Remote microscope diagnostics: Improving Australia's diagnostic capacity and biosecurity

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Abstract. Diagnostics is a critical first step in determining the significance of a suspected biosecurity threat posed by Emergency Plant Pests (EPPs) and other pests and pathogens. Traditionally the biological specimens involved in these threats requiring identification are physically mailed to taxonomic experts for determination. While effective, this is an expensive, labour-intensive and slow process, often taking days to receive a confirmed identification. To address these shortcomings, a web-based, real-time diagnostics system, the Remote Microscopy (RM) system, was developed. This system allows identifications to be undertaken directly between those with EPPs and taxonomic experts capable of providing instant diagnostic services – regardless of the geographic location of either party, so saving money and resources. The RM network is launched from the Pest and Diseases Image Library (PaDIL), and acts as part of a one-stop diagnostic shop that also includes PaDIL, the Plant Biosecurity ToolBox (diagnostic database) and the BioSecurity Bank (genetic information). RM effectively aids in identifying pests in quarantine settings, providing both economic and biosecurity benefits. Applications of RM domestically and internationally present immense value in training as well as diagnosis. The RM network will also play a part in the training of diagnostic and quarantine personnel or in general education settings in our national collections, museums and universities. RM will also build on existing databases and resource pools such as those based in the PaDIL. This will be achieved through the application of dynamic software to allow authors to develop tools such as identification keys and other elements of existing databases. Recording of live video feeds to PaDIL via the RM and the subsequent availability of this and other PaDIL based data to PDA's and podcast applications will be developed. Three key learning's: RM has the ability to overcome time and distance factors to provide an accurate and interactive training. RM will provide a diagnostic facility that will vastly increase diagnostic capacity and enable fast and accurate responses to biosecurity threats. Future extensions of the RM system include PDA applications and dynamic authorship tools such as identification keys and data-basing.

Introduction

Emergency Plant Pests (EPPs) and other pests and pathogens pose a serious threat to Australia's biosecurity, with potential impacts in agriculture, the environment and human society. EPPs involve a wide range of taxa including insects, fungi, viral, bacterial and nematode groups. This means that identifying the species involved in any given incident requires working with a wide range of taxonomic experts drawn from a diverse range of disciplines.

Currently biological specimens needing identification are mailed to taxonomic experts for determination. This involves considerable time in preparation and shipping of specimens to experts, additional paperwork in tracking the location and status of specimens and often requires extended periods of time waiting for a response. This process can also be onerous for the expert as details regarding the specimen must be noted and specimens returned after the identification has been completed. These high costs and delays are becoming increasingly unacceptable and may result in increased risk of serious damage caused by delayed detection of EPPs.

To address these shortcomings a new approach to diagnostics has been developed. Rather than sending specimens to the expert, the RM system brings the taxonomic expertise to the specimen, and it does so in real-time. This has the advantages of saving time, effort and money, simplifying the diagnostics process and providing almost immediate identifications.

Taxonomic expertise in Australia is dwindling. High level expertise in many specialist fields has become or is becoming less common, and limited to certain geographical areas. RM technology will capitalise on the expertise that still exists to affect diagnosis and training where possible. Connecting experts with others in their fields for identification purposes will also enable up-skilling and training those currently building their own taxonomic knowledge bases.

RM is the first step in creating a distributed system of taxonomic experts connected to those intercepting and detecting EPPs. This system supports real-time observation and manipulation

of specimens, permitting identifications to be undertaken without the need to transfer specimens from their collection site(s). This infrastructure will enable the rapid provision of identifications to anyone requiring them, regardless of the geographic localities of those involved.

The Remote Microscopy (RM) Diagnostics System

The remote diagnostics system developed here is a real time web-based tool that allows non-experts to rapidly and easily collaborate with experts to identify potentially threatening specimens instantly (Figure 1). RM allows a rapid informed response to biosecurity threats that will prevent incursions and so save money and resources.

The remote diagnostics system consists of a series of loosely coupled components. These components, while standalone, are part of an expanding system which will increase in richness, features and functionality over time as new needs are identified and new directions are taken. The initial system includes the following components:

- Microscope or other visualisation system.
- Web-enabled digital camera.
- Internet connection with externally exposed web server permissions.
- Standard voice telephone or alternative supplementary communication tool.

