

Online Product Maintenance by Web-Based Augmented Reality

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Abstract

Contemporary product maintenance (including preventive services, repairs and upgrading) is becoming increasingly complex as products become more versatile and inherently complicated and as the number of available model variants multiplies. Consequently, maintenance is becoming a bottleneck in many engineering systems. This paper discusses a new online product maintenance approach based on augmented reality. According to this approach, graphical maintenance instruction and animation sequences are pre-coded (in VRML) at the design stage for typical procedures. These sequences are then transmitted upon request and virtually overlaid on the real product at the maintenance site, where and when they are needed. The instructions are conditional and adjust automatically to conditions at the maintenance site, according to input from the machine and updated knowledge at the manufacturer. This approach can alleviate much of the information overload and training required from maintenance personnel. Moreover, it can improve maintenance procedure efficiency by bringing updated expert knowledge to the field. This paper discusses the concept, function and components of the system and reports preliminary results of a non-immersive implementation.

Keywords

Maintenance, Life cycle engineering, Augmented reality, Remote Diagnostics, Expert systems

1 INTRODUCTION

In a recent paper (Shpitalni *et al*, 1998) we have presents the concept of Total Maintenance as part of Life Cycle Engineering (Alting and Legarth, 1995). Within Life Cycle Engineering, the subject of maintenance is attracting widespread attention and its role as a central component in the life of a product is being redefined. The driving force for this transition is threefold; first, as market competition becomes more prominent (Bar Cohen, 1995), manufacturers can afford less down time of their equipment while at the same time they also spend less on predictive maintenance (Butler, 1996) and on training maintenance personnel. Secondly, maintenance service providers are facing increasingly complex platforms and sophisticated maintenance procedures. The resulting prolonged training or non availability of skilled personnel poses a threat to the readiness conditions for critical equipment, as well as placing an information overload on the service personnel themselves (Kimura *et al*, 1998). Finally, environmental awareness (Wenzel *et al*, 1997) poses harsher constraints on product/component disposal, and hence encourages recycling and repairing by maintenance. This redefinition of maintenance as a discipline demands that the maintenance process be more systematic and much more economically competitive. This paper presents one concept for achieving this goal.

We propose a global maintenance approach of Online Guided Maintenance (OGM), based on merging principles of reactive environments and remote diagnostics. While each of these fields is an emerging discipline attracting attention in itself, merging these concepts provides an opportunity for realizing some of the basic principles of Total Maintenance. This paper describes the concept of OGM and then describes a non-immersive implementation.

2 ONLINE GUIDED MAINTENANCE (OGM)

The concept of OGM aims to reduce the dependency on trained maintenance personnel, while at the same time to improve the efficiency of maintenance operations, both preventive and corrective. The approach is directed primarily at maintenance-intensive equipment which requires extensive training, such as aircrafts, medical equipment and production plants. The basic idea is that the knowledge base of preventive and corrective maintenance is accumulated at the manufacturer but is used online at the maintenance site. The maintenance knowledge is formulated as 3D multimedia and graphic maintenance sequences. These programs, conditional on the machine type, its current state and its history are conveyed to the maintenance site via a WWW link upon request. The sequence is then optically overlaid on the maintained machine so that an untrained maintenance person can be guided through the procedure. The program may optionally report back to the headquarters on the state of the machine and the maintenance steps performed. The basic concept is schematically illustrated in Figure 1.

OGM is based on the following components:

1. Precoded maintenance programs, in the form of 3D multimedia sequences (VRML)
2. A web link, to obtain the maintenance sequence and report condition
3. Augmented reality display to overlay procedures on the serviced machine
4. A 3D interaction device to convey user indications
5. Optional sensors on the platform, to drive the maintenance and diagnostic sequence

