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Development of a Robot Accessory for Fuming Fingerprint Evidence

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Prepared by the University of Calgary for the National Research Council

Authors:

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Executive Summary

A device was developed for fuming fingerprints with cyanoacrylate (super glue) to enable police tactical units to obtain fingerprint evidence from suspicious packages using a remote-controlled robot. This report describes the development and testing of a number fuming devices. The tests revealed that effective cyanoacylate fuming requires sufficient heat, humidity, and airflow. A final working prototype (Figure 11, page 26), called Robot Accessory for Fuming Fingerprint Evidence (RAFFE), was designed, developed, tested, and delivered to the Calgary Police Service.

1. Motivation and Background

Recent world events have increased demand for safer and more effective means of dealing with potential terrorist threats. In its preparation for the recent Kanasksis 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, there was no method other than to have an officer personally approach the suspected bomb and manually dust it for prints. The officer would be encumbered by a heavy bomb suit and the fine dexterity required to produce high quality prints would be difficult to achieve- thus the officer must spend a considerable amount of time in close proximity to a potentially explosive device. This creates an unacceptable risk and authorities are therefore restricted to the evidence they can gather after the device has been disabled. In most cases this destroys any high quality fingerprints and hinders prosecution of those responsible.

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. The robot is equipped with a number of sensors used to determine the contents of, and the threat posed by the package. Using the information gathered from 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. The water cannon can safely obliterate the device from the robots control mechanism. The shattered remains are then examined by Crime Scene Unit officers and subject to conventional fingerprint visualization and analysis.

Captain Dave Wood, (an officer with the Calgary Police Service Tactical Unit) experimented with conducting on-site latent fingerprint visualization with suspicious packages prior to their disposal. He utilized a scaled down version of a Cyanoacrylate (also known as Super Glue™) fuming chamber used often in conventional latent fingerprint development. In testing, this method turned out to be successful and further study and refinement of this concept was needed. Officer Wood approached the University of Calgary for support in his efforts, and thus project RAFFE was conceived.

Project Objective:

Our goal is to create a mountable device for the Bomb Disposal Unit's Pedsco RMI-9WT robot, which will allow officers to quickly, safely and remotely develop latent fingerprints. The visualized prints would then be photographed via the robot's cameras, thus removing the evidence without damaging the package in any way. There are numerous physical and chemical means that can be employed to develop the latent prints. However considering our application, super glue fuming was determined to achieve the best compromise between development speed and print resolution.

2. A Perspective on the Development of Latent Fingerprints

Traditional methods of fingerprint visualization utilize fine dusting powders. “The principle upon which dusting works is simple. Most people's fingers carry a coating of perspiration and oil. When fingers come into contact with any relatively smooth surface, they leave a print of the friction ridges in the same manner as a rubber stamp. When a powder is dusted lightly over a surface, it sticks to the oil and perspiration and brings out the pattern. Dusting is ideal on polished wood, metal, glass, plastics, Formica, and tile. It is less than ideal, but still may work, on paper, cardboard, and leather. With porous materials (such as leather, raw wood, paper and cardboard), the preferred technique is to use a MAGNETIC powder. Finely ground iron particles are suspended onto the surface using a magnetic wand.” (9) They cling onto the print revealing the detailing required for identification.

However, the popular dusting technique 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 are incompatible with our requirements.

“At least three other methods exist for developing prints other than dusting. Iodine fuming works well on porous surfaces such as paper and unfinished wood, especially if the prints are fresh and/or if the purpose is to find out if they're fresh. This technique also leaves no trace that one has looked for prints, so it works well in situations where concealment is necessary. The procedure involves placing a few iodine crystals in a fuming pipe, heating the pipe with a lighter or match, and blowing the iodine fumes through the mouthpiece of the pipe onto the surface. Iodine fumes are purple in color, although the prints that develop will be yellowish brown. Prints developed by this method disappear rapidly, so they must be photographed, and analysis is done via photography.

Another method is ninhydrin spray. This is a particularly useful method for all kinds of surfaces, including books and wallpaper, and is designed to develop prints that may be very old. Ninhydrin will develop prints made over 30 years ago, and may come in handy when checking out old documents. Ninhydrin produces a blue-violet color on the developed print. The area is sprayed until it is damp but not saturated. It is important to make sure the area is well ventilated because the liquid used to dilute ninhydrin can be toxic. Drying takes from ten to twenty minutes, but the process can be hastened by using a heat lamp.

Another method is silver nitrate. This involves spraying silver nitrate onto a surface (such as wood or cardboard) with an aspirator, or it can be applied with a brush or swab. After the liquid is in place on the surface, it is left to dry for about five or ten minutes, then the area is exposed to ultraviolet light, but regular bright light works just as well sometimes. This method produces a clear, crisp print because the chemical picks up on the salts in the perspiration. Prints developed this way also disappear after a short time, so lifting and analysis is done via photography.” (9)

In addition, techniques such as iodine fuming, ninhydrin spraying, and silver nitrate often require development beyond the initial fuming; calling for the use of colored dyes and fluorescent lighting in order to unable the fingerprint to be visible. This is a disadvantage for both the robot and Tactical officers extracting the prints. Color dyes require the immersion of the treated print this is not an option, because it would unduly disrupt the package. Fluorescent lighting would add complexity and clumsiness to the process. 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. Thus, the super glue fuming technique is the best method by comparison, despite concerns with development times.

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 (1). It was also discovered independently shortly thereafter in Britain in 1979 (2). 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 vapours 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 serve to volatility resulting in a faster vaporization rate. Unassisted, CA fuming is a lengthy process taking several hours or a few days (3) - depending on the size of the fumed object. With the addition of heat, a catalyst such as Sodium Hydroxide (4) or a pressure reduction, fuming can take mere minutes to an hour. Once developed, the fingerprints become visible via a hardened white residue.

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 (5). 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 which have been aged (6). The vapours 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 one is no longer able to decipher the intricate ridges or minutiae that are required by fingerprint specialists to make a positive identification.

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 vapour. This has been observed in a number of crime scene investigators in the United States who were exposed to high levels of CA fumes. (REF HERE). 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 (5). 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) (5) 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 smouldering.

There are several substances which are known to retard polymerisation; the most commonly used are aluminium and phosphoric acid (5, 6). CA and its vapours are also flammable; its combustion can produce quantities of cyanide gas that are considered dangerous and eventually lethal if not ventilated quickly (7). 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 require no further processing, beyond taking high-resolution photographs. Even after a suspicious package is disrupted (i.e. shattered to pieces) the fragments may still be used to reconstruct the original fingerprint. CA fumes are also able to develop fingerprints on many non-porous surfaces previously considered unsuitable for latent fingerprints visualization, 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. This allows a swab to be taken of the print so that DNA identification is possible (8).

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) which are inserted into the barrel of the fuming wand. The torch is lit much like a lighter and the resultant heat produces fumes which 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.

3. Project Concept:

Our ‘fume generator’ design utilizes directed CA vapours to visualize latent fingerprints. It would be fully mountable and would not interfere with the mobility of the RMI-9 bomb disposal robot. Since the device will be operating in all possible conditions, it shall produce vapours 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 would be erected around the suspicious package to help contain the fumes. Latent fingerprints will be re-hydrated using a steaming device, which would shoot a jet of steam onto the object prior to fuming and enable faster development. Once visualization is complete, the fingerprints will be photographed via high-resolution cameras onboard the robot.