Figure 1. Remote microscopy: connecting specimens and experts

Source: Michael Thompson

While currently largely “stand-alone”, it is anticipated that this system will be integrated into larger projects which add functionality and management of a broad range of information. These extensions include, but are not limited to, components such as:

- Web-based collaboration tools that include:
  - Voice and video conferencing system
  - Web-enabled “white-board” software
  - Application and file sharing
  - Instant messaging
  - Facilities for recording identification and training sessions
- Linkages to online, web-based resources for storing and sharing data.

Some of these extensions exist and integration with RM is currently being planned or is underway. Some of these are discussed in more detail below.

The system

The basic components of the Remote Microscope (RM) system consist of a digital camera attached to a microscope or other lens system and a web connection which allows experts to connect to the camera using a web browser (Figure 2). Using the web browser, the expert can effectively look down the microscope and examine the specimen as if were under their microscope, and not located across the country or around the world.

The RM system developed here utilises some basic Nikon equipment. This equipment has an embedded web server that allows access by anyone with internet access and a web browser. Specifically, the camera body is a Nikon DS-Fi1, a 5 mega-pixel full colour head, which is connected to a DS-L2 Digital Sight console. The camera features a standard C-mount connection that can be attached to most modern microscopes as well as a number of video-based lens systems. This results in tremendous flexibility in selecting an imaging system or adapting an existing one. For example, if the specimens of interest are large, such as entire fruits or vegetables showing pathological symptoms, then a low-power video lens can be attached, giving a field of view of many centimetres to several metres. On the other hand, if the specimens are the size of smalls insects then the camera can be transferred to a stereoscope giving a magnification of 5 to 100 times or greater. Finally, for very small specimens that are

typically slide-mounted, then the camera can be mounted to a microscope offering magnification of 100 to 1000 times. This extreme flexibility is one of the key features of this camera system.

Figure 2. Remote microscopy: Nikon DS-L2 console and DS-Fi1 camera connected to microscope

Source: Steve Shattuck

The camera is attached to a control console which is free-standing and does not require a separate desktop or laptop computer. This independence reduces costs and complexity while offering significant security features over PC-based camera systems. Security is an important consideration, given that this is an open system that is connected to the internet and must be accessible to those outside the local area network where the system is installed. The console not only controls the camera but also contains a web server which broadcasts images from the camera across the internet. By acting as a web server, images of the specimen being examined can be viewed from anywhere in the world with an internet connection and a web browser. This functionality, together with the extensive image capturing functions of the console, enables remote experts to provide diagnostic services regardless of their location. The independent nature of the web server, which uses standard web server networking protocols and ports, allows IT staff to implement a range of security protocols based on local policies and procedures. This flexibility in supporting a number of security protocols is critical as the RM system must be embedded within local IT and networking infrastructure, and if it cannot meet local security protocols then it is unlikely to be accepted and deployed. As this network evolves these factors are proving to be critical to continued expansion. As the collaborative systems discussed below begin to feature more heavily in the RM landscape many of these issues are circumvented.

While the above listed Nikon equipment currently meets the needs of the RM system, it is anticipated that other brands of equivalent equipment may become available in the future. In fact, given the pace of technological change it seems likely that this will occur at some point. These inevitable events are being kept in mind as the system is developed, and, as much as possible, each component is treated as stand-alone so changes in one part of the system will have minimal impact on other components. This should not only future-proof the system but also provide some level of flexibility in interchanging components to meet local conditions.

The various needs and restrictions on technology availability and use within unique organisations is also a factor that has been considered with RM. There are a variety of combinations of equipment, methods of use and IT protective procedures and protocols that will all result in a functional RM setup. This flexibility will ensure the wider use and longevity of the technology and network as it grows and evolves.

Voice, Video Conferencing and Collaborative Systems

Communication between those requiring identifications and those providing them is essential during the identification process. Conventionally, email and telephone form the basis for this.