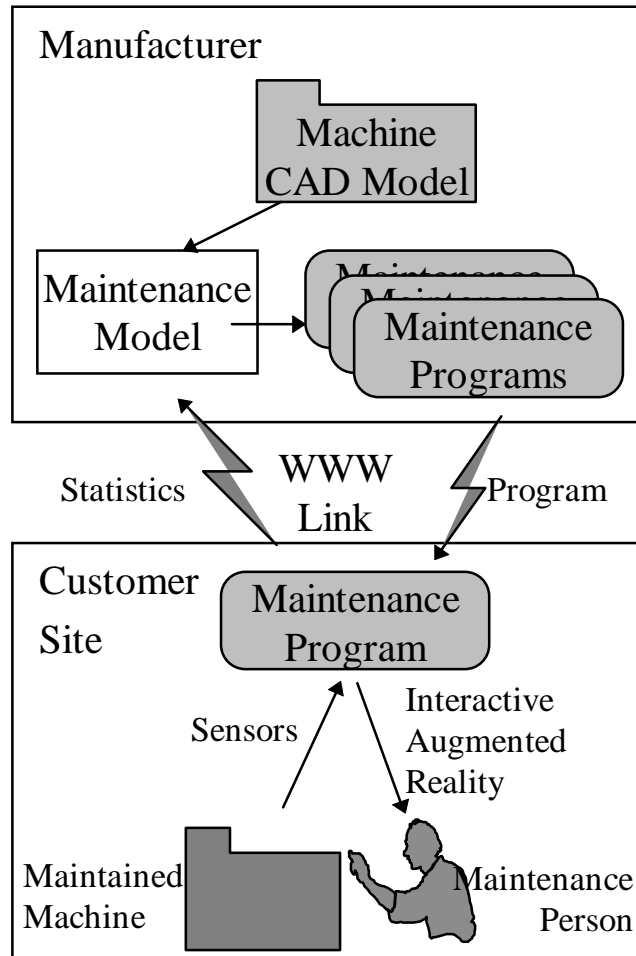


Figure 1. The basic concept of online guided Maintenance (OGM)

Precoded maintenance programs. In an OGM setup, the manufacturer is responsible for developing a set of maintenance procedures for routine services and for plausible malfunctions, based on anticipated deterioration modes (Takata *et al*, 1997) and maintenance models (Shpitalni *et al*, 1998). These procedures can be constant, to be activated by the user (for example, a routine calibration procedure), or elaborate and conditional, based on states of sensors on the machine, and self-activating (for example, replacing a jammed component in a photocopier). Instead of coding these routines in technical manuals, they are recorded as three dimensional graphical animation sequences accompanied by text and vocal annotation (in VRML). This also allows the routines to interact with the user, and collect data from onboard sensors if any are available. The preparation of maintenance programs is based on the assumption that currently most manufacturers already have a three dimensional CAD model of their equipment, which serves at the design stage. Hence generating three dimensional sequences can be based of geometrical and functional information readily available.

An important aspect of maintenance programs which should be noted is the protection of user privacy. Traditionally, centralized maintenance involved having the condition of distributed equipment being monitored by a centralized service unit (Laugier *et al*, 1996). However, this approach is suitable mostly for distributed equipment belonging to the same organization (Olson, 1996). In a competitive market, equipment users may be reluctant to provide direct access to their performance and operating habits. Yet this information is required in order to guide the maintenance procedure. Using the maintenance programs, therefore, avoids this possible conflict of interests: the relevant maintenance know-how is conveyed in whole to the

customer site. There, it has local access to the machine state and history, and it is able to make the appropriate decisions. With permission of the end user, statistical data on the nature of the maintenance operation may be conveyed back to the central site.

Web Link. According to the OGM concept, maintenance programs should initially be supplied with the machine in a standard electronic form (say, on a CD ROM). However, one of the main advantages of using a centralized maintenance site is that as compared with a local system, the center has an increased access to more information and experience from a large number of installation (Laugier *et al*, 1996). Hence it has the capacity to learn and recognize typical problems faster. The Internet is a first-rate, accessible and standard means for conveying this information to the user. Thus, a maintenance person approaching a platform for maintenance automatically activates its Internet link. In essence, the machine *is* the link, and approaching it is equivalent to visiting the link. Moreover, evolving ‘push technology’ (Richardson, 1997) can be used to move information from the center to the client without the need of a user request. This technique will enable maintenance on a regular base, replacing less effective paper manuals updates which are cumbersome, expensive, and are hardly ever thoroughly read.

Augmented reality. We base our approach on a *computer-augmented* environment. Fundamental to this approach is the notion that information use and retrieval does not necessitate sitting in front of a of a screen in isolation from the world, nor does it necessitate explicit provocation from the user. Instead, in a computer augmented environment, electronic systems are merged into the physical world in order provide computer functionality to everyday objects. Such *reactive environments* (Cooperstock *et al*, 97) break the traditional barriers of keyboard and mouse computing, and offer a new intuitive way for interacting with the surrounding and for the surrounding to interact with us. As most aspects of maintenance involve interaction with the real world, a computer-augmented environment seems appropriate for this task by bringing concise information where and when it is needed, in context of the physical surrounding, in a most natural and intuitive form. A reactive environment is primarily based on optically superimposing synthetically generated visual augmentations on the surroundings, and using three-dimensional sensing as feedback. An illustrative application is shown in Figure 2, where a maintenance person is seen to address an motor ignition failure while being guided by OGM.



