between research organisations (AgResearch and Plant & Food Research) connected to the Kiwi Advanced Research and Education Network (KAREN) within New Zealand, from New Zealand to Australia (Western Australia Museum and University of Western Australia), and from New Zealand to Canada (Agriculture and Agri-Food Canada).
- Specific usability issues were identified for each of the four systems tested, and protocols were developed to allow scientists to easily adopt appropriate real-time remote diagnostic microscopy systems.
- The most important features of a good remote microscopy system were identified as cost, ease of set-up and use, image quality, latency (i.e. the ability to capitalise on the speed of KAREN), vocal communication capability, and a remote pointer.
- We found that all of the systems tested were suitable for remote diagnosis of relatively large specimens, but there were difficulties with smaller specimens and diagnostic features that may have been related to the resolution of the microscope camera rather than the middleware used to view it remotely. Therefore, a review of microscope cameras for remote diagnostics is recommended.
- EVO is free, and has perhaps the most complete list of desirable features, but is hampered by set-up difficulties and its non-intuitive user interface.
- Mirial was the easiest to use of the systems tested, but had relatively poor image quality and lacks a remote pointer.
- Webex had good image quality, but is relatively costly and challenging to use for remote diagnostics due to its lack of voice communication and a remote pointer.
- Nikon's Digital Sight system had the best image quality, but lacks audio and a pointer. It was also the most expensive, requiring proprietary hardware and software.
- There are many other web-based products available now that may or may not be suitable for remote diagnostics and we suggest further evaluation be considered in the future as these technologies mature.
- The greatest impediment to adoption of remote microscopy for biosecurity applications is obtaining access to the internet software systems through institutional firewalls. A generic solution is required to this problem if the full potential of remote communication technologies is to be realised.
- Many researchers feel apprehensive about undertaking diagnostic collaborations without a better understanding of the range of skills needed to set up and use the required equipment and programs. On-site coaching will help overcome this hurdle and foster greater levels of international collaboration through associated R&E networks.

## 2 Introduction

Rapid and accurate identification of pests and diseases is critical for effective biosecurity risk management and for meeting New Zealand's legislative requirements (Biosecurity Science Strategy, Objective 1.6)(MAF BNZ 2007). Organisms intercepted at the border in association with imports or caught in surveillance monitoring traps must be rapidly and accurately identified to determine whether they are new to NZ and, if so, whether they pose a significant risk to NZ's natural and productive ecosystems. The decision whether to mount a costly response (e.g. treatment of imported items in which the organism was detected, or eradication of a detected incursion) must be made rapidly and with confidence in the identity of the organism.

However, NZ has limited taxonomic expertise. There are few specialists, and they are widely scattered and distant from the border. In addition, their expertise is usually restricted to particular groups, so verification by overseas experts is often needed to ensure accurate identification. This process can be time-consuming and risky, since specimens are sent by post, and delays can be costly and in some cases even disastrous. Dwindling taxonomic expertise is a world-wide crisis (Wheeler et al. 2004), and building taxonomic capability is recognised as a key priority for maintaining New Zealand's biosecurity in MAF's recent Biosecurity Science Strategy (Objective 2.1)(MAF BNZ 2007). One way to overcome this problem is to use virtual identification tools: instead of transporting the physical specimens to the taxonomic expert, who is often located overseas or outside the scientific community, the taxonomist is brought together with the pest or disease in a virtual setting, using an on-line remote microscopy system.

A basic remote diagnostic microscopy system consists of a microscope with digital camera and monitor attached to a web server with suitable software. Some manufacturers, such as Nikon, offer proprietary hardware/software packages, but we have found suitable alternatives using a standard pc together with remote conferencing software. Images of biological specimens may be transmitted through KAREN or the standard internet for viewing and diagnosis. This offers many benefits for researchers and practitioners of conservation, pest management, biodiversity and biosecurity, such as savings in time and money, increased security of specimens since they do not need to be mailed, and rapid identification. It may also enable remote training for future diagnosticians.

Technologies for real-time remote microscopy are relatively well developed in the field of human medicine, where "telepathology" systems emerged a decade ago (Grimes 1997; McClellan et al. 1998; Szymaś & Wolf G 1999; Petersen et al. 2000; Wellnitz et al. 2000; Wells & Sowter 2000; Brauchli et al. 2002). These technologies are now widely used by health services, including NZ's Mobile Surgical Service (MSS). More recent innovations include remotely controlled robotic systems for manipulating and identifying live cell specimens (e.g. Botvinick & Berns 2005).

Several remote viewing and specimen manipulation systems have also been developed for electron microscopes (e.g. Caldwell et al. 1997; Chand et al. 1997; Morgan et al. 2006; Voelkl et al. 2006). One such system is used by the CSIRO Telepresence microscopy service, and another is being developed under the KAREN Capability Fund for AgResearch's transmission-electron microscopes. Bugscope is an educational programme which allows US classrooms to submit insects which are later available for remote manipulation and viewing using a scanning electron microscope (Potter et al. 2001). Another educational application, The Virtual Microscope simulates remote

operation of electron and other microscopes, based on very detailed pre-captured images of biological and geological specimens.

In contrast to the medical and physical sciences, remote microscopy has not been widely exploited in ecology and biosecurity. There are, however, several notable exceptions, the most important of which is the Distance Diagnostics through Digital Imaging (DDDI) project. DDDI, based at the University of Georgia, allows saved microscope images to be submitted by a field agent via the internet, and subsequently evaluated by a diagnostic facility. The appropriate diagnostician is allocated automatically from a database of participating experts, based on information submitted by the sample collector. Despite there being no real-time interaction between collector and diagnostician, DDDI has been successfully used across a number of (primarily developing) countries, and has been estimated to have saved over USD17 million in diagnostic costs to date. A similar, though smaller scale, system is currently used in New Zealand for identifying mosquito specimens (Disbury et al. 2008). Meanwhile, a joint USA-European project has constructed a prototype remote controlled microscope for biosecurity diagnoses (Schauff 2008). MAF Biosecurity New Zealand (MAF BNZ) is currently trialing the Nikon Digital Sight hardware/software system for remote microscopy (Kumarasinghe 2008). This has been tested and is being used by the Australian National Insect Collection and the CRC for National Plant Biosecurity.

