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Development of a Finger Printing Device for Use on a Mobile Robot*

ABSTRACT: In this paper, we describe the development of a device for fuming fingerprints with cyanoacrylate (Super Glue™) to enable police tactical units to obtain fingerprint evidence from suspicious packages using a remote-controlled robot. Through a series of initial experiments and preliminary designs, we show that effective cyanoacylate fuming requires sufficient heat, humidity, and airflow. This work led to the development of a final working prototype, called robot accessory for fuming fingerprint evidence (RAFFE), which is currently being field tested by the Calgary Police Service.

KEYWORDS: forensic science, latent fingerprinting, cyanoacrylate, robotics

Recent world events have increased demand for safer and more effective means of dealing with potential terrorist threats. In its preparation for the recent Kananasksis G-8 Summit, and in response to mail-bomb attacks on Calgary's former Chief of Police, the Calgary Police Service identified a need for a safer and more reliable technique of retrieving fingerprints from suspicious packages. Until this point, two techniques were used: manual dusting before the package is disrupted (by a robot-deployed water cannon); and manual dusting after the package is disrupted. The first approach puts an officer at risk and is made difficult by the heavy bomb suit required, while the second approach tends to destroy any high-quality fingerprints.

The Calgary Police Service has developed a standard protocol during "suspicious package" situations whereby the parcel is approached by a remotely controlled, battery-powered robot. Based on the information gathered from the robot's cameras and X-ray scanner, Bomb Disposal Unit officers determine whether the package warrants disruption using the robot's water cannon or if some other course of action should be taken. If the water cannon is used, the shattered remains are then examined by Crime Scene Unit officers and subject to conventional fingerprint visualization and analysis.

The Calgary Police Service Tactical Unit (CPSTU) developed a small bottomless Cyanoacrylate fuming chamber, which their robot (a Pedsco RMI-9WT shown in Fig. 1) can place over a small package. This approach has two main disadvantages however: (1) it can only be used to fume small, accessible packages lying on flat surfaces, and (2) it could disturb the package. The goal of the work reported in this paper was to design and develop a system that does not suffer from these limitations. In particular, our approach was to eliminate the fuming chamber and generate a higher volume of fumes.

The fume generator design described in this paper uses directed Cyanoacrylate vapors to develop latent fingerprints. It is fully mountable and does not interfere with the mobility of the RMI-9 bomb disposal robot. Because the device will be operating in all possible conditions, it is designed to produce vapors in large enough quantities so as to compensate for losses due to atmospheric conditions. In cases where excessive fumes are lost to high winds, an expandable "fuming tent" apparatus can be erected around the suspicious package to help contain the fumes. Once visualization is complete, the fingerprints will be photographed via high-resolution cameras onboard the robot.

Although CA has been used as latent fingerprinting technique since the late 1970's and commercial products are available for CA vaporization, existing CA vaporization techniques are not well suited to robotics applications. In order to determine how Cyanoacrylate fuming can be applied using a remote control robot, research was initiated into the safety of the heating technique, power availability, control, and the CA vaporization process.

In the next section, we provide an overview of the basic techniques for latent fingerprint development and describe the methodology followed to develop our prototype fingerprinting device. Next, we present the results of our preliminary experiments into cyanoacrylate vaporization and fingerprint development as well as the results of our experiments into various aspects of the device's design. We conclude with a discussion of our experience with the prototype and our recommendations for future designs.

Materials and Methods

In this section, we first provide an overview of traditional and latent fingerprinting development. In particular, we focus on latent fingerprint development using Cyanoacrylate (CA). The remainder of this section focuses on extending this work for use on a small, remote controlled robot.

The Development of Latent Fingerprints

Traditional methods of fingerprint visualization utilize fine dusting powders. This technique relies on highlighting the friction ridges left by the finger's perspiration and oil by dusting with a light powder (2). Best results are obtained on smooth surfaces (e.g., polished wood, metal, glass, plastics, Formica, and tile); for porous materials, a magnetic powder may be used. This traditional dusting technique

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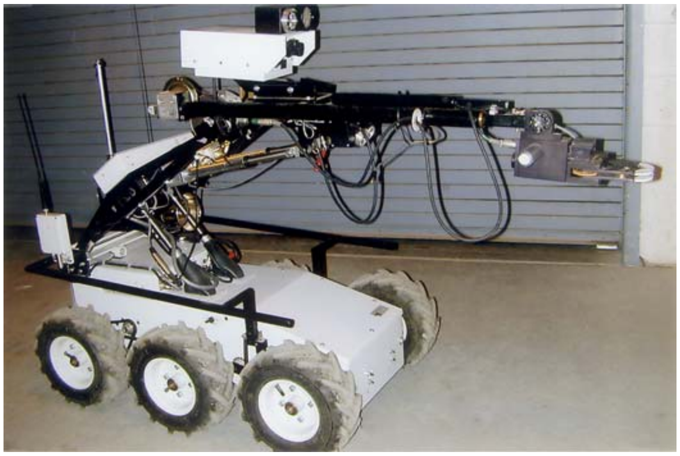

FIG. 1—*Pedsco RMI-9WT robot (1).*

requires a degree of dexterity, which is beyond the abilities of most remotely controlled robot arms, and having an officer perform the dusting is too dangerous. Therefore, conventional dusting powder methods were found to be incompatible with our requirements.

Other popular methods for developing prints include iodine fuming, ninhydrin spray, and silver nitrate (2). Although each of these techniques has specific advantages over dusting, they do not address the specific requirements of our research. For example, techniques such as iodine fuming, ninhydrin spraying, and silver nitrate often require development beyond the initial fuming. When using iodine fuming, a "liquid iodine" technique may be used when it is necessary to retard the dissipation of the developed detail. In order to increase the intensity of the purple dye, ninhydrin treated items may be immersed in a tray of blank organic solvent to (3). Both of these post treatment techniques are typically not an option since they unduly disrupt the package. Silver nitrate requires sunlight or fluorescent lighting to develop the impression detail treated with the working solution. This increases the time and potentially adds complexity and clumsiness to the process (i.e., when florescent lighting is used). These post treatment techniques are a disadvantage for both the robot and Tactical officers extracting the prints. More importantly, only a small time window is available to extract the fingerprints so additional treatments will not be possible. Furthermore, two of these methods only produce temporary fingerprints. Thus, these techniques are unacceptable due to the complexity of the fingerprinting processes and the temporary nature of the prints.