Figure 2. Synthetic image of a maintenance person addressing an motor ignition using OGM

Two of the fundamental problems in creating the visual illusion are (a) optically merging a synthetic image into the line of sight of the user, and (b) ensuring seamless and precise integration of the image and its surrounding.

Optical synthesis

The primary method for integration of a visual stimulus into the line of sight of a user is using a partially reflecting mirror (beam splitter). A schematic illustration of this method is shown in Figure 3, where the image merging system is either portable and located within the goggles, as a head-mounted display (a) or on a fixed system (b) as in pilot head-up displays. In both cases the synthetic image must be brought to the same focal length as the target image, so that the user will be able to visualize both with comfort. Both methods have their advantages and disadvantages. The primary advantages of the head-mounted system is that the user is free to move and look in all directions, and that the generated image is fully stereoscopic. The disadvantage is that the head mount gear may be uncomfortable in prolonged use. On the other hand, a fixed head-up display (b) may be more suitable when the user is relatively stationary and operating in a fixed environment, for example in front of a workbench. In this case the user is freed from wearing eye-gear, but the relatively large beam splitter (say a glass plate) may interfere and limit maneuvering capability, and is more likely to become dirty due to scattered dust, oil etc. Both these methods require a head tracking device to enable updating the image in accordance with head movement. A third method of augmentation can be achieved by projecting an image directly onto the target, using a projector. This has the advantage of freeing the user completely (both from eye-gear and from head-tracking), but can be used only to project augmentation on physical objects. Hence this approach is more suitable for annotation than for creating virtual objects. This method has the additional advantage of being tolerable to severe working conditions and being suitable for simultaneous use by several users. Software algorithms must be used to compensate for distortion created when the target surface is not flat and perpendicular to the projection axis. Care must also be taken to ensure the user does not interfere with the projection beam. This solution is relatively non-portable. For a taxonomy of AR displays see (Milgram and Kishino, 1994) and (Caudell, 1995).

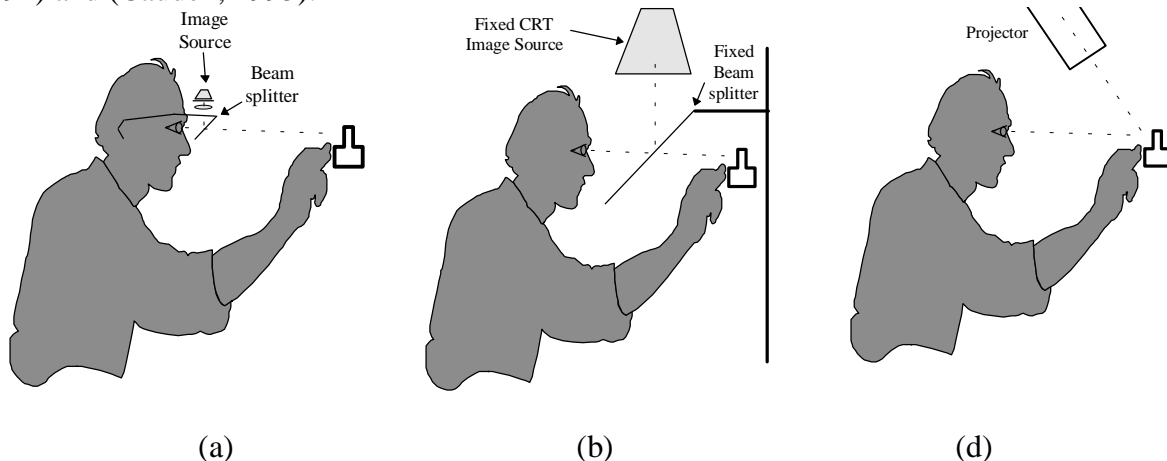


Fig 3. Image augmentation techniques: (a) head mounted display, (b) fixed head-up display, and (c) direct projection display

The three methods described above suffer from a basic problem of operating in an open loop. That is, although the computer is generating the augmented image, but has no means of measuring the success of the optic alignment. Since many maintenance tasks, and especially those involving precision machinery, require high accuracy, we propose a simple optical system to overcome this problem, as illustrated in Figure 4. With proper a geometrical and

optical setup, the camera can be used to 'see' the exact merged image as was seen by the user, and then be used for fine tuning the alignment using image processing techniques. Merging camera and eye viewpoints can help overcome severe human sensory problems (Rolland *et al*, 1995).