Technologies for virtual research environments are maturing rapidly, but many researchers are either unaware of their capabilities or apprehensive about their ability to actually implement and use them. Therefore, we aimed to scope and evaluate the tools currently available for real-time remote diagnostics, and develop protocols to help biosecurity practitioners and researchers adopt suitable systems for their everyday collaborative activities.

## 3 Methods

Potential middleware technologies for remote diagnostics for biosecurity were scoped and reviewed. From these, four candidate systems were selected for detailed testing. This involved quantitative measurement of image quality and latency as well as real diagnostic challenges conducted with remote experts. Logitech Quickcam Pro 9000 or Logitech QuickCam Orbit AF webcams and Logitech ClearChat Pro USB headsets were used for all tests.

### 3.1 Review of potential remote microscopy middleware

Internet searches were used to identify potential middleware technologies for use in web-based real-time remote diagnostics. These included general-purpose collaboration software, diagnostic-specific systems and relevant technologies used in other fields such as medical science. Each system was summarised from the information available from its website and/or manuals. The parameters recorded included the ability to exploit KAREN's speed, the range of operating systems supported, any specialist hardware requirements, maximum number of participants, costs of purchase and operation, current use in biosecurity operations and research, and supported features: image resolution, refresh rate, screen sharing, image capture, remote pointer, shared whiteboard, file sharing, communication formats, and session recording.

Since these technologies are developing rapidly, our review represents a snap-shot of the situation in mid-2008 when the review was conducted. The results do not necessarily reflect the full range of technologies available, or their capabilities, at subsequent times. Therefore, in choosing four of these systems for subsequent testing, the main criterion was the apparent maturity of the system. In addition, preference was given to technologies that are currently being used for remote microscopy for biosecurity and/or are already being used on KAREN.

### 3.2 Standardised tests for image quality and latency

A series of five quantitative tests (Appendix 1) were designed as a standardised, repeatable way of measuring key usability parameters of candidate remote diagnostics systems.

**Test 1** was designed to measure the resolution or sharpness of the transmitted image, i.e. how much detail may be lost or blurred by the compression algorithms used during transmission. A series of black and white checker board patterns with scale 1 to 10 pixels was used. These, and all other images used, were saved as portable network graphics (png) files, accessed from our project website as needed, and always displayed at actual size. Diagnosticians recorded the pixel resolution at which the regular checker board pattern broke down, both in the source image and in the same image after transmission from the remote computer.

**Test 2** was also designed to test the image resolution, but this time using random text of different font sizes, similar to the standard eyesight test using a wall chart with letters of different sizes. Diagnosticians recorded the smallest point size at which text was still legible with no uncertainty, both in the source image and after transmission.

**Test 3** measured colour degradation in transmitted images. Colour is sometimes an important diagnostic feature, so any degradation in colour resolution may affect the ability to make an accurate diagnosis. Four base colours were selected: green (HSL = 100,129,128), gray-green (HSL = 100,42,128), yellow (HSL = 41,205,128) and brown

(HSL = 41,43,129). These were chosen to be similar to those likely to be of diagnostic significance in insect specimens. For each base colour, a test image was constructed with gradually varying values of hue, saturation and lightness and diagnosticians scored the change in these values at which the colour became visibly different from the base colour. This was done for the original images as well as after transmission.

**Test 4** was designed to measure the latency or delay implicit in the system. This is important, for example, when giving instructions about moving the specimen or adjusting the focus of the microscope. Computer clocks were first synchronised. A simple computer program was used to display the local computer time on screen, and this was then shared between participants. At least 10 screen grabs were made, and latency measured by calculating the difference in times shown on the local and transmitted clocks, adjusting for time zone differences. Action latency was measured for the Nikon system using a wristwatch with a stopwatch function placed under the microscope at lowest magnification.

**Test 5** was similar to the previous test but included the delays implicit in the communication channel (i.e. how verbal instructions are transmitted by telephone, or internet audio channel) and the human reaction needed to carry out a simple instruction. This was designed to measure the “action latency”: the total delays involved for the microscope image to travel to the diagnostician, for her to react by giving an instruction, and for that instruction to be transmitted back and acted on by the microscope operator. For example, if the specimen’s position or the focus of the microscope is being adjusted, then this test suggests how much over-adjustment will occur before the diagnostician’s instruction to stop comes through and is acted on. The same clock display program was run and shared with the remote diagnostician. At an easily-identified “trigger” time (e.g. on the minute) according to the transmitted clock, the diagnostician said “Stop”. When she heard this, the local participant “froze” her clock. The difference between the frozen clock time and the diagnostician’s trigger time measured the action latency. This test was repeated at least 10 times.

In each case, the specific software settings were adjusted to maximise performance in the tests. Tests were conducted within New Zealand between two Crown Research Institutes (AgResearch and Plant & Food Research) running on KAREN, and internationally between AgResearch and the University of Western Australia. Further international tests were planned between Plant & Food Research and Agriculture and Agri-Food Canada, but were unable to be carried out because of refusal by the Canadian IT system administrators to enable access through their firewall.

### 3.3 Real diagnostic challenges

In addition to the standardised tests, real diagnostic challenges were used to test the systems in a more realistic setting. Remote diagnosticians were asked to identify preserved aphid and spider specimens using each of the software systems, and to comment on the experience.

#### 3.3.1 Aphids

Specimens of six commonly occurring aphid species (Table 1) were used: *Myzus persicae* (Macrosiphini), *Brevicoryne brassicae* (Macrosiphini), *Capitophorus eleagni* (Macrosiphini), *Cavariella aegopodii* (Macrosiphini), *Pemphigus bursarius* (Pemphigae) and *Macrosiphum euphorbiae* (Macrosiphini). The body length of all aphid species tested was < 3mm. Important diagnostic features used in aphid identification, such as the shape of the frons, the siphunculi, and abdominal markings were used in the tests.