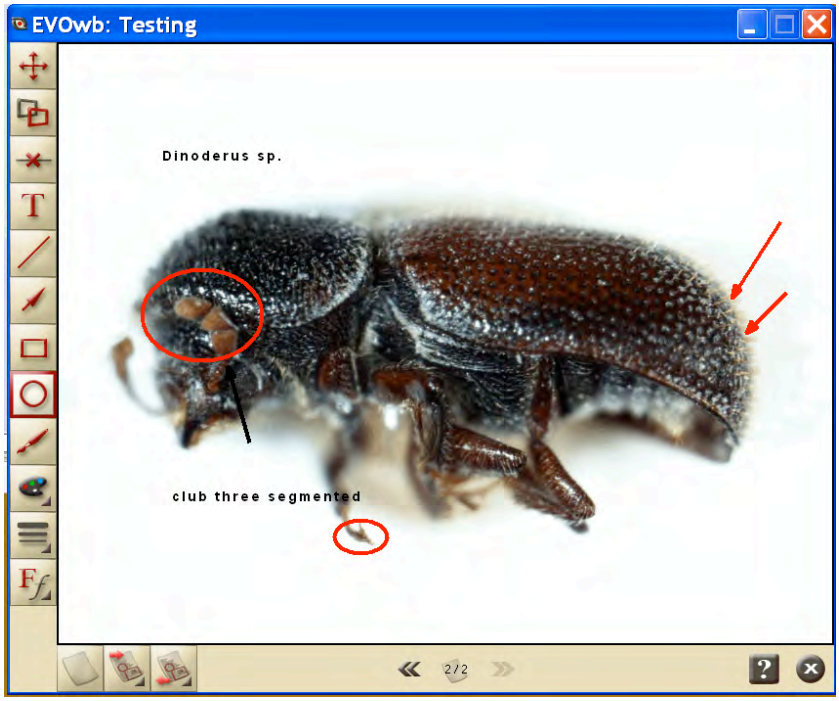
However, the RM system allows experts to communicate with the person handling the specimen in real-time while both view the specimen. This saves considerable time, as well as being much simpler. In addition to providing identifications, this system supports training such as ensuring correct specimen preparation, or simply sharing knowledge about the specimen of interest. Flexibility is required in selecting specific communication tool options as different places will have different user capabilities, restrictions and needs. The stand-alone nature of the RM system is designed to be just as effective when used in combination with a range of communication tools, recognising that some tools have additional features that can increase the value of the technology in meeting local requirements or solving local IT concerns.

Enhanced web-based collaboration functionality, supplementing the core RM technology, will allow increased interactivity between the specimen and expert end users. Web-based collaboration tools provide an exciting alternative to telephone and email. They include many functions that make them an ideal companion to RM and may extend its application. For example, tools such as WebEx (a commercial package, www.webex.com.au) or EVO ("Enabling Virtual Organizations", a free but complex software package, http://evo.arcs.org.au/evoAU/) can provide a platform for video and audio communication, instant messaging, file sharing, desktop sharing and white-boarding. White-boarding and file sharing are of particular interest. When used in conjunction with the live video feed from the web-based camera these functions provide a superior level of interactivity. Recording these highly interactive and visible identification sessions is also possible using these applications. This is of particular relevance in quarantine settings and for developing and reusing training materials. Increasing the group size of meetings with these tools is also possible, and could have nearly limitless application to diagnosis, training large groups and knowledge sharing. These tools are often available for little or no cost to individual RM users, while other options can be purchased at varying costs.

White-boarding

Interactive, real-time white boarding, demonstrated below (Figure 3) using EVO ("Enabling Virtual Organizations", a free software platform). An image can be uploaded to the screen and text, arrows and other visual assistance can be added to illustrate points of discussion. This is only one example of the extensions and enhancements being developed to extend the usefulness and functionality of the basic image-sharing RM system.

Figure 3. Example of image used for real-time white boarding



Source: Michael Thompson

Unfortunately, issues around security policies and computer infrastructure in individual organisations, combined with funding limitations, may mean that these extensions may not become widely available for some time. Free web-based communication such as Skype and Instant Messaging, may have a use in the RM community, but again, some organisations restrict their use for a number of reasons including bandwidth usage and security concerns. While the

possibilities are nearly endless, the reality of working across a range of individually and locally controlled networks often place significant restrictions on developing broadly acceptable solutions. It seems more likely that a suite of software packages will be utilised, giving individual institutions and user the option to select the packages that meet their local needs and while addressing restrictions.