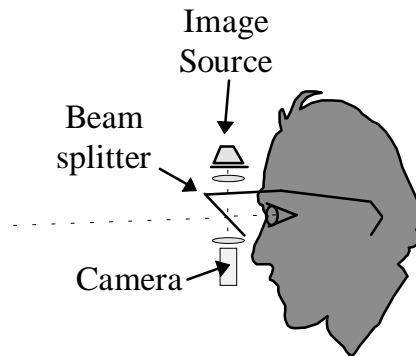


Figure 4. Augmented reality system with feedback

Head tracking

The most crucial aspect of augmented visualization is that of perfectly aligning the synthesized image into the surrounding reality (Milgram and Drascic, 1997). In order to achieve this, the controller needs to measure the position and orientation of the user's head ('head tracking') to millimeter and sub-degree accuracies, and compute the corresponding display transformation. Spatial tracking to these accuracies can only be done using absolute tracking mechanisms (i.e., not accumulation techniques based on integrating accelerations).

The most common tracking device used for this purpose is the magnetic tracker. This tracker measures the electric/magnetic field induced by a transmitter. The field is a function of the position and orientation with respect to the transmitter and mode of transmission (AC, DC, pulsed DC). Although this technique is relatively accurate, it is extremely sensitive to conducting materials and electric currents within the induced field, which are common in industrial environments. Optical tracking methods (Hoff *et al*, 96) are hence becoming a plausible solution.

The tracking method used in this research utilizes the fact that the user is working in front of a known platform, in which we can place in advance a number of optical beacons in the form of light emitting diodes (LED's) emitting a known wavelengths. A camera attached to the head-mounted display is filtered to the corresponding wavelengths and can easily distinguish the landmarks. This process is known as fiducial point tracking (Cho *et al*, 1997). If the three-dimensional coordinates of each of the beacons is known, it is possible to compute a linear perspective transformation that maps the camera image onto the 3D environment. The inverse of this transformation is then used to create the synthesized image in correct alignment, by mapping the 3D virtual object back onto the 2D image plane. Improved accuracy and occlusion robustness are obtained by using the least-squares technique with an excess number of fiducial points.

3 IMPLEMENTATION

In this section we report progress in preliminary implementation and testbed for exploration of the OGM concept. A similar maintenance setup has been discussed by (Feiner *et al*, 93). Our implementation is based on VRML. The Virtual Reality Modeling Language (VRML) is a standard language for describing interactive 3-D objects and worlds delivered across the Internet. It is a powerful protocol for describing shapes, sensors and scripts and multimedia,

as well as specifying links to external sources. Hence it is directly suitable for an implementation of OGM. Our implementation is initially non-immersive, in that the user does not visualize the augmented scene through a head mounted display, but rather via a standard display on a portable computer carried by the maintenance person. A video camera is used to capture the user environment and automatically augment it according to user interaction and according to a pre-coded VRML file describing a particular maintenance task.

Figure 5(a) below shows a hard-disk cabinet as a sample item for maintenance. The general arrangement of the product has been modeled as a VRML file plotted in Figure 5(b), with major components and labels (in the file). Note that the VRML format is relatively compact; the model shown in figure 5 in compressed format occupied a mere half of a kilobyte.