4. Design Acceptance Criteria:

- Ease of Maintenance

  The device should require a minimum of maintenance after each usage. The residue associated with CA vaporization will need to be confined so that it can be easily cleaned or removed completely. The device should be designed in a way such that many of the unwanted effects of dealing with CA, such as its superior adhesive properties do not interfere with the effectiveness of the device, consequently glue spillage should be minimized or eliminated. Furthermore, given its field application, an easy to maintain device is ideal for the hectic schedule of the tactical team using the apparatus.

- Modular construction

  The device will allow for easy assembly and disassembly. This is an advantage from both a maintenance, and repair standpoint. A damaged component should be easily replaced without affecting the rest of the system.

- Ease of Operation

  This device needs to be easy to use, since it is being attached to a remote controlled robot with limited mobility and dexterity. The tactical team needs to concentrate on the situation at hand and not on the operation of our fume generator. Thus, a simple on/off switch would be best.

- Cost Effectiveness
  Since our design is a first generation prototype is it necessary for the device to manufactured out of easily obtainable, inexpensive and thus conventional materials. That said, alterations will be easier to carry out and replacement parts faster to manufacture. Only with further refinement, optimization and several more design iterations will higher performance materials be warranted.

- Safety
  Safety is an essential factor for this design, because of the risk involved with close proximity to explosives and or chemical/biological weapons. The device must operate in a safe manner so as to protect the officers using it from harm and to not inadvertently detonate the package. Because of the remote nature of operation, fume levels should not cause harmful side-effects.

- Robustness / Size Constraints
  The fuming apparatus must fit onto the remote robot and must be robust enough to withstand all the jerky and bumpy movements it may encounter. Moreover, its size should not hinder the robot's mobility or manoeuvrability.

- Efficiency
  A sufficient amount of vapours need to be produced to ensure acceptable development of fingerprints without excessive power requirements or glue usage. This needs to be done without incurring the large amounts of waste or residue, which would lengthen its maintenance time.

5. Initial Experiments

Our initial investigation was focussed on solving two distinct problems key to our project concept; vaporization of the glue and producing high quality prints in a timely fashion.

5.1 Vaporization Techniques

Three general methods of fuming the glue were tested for their effectiveness, and from these results, an optimal condition for vaporization was determined. 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.

5.1.1 Open Conduction Heating

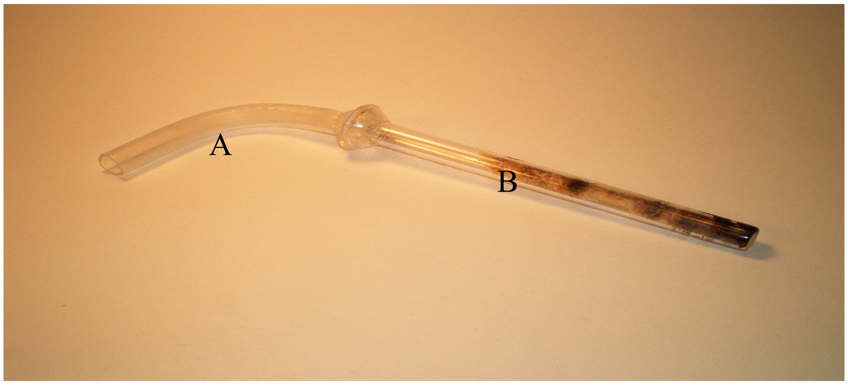
This experiment was a simple test to see how well a nichrome wire heating element would vaporize super glue. The test consisted of the wire wound into a tight spiral with a total resistance of 3 Ω, which was connected to a power supply and heated. Once the wire reached around 450°C, glue was dripped onto the hot wire. Fumes were achieved, however much of the glue simply dripped off the element to form a small pool below. As this pool slowly increased in temperature, vapours were produced there as well. When the wire was heated to 850°C in another trial, the same behaviour was observed, and while more fumes were produced, the pool below the wire eventually caught fire. This was extremely undesirable as the combustion of CA produces poisonous cyanide gas and other harmful by-products. It was learned later that (for the same reasons) CA should never be exposed to temperatures over 800°C regardless of whether or not it is being burned. From these tests it was determined that a larger heated surface area was needed to hold all the glue while it gained enough energy to vaporize and controlled heat of 300-500 °C would be best for safe vaporization.

5.1.2 Contained Conduction Heating (Boiling)

A few 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” ext. Ø 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. This method yielded vapours but the violent manner in which the CA boiled meant that roughly half of the glue was wasted. Secondly, the test tube would need to be either cleaned with acetone after each use or discarded, because a dark residue crystallized inside the tube after fuming.

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. It was hoped that the steel wool would increase the effective surface area of the glue and accelerate vaporization. Upon testing, the results dramatically improved as the steel wool helped trap the glue, thus eliminating splashing and the subsequent waste. Consequently, the heating time was reduced, and the amount of vapours released increased.

In the third experiment an attempt was made at directing the CA fumes. The apparatus was comprised of a long ½” ext. Ø vertical heating tube attached to a glass nozzle bent in a circular fashion at 90 degrees so the fumes would exit horizontally.
Upon heating, the super glue vapours were unable to escape the nozzle, but instead condensed onto its sides. This illustrated that uniform heating of the entire container was necessary to prevent condensation and eventual clogging.



A - 90º nozzle
B - Tube container

Figure 1 - 90º nozzle and tube

5.1.3 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. It was found that the optimal temperatures were once again between 300ºC and 500ºC and visible vapours were best produced under low flow rate conditions under 22 CFM. A low flow rate generally reduces the flow speed and allows more heat to transfer from the heated air to the steel wool and glue thus resulting in more vapours. Fuming duration was found to be roughly a function of heating temperature, density of the packed steel wool and amount of glue present. Assuming constant wool density and glue usage, a higher heat would result in larger quantities of visible fumes for a shorter period of time, and conversely for a lower heating temperature fewer visible fumes were produced for a longer period of time. A high density of steel wool also served to lengthen the fuming duration; at the expense of visible fume quantity (increasing density would of course eventually stop all airflow and therefore all visible fumes). The steel wool needed to be discarded after each use; as residue from fuming left it clogged and unsuitable for another application.

5.1.4 Results Summary and Insights Gained

From these simple experiments several parameters were established for successful CA vaporization.

- *High Temperature Heating*

  A recurring condition was the need for sustained high heats from 300°C to 500C; this was consistent with the temperatures observed in 3M's commercially marketed fuming wand. The temperature of the heating elements also needs proper regulation to ensure the glue or steel wool does not catch fire.

- *Glue Containment*

The CA needs to remain in close contact with the heating elements long enough so that it absorbs an adequate amount energy to vaporize. A container also prevents waste by stopping leakage.

- *Large Heated Surface Area*
  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 vapour 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.

- *Evenly Distributed Heating*
  Heating the entire container evenly ensures a constant vapour release and the prevention of condensation or glue build-up on cooler parts of the container which may clog the apparatus.