Latent fingerprint development using the cyanoacrylate (CA) fuming technique has been in common use with law enforcement agencies since the early eighties. The ability of CA fumes to help visualize latent fingerprints was first developed by the Criminal Identification Division of the Japanese National Police Agency in 1978 (4). It was also discovered independently shortly thereafter in Britain in 1979 (5). In its present state, this technique is simple but time consuming. The standard method of CA fuming places the article to be processed in an airtight enclosure, which serves to hold the vapors and increase their contact with the latent prints. Super glue is then vaporized to create CA fumes within this enclosure either through its natural volatility, or by the addition of heat or a reduction of pressure, both of which increase volatility resulting in a faster vaporization rate. Unassisted, CA fuming is a lengthy process taking several hours or a few days depending on the size of the fumed object (6). With the addition of heat, a catalyst such as sodium hydroxide (7) or a pressure reduction, fuming can take mere minutes to an hour.

Once developed, the fingerprints become visible via a hardened white residue (depending on the color of the surface and the lighting conditions). This residue is formed as result of a polymerization reaction that occurs between the cyanoacrylate esters and the oils and moisture within the latent print. Fingerprint residues consist of 98.5% water, 0.5% inorganic and 1% organic materials (8). CA polymerization is thought to be initiated by water-soluble organic components of the fingerprint residue; this explains why humidity plays a strong role in the proper development of fingerprints, especially those that have been aged (9). The vapors require a sufficient amount of time to linger around the fingerprints in order for the chemical reaction to occur, this depends upon the concentration of the CA fumes, age of the print, humidity and temperature. Furthermore, it is possible to over-develop a print. When this occurs it becomes more difficult to decipher the intricate ridges or minutiae that are required by fingerprint specialists to make a positive identification. However, it is possible to use special techniques to recover an over-developed print such as BVDA International's Gellifter (10); the recovery of over-developed prints is also reported in (11).

The ability of CA to polymerize in the presence of moisture and oils also presents some complications in its application as a visualization agent. CA fumes are classified as an irritant to the eyes, respiratory tract and any other exposed mucous membranes. Long-term exposure to CA fumes can lead to a built up "resistance" that allows an individual to tolerate higher levels of CA. This occurs until the individual's body suddenly reaches a finite exposure limit where the body's respiratory system and mucous membranes react violently to any trace of CA vapor. This has been observed in a number of crime scene investigators in the United States who were exposed to high levels of CA fumes. CA also bonds skin rather effectively (as many of us discovered in our childhood), and while not especially toxic to the skin, it can remove a layer of skin if the two bonded surfaces are torn apart forcefully (8). Excessive exposure to CA fumes will also bond contact lenses to the wearer's corneas. This will cause not permanent damage, (butyl and isobutyl CA adhesives has been used as an effective alternative to sutures in eye surgery) (8) but the contact lenses need to be removed by a qualified ophthalmologist. CA will also undergo highly exothermic reactions with many common fabrics. If splashed on cotton in a significant quantity the CA will heat the cotton to the point of smoldering.

There are several substances that are known to retard polymerization; the most commonly used are aluminum and phosphoric acid (8,9). CA and its vapors are also flammable; its combustion can produce quantities of cyanide gas that are considered dangerous and eventually lethal if not ventilated quickly (12). The release of cyanide gas is the greatest potential danger posed by the CA fuming technique, and combustion must be avoided at all cost. With the proper safety precautions, CA can be used in a safe and effective manner without adverse affects.

Despite these flaws, there are many advantages in applying the CA technique. Once the fingerprint is polymerized, it is permanently hardened onto its substrate. The prints do not require special handling and are only removed by harsh cleaners or acetone (this can however be detrimental to valuable fumed objects because any attempt to remove the CA residue usually results in damage to the object's surface). The prints typically require no further processing, beyond taking high-resolution photographs. However, additional processing may be required in some cases (e.g., the use of a gel filter for overdeveloped prints as noted previously or dye stains and powders to create better contrast). Even after a suspicious package is disrupted (i.e., shattered to pieces) the fragments may still be used to reconstruct the original fingerprint. Like powders, CA fumes are also able to develop fingerprints on many non-porous surfaces such as metals, glass, and plastics. Once a print is preserved in CA it will maintain its ridge detail (and thus minutiae) for many years, allowing detectives to review old evidence to gain new insight. CA will also protect genetic material within the oils of the fingerprint provided that the DNA analysis is done shortly after the CA treatment. This allows a swab to be taken of the print so that DNA identification is possible (13).

If fuming conditions are correctly optimized, development time can considerably improved so that the least amount of time is spent in close proximity to an armed explosive device. The CA fuming technique is well suited to the constraints implicit in robotic latent fingerprint recovery. All that is required of the robot is to position our device close enough to effectively fume the package, and then take high-resolution pictures of the visualized latent prints. This inherent compatibility adds to the safety and effectiveness with which bomb disposal experts will be able to approach their difficult task.

Since its discovery, the visualization abilities of CA have been taken advantage of by various manufacturers who have marketed several commercial products for latent fingerprint visualization. 3M® has developed a fuming wand which vaporizes CA using a small butane torch. Glue is placed onto disposable fuming attachments (which consist of steel wool and a brass holder) that are inserted into the barrel of the fuming wand. The torch is lit much like a lighter and the resultant heat produces fumes that emanate out of the tip of the wand. This fuming wand is ideal for fuming small areas with precision. Several other manufacturers have developed similar products using a butane torch in the same manner. The flammable nature of butane and the unreliable lighting mechanism made this device incompatible with our application. Loctite, a manufacturer of CA adhesives developed "Hard Evidence," a disposable and ready to use pouch. Upon use these pouches are peeled open exposing the super glue gel, which reacts when exposed to the air. It is ideal for fuming in remote locations because of its compact nature.