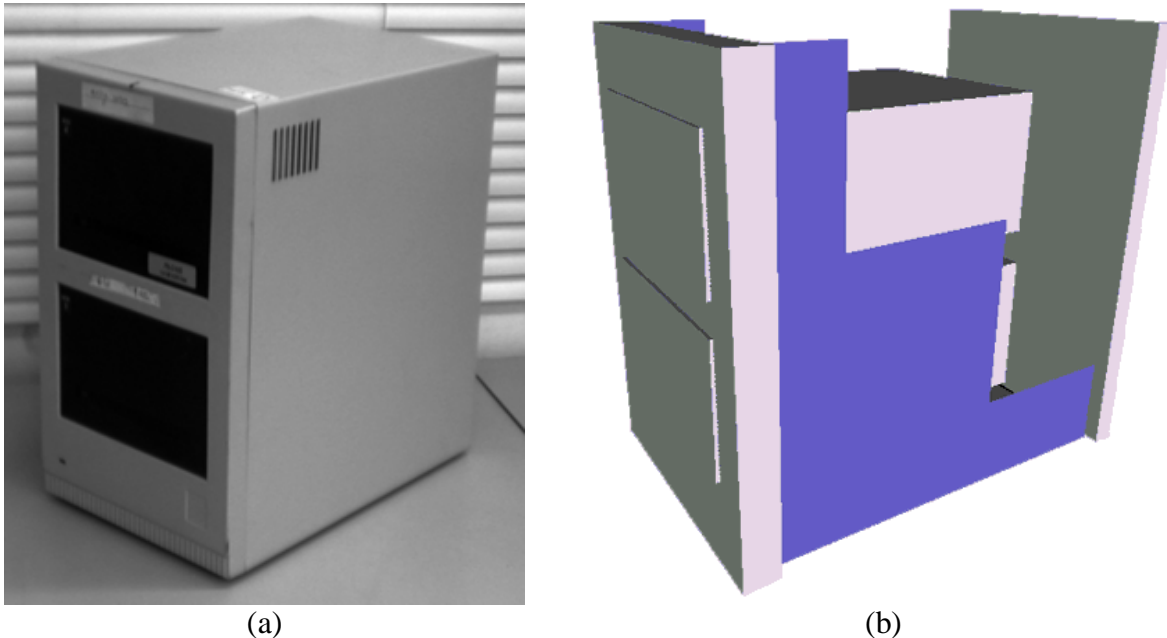


Figure 5. (a) A disk cabinet, (b) corresponding VRML model.

When the external case of the cabinet is removed, it exposes several fiducial markers, which are visible to the camera system. These markers are also described in the corresponding VRML file as registration points. Using a subset of these points, we compute the transformation matrix used to transform the known three-dimensional landmarks into the observed two-dimensional image. The computed transformation can then be used to map any other spatial location onto the image. Figure 6 shows how the entire wireframe representation of the cabinet has been overlaid onto the image using the computed transformation. This kind of overlay can help the user visualize hidden components not otherwise visible. Figure 6 also shows how this mapping is maintained through different orientations. Normally, the wireframe is not overlaid entirely but is used to highlight specific components or points of interest (Fig 9).

Beyond mere visualization, the system supports basic interaction. Interaction encourages the user to query the objects in his real surroundings; the system may respond by providing relevant information and guidance where needed. The interaction is based on the same mechanism used for landmark registration. A stylus with an illuminating tip is used for indication. The stylus emits invisible light (Figure 7(a)), which is seen very well by the camera (Figure 7(b)) especially after filtering out other wavelengths (Figure 7(c)). When the system identifies the tip of the pen or a part illuminated by the pen, it may use the inverse

transformation to compute the location of the pen with respect to the queried object, up to the missing depth coordinate. However, the depth coordinate is estimated as the closest surface of the object to intersect the pens' unknown degree of freedom.