Integration with other Biosecurity Activities and Extension Applications

The RM system is a single component within a larger biosecurity activity, and is linked with a growing number of additional modules and developments. For example, RM will be launched from the Pest and Diseases Image Library (PaDIL), and acts as part of a one-stop diagnostic shop that also includes PaDIL, the Plant Biosecurity ToolBox (diagnostic database) and the BioSecurity Bank (genetic information). RM will also expand into international regions and play an extended role in training.

The extension of RM internationally by establishing RM nodes in New Zealand and South East Asia offers the opportunity to add immense value to training and diagnostics in the region and vastly increase Australia's diagnostic capacity and strengthen our biosecurity network. Expansion into Asia and New Zealand is important in pre-border EPP detection. Cooperation and collaboration with valuable personnel in these regions will increase our pool of taxonomic expertise for diagnostics and training within Australia. Quarantine relationships will be greatly enhanced by such participation in the RM network.

The RM network plays a role in training operational personnel in diagnostic and quarantine roles as well as in more general education within our national collections, museums and universities. Making use of the web-based tools mentioned above, training using type specimens can provide valuable practical diagnostic experience to our emerging taxonomic experts. This very hands-on, interactive training is what will make the RM network and its extended application to training very valuable into the future.

Future developments

RM aims to provide functionality to build on existing databases and resource pools such as those based in the PaDIL. This will be achieved through the application of dynamic software to assist authors to potentially develop identification keys and to add information to existing databases. Building on existing databases will allow RM applications to contribute to wider initiatives that are striving to build online collections and databases. Providing a dynamic online environment where authors can describe and illustrate diagnostic features on the specimen images they are uploading, has great potential value in knowledge sharing and aiding diagnosis. Implementing search features would make information of this kind widely useful and enhance collaboration opportunities.

Dynamically identifying diagnostic features, describing and uploading images to PaDIL using RM has great potential if the same authors were populating the tables. This could permit the building of an identification key on the fly. This could allow taxonomic experts to contribute to a widely available set of diagnostic guides. Once established, these keys would be a great tool to complement the use of RM in identifications and training.

Recording of live video feeds to PaDIL via the RM and their subsequent availability, together with other PaDIL based data, PDAs and podcast applications demonstrate the great scope of such a facility. Video feeds that illustrate techniques, specific identification and information modules with images and supporting information that focus on specific pests or crops would be very convenient for field operatives, particularly utilising portable technologies such as PDAs. Having this information close at hand would be very advantageous when making immediate decisions in agricultural and quarantine situations. These functions would be well complimented by the interactive live features of RM.

PaDIL is used widely worldwide. RM will be available to a very wide audience through this portal. Access to expert lists and the existing data located in PaDIL make it a formidable diagnostic tool. In the 90 days between the 29 March and the 26 June 2009 PaDIL had:

- 104,363 visitors
- Use in 182 countries
- 1,503,352 hits
- Used mostly in the USA, Australia, Western Europe, United Kingdom and Germany

RM form part of a one-stop diagnostic shop launched from PaDIL that will form part of the repertoire of tools available to those protecting Australia's biosecurity.

Conclusion

Remote microscopy provides the tools necessary for real-time diagnostic services which are not restricted by geographic consideration. It overcomes traditional problems with having to physically deliver biological specimens to taxonomic experts for identification by allowing these experts to 'virtually' visit the specimens without leaving their offices. It also provides tools for training and knowledge capture and sharing and integrates with a wide range of other tools, including identification and image libraries, diagnostic databases and genetic and biological information systems. While IT requirements are significant when developing distributed systems such as this, strategies for meeting the needs of local IT staff have been taken into consideration. This should provide options for meeting local IT policies and regulations. It is anticipated that RM systems will play an increasing important role in biosecurity diagnostics in the future, offering a greater level of service much more quickly and at reduced cost.