Initial Experiments

A series of initial experiments were conducted to investigate: (i) vaporization of the glue, and (ii) producing high quality prints in a timely manner.

To investigate vaporization, three general methods of fuming the glue were tested for their effectiveness. While there are other ways of creating CA fumes (such as a pressure reduction to increase volatility) only those that could be adapted to our acceptance criteria and objective were investigated. The three experiments are summarized as follows:

- *Open Conduction Heating*: This experiment was a simple test to see how well a nichrome wire heating element would vaporize super glue. The test consisted of the wire wound into a tight spiral with a total resistance of 3 Ω, which was connected to a power supply and heated. Once the wire reached around 450°C, glue was dripped onto the hot wire.
- *Contained Conduction Heating*: Experiments where performed to determine the effectiveness of boiling super glue. The first test had nichrome wire as a heating element wound around a 3/8 in. external diameter test tube. The tube was filled 2/3 full with super glue, and then connected to a power supply, thereby heating the entire tube, and causing the glue to boil. A second experiment was performed in the exact manner as the first, except steel wool was inserted into the test tube with the glue prior to fuming. In the third experiment an attempt was made at directing the CA fumes. The apparatus, shown in Fig. 2, was comprised of a long 1/2 in. external diameter vertical heating tube attached to a glass nozzle bent in a circular fashion at 90° so the fumes would exit horizontally.
- *Convection Heating*: The heat convection principle was examined through a number of minor experiments involving various commercial heat guns. They were used to blow heated air into a short metal tube filled with steel wool or brass meshing saturated with super glue. The heat guns were able to vary their flow rates and exit temperatures.

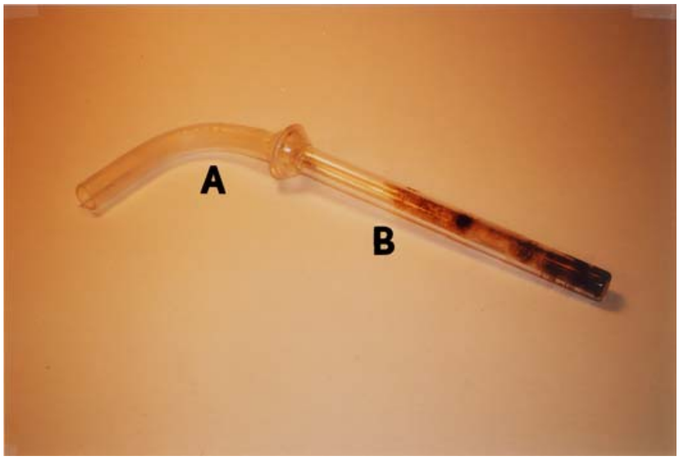

FIG. 2—*90° Nozzle and Tube (A: 90° nozzle, B: tube container).*

In order to investigate fingerprint development techniques, initially each of the three experiments described above was performed again under optimum conditions to determine its ability to develop a "control" fingerprint (supplied by the experimenter). As well, two accelerated development techniques were investigated:

- *Water Steaming*: The development accelerating properties of steam were examined in one of the heat gun experiments. It has been shown that 80% humidity is ideal for CA fingerprint visualization. The extra water vapor serves to rehydrate the print, which accelerates the polymerization reaction. Because of Calgary's notoriously dry weather, a way of quickly rehydrating the prints would reduce development time. Thus, a few experiments regarding the use of steam emerged. The first test involved using the same short metal tube, steel wool and glue as used in the convection heating experiments. This time a few drops of water were added to the steel wool along with the super glue. All other test conditions as well as the procedure remained constant. Fingerprints were placed on a transparency and fuming commenced. The vapors produced were aimed at the fingerprints, and the device was approximately 2 in. from the transparency.
- *Water Misting*: Several water-misting trials were performed to evaluate the effects of adding liquid moisture to development time. Upon contact with water, the super glue almost instantaneously polymerizes; thus, it was of interest to determine if this could be used to shorten development time or even help direct the fumes. This experiment involved the use of a paint sprayer that was able to create a very fine mist of water. In trial one, the vapor fumes were directed onto the fingerprinted surface in conjunction with the misting spray. In trial two, water was sparingly sprayed onto the fingerprinted surface prior to fuming.