Live microscope images were transmitted via the KAREN network from the entomology laboratory to a visiting aphid expert in an office nearby.

**Table 1:** Protocol for diagnostic testing using aphids.

Morphological feature	Question for expert
Frons shape of <i>Myzus persicae</i>	What is this feature?
Siphunculi shape of <i>Brevicoryne brassicae</i>	What is this feature?
Abdominal markings of <i>Capitophorus eleagni</i>	Is the image good enough to confidently identify the species?
<i>Cavariella aegopodii</i>	Is the image good enough to confidently identify the species?
<i>Pemphigus bursarius</i>	Is the image good enough to confidently identify the species?
<i>Macrosiphum euphorbiae</i>	Is the image good enough to confidently identify the species?

### 3.3.2 Spiders

Four common spider species (Table 2) were used: *Allotrochosina schauinslandi* (Lycosidae), *Tenuiphantes tenuis* (Linyphiidae), *Steatoda lepida* (Theridiidae) and *Cryptachea veruculata* (Theridiidae). The latter three spiders are small (body length < 5 mm). The tarsal comb is an important feature in identifying the family Theridiidae, which are disproportionately highly represented in introduced spider species in New Zealand (C J Vink, unpubl. data). The structures of the female genitalia and the male pedipalp are the most important characters in the identification of spider species. The configuration of eyes can be useful when identifying some families of spiders (e.g. Lycosidae). Microscope images of spiders were transmitted via KAREN from the entomology laboratory to a spider taxonomist at the University of Western Australia.

**Table 2:** Protocol for diagnostic testing using spiders.

<b>Morphological feature</b>	<b>Question for expert</b>
Tarsal comb of female <i>Cryptachea veruculata</i>	What is this feature?
Tarsal comb of male <i>Steatoda lepida</i>	What is this feature?
External genitalia of <i>Cryptachea veruculata</i>	Is the image good enough to confidently identify the species?
Pedipalp of <i>Tenuiphantes tenuis</i>	Is the image good enough to confidently identify the species?
External genitalia of <i>Allotrochosina scauinslandi</i>	Is the image good enough to confidently identify the species?
Eyes of <i>Allotrochosina scauinslandi</i>	Is the image good enough to confidently identify the family?

## 4 Results

### 4.1 Selection of suitable middleware technologies

A plethora of remote collaboration middleware technologies were identified, including: EVO; Mirial SoftPhone; Webex; TeamViewer; GoToMeeting; Yugma; DimDim; Confer & Inform; Microsoft SharedView (beta); ShowMyPC; Skype; LogMeIn; and various proprietary systems from microscope camera manufacturers such as Nikon, Olympus and Leica. From these, the four systems summarised in Table 3 were chosen for detailed testing.

**Table 3:** Summary of the main features of the four middleware technologies chosen for detailed testing of their suitability for remote microscopy for biosecurity.

Feature	EVO	Mirial SoftPhone	Webex	Nikon Digital Sight
Specialist hardware required	No	No	No	Yes
Operating systems	Any	Windows	Windows, Mac, Linux	Any
Image resolution	Adjustable (352x288, 704x576, 1024x768)	In "Presentation Mode" up to 1280x768	Video image is adjustable, there is no set pixel sizes and it depends on the floating window	Adjustable (320x240, 640x480, 1280x960)
Refresh rate	Adjustable (1 to 30 f/s)	Up to 30 f/s	Up to 15 f/s is the maximum	Adjustable (0.1 to 4 f/s)
Shared region	Any	One application	Desktop or application	Microscope image only
Screen grab	Yes	No	Yes	Yes
Remote control	No	Of compatible webcams only, no computer control	Yes	No

Feature	EVO	Mirial SoftPhone	Webex	Nikon Digital Sight
Remote pointer	Yes	No	Yes	No
Shared whiteboard	Yes	No	Yes	No
File sharing	Yes	No	Yes	No
Communication	Chat, webcam	Webcam	Webcam	None
Session recording	Yes	Yes	Yes	No
Number of participants	Unlimited	Up to 3	Unlimited	Noticeable performance degradation for >3
Cost	Free	\$166 Euro = \$360 NZD per license	From \$60 US /month	\$7000 NZ for hardware
Ability to exploit KAREN	Yes: runs via a central server, which is on a high-speed network	Yes: works one-to-one	No: runs via servers that are not on the high-speed network	Yes: acts as a web server
Existing users	Auckland University	HITLab NZ	Australian CRC for National Plant Biosecurity	Australian CRC for National Plant Biosecurity, Australian National Insect Collection, MAFBNZ (trial)

Enabling Virtual Organisations (EVO) is a general purpose collaboration software that has been promoted by the University of Auckland and several other institutes. At the time of review, EVO was the only technologically mature option that is free (though other free systems are rapidly maturing). Communication occurs between participants via a central server. Although this is on the high-speed network, bottlenecks may occur when user numbers are high.

Mirial SoftPhone was recommended by the HITlab NZ staff. This technology is also used by a number of other institutes due to its simple nature. Communication occurs directly between participants without the need to go through a dedicated server, so it can offer the maximum exploitation of KAREN's speed. A NZ licence costs about \$360 NZD.

Webex is one of the most popular video-conferencing technologies currently available. It is used by other researchers (e.g. Australian CRC for National Plant Biosecurity) for their video conferencing, but not currently for remote microscopy. No additional software is required to utilise WebEx but communication occurs between participants via a central server that is not part of the high-speed KAREN network. User fees cost approximately \$2.43 NZD/min.

The Nikon Digital Sight hardware/software system was also chosen to test because it is being trialed by biosecurity researchers working for the Australian National Insect Collection and by MAFBNZ. It relies on proprietary Nikon hardware, which costs about \$7000 NZD/unit plus the additional cost of telephone or video conferencing fees.