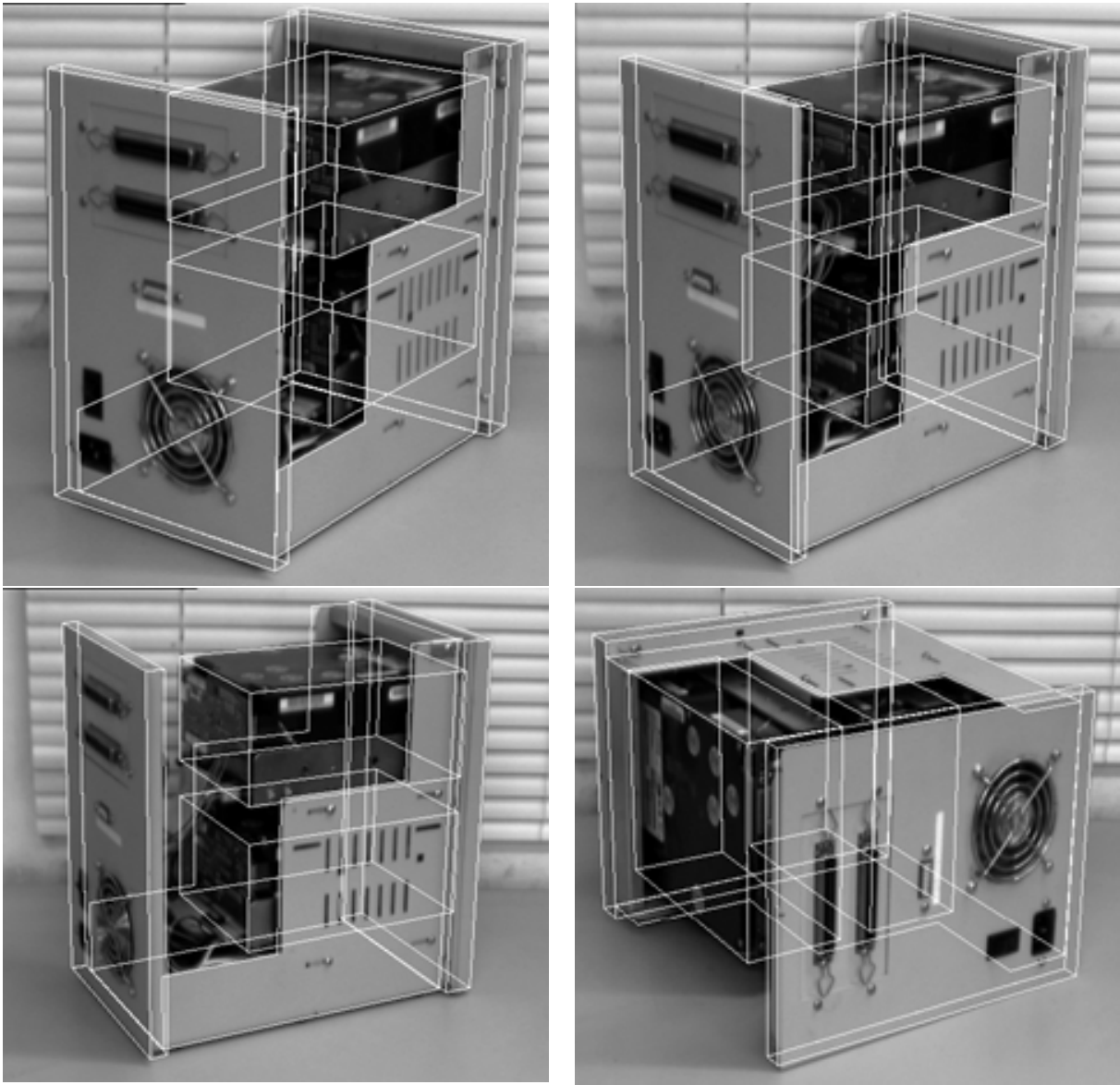


Figure 6. A wireframe representation of the cabinet overlaid onto the image.

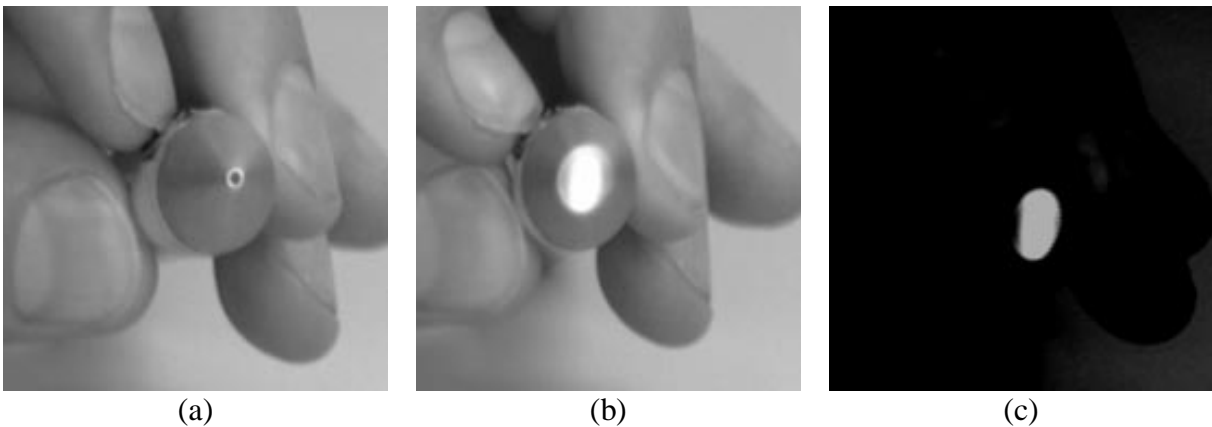


Figure 7. Indication pen as seen by (a) the naked eye, (b) gray camera, (c) filtered camera.