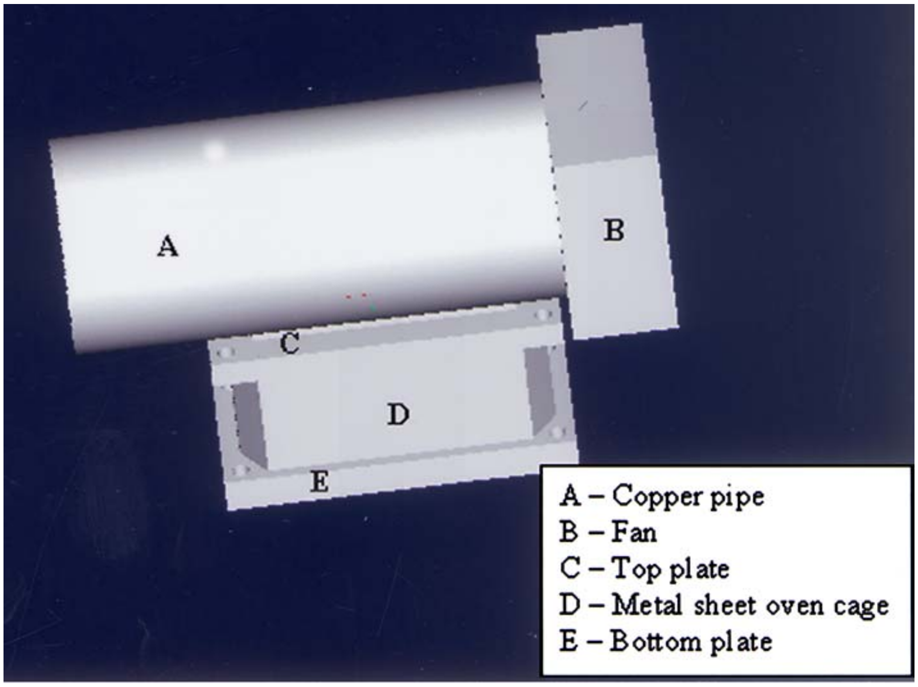

FIG. 3—*AFFE assembly.*

Design Criteria

Although CA has been used as latent fingerprinting technique since the late 1970's and commercial products are available for CA vaporization, existing CA vaporization designs do not meet the specific requirements of the CPSTU mobile robot. Specifically, our design had to meet a unique set of design criteria concerning the safety of the heating technique, power availability, control, and performance.

Safety is of paramount importance to our design. For this reason, any heating methods utilizing open flames or flammable fuels are unacceptable. Anything, which may detonate an explosive device, is considered unsafe for our application. Therefore, only nichrome wire will be used for heating in our designs. Nichrome is inexpensive, easy to work with, reliable and readily available. Using only electricity, nichrome also allows us to control its power output with ease.

Power for the nichrome heating elements must be supplied outside of the robot's own power source. Should our device drain the robot's batteries, it would force an officer to manually retrieve the robot—creating an unacceptable level of risk. Therefore, nichrome power must either be supplied though an onboard battery pack or via an umbilical trailed behind the robot. Citing a reduction in the mobility of their robot, the Calgary Police Service requested that the nichrome power source be carried onboard. Consequently, Deep cycle RV (Recreational Vehicle) batteries were chosen to power the mobile fingerprinting system because of their ability to withstand long periods of moderate current drain. Car or motorcycle batteries are more suited to a short period of heavy current drain during starting, rather then for long term usage.

The RMI-9 robot is only equipped with an on/off switch capable of operating a shotgun or water cannon. As a result, our device must not require any user input beyond its initial activation for control (i.e., the device should operate autonomously). As well, the device must visualize latent fingerprints within a reasonable amount of time and with sufficient quality so that they are usable by police to obtain a positive identification.

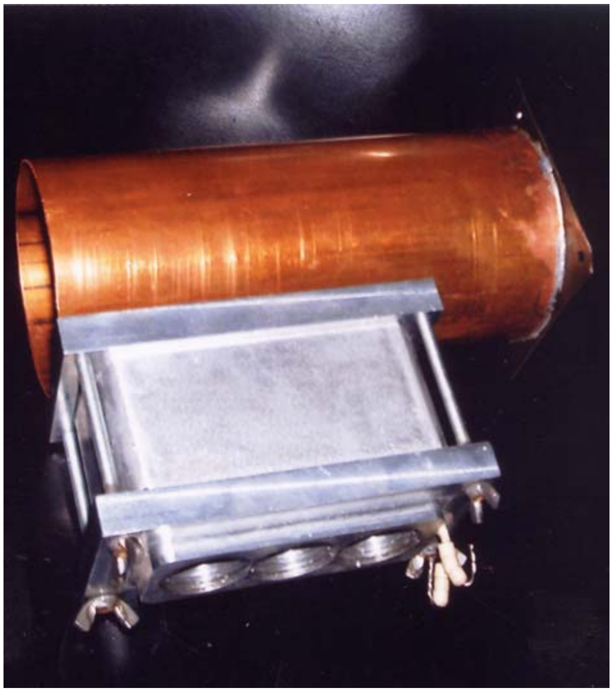

FIG. 4—*Final RAFFE Prototype.*

Fingerprinting Device Design

Using the knowledge gained in our initial investigations, an iterative process was undertaken to achieve a final design solution. In this paper, we will focus on the final design solution, shown in Figs. 3 and 4, called Robot Accessory for Fuming Fingerprint Evidence (RAFFE). This design uses three vials of glue, which are heated in oven D by nichrome wires connected to a 24 V battery (not shown). The fumes are blown out of pipe A by fan B.

In the next section we describe the RAFFE design in more detail and discuss the rationale for our design decisions.

Results

In this section, we begin with the results of our initial experiments on CA vaporization and fingerprint production then focus on the results of the RAFFE fingerprinting device design.

Initial Experiments

As noted previously, three experiments were conducted to investigate vaporization of cyanoacrylate (CA) glue. From these simple experiments, several parameters were established for successful CA vaporization that proved useful in our design. For example, a recurring condition was the need for sustained high temperatures from 300°C to 500°C; this was consistent with the temperatures observed in 3M's commercially marketed fuming wand. The temperature of the heating elements also needed proper regulation to ensure the glue or steel wool did not catch fire.

We also found that the CA needs to remain in close contact with the heating elements long enough so that it can absorb adequate energy to vaporize. As well, the idea of high heat distributed over a large surface area in direct contact with the glue proved successful. Steel wool was used to greatly increase the surface area of the glue. It served to provide many more sites for nucleation(development of vapor pockets which eventually grow in size and escape to the surface), which speeds up vaporization and aided in the even distribution of heat inside the test tubes. The wool also prevented excessive splashing and thus prevented glue waste.

We also found that heating the entire container evenly ensures a constant vapor release and the prevention of condensation or glue build-up on cooler parts of the container that may clog the apparatus. Our experiments showed that fuming causes CA residues to form on the vaporizing apparatus, requiring lengthy cleaning or the complete destruction of the device (i.e., clogging). Therefore, either disposable or easily cleaned and reusable glue containers are required.

Finally, for heat convection methods, a lower flow rate was necessary to ensure visible vapors. However, given the right conditions (i.e., higher heating temperature) a larger flow rate is possible.

In our second set of preliminary experiments, we used our preliminary CA vaporization techniques to investigate fingerprint development. From these experiments, we found that CA fumes need sufficient time to linger around the package in question in order to properly visualize fingerprints. A flexible enclosure would best help protect the fumes from random airflow, but this adds another degree of complexity to a situation where long set-up times are undesirable.