- *Apparatus Maintainability*
  Fuming causes CA residues to form on the vaporizing apparatus. This either requires lengthy cleaning or it completely destroys (i.e. clogs) the device. Therefore either disposable or easily cleaned and reusable glue containers are required.

- *Low Flow*
  For heat convection methods a lower flow rate was necessary to ensure visible vapours. However, given the right conditions (i.e. higher heating temperature) a larger flow rate is possible.

5.2 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). All three methods had mediocre results. It took considerable time (anywhere from 5-10 minutes) for the prints to develop in each experiment. The ambient airflow conditions made the results inconsistent between trials. Since the fuming must be done in a well-ventilated area (a fume hood or outdoors) a controlled airflow was difficult to achieve. Unwanted flow such as that from fans or the wind, were able to wreak havoc with the procedure. They instantly swept away any vapours produced and prevented visualization of the fingerprints. A portable enclosure that is versatile enough to accommodate various sizes could be the solution to this problem.

Furthermore, the type of fingerprint played a significant role in its visualization time. Fresh prints that were fairly greasy produced the best quality of prints in the least amount of time. The detailed ridging required for identification was hardened on and visible. Smudged, overly greasy, and old prints were temperamental to the process. They developed slower and the quality ranged anywhere from adequate to terrible. The control print used to evaluate the different methods was fresh and fairly greasy.

Accelerated Development Techniques:

5.2.1 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 (10). The extra water vapour serves to re-hydrate the print, this accelerates the polymerization reaction. Because of Calgary's notoriously dry weather, a way of quickly re-hydrating 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 vapours produced were aimed at the fingerprints, and the device was approximately 2 inches from the transparency. This procedure revealed good quality prints within a matter of 2-3 minutes. After the 3-minutes, the steel wool clogged and fuming ceased. The premature polymerization occurred much sooner than anticipated, and was probably caused by the glue being in direct contact with water. CA is known to quickly polymerize in the presence of excessive moisture.

In our second experiment, an additional metal tube was added in an attempt to correct this problem. Both tubes were stuffed with steel wool in the same manner as before- however the water and glue were applied in separate tubes. Heat was applied to the water then the glue, switching back and forth in 10-second intervals. After 2-3 minutes, in comparison to the first experiment the prints had developed only halfway and had not fully hardening onto the surface. This is because both the glue and water cooled between each interval, so a little more than half of the heating time was spent trying to reheat each tube. This alternating heating idea was abandoned but a dual tube scheme was explored further in the development of our final design solution (see page 20).

5.2.2 Water Misting

Several water-misting trials were performed to evaluate the effects of added liquid moisture to development time. Water upon contact with 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 vapour fumes were directed onto the fingerprinted surface in conjunction with the misting spray. This method did not speed up the fingerprinting time and only served to coat the fingerprint transparency in water droplets. In trial two, water was sparingly sprayed onto the fingerprinted surface prior to fuming. Resulting fingerprints were visible within 20 seconds, although, the quality of these fingerprints was heavily dependent on the amount of water misted. If excess water was used the prints became blobs of white residue, hiding detailed ridging. Also, prints developed in this fashion did not harden onto the surface; instead they were easily wiped clean. If print location was of more importance than quality (such as in DNA retrieval from fingerprints) then this method is unparalleled in its speed of locating fingerprints on a large surface.

5.2.4 Results Summary and Insights gained

- *Ambient Airflow Conditions*
  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. The enclosure does however, allow for fuming of the entire object at once instead of locally targeting fuming. The use of an enclosure should depend on the size of package to be fumed.

- *Water Steaming*
  Re-hydration of the fingerprint will significantly improve fuming time and the quality of the print if done correctly. Officers at Calgary's CSU often use a guttural breath to re-hydrate prints prior to lifting them. A pre-steam method such as this could enable accelerated visualization.

- *Water Misting*
  While this method 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.

6. Design Evolution

Using the knowledge gained in our initial investigation, the iterative process to achieve a final design solution was undertaken. The final design must satisfy our acceptance criteria (outlined on pages 4-5) in addition to a number of other design constraints outlined below. These restrictions are imposed by the operational situations our device will face upon final application.

- ***Safety of Heating Technique***

  While this factor was part of our acceptance criteria- it deserves further treatment here in light of the dangerous circumstances under which RAFFE will operate. 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 Requirements***

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 batteries were chosen to power the RAFFE 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.

- ***Limited Control Requirement***

The RMI-9 robot is only equipped with an on/off switch capable of operating a shotgun or water cannon. Thus our device must not require any user input beyond its initial activation. The device should operate autonomously.

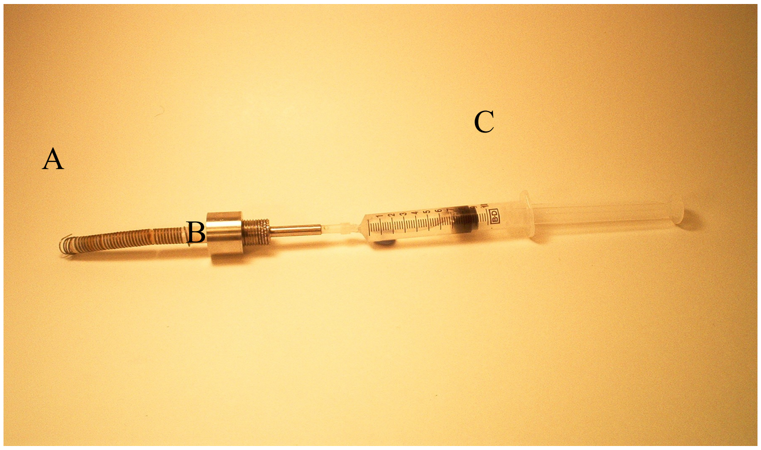
- ***Performance requirement***

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.

6.1. Ceramic Fuming Rod

6.1.1 Design and Material Selection

The ceramic fuming rod concept was based upon vaporizing CA using high heat distributed over a large surface area of super glue. 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. The ceramic rod was 2 ½" long and 3/8" in diameter with threading on its exterior. A central blind hole was drilled to 2 3/8" in length. A 1/8" wide slot was then machined down to this hole along the length of the cylinder. This served to channel the glue down the length of the fuming rod while allowing an opening for the CA to overspill and run down the hot wire. A 0.7mm diameter nichrome wire was wrapped around the threading grooves on the exterior and provided the heating necessary to vaporize the CA. This ceramic rod assembly was then mated to a stainless steel connector, which could be attached to either a mini pump or a syringe filled with glue. Stainless steel was used because it was readily available and could be easily cleaned.



A – Ceramic smoker body wound with nichrome
B – Stainless steel connector
C – Syringe glue pump

Figure 2 – Ceramic smoker assembly

6.1.2 Results and Discussion

Quantitative results for this experiment are not available because the device was irreversibly damaged before being able to perform any significant testing. For an initial test, water was injected into the ceramic device after the heating element was allowed to reach 450°C. This resulted in both steam and water dripping off the main ceramic body through the lengthwise slot. Unfortunately, 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. Nonetheless, curiosity prompted another trial using the super glue instead of water. Qualitatively, the results were encouraging, as acceptable amount of fumes were produced despite the cracks in the ceramic.