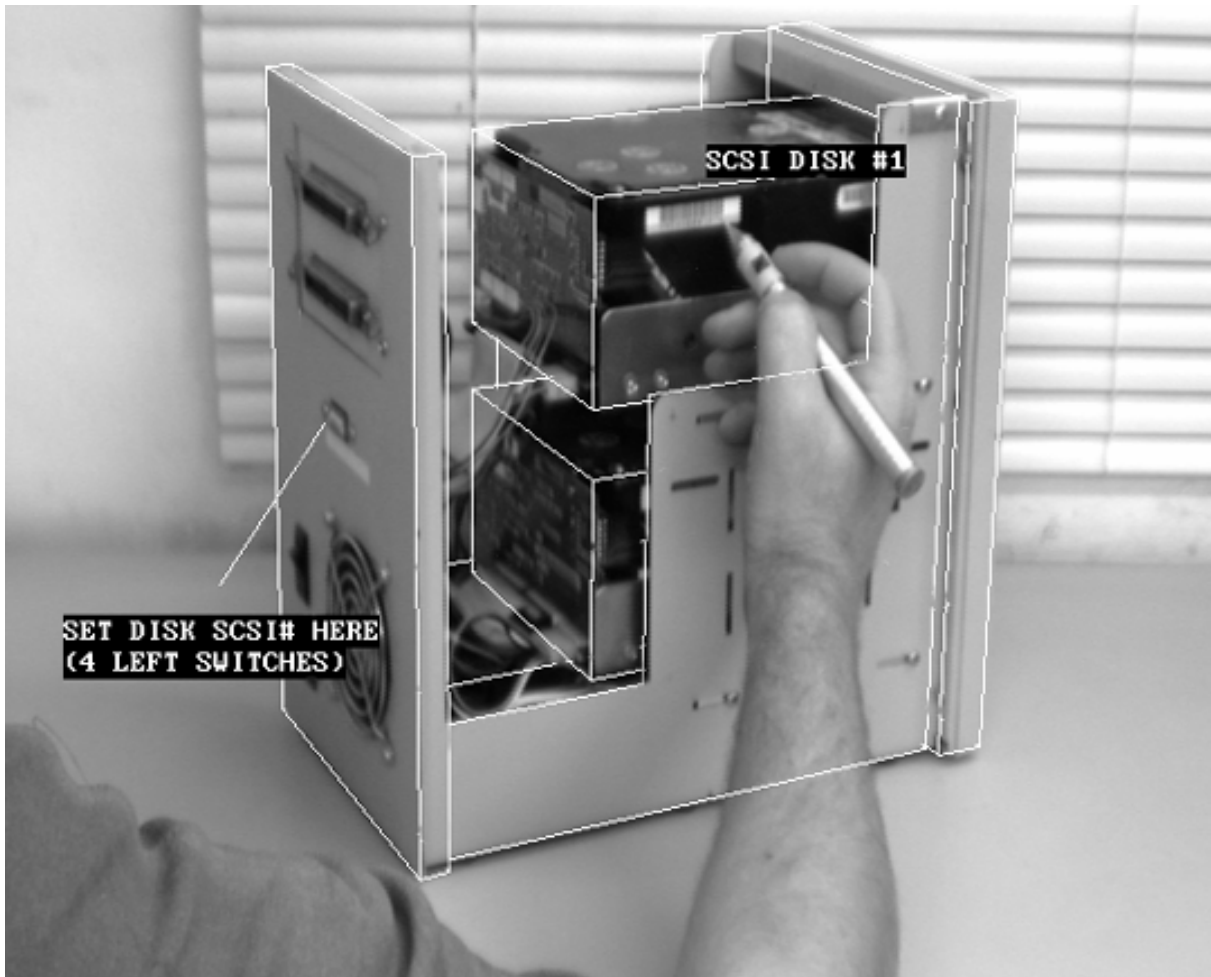


Figure 8. An interactive query of a component. Note the occlusion problem, despite the hidden line removal.

When the interaction mechanism is combined with information and interactive scripts in the VRML code, user activity may initiate system responses and guidance. Figure 8 shows an example of such an instance, where the user has queried a component. The system responds by labeling the indicated item and providing further information related to the maintenance of that particular item. Note the occlusion problem, despite the hidden line removal. The system cannot remove lines hidden by dynamic obstacles of which it is unaware of, such as the users hand. The PC-based non-immersive OGM system is shown in operation in Figure 9.

4 CONCLUSIONS

Contemporary product maintenance (including preventive services, repairs and upgrading) is becoming increasingly complex as products become more versatile and inherently complicated and as the number of available model variants multiplies. Consequently, maintenance is becoming a bottleneck in many engineering systems. This paper proposed a new online product maintenance approach based on augmented reality. According to this approach, graphical maintenance instruction and animation sequences are pre-coded at the design stage for typical procedures. These sequences are then transmitted upon request and virtually overlaid on the real product at the maintenance site, where and when they are needed. The instructions are conditional and adjust automatically to conditions at the maintenance site, according to input from the machine and updated knowledge at the manufacturer. This approach can alleviate much of the information overload and training

required from maintenance personnel. Moreover, it can improve maintenance procedure efficiency by bringing updated expert knowledge to the field. We have discussed the concept, function and components of the system and reported preliminary results with a non-immersive implementation. We intend to further develop this system into a fully immersive system and test its viability in comparison with current methods.