## 4.2 Installation and set-up

EVO installed easily on the AgResearch IT system, possibly because it had already been used, but proved problematic on the Plant & Food Research system. Installation was eventually successful at Plant & Food Research, but stopped working when a system change was made. Our collaborator in Western Australia reported no major issues with installing EVO.

Mirial's installation was relatively simple, but some minor problems were identified. Because it uses a direct-dial connection between participants, Mirial was unable to dial in through firewalls, which present a single out-facing IP address, although individuals from within were able to dial out. The microphone headset needed to be plugged in before starting up the software, and Mirial appeared unable to share the webcam drivers with other applications.

Webex installation was problem-free. The main usability issue identified was the need to book both tele- and video-conference sessions separately for the same meeting.

An unexpected hurdle was encountered in transmitting microscope images using any of the above systems. It was found that the software accompanying some microscope cameras transmits the image directly to the graphics card of the connected computer, bypassing the main processor. While this results in a greater local refresh rate, it also means that when the screen image is shared a blank box appears where the microscope image should be. We were able to resolve this using TWAIN drivers for the microscope camera, or by connecting the camera to the computer hard drive using a firewire cable.

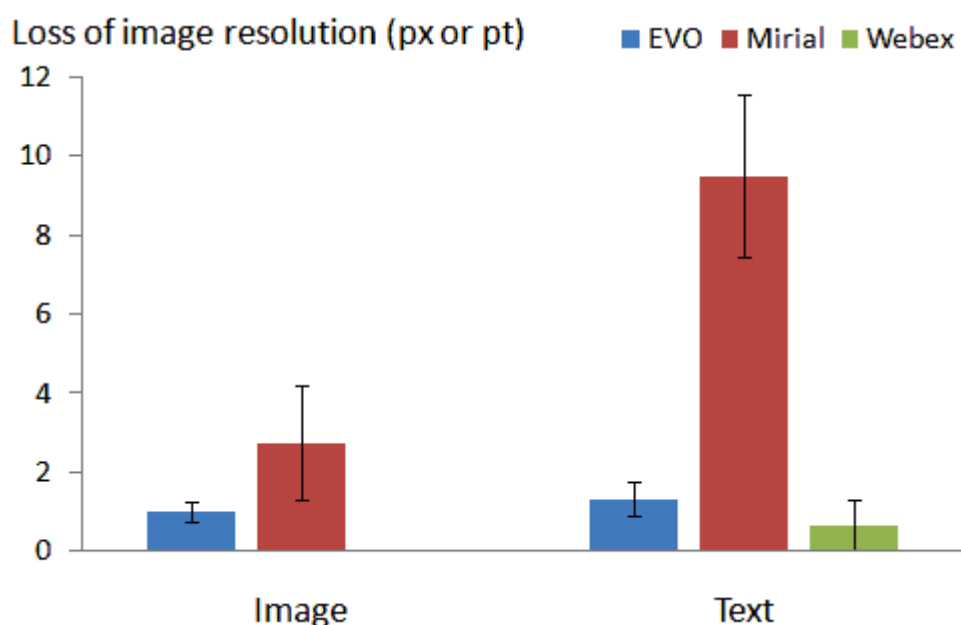
Because the Nikon system involves dedicated webserver hardware being attached directly to a microscope camera with no intermediary pc, it could not be evaluated in the same way as the other systems. However, a unit was borrowed from MAF BNZ and

evaluated within the AgResearch intranet environment. MAF BNZ also demonstrated its use between their Identification and Diagnostic laboratories in Christchurch and Auckland (not yet on KAREN), but their firewall policies prevented more widespread testing.

### 4.3 Performance in standardised tests

#### 4.3.1 Image resolution

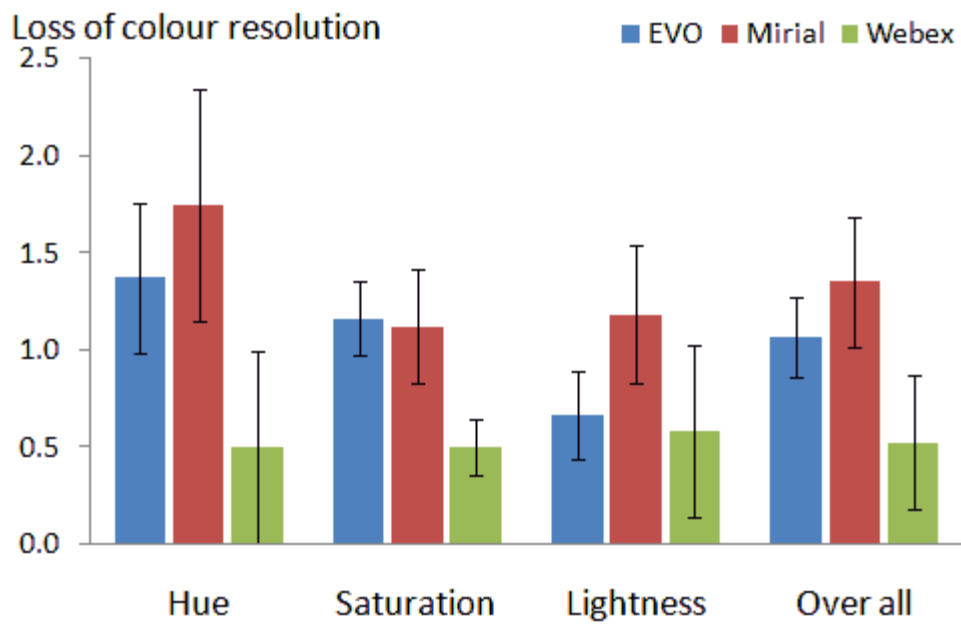
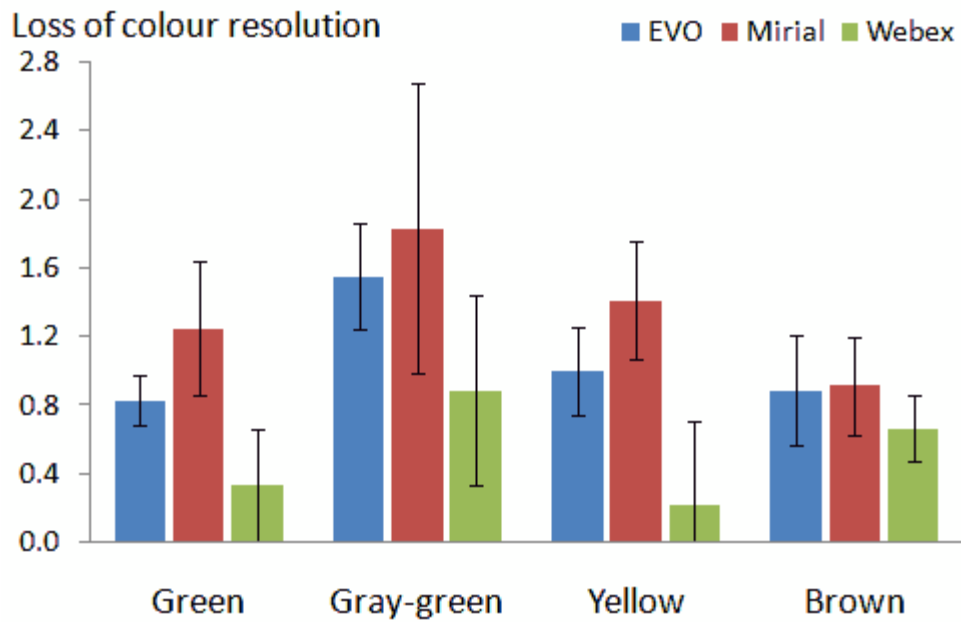
Webex had the best image resolution, with EVO a close second (Figure 1). Mirial's results were poor, probably due to image scaling at the receiving end as the transmitted image appears to be scaled to fill the receiver's window, introducing an additional step of image manipulation and resultant loss of quality. The same effect was not seen in either EVO or Webex. In similar tests, the Nikon Digital Sight system was found to have superior image resolution to the other three technologies.