An alternative solution is to use an accelerated development technique such as water steaming or misting. For example, officers at CPSTU often use a guttural breath to rehydrate prints prior to lifting them. A pre-steam method such as this could enable accelerated visualization. We found that rehydration of the fingerprint can significantly improve fuming time and the quality of the print if done correctly. As well, although water misting does not generally produce high quality or durable prints, it can show promising results in print location. This technique needs further exploration to determine the optimal misting required for an acceptable fingerprint.

The RAFFE Prototype

As noted previously, the key RAFFE design features incorporate many desirable aspects from previous designs. A detailed description of each of the preliminary designs is beyond the scope of this paper. However, in describing the final RAFFE design in this section, we will refer back to earlier designs in order to provide insights into our design choices.

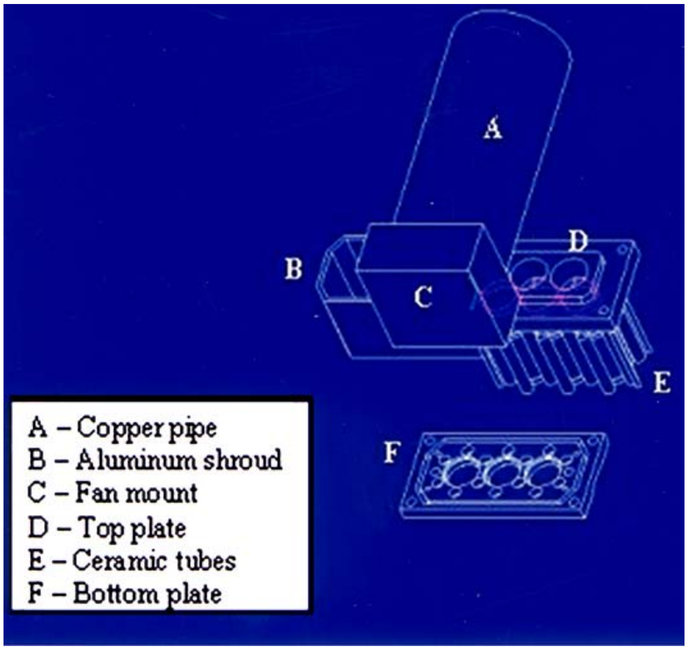

FIG. 5—*RAFFE assembly.*

The complete RAFFE assembly, illustrated in Fig. 5, consists of six main subassemblies: (i) copper pipe, (ii) aluminum shroud, (iii) fan mount, (iv) top plate, (v) ceramic tubes, and (vi) bottom plate. As well, three standard 1in. diameter, 2 in. long laboratory vials, lightly packed with coarse grade steel wool, are included as disposable glue cartridges.

The basic design is based on the contained boiling concept explored in our earlier experiments. It was hoped that this design would confine the mess associated with CA vaporization to the boiling containers, which would be disposed of after each use.

In order to verify this approach, we performed a series of preliminary experiments 1 in. diameter by 2–3/4 in. long ceramic oven heated by a 3.6 Ω wound nicrome element. A single 10 mm × 75 mm Pyrex test tube, lightly packed with steel wool, was filled to approximately 2/3 full (2 mL) with CA and a low flow 22 cfm fan was attached to the oven end of the apparatus illustrated in Fig. 6.

The initial ceramic oven experiments were performed by varying voltages to the heating element to determine its optimal performance conditions. The mass of the test tube and steel wool was measured before and after applying the CA. It was then placed into the ceramic oven for fuming. Each experiment was timed to determine when fuming began and when it ceased. The equilibrium temperature of the ceramic oven was also measured using a thermocouple. Once the fumes were no longer visible the experiment was stopped, and the amount of glue fumed was determined through the mass difference of the test tube. This procedure was repeated for voltages ranging from 3 V to 24 V (at 3 Volt increments).

The results from these experiments are shown in Table 1. Clearly, fuming at voltages from 3 V to 15 V was not effective, as the temperatures required for rapid fuming were not achieved. Once the experiments reached the 18 V threshold the results dramatically improved. Differences between 18 V and 24 V trials were minimal and voltages beyond 24 V produced temperatures that exceeded the melting point of the test tubes. Efficiencies were 75.68%