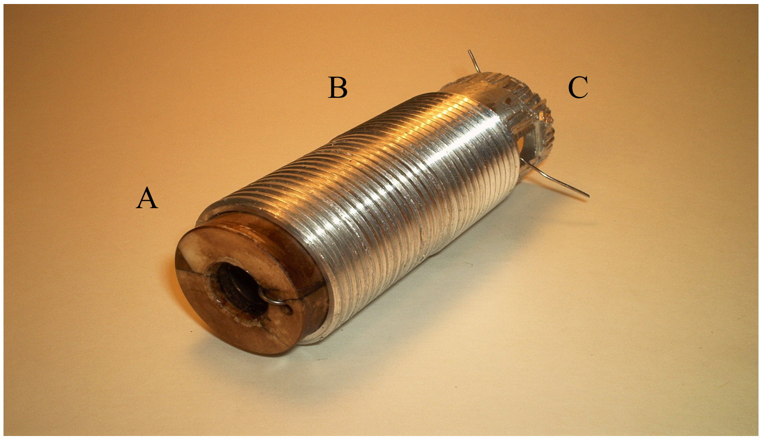
6.1.3 Conclusion

This design was successful in utilizing a large heated surface area (i.e. the length of the coiled wire) to vaporize the super glue. Its downfall lied in the ceramic material used. A stronger material would have prevented the premature failure experienced in this prototype. However, due to time constraints and material costs this was not a possibility.

6.2 Ceramic Oven

6.2.1 Design and Material selection

The ceramic oven design was based upon the contained boiling concept explored in our initial experiments. It was hoped that this design would confine the mess associated with CA vaporization to the boiling container, which would be disposed of after each use. This would allow for easy maintenance without extensive cleaning.



A – Ceramic oven internally wound with nichrome
B – Aluminium bottom housing
C – Nichrome leads

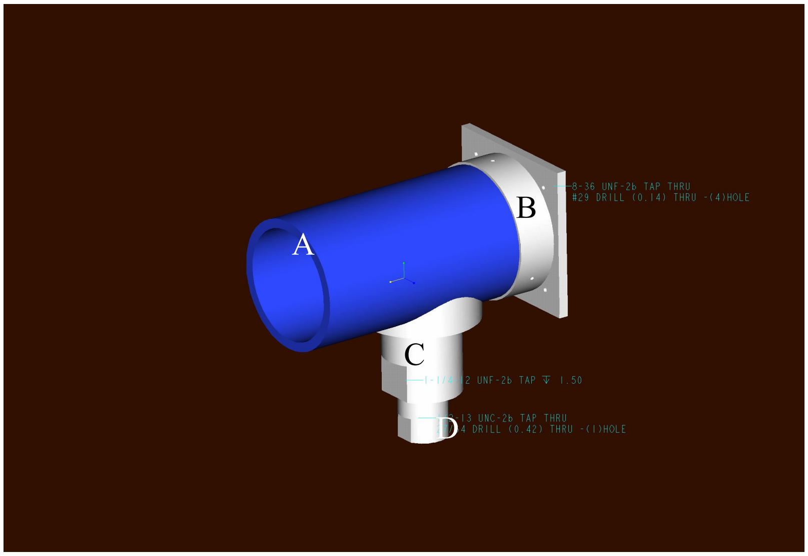
Figure 3 – Ceramic oven and housing

- ***Ceramic Oven:***
  This component was machined out of Macor® glass-ceramic and consisted of three separate ceramic pieces: a main cylindrical housing and two washer end caps. The main housing was 1" Ø by 2¾"long, with a ½" Ø hole drilled lengthwise through its centre. Standard UNC threading was machined inside the hole into which the 3.6 Ω nichrome element was wound. A separate 1/16"Ø hole was drilled into the side of the cylinder, which ran a lead from the element so both leads could be attached to the power source from the same location. The standard threading ensured that the element would heat the glue cartridge in an even fashion, with minimal heat losses to the surroundings. The two ceramic washers each 1/8" thick, were then placed at either end of the cylinder to help insulate the oven. These were all held in place by the aluminium housing.

- ***Aluminium housing/ PVC Pipe***
  The housing protected and supported all the components of the oven. This gave the oven the strength required for practical operations. It was constructed out of aluminium because it was easy and inexpensive to both obtain and machine. An inner aluminium housing secured the ceramic oven and its glue cartridge and had threading on its exterior. This part was screwed into a second outer housing that was machined at one end so it could be mounted to a 3" PVC pipe. A hole in the center of the outer housing allowed the CA vapours to escape into the PVC pipe. PVC was used because it was readily available and could be easily altered to suit our needs.

- ***Glue Cartridge:***
  This component consisted of a 10 X 75mm Pyrex® test tube lightly packed with steel wool. The tube was then filled to approximately 2/3 full (2 mL) with super glue. The cartridge was then inserted into the hollow centre of the ceramic oven and held in place by the ceramic washers and the aluminium housing. Pyrex tubes are inexpensive, readily available and are able to withstand a temperature of 560ºC; this was sufficient for our needs.

- ***Low Flow Fan***
  Lastly, there was a low flow 22-CFM PC fan attached nearest to the oven end of the pipe. By mounting the ceramic oven onto the PVC pipe and fan assembly the device was able to achieve a degree of directional control over the vapour flow.



A – PVC tubing
B – Fan mounting collar
C – Aluminum housing top
D – Aluminum housing bottom

Figure 4 – Ceramic oven heater assembly

6.2.2 Results and Discussion

The ceramic oven device was tested at varying voltages to determine its optimal performance conditions. The mass of the test tube and steel wool was measured before and after applying the super glue. 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 3-24 at 3-volt increments.

The results from this experiment are displayed in Table 1, Appendix A. It was obvious that fuming at voltages from 3-15 was not effective, as the temperatures required for rapid fuming were not achieved. Once the experiments reached the 18V threshold, the results dramatically improved. Differences between 18V and 24V trials were minimal and voltages beyond 24V produced temperatures, which exceeded the melting point of the test tubes. Efficiencies were 75.68% and 77.75% with corresponding fuming times of 603 seconds and 728 seconds for the 18 and 24-volt trials respectively. In both trials it took about 30 seconds for the glue to begin vaporization.

There were several problems in regards to this design, the first was clogging. Clogging was also observed at the mouth of the test tube. 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. This offers insight into why the 24V test had a higher efficiency and fume time despite the fact that logical thinking would lead one to assume a shorter fume time since its hotter temperature should vaporize the glue faster. A hotter boiling temperature would seem to prevent clogging by heating the test tube sufficiently so that condensation becomes more difficult despite the cooler exposed rim. It was also observed that a test tube lightly packed with steel wool would perform better than one with higher density. This phenomenon could be explained by the fact that the dense steel wool may be preventing the escape of fumes from the bottom of the test tube. These trapped fumes would clog the steel wool, exacerbating the problem further until fuming stops.

Once the test tube mouth was completely blocked, the fume pressure inside would build until it was able to break though the crystallized blockage. This presented an unwanted safety hazard to the officers using our device. A sudden release of high-pressure fumes could affect the suspicious package in question.