**Figure 1:** Comparison of loss of image resolution as measured by the image (test 1) or text (test 2) standard tests. Image loss was measured in pixels (px) and text loss was measured in points (pt). Bars show standard errors. There was no loss of image in Webex.

#### 4.3.2 Colour resolution

There were no significant differences between the systems in terms of colour resolution loss across the four diagnostic colours tested (Figure 2). Webex may have better colour integrity than either EVO or Mirial, but further replicates would be needed to detect significant differences.

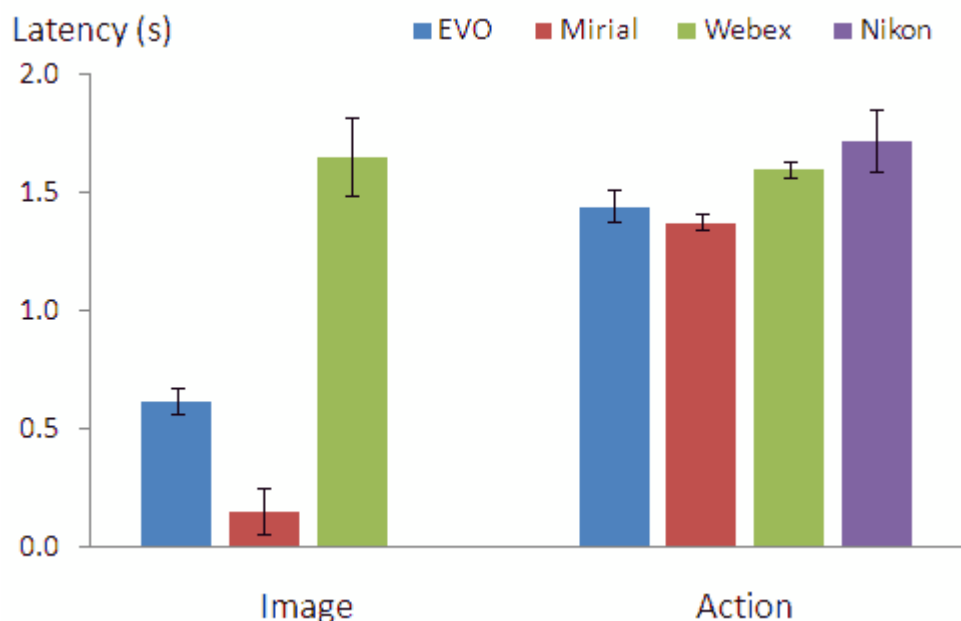


**Figure 2:** Comparison of loss of image resolution as measured by the colour resolution (test 3) standard test. Left: overall loss of resolution measured for each of the four test colours. Right: loss of resolution averaged across the four test colours, in terms of hue, saturation, lightness, and over all. Y-axis scale is arbitrary. Bars show standard errors.

#### 4.3.3 Latency

There was no difference in image latency between EVO and Mirial, whereas Webex was significantly slower (Figure 3). However, these results are based on few replicates and there is some doubt as to whether the computer clocks were synchronised properly in all trials.

Action latency was similar in all systems, but slightly greater for Webex and Nikon Digital Sight.



**Figure 3:** Comparison of latency for images (test 4) or actions (test 5) according to the standard tests. Bars show standard errors.

#### 4.3.4 Performance with diagnostic specimens

EVO was unable to be tested with diagnostic specimens because it could not be reliably installed on the Plant & Food Research IT system. Similarly, the Nikon system could not be trialed with outside experts because it was set up for use only within MAF BNZ. However, successful trials were conducted with Mirial and Webex, though planned trials with a Canadian aphid taxonomist had to be conducted during his visit to New Zealand due to the refusal of the Canadian IT administrators to allow access through their firewall.