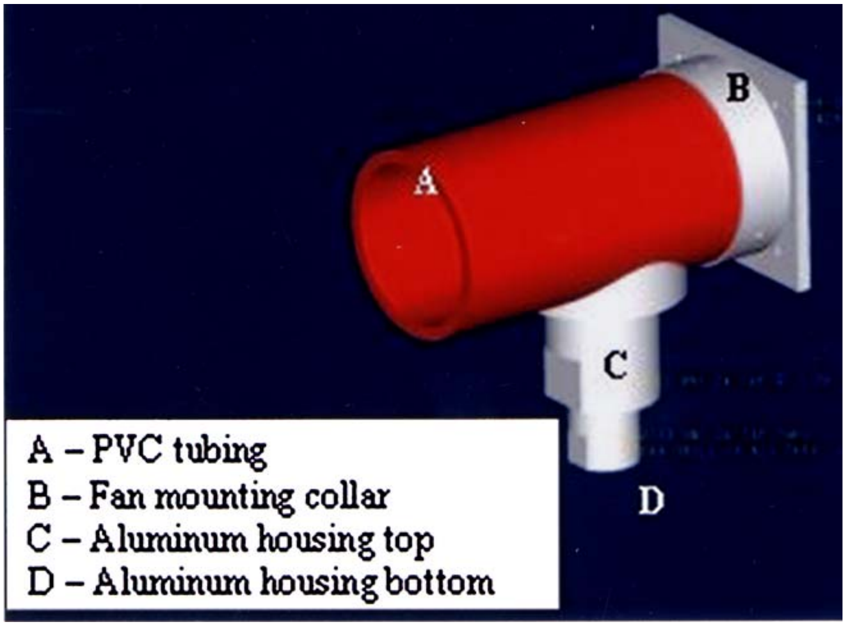

FIG. 6—*Ceramic oven experimental system.*

TABLE 1—*Ceramic oven results.*

Ceramic oven experimental results							
Voltage (V)	Current (A)	Mass of Glue (g)	Glue Fumed (g)	Total Fuming Time (sec)	Visible Fuming Time (sec)	Oven Temperature (C)	Efficiency %
3	1.0	12.85	0.063	1200	N/A	27	0.49
6	1.5	13.06	0.063	1200	N/A	29	0.48
9	2.5	13.44	0.42	1200	N/A	70	3.13
12	3.0	13.82	1.64	1200	N/A	N/A	11.87
15	4.0	11.47	2.31	900	N/A	N/A	20.14
18	5.0	10.73	8.12	643	603	180	75.68
21	5.5	9.99	6.34	390	320	250	63.46
24	6.0	10.56	8.21	758	728	267	77.75

TABLE 2—*Convection/conduction results.*

Convection based heating gun – experimental results							
Voltage (V)	Current (A)	Mass of Glue (g)	Glue Fumed (g)	Total Fuming Time (sec)	Visible Fuming Time (sec)	Steel Wood Temperature (C)	Efficiency %
18	4.2	3.9	1.2	600	N/A	33	30.77
21	5.0	6.0	3.7	690	N/A	51	61.67
24	5.5	4.1	2.0	630	N/A	82	48.78
Conduction based heating gun – experimental results							
Voltage (V)	Current (A)	Mass of Glue (g)	Glue Fumed (g)	Total Fuming Time (sec)	Visible Fuming Time (sec)	Steel Wood Temperature (C)	Efficiency %
18	5.5	4.5	1.0	600	N/A	167	22.22
21		4.2	2.3	720	N/A	N/A	54.76
24	7.1	4.6	1.3	741	N/A	N/A	28.26

and 77.75% with corresponding fuming times of 603 seconds and 728 seconds for the 18 V and 24 V trials respectively.

The final RAFFE design relies on forced convective heating (i.e., utilizing the fan assembly shown in Fig. 5). Before making the decision to use forced convective heating to enable faster development of fingerprints, we first compared convection with direct heating of CA saturated steel wool in a second series of preliminary experiments using the apparatus shown in Fig. 7(*a*).

The results of these experiments are shown in Table 2. For the convection experiments (Table 2(*a*)), we used a low-flow 22 cfm fan to provide the airflow necessary to channel CA vapors out the opposite end of a 3 in. diameter, 7 in. long copper tube. To heat the CA, the heating collar shown in Fig. 7(*b*) was placed in the tube 3–1/2 in. from the fan and a 1 in. wide cage, which housed CA saturated steel wool, was placed next to the heating collar.

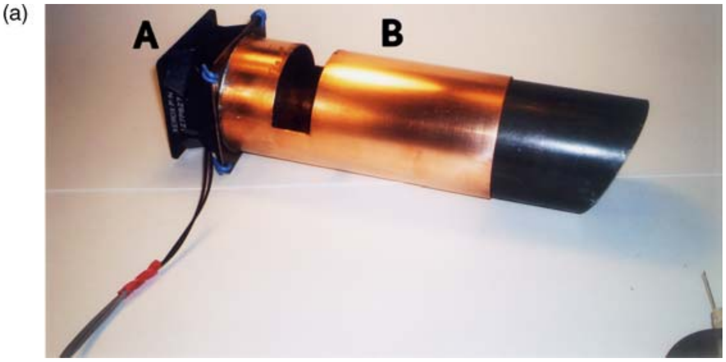

FIG. 7(*a*)—*Convection/Conduction Experimental System—copper tube (B), steel wool cage, and fan (A) assembly.*

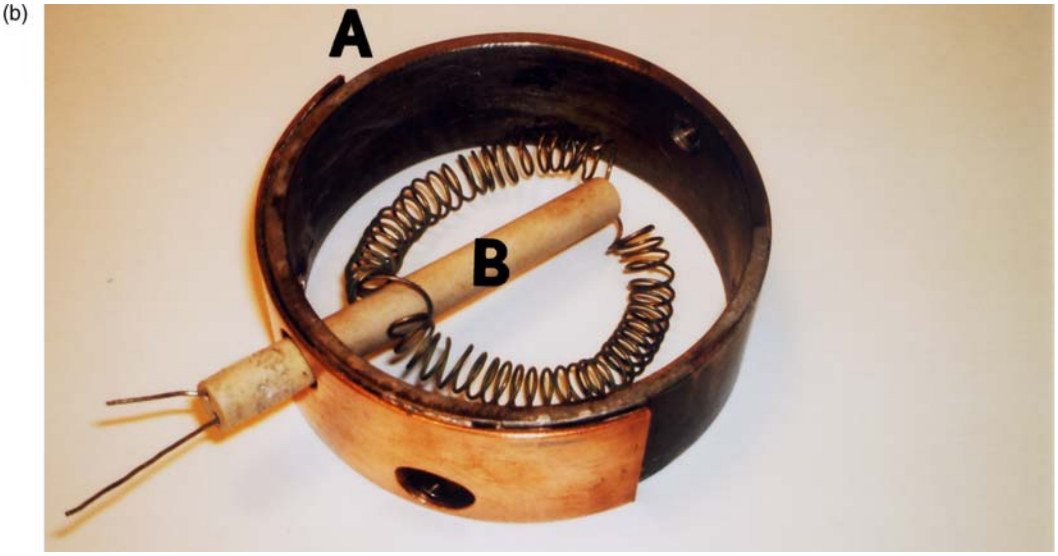

FIG. 7(*b*)—*Convection/conduction experimental system—convection design heating element (A: heating collar, B: heating elements).*