Glue spillage was also observed in several lower voltage (9V-15V) trials. When heating began the glue bubbled out of its container and flowed down the sides of the test tube into the ceramic oven - causing the components to stick together. Acetone was needed to remove the test tube from the oven. Fortunately in the 18-24 volt tests only small amounts of glue ran down the sides of the test tube and were vaporized by the heating element.

Unfortunately, during the second set of experiments the ceramic oven component cracked in a symmetrical fashion. This was likely due to the structural stresses incurred by machining the central hole in conjunction with thermal loads induced by the overly thick ceramic wall. The non-uniform heating and cooling of the Macor® wall was a result of it being in contact with the rapidly heated nichrome element and the aluminium housing, which was exposed to ambient conditions. Despite this, the device was still functional as its aluminium housing held it together.

Excessive heating also caused threading on the two housing components to bind with considerable strength. It is possible that some glue residue could have caused the threads to lodge together; or more likely the extreme heat resulted in aluminium on aluminium bonding. Despite the ceramic's insulating properties it does not entirely prevent heat transfer and as such the aluminium reached a temperature high enough to enable cohesive bonding and the melting of the PVC pipe near its mounting point. This was a design oversight as it was learned later that heated components in direct contact, should not be of the same metal material, to avoid bonding. Furthermore, a copper pipe would have been a better alternative to PVC as it would be able to withstand high heat with relative ease.

In trying to disassemble the ceramic oven to understand the cause of the failure, the device was irreversibly damaged. Further testing was no longer an option.

6.2.3 Conclusions

This design was a failure, due to unforeseen material limitations and poor design choices. Potential solutions to the problems observed are listed below

- ***Larger Boiling Container Diameter***
  The small test tube diameter was largely responsible for both the clogging and spillage of the glue. A future improvement upon this design would utilize a larger diameter boiling-container.

- ***A Better Analysis of the Stresses Incurred in Manufacture and the Affects of Intense Heating***
  To avoid future material failures, subsequent designs should only select materials capable of withstanding the stress of manufacture and intense heating. The design should allow for thermal expansion and contraction associated with the high temperatures required to vaporise the glue. Components in direct contact especially those with delicate features such as threading should not be manufactured out of the same material so as to limit unwanted cohesive bonding. Finally, a better knowledge of heat transfer within the device should be gained so that material limitations are not exceeded- such as the melted PVC pipe.

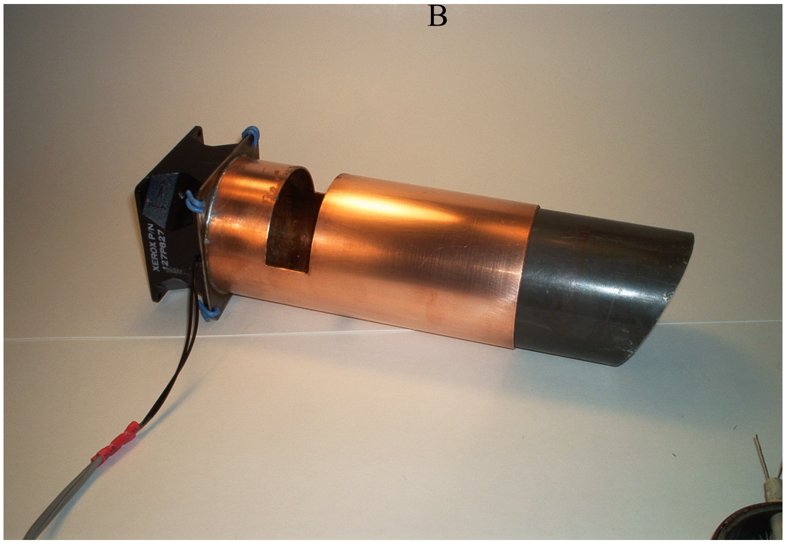
6.3 Enlarged heat gun – (Convection (A) & Conduction (B) Configurations)

6.3.1 Design and material selection

This design explored vaporizing the glue using forced convective heating as well as direct heating of saturated steel wool. Both methods were tested using the same easily re-configurable apparatus. The goal of this design was to create a larger volume of fumes, which would enable faster development of fingerprints.

- ***Copper Tube and Low Flow Fan Assembly:***
  This assembly consisted of a 3” inner Ø, 7” length of copper tubing. Copper was selected because of its ability to tolerate high heat and it was readily available. One end of the pipe was fitted with a steel plate with four 1/8” holes drilled in each corner and a large 3” hole in its centre to allow airflow through the pipe. A low-flow, (22-CFM) 12 V PC fan was screwed onto the plate via the corner holes. This fan provided the airflow necessary to channel the CA vapours out the opposite end of the tube. The mounting plate allowed the fan to be easily replaced so as to vary the airflow rate if required. There was a 1” wide section cut from the top of the pipe to its midsection, 1½” away from the fan mount. This section allowed the heating collar to slide in and out of the pipe, so that the device could be easily transformed from the convection to a conduction configuration.

A



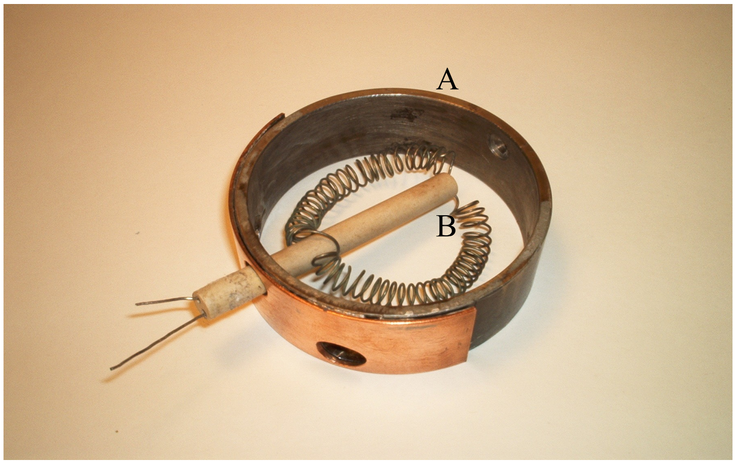
A – Fan
B – Copper tube

Figure 5 – Copper tube, steel wool cage, and fan assembly

- ***Heating Collar***
  The heating collar was composed of a 1” wide section of 3” Ø steel pipe. A copper section, the same size as the one removed from copper tube/fan assembly was soldered onto the steel pipe. Three holes of 10mm diameter were drilled through the collar in a triangular configuration, on the top side where the copper was soldered. These facilitated heating element attachment in both configurations.

(A) Convection based configuration

- ***Heating Element:***
  A 3” long and 5/16” Ø ceramic rod was placed in the centre hole drilled into the heating collar. The leads of a tightly coiled 4.1 Ω nichrome heating element were then passed through two small holes drilled through the length of the rod. The element coiled upwards from the end of the ceramic rod forming a circular shape inside the heating collar. Efforts were made to secure the top of the rod so that the heating element would not touch any part of the steel collar (avoiding a dangerous short circuit).