All six aphid species were correctly identified using remote microscopy (Table 4). Although one of the three key diagnostic features of two of the aphids was unclear in transmitted images, other features were sufficient to positively identify the specimens. At the completion of testing Webex, an inexperienced bystander was asked to present the remote expert with another aphid species outside the designed test. The main challenge was found to be handling the specimen, microscope, computer and telephone (Webex lacks an inbuilt audio connection) simultaneously. The process was time consuming, particularly the extra effort needed by the expert to describe in detail which part of the specimen to focus on (Webex lacks a remote pointer). Eventually the aphid was correctly identified as *Rhopalosiphum padi* (Linnaeus) (Aphidini).

**Table 4:** Results for protocol for diagnostic testing using aphids.

Morphological feature	Question for expert	Mirial	Webex
Frons shape of <i>Myzus persicae</i>	What is this feature?	Identified correctly - only just discernable	Identified correctly - much clearer
Siphunculi shape of <i>Brevicoryne brassicae</i>	What is this feature?	Identified correctly - clear	Identified correctly - very clear
Abdominal markings of <i>Capitophorus eleagni</i>	Is the image good enough to confidently identify the species?	Yes, clear image	Yes, clear image
<i>Cavariella aegopodii</i>	Is the image good enough to confidently identify the species?	Yes, but quite grainy	Yes - better image
<i>Pemphigus bursarius</i>	Is the image good enough to confidently identify the species?	Yes, clear image	Yes, clear image
<i>Macrosiphum euphorbiae</i>	Is the image good enough to confidently identify the species?	Yes, but reticulation unable to be seen (too finer detail)	Yes - image more discernable, but reticulation still unable to be viewed

While some of the images of the spiders were clear enough to enable identification, smaller features such as genitalia were of insufficient resolution to enable correct identification (Table 5). In this case, the problem was with the lack of magnification power of the source microscope rather than the resolution and integrity of the transmitted images. Mirial Softphone was cut off several times during the New Zealand-Australia tests. However, it was used successfully as an alternative to the telephone to provide an audio link while testing Webex.

**Table 5:** Results of protocol for diagnostic testing using spiders.

Morphological feature	Question for expert	Mirial	Webex
Tarsal comb of female <i>Cryptachea veruculata</i> Figure	What is this feature?	Identified correctly - clear image	Identified correctly - clear image
Tarsal comb of male <i>Steatoda lepida</i>	What is this feature?	Identified correctly - just discernable	Identified correctly - clear image
External genitalia of <i>Cryptachea veruculata</i>	Is the image good enough to confidently identify the species?	Not clear enough	Clearer but not discernable
Pedipalp of <i>Tenuiphantes tenuis</i>	Is the image good enough to confidently identify the species?	Not clear enough	Clearer but not discernable
External genitalia of <i>Allotrochosina scauinlandi</i>	Is the image good enough to confidently identify the species?	Not clear enough	Clearer but not discernable
Eyes of <i>Allotrochosina scauinlandi</i>	Is the image good enough to confidently identify the family?	Yes, clear image	Yes, clear image

After performing the tests, an unidentified male in the family Araneidae that had been intercepted by MAF BNZ was also examined remotely by the Australian expert. He was able to identify it correctly as an undescribed Australian species close to *Cyclosa fuliginata* (L. Koch 1872). Several New Zealand female specimens thought to be *Eriphora heroine* (L. Koch 1871) (Araneidae) were also examined by an expert New Zealand spider taxonomist. The combination of live, transmitted images and an audio link between Australia and New Zealand enabled the remote diagnosis of the specimens and thereby avoided the time delays and possible damage of specimens incurred due to postage. It was determined that the specimens were not *Eriphora heroine* but were a closely related species, "*Epeira brounii* Urquhart 1885, which is also found in Australia.

Feedback on the Nikon Digital Sight system was sought from MAF BNZ staff who had been using it on a trial basis. They found that it could be used successfully for rapidly identifying, to the required level of detail, almost all of the specimens tried to date.

However, they also identified several shortcomings of the system, including the lack of a remote pointer, the difficulty and cost of using a separate telephone call for vocal interaction, the built-in monitor being too small, and the lack of a document sharing feature.

## 5 Discussion

This study found that there are several middleware technologies that may be used to implement successful remote microscopy. In particular, we found that for relatively large specimens, general-purpose web conferencing software could be used as successfully as the customised Nikon Digital View hardware/software system. Our standard protocols found little difference between each of the three software systems tested. Although EVO and Webex had significantly better image resolution than Mirial, this was still not sufficient for diagnosis of the smallest test specimens. This difference was probably due to Mirial's smoothly scaling window size; although this worked well as part of its attractive and easy user interface, images were subject to distortion due to the scaling algorithms. In contrast to Mirial, EVO's user interface was very difficult to master, and set-up difficulties experienced by each of the researchers prevented it from being used in all of the diagnostic challenges.

While EVO and Mirial operated through the high-speed network, Webex sessions were routed through servers on the general internet, and this was reflected in its relatively poor performance in image latency tests. However, in the more realistic action latency tests there was little difference between any of the systems, suggesting that the advantage of high speed image transmission may be compromised by the human reaction time involved in responding to the image and carrying out instructions. It is important to note, however, that these results were based on relatively few tests, and also an element of user learning involved in replicated tests.

One important disadvantage of both Webex and the Nikon Digital Sight system was their lack of an audio communication channel – session participants had to use teleconferencing for vocal interaction. This raises particular challenges with simultaneously handling biological specimens, microscopes, computers, and telephones in order to make a successful identification. One solution was to use EVO or Mirial for voice communication while operating Webex, but since the former could also have handled image transmission, Webex was effectively redundant in this configuration. The lack of a remote pointer in Mirial and Nikon Digital Sight was also a major impediment to their effective use for remote microscopy for biosecurity.

Three main technical challenges were identified by this study. First, the software accompanying some microscope cameras transmits the image directly to the graphics card of the connected computer, effectively disabling the ability to share the on-screen image via web conferencing software. We were able to overcome this through the use of TWAIN drivers or a firewire connection to the pc, but it is one of the most surprising and potentially disheartening problems likely to be faced by biologists trying to use a remote diagnostics system. Providing straightforward protocols to KAREN users to work around their proprietary microscope issues will aid adoption of KAREN-based technologies for remote microscopy.