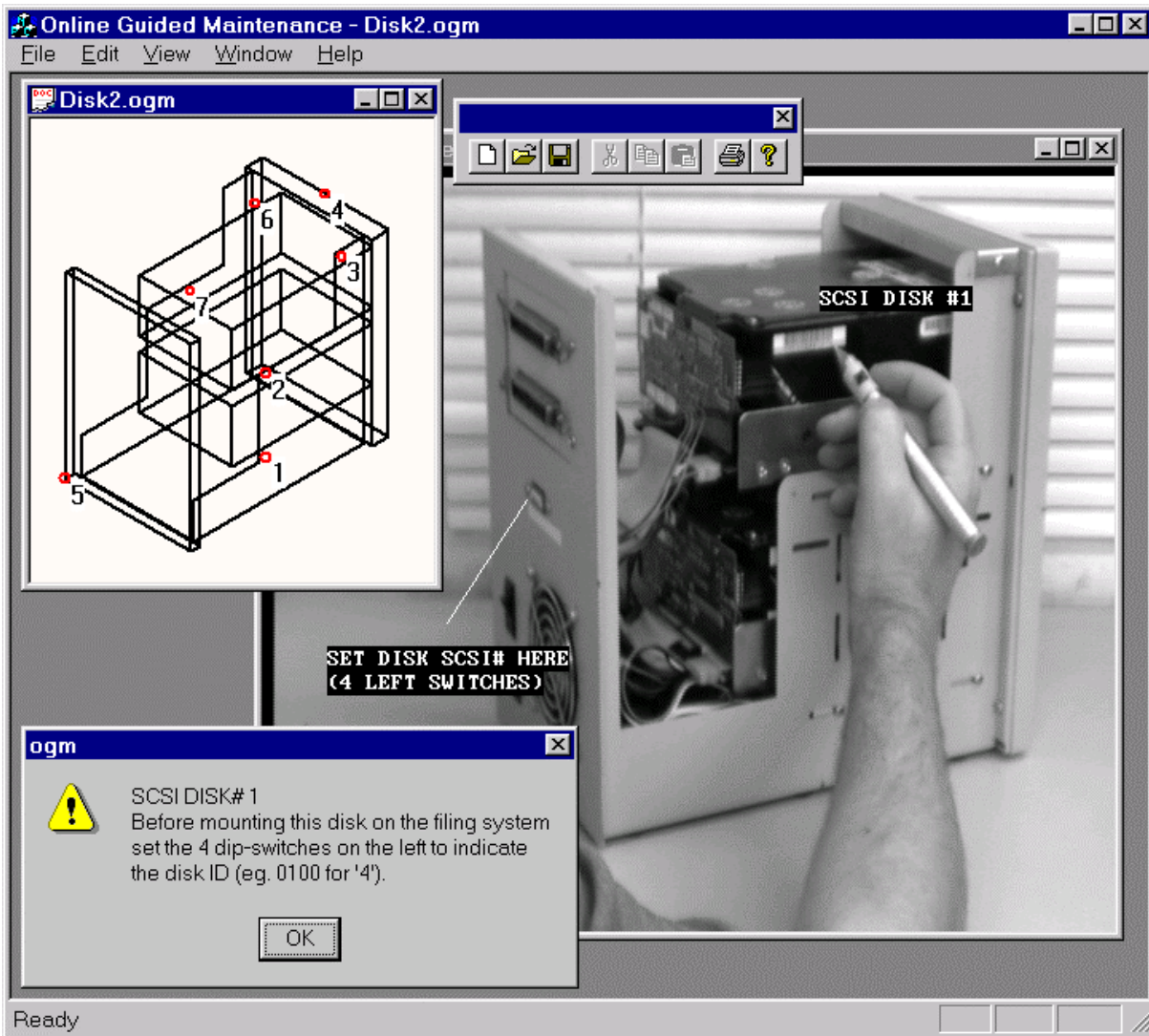


Figure 9. The non-immersive PC-based OGM system, displaying a VRML model, and using it to answer user queries and provide guidance in maintaining a disk cabinet.

5 ACKNOWLEDGMENTS

Hod Lipson acknowledges the generous support of the Charles Clore Fellowship. This research has been supported in part by the Fund for the Promotion of Research at the Technion (Research No. 033-028). This paper was written during Prof. Shpitalni's Sabbatical leave at the Maintenance Laboratory in Department of Precision Engineering at the University of Tokyo. Prof. Shpitalni extends his thanks to the East Japan Railway Company for making his stay in Japan possible and to Prof. F. Kimura for making this period so productive and enjoyable.

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