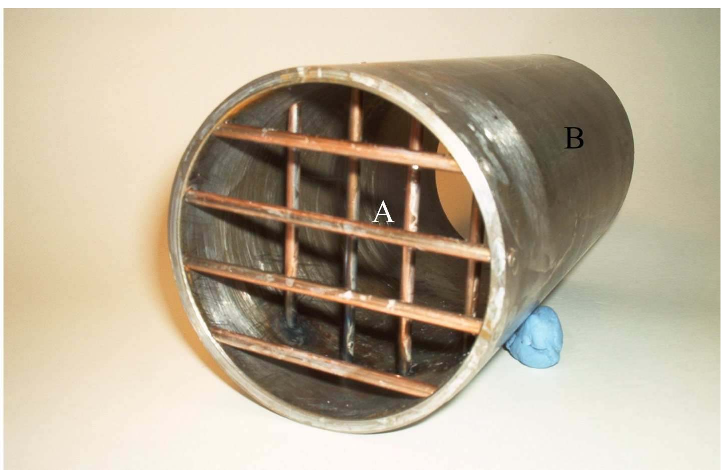


A – Heating collar
B – Heating elements

Figure 6 – Convection design heating element

- ***Glue Caging Tube***
  This component was constructed from the same steel pipe as the heating tray and was 5½ inches long. It slide snugly into the end of the copper pipe and sat 3 ½" from the fan. On the end closest to the heating element, there was a 'cage', which housed the saturated steel wool. The cage was 1" wide and consisted of horizontal welding rods at one end and vertical ones at the other. The outermost rods were removable to allow the steel wool to be packed into the cage. Glue was dripped onto the steel wool, which held it in place for vaporization. By removing the rods the user was able to replace the steel wool after each usage.

  When the device was in operation the fan blew air through the circular heating element in the heating collar similar to a hair dryer. The heated air then reached the glue trap and vaporized the super glue. The steel wool also served to ensure even heating between all areas of the 'cage' cross-section.



A – Glue cage
B – Steel pipe

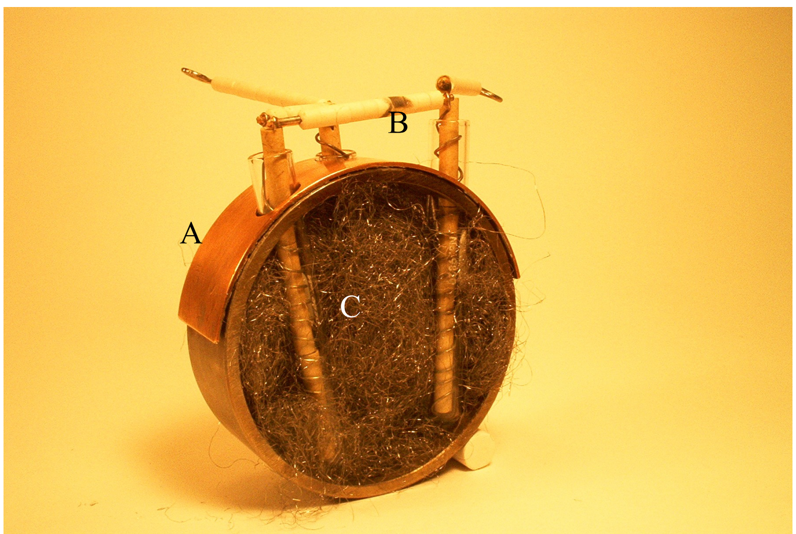
Figure 7 – Glue cage

(B) Conduction based configuration

In this configuration, the heating element and glue container were incorporated into a single assembly. This ensured faster heat transfer to the glue and less heat loss to the air and copper tube.

- ***Heating Element***
  A 10 X 75 mm test tube was inserted into each of the holes drilled into the heating collar. Nichrome wire was wrapped around a 3/16" Ø and 2 ¾" long ceramic tube forming a 1 Ω element which was inserted into each test tube. The three elements were then connected in series. Once the test tubes were in place, steel wool was pressed into the gaps between each test tube heater. Super Glue was then dripped onto the wool and was quickly vaporized once the elements were activated. The test tubes were used to enclose the nichrome wire because direct contact would cause the steel wool to ignite during the fuming process. Test tubes were also selected because they can withstand high heat, are inexpensive, and are easy to replace. This was important because the test tubes would be in contact with the steel wool, so both items might need replacement after each fuming, due to residue build-up.

  During operation the test tube heating elements provide direct heat to the steel wool and glue. This causes CA vaporization through heat conduction. The vapours are then directed through the remainder of the pipe by the fan.



A – Heating collar
B – Heating elements connected in series
C – Steel wool

Figure 8

6.3.2 Results and Discussion

The enlarged heat gun device was tested at 18, 21 and 24 V to determine its optimal performance conditions. The same method used for the ceramic oven testing was employed. The only difference was that the mass of the entire device was measured before and after applying the super glue and lower voltages (deemed to be ineffective) were not tested.

(A) Convection based configuration

The results from this experiment are displayed in Table 2(A), Appendix A. Efficiency percentages for this design are unacceptable, with 30.77%, 61.67%, and 48.78% for 18, 21, and 24 volts respectively. Fumes were not visible during all three trials. Furthermore, the steel wool temperature readings were quite low, which accounts for the poor efficiency and the lack of visible vapours.

It was obvious that not enough heat was transferred to the steel wool. This particular design may require the heating elements to be a closer than 1 inch away from the glue cage (this however would pose a risk of lighting the steel wool on fire). The 22-CFM fan may also have provided an airflow that was too turbulent to enable visible vapours. An excessive amount of energy was probably lost to heating the air, steel wool and the copper tube itself- hence, this was most likely the cause of the low steel wool temperatures observed.

Heating the glue resulted in a lowered viscosity and as such the glue readily ran out of the steel wool. By doing so, the glue was able to wreak havoc- bonding the caging tube and heating collar to the outer copper tube. The device needed to be soaked in acetone before any of the parts could be removed or the device used again.

This glue leakage was most severe during the 21-volt trail, explaining the higher efficiency value. There was moderate leakage during the 18-volt test and none during the 24-volt test. It was possible that a sufficient amount of heat was generated at 24V to vaporize the glue that leaked out of the steel wool.

(B)Conduction based configuration

Results from the experiments performed on this device are in Table 2(B), Appendix A. The meagre efficiency values for this design are unacceptable. They were 22.22%, 54.76%, and 28.26% for 18, 21, and 24 volts respectively. Again no visible fumes during regular operation were observed exiting the pipe.

However, after turning off the fan fumes became visible, exiting from both ends of the pipe. Thus, it is inferred that a major reason for this failure is the inadequate selection of the fan. Both the factors of unsuitable flow-rate and turbulent flow from the fan need further investigation.

During the 21-volt and 24-volt tests fumes were visible within the copper pipe as they moved toward the end swirling along its inner diameter. Although once reaching the mouth of the pipe they simply vanished. Shortening the pipe may rectify this problem.

Leakage was observed but was restricted to the immediate vicinity of the heating collar. This caused considerable bonding between the collar and pipe. As well, there was extensive bonding between the test tubes and steel wool. Attempts to remove the steel wool intertwined between the test tube heaters usually resulted in the test tubes cracking and breaking. It became quite tricky to clean out the collar due to the jagged Pyrex remains. An acetone bath after each usage was able to rectify most problems associated with glue bonding.