Second, and unsurprisingly, we found that the ability to identify specimens using small diagnostic features was limited by the quality of the microscope camera being used. Given the high purchase price of microscope cameras, potential users need to be warned of this, and informed of the best camera options for different specimen types. We are unaware of any such review of microscope cameras, but this would be a useful resource to encourage uptake of remote microscopy for biosecurity applications.

The biggest technical challenge we found with implementing remote microscopy was overcoming the various firewall configurations of collaborating institutions. Only experienced and authorised IT staff can overcome with this problem, and we

experienced a wide range of willingness to co-operate among those we dealt with. At one extreme, no remote microscopy system of any kind could be used with our Canadian collaborator because of the unwillingness of his IT administrators to tweak their firewall. A generic solution must be found to accommodate both the security required by organisations and the freedom of communication that is essential for collaborative research to be undertaken. The potential future adoption of remote diagnostic applications is critically limited by the access provided to collaborators by their institute's IT systems.

Protocols to quantify usability parameters of potential remote diagnostics systems were also shared with IT personnel. Collecting additional quantitative data about the different technologies being assessed, independently from this project, could provide useful information if compiled or published in some form for other KAREN users.

Relevant information on middleware products and remote diagnostics approaches is scattered globally and throughout disparate fields (e.g. telepathology). In addition, these technologies are developing very rapidly. Therefore, it is difficult to be confident that we have reviewed the full scope of up-to-date technologies available. There are literally hundreds of web-based products available now, which may or may not be suitable for remote diagnostics and we suggest further testing be considered in the future.

In order to simplify the difficulties many scientists have in understanding the emerging IT jargon and allow them to work with different computer hardware/middleware/software it will be necessary for organisations to acknowledge that funding time to learn these new skills is required. Time for unstructured professional development (e.g. having time to experiment with new tools to get familiar with them) is hard to find when time has to be accounted for against project codes used commonly in Crown Research Institutes.

There is a disconnect between the kind of information conveyed by IT staff in this area versus the kind of information researchers are requesting. In general, many researchers feel apprehensive about undertaking diagnostic collaborations without a better understanding of the range of skills needed to set up and use the required equipment and programs. On-site coaching will help overcome this hurdle and foster greater levels of international collaboration through associated R&E networks.

## 6 Conclusions

- Several software technologies are suitable for remote microscopy for biosecurity, and may potentially be used with a wide range of microscope cameras. The most important features of a good system are probably cost, ease of set-up and use, image quality, latency (i.e. the ability to capitalise on the speed of KAREN), vocal communication capability, and a remote pointer.
- Protocols to quantify usability parameters of potential remote diagnostics systems were also shared with IT personnel. Collecting additional quantitative data about the different technologies being assessed, independently from this project, could provide useful information if compiled or published in some form for other KAREN users.
- EVO is free, and has perhaps the most complete list of desirable features, but is hampered by set-up difficulties and its non-intuitive user interface.
- Mirial was the easiest to use of the systems tested, but had relatively poor image quality and lacks a remote pointer.
- Webex had good image quality, but is relatively costly and challenging to use for remote diagnostics due to its lack of voice communication and a remote pointer.
- Nikon's Digital Sight system had the best image quality, but lacks audio and a pointer. It was also the most expensive, requiring proprietary hardware and software.
- There are many other web-based products available now, which may or may not be suitable for remote diagnostics and we suggest further testing be considered in the future as these technologies mature.
- All of the systems tested were suitable for remote diagnosis of relatively large specimens, but there were difficulties with smaller specimens and diagnostic features that may have been related to the resolution of the microscope camera rather than the middleware used to view it remotely. Therefore, a review of microscope cameras for remote diagnostics is recommended.
- The greatest impediment to adoption of remote microscopy for biosecurity is obtaining access through institutional firewalls. A generic solution is required to this problem if the full potential of remote communication technologies is to be realised.
- Many researchers feel apprehensive about undertaking diagnostic collaborations without a better understanding of the range of skills needed to set up and use the required equipment and programs. On-site coaching will help overcome this hurdle and foster greater levels of international collaboration through associated R&E networks.

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# APPENDIX 1 Test protocol for evaluating remote diagnostics systems

This series of tests has been designed as a standardised, repeatable way of quantifying some usability parameters of potential remote diagnostics systems.

In the instructions below, Sam (female) is the person holding the specimen for identification, and Doug is the expert who is to make a diagnosis.

## Test 1: Image resolution (sharpness)

This test is designed to test the resolution of transmitted images i.e. how much detail may be lost or blurred by the compression algorithms used during transmission.

Sam displays the file Test 1 (Fig. A1) in her web browser, making sure it is shown at exactly 100% magnification, and shares that with Doug.

1. Doug records the pixel size at which the regular checker-board pattern breaks down.
2. Doug displays the same file on his own computer and repeats step 2 with this image.

## Test 2: Image resolution (text)

This test is also designed to test the image resolution, this time using random text of different font sizes. This is similar to the standard eyesight test using a wall chart with letters of different sizes.

1. Sam displays the file Test 2 (Fig. A2) in her web browser, making sure it is shown at exactly 100% zoom, and shares that with Doug.
2. Doug records the smallest point size (first number in each line) at which the text is still legible with no uncertainty.
3. Doug displays the same file on his own computer and repeats step 2 with this image.

## Test 3: Colour resolution

This test is designed to measure degradation in colour. Colour is sometimes an important diagnostic feature, so degradation in colour resolution may affect the ability to make accurate diagnoses. The colours used in this test (green, gray-green, yellow, and brown) were chosen to be similar to those likely to be of diagnostic significance in insect specimens.

1. Sam displays the file Test 3a (Fig. A3) in her web browser, making sure it is shown at exactly 100% zoom, and shares that with Doug.
2. For each of the three rows of the table, Doug records the number of the box within which three clear bands are visible.
3. Repeat steps 2 and 3 using the files Test 3b, Test 3c and Test 3d (Fig. A3).
4. Doug displays the same four files on his own computer and repeats step 2 with each of these images.