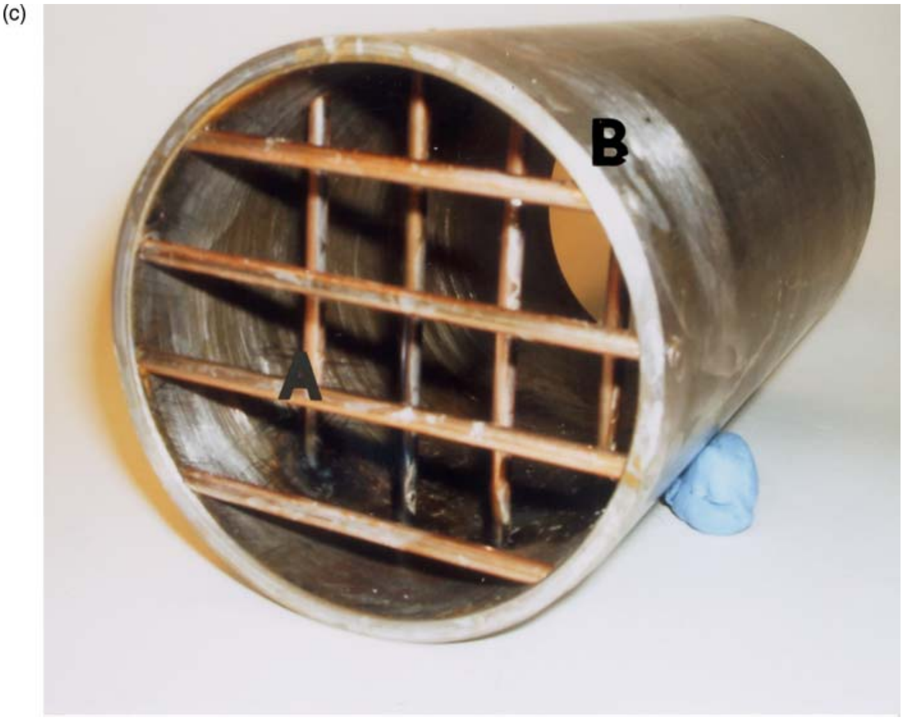

FIG. 7(*c*)—*Convection/conduction experimental system—glue cage (A), steel pipe (B).*

TABLE 3—*Heating tray results.*

Heating tray experimental results							
Voltage (V)	Current (A)	Massa of Glue (g)	Glue Fumed (g)	Total Fuming Time (sec)	Visible Fuming Time (sec)	Steel Wood Temperature (C)	Efficiency %
18		3.33	3.08	465	420	420	92.49
21	6.2	3.05	2.92	454	417	527	95.74
24	7.2	4	3.8	359	345	581	95.00

(d)

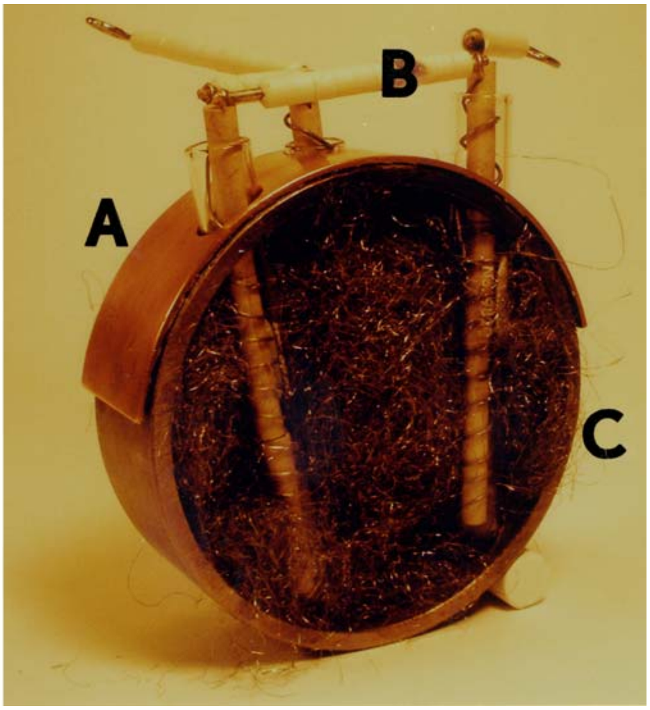

FIG. 7(*d*)—*Convection/conduction experimental system—combined steel wool and heating assembly (A: heating collar, B: heating elements connected in series, C: steel wool).*

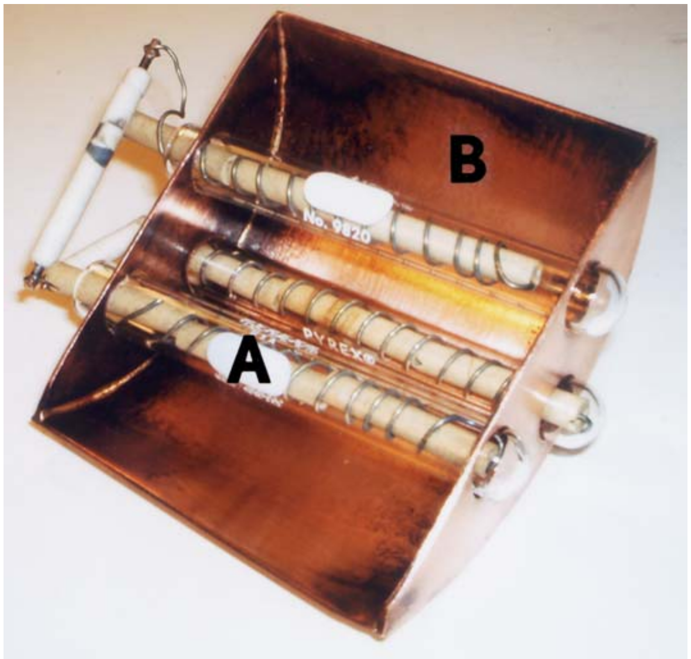

FIG. 8—*Simplified conduction experimental system (A: conduction heating elements, B: copper heating tray).*

For the conduction experiments (Table 2(*b*)), the heating element and glue container were incorporated into a single assembly shown in Fig. 7(*c*). The intention was to ensure faster heat transfer to the glue and less heat loss to the air and the copper tube.