6.3.3 Conclusion

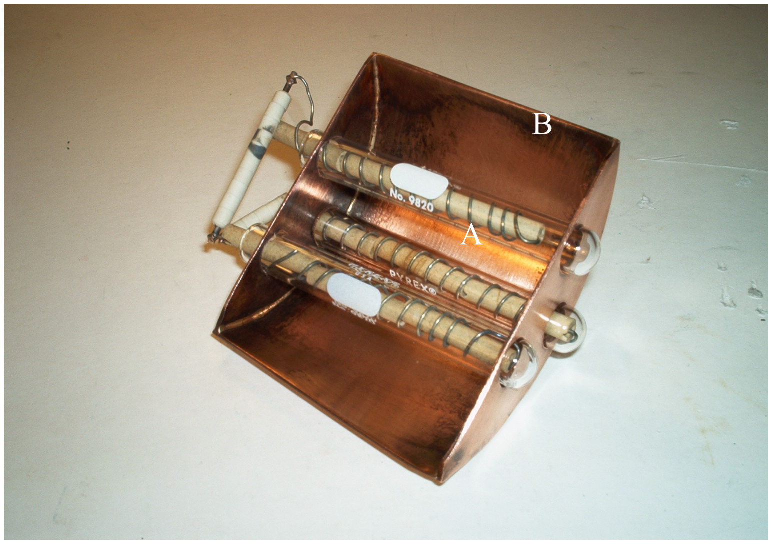
These two designs require further testing to determine the best operating conditions. There were many variables in both designs that should be investigated, such as flow rate, type of flow (laminar vs. turbulent), shorter pipe length, and optimal operating temperature. For the convection-based configuration, a better glue-trapping element would improve the design. As well as placing the heating element closer to the glue. The conduction based design would benefit from a cleaner glue trapping element and sturdier heater exterior.

6.4 Heating Tray

6.4.1 Design and Material Selection

The geometry of the heating tray was that of a semi-circular prism. A 1" deep and 2 ½" wide section was cut out of a 3" diameter copper pipe. This formed the bottom of the tray. Two sidewalls were cut from a copper sheet so that they matched the curvature of the bottom piece; each sidewall contained 3 triangularly spaced 10mm diameter holes. These sidewalls where soldered onto the ends of the tray. Copper was chosen because it was readily available, robust, and able to handle high temperatures. The three holes drilled into the sidewalls were used to hold the test tube heater configuration. The test tube heater was the same one used in the enlarged heat gun design based on conduction heating.

This heating tray design was based on the conduction principle. It was designed based on the knowledge gained from the original conduction heat gun prototype. The tray was intended to make sure 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.



A – Conduction heating elements
B – Copper heating tray

Figure 9 – Heating tray

6.4.2 Results and Discussion

The efficiency results for this design were 92.49%, 95.74%, and 95.00% for the 18, 21, and 24-volt trials respectively. Visible and consistent fumes were present for practically the entire running time, fuming for approximately half a minute each trial. Temperature readings for these trials were 420°C, 527°C, and 581°C for the 18, 21, and 24-volt tests.

It was apparent that the success of this design was in part because the device reached the optimal temperature range of 400°C - 500°C. Another vital factor was that all the glue was kept within the tray and splashing was eliminated by the steel wool-beds. Thus, almost all of the glue was able to be fumed. Furthermore, once the steel wool and heating elements were removed the tray was easy to clean.

Occasionally however, after fuming, the test tubes would become bonded to the holes drilled in the sidewalls. While a short soak in acetone was all that was required to free the tubes, they often shattered upon removal. Since the test tubes were easily replaced, this was not a problem, however for future designs; a better method of securing the heating element should be pursued.

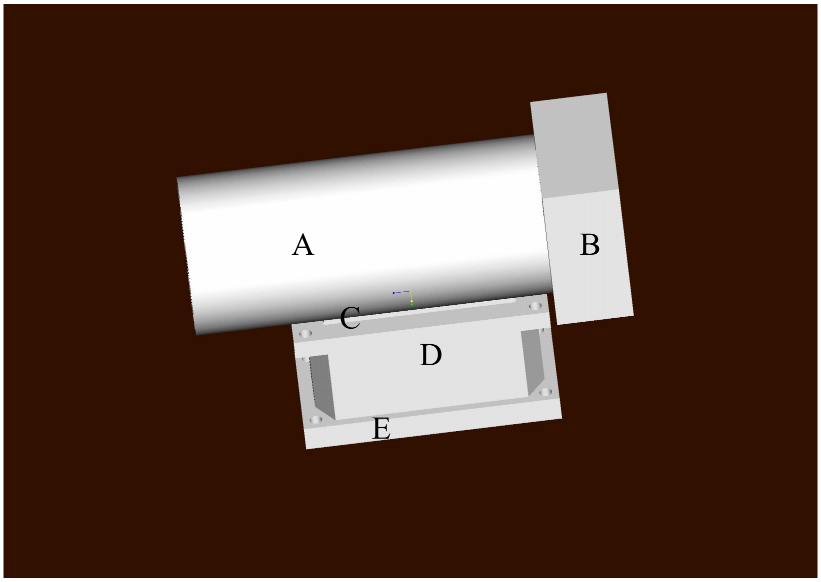
It was also determined that for this device the voltages should not exceed 24V as the temperature of the elements reached 581°C which is above the melting temperature of the glass. While the Pyrex tubes stayed intact- they did become slightly malleable. The soldering on the sidewalls also showed signs of gradual heat failure, as 581°C is close to its melting point. We felt that further testing should be restricted to the 18-21 volt range, as this would not appreciably reduce the amount of glue fumed and would allow our apparatus to remain undamaged.

6.4.3 Conclusions

This design uses the principle of conduction to vaporize all the super glue in less time than the other devices. However, a method is required to secure the heating elements so the test tubes do not shatter and to control vapour flow.

7. Final Design Solution: RAFFE

The final design solution, called a Robot Accessory for Fuming Fingerprint Evidence (RAFFE) is shown in Figure 10. Three vials of glue are heated in oven D by nichrome wires connected to a 24 volt battery (not shown). The fumes are blown out of pipe A by fan B. A photograph of the final prototype is shown in Figure 11.