#### Test 4: Image latency

This test is designed to measure the latency (delay) implicit in the system. This is important, for example, when giving instructions about moving the specimen or adjusting the focus of the microscope.

1. First Sam and Doug must both synchronise their computer clocks to the same atomic clock. To do this, both should run the free clock synchronisation program available from [worldtimeserver.com](http://worldtimeserver.com) (NB to run this requires local administrator rights). On the "Synchronisation interval" tab, click "Sync now". The program can then be closed.
2. Now both Sam and Doug run the clock display software. Sam shares her clock with Doug.
3. Doug makes a screen grab (Ctrl+PrintScreen on Windows computers) and views this to see the two clocks (his own plus Sam's transmitted one) at the same instant. The easiest way to view a screen grab on Windows computers is to use the clipboard viewer. (On Windows XP this may be found at `c:/windows/system32/clipbrd.exe`. Windows Vista doesn't have a clipboard viewer, but the XP one, available here, apparently works fine.)
4. Doug records the difference in time between the times shown on the two clocks. Note that he may have to adjust for time zone differences. For example, if Sam's transmitted clock says 1:27:43.761 while Doug's local clock says 4:27:44.256, and if there is a three-hour time zone difference, then the measured image latency is  $44.256 - 43.761 = 0.495$  seconds.
5. Doug repeats steps 3 and 4 a further nine times, to give ten measurements in total.

#### Test 5: Action latency

This test is similar to the last, but also includes the delays implicit in the communication channel (i.e. how verbal instructions are transmitted e.g. by phone or internet audio channel) and the human reaction time needed to carry out a simple instruction. It is designed to give some indication of the total delays involved for the image from Sam's microscope to travel to Doug, who then responds to that by giving an instruction, and then for Sam to react to that instruction. For example, if Sam is adjusting the specimen's position or the focus of the microscope, then this test measures how much she will overshoot the mark before Doug's instruction to stop comes through.

1. Sam runs the clock display program and shares this with Doug. Sam makes sure that her clock program is the active window (by clicking on the title bar) then places her hand above the space-bar and closes her eyes. (Note that Doug should close down the clock program used in the previous test).
2. At an easily-identified time (e.g. on the minute, or at 15 seconds after the minute, etc) according to the transmitted clock, Doug says "Stop".
3. When Sam hears "Stop" she presses the space bar to freeze her clock.
4. Sam opens her eyes and records the difference between the time frozen on his clock and the time at which Doug said "Stop". For example, if Doug says "Stop" when his image of Sam's clock is at 1:43:15.000, and Sam subsequently stops

her clock at 1:43:16.163, then the measured action latency is 16.163 - 15.000 = 1.163 seconds.

- Repeat steps 2 to 4 a further nine times, to give ten measurements in total.

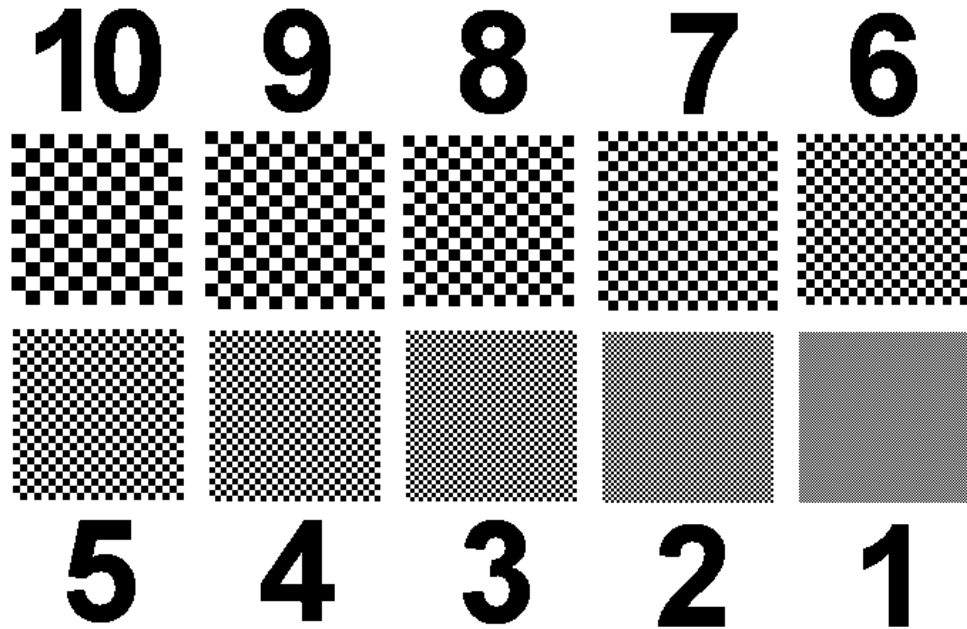


Figure A1. Image used for Test 1.



Figure A2: Image used for Test 2.

**Test 3a:** For each row, in which box (0-9) can you first see three distinct stripes?

H = 100 S = 129 L = 128	0	1	2	3	4	5	6	7	8	9
H = +20										
H = -20										
S = +40										
S = -40										
L = +20										
L = -20										

**Test 3b:** For each row, in which box (0-9) can you first see three distinct stripes?

H = 100 S = 42 L = 128	0	1	2	3	4	5	6	7	8	9
H = +20										
H = -20										
S = +40										
S = -40										
L = +20										
L = -20										

**Test 3c:** For each row, in which box (0-9) can you first see three distinct stripes?

H = 41 S = 205 L = 128	0	1	2	3	4	5	6	7	8	9
H = +20										
H = -20										
S = +40										
S = -40										
L = +20										
L = -20										

**Test 3d:** For each row, in which box (0-9) can you first see three distinct stripes?

H = 41 S = 43 L = 129	0	1	2	3	4	5	6	7	8	9
H = +20										
H = -20										
S = +40										
S = -40										
L = +20										
L = -20										

**Figure A3:** Images used for Test 3.