The efficiency results for the convection-based configuration were clearly unacceptable as seen in Table 2(*a*). We define efficiency in Tables 1–3 as the percentage of super glue that is fumed: i.e., mass of glue fumed over original mass of glue. During all three trials, fumes were not visible and the steel wool temperatures were quite low, indicating that not enough heat was transferred to the steel wool. One possible solution to this problem would be to place the heating element closer to the cage; this however, would pose the risk of fire.

Similarly, the efficiency results for the conduction-based configuration were clearly unacceptable as seen in Table 2(*b*). Once again, fumes were not visible, however, after turning off the fan, fumes became visible from both ends of the pipe.

These preliminary experiments clearly indicated that the arrangement illustrated in Fig. 7 would require further investigation of many variables such as flow rate, type of flow (laminar v. turbulent), pipe length, and operating temperature. Because of the problematic nature of this type of in-pipe collar assembly for CA vaporization, we decided to investigate a simpler heating tray arrangement shown in Fig. 8 based on the conduction principle. The basic principle here is to ensure that all of the glue applied to the steel wool would be contained and heated. Furthermore, the minimal tray design was kept free from the pipe and fan mechanism so that only the fuming aspects of the glue would be examined.

As shown in Table 3, the efficiency results for the heating tray apparatus showed a considerable improvement over the previous approach. The success of this approach was in part because the device reached the optimal temperature range of 400°C to 500°C. Another important factor was that all the glue was kept within the tray and splashing was eliminated by steel wool beds on the base of the tray.

Since the CA container will be disposable, we chose to use three standard 1 in. diameter, 2 in. long laboratory vials for the final RAFFE design to reduce operating costs for the prototype design. In future designs, a disposable tray assembly will be investigated.

In order to save time in the field, it is important that bomb disposal officers are able to prepare the CA vials in advance. However, if the CA container is not used immediately, an exothermic reaction that occurs between the steel wool and the CA will cause the glue to crystallize within a few hours. One method of counteracting this problem is to add a polymerization retardant such as phosphoric acid. 10–25 drops of acid were found to be effective enough to

FIG. 9—*Fingerprinted vial container.*

allow storage of a glue cartridge at room temperature for several days.

The maximum efficiency for the final RAFFE design (illustrated in Fig. 4) was 56.6%, which occurred at 24 V. Consistent fumes were visible throughout a 25-min trial. A higher efficiency rate may result from longer trials. This device vaporized a large volume of glue, 17.15 g, in a consistent and controlled manner. In contrast to the steel-wool/test-tube design, it may be possible to vaporize all of the glue in the vials. The fan/tube design allowed control over the direction of the fumes. Also, the vials were easy to remove from the tray, in spite of a hard white residue that formed around the top of the vials, which could be removed with acetone.

The device was tested on a fingerprinted glass vial, shown in Fig 9 using a fume hood. At this stage, field tests of the final RAFFE design are unavailable, though the device has been delivered to the Calgary Police Service for field testing.

Discussion

In this paper, we have described the design of a custom cyanoacrylate vaporization device for a remotely controlled device for acquiring fingerprints from suspicious packages. It was found that the cyanoacrylate fuming process requires high heat, controlled low airflow conditions, and a degree of humidity.

Our final RAFFE design was the result of an iterative process of evaluating six design alternatives based on principles of conduction, convection, and maximizing the amount of glue surface area to heat. In summary, the key RAFFE design features include: (i) a large circumference boiling container, (ii) a sealable and disposable glue container, and (iii) preformed ceramic.

The choice was made to use a vial with a larger mouth to hold the glue (rather than the narrow test tube used in our earlier designs), in order to eliminate the clogging that was so detrimental to the performance of earlier designs with smaller diameter Pyrex® test tubes. Experiments with these earlier designs showed that CA fumes and hot liquid glue had a tendency to condense on the cooler test tube rim. The clogging caused premature fume stoppage and reduced the efficiency of our ceramic oven. In some tests the efficiency was seen to deviate by up to 12% as a result of clogging. The onset of clogging varied widely between tests but generally those test tubes boiled at higher temperatures were less susceptible to its effects.

A larger container lightly packed with steel wool was used to facilitate a greater effective surface area of glue so that a larger quantity of vapors can be produced. However, because the vial's length is longer than its diameter, it is able to hold more glue and allow for longer fuming durations.

The vials in the RAFFE design are disposed of after each use, thus removing most CA residues in one easy step. This dramatically reduces the amount of maintenance required by our device as it does not need to be soaked in acetone after each usage. The vials are also sealable so an officer may prepare glue cartridges in advance.

Finally, we found that while machinable ceramic could make the design process simpler by allowing essentially any geometry of ceramic, experiments with preliminary designs showed that their material properties are not conducive to the robustness required by our application. In our earlier designs, the main component (the ceramic rod) was machined out of Macor®. A fully machinable glass-ceramic, Macor® is capable of withstanding sustained temperatures of up to 800°C while serving as an electro-thermal insulator. However, the stresses of extensive machining combined with rapid heating and cooling seemed to have weakened the structural integrity of the ceramic rod. It developed numerous cracks along several threading grooves, becoming very fragile. Therefore only preformed ceramic parts were used in our final design. This also saved a considerable amount of money as machinable ceramic is extremely expensive.

In order to accelerate the prototyping process, the Pro/Engineer (Pro/E) (14) computer-aided design (CAD) software package was utilized throughout the design process. Our Pro/E drawings were then easily imported into Mastercam where they could be translated into the machine code (G-code) required to control a computer numeric controlled (CNC) machining center for automatic machining.

Based on our experience with the RAFFE prototype, we felt that future design enhancements consider the addition of a fuming shelter and a steam emitter. As well, field testing on RAFFE is required to determine how best to deploy the device with the robot under various operating scenarios (e.g. indoor, outdoor). The working prototype has been delivered to the Calgary Police Service for such testing.

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