A – Copper pipe
B – Fan
C – Top plate
D – Metal sheet oven cage
E – Bottom plate

Figure 10 – RAFFE assembly

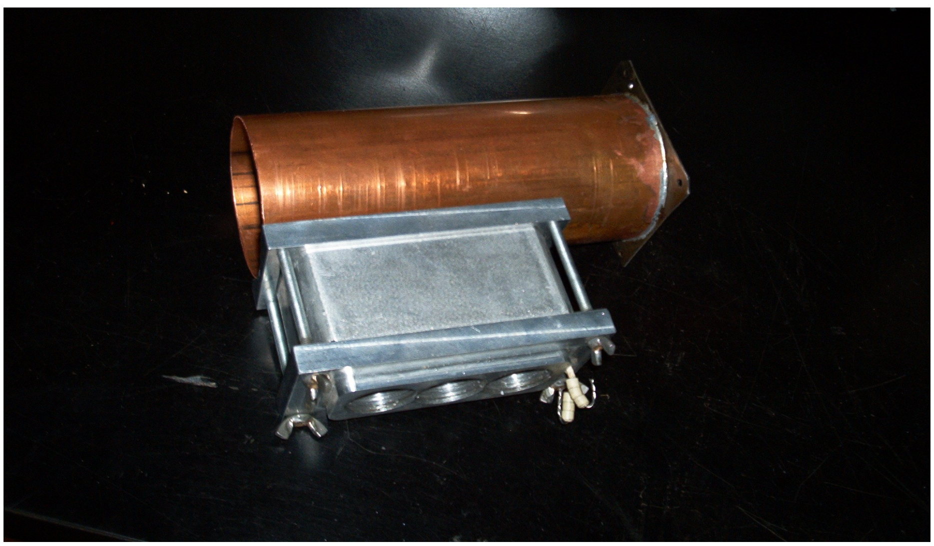


Figure 11 - Final RAFFE prototype

7.1: Design Features

The RAFFE system incorporates many desirable features from previous designs. Key design features include:

- ***Large circumference boiling container***

  A vial with a larger mouth is used to hold the glue rather than the narrow test tube used in the ceramic oven testing. This will eliminate the clogging that was so detrimental to the ceramic oven's performance. Much like the heating tray, a larger container lightly packed with steel wool will facilitate a greater effective surface area of glue so that a larger quantity of vapours 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.

- ***Sealable and Disposable glue container:***

  The vials are disposed of after each use, thus removing most CA residues in one easy step. This dramatically reduces the amount 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.

- ***Use of Preformed Ceramic Instead of Machinable Ceramic:***

  While machinable ceramic could make the design process simpler by allowing essentially any geometry of ceramic, its material properties (as explained earlier on pages 12-13, 15) are not conducive to the robustness required by our application. 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.

- ***Heating effects***

  Pro/E was utilized to accelerate the prototyping process and allow for easy changes to the final design. Our Pro/e drawings were then easily imported into Mastercam where they could be translated into G-code and machined on a CNC.

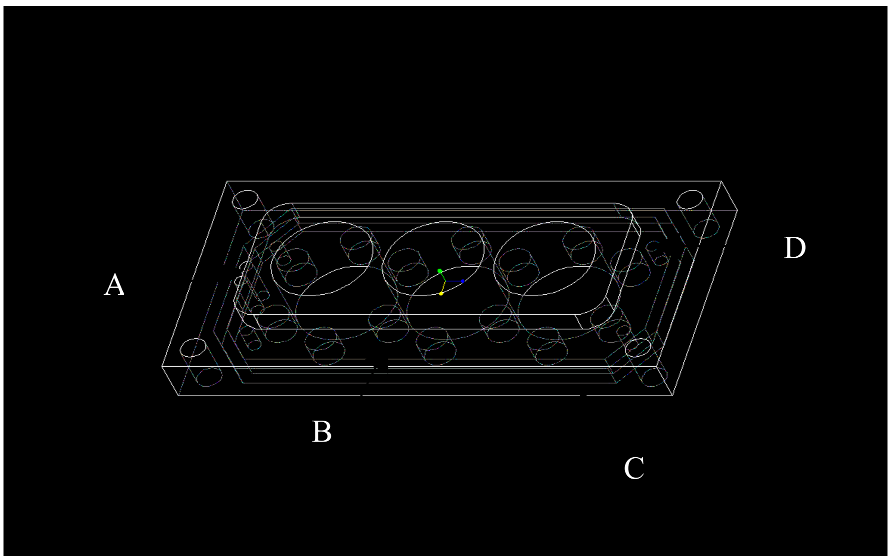
7.2 Design and Material Selection

Top and Bottom Plates:

The top and bottom plates serve to hold the three-vial oven together and to anchor all its internal components. They are both machined out of aluminium primarily because its easy to machine and this drastically reduces the time required to manufacture the plates. While aluminium's soft nature allows for quick construction, it has the major disadvantage in this application of being an excellent conductor of heat. Other metals, such as stainless steel, do not conduct heat as readily but take far longer (up to 9 times) to machine. It was decided that with proper insulation unwanted heat transfer could be minimized and our design could take advantage of the easier construction inherent in using aluminium.

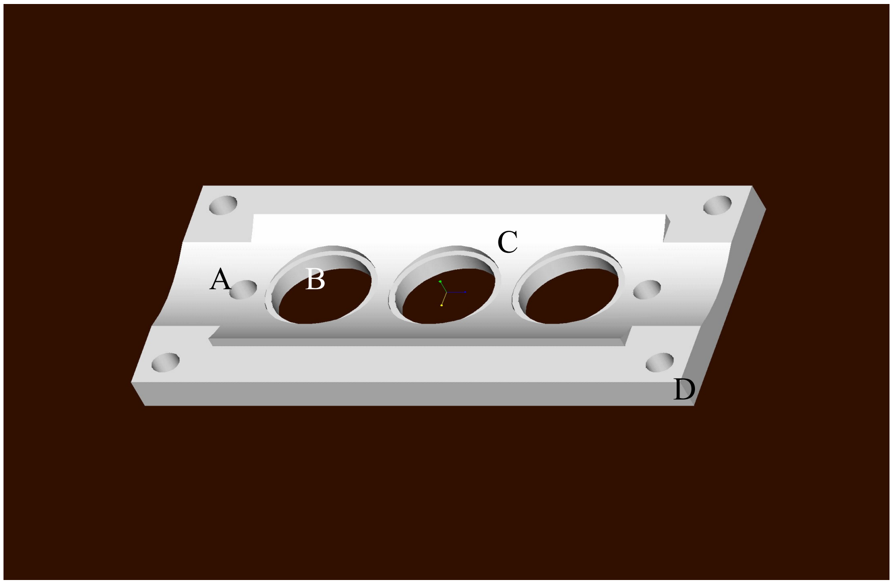
Both Plates are 2 1/2" wide and 5" long with the top plate being 3/8" thick and the bottom plate ¾" thick. Each plate has an identical pattern of 14, 5/16" Ø ceramic rod holes drilled to a ¼” depth on their interior faces. In addition to the ceramic rod holes, three 1” Ø vial holes are drilled through both plates in the configuration shown in figures 11 and 12. The internal surface of these holes on the bottom plate is threaded to allow a brass stopper to be screwed into the oven to hold the vials inside. On the top plate, the hole diameter narrows by 1/32” so that the smaller neck of the vials may protrude through the pipe while its body remains in the oven. This is done so that the glue vapours have no contact the aluminium plates so CA condensation is avoided.

Power for the nichrome element is brought into the oven via two small 1/8” Ø holes drilled through one end of the bottom plate. The electrical wires are protected from shorting and the oven’s extreme heat by small ceramic beads, which are slid onto the wires. Four small 1/8” Ø holes are also drilled to a depth of ¼” in each corner of the interior faces of both plates. These holes facilitate small steel rods, which prevent the ceramic tape insulation from directly contacting the heating elements. A 1/8” wide slot was then machined to a depth of ¼” along a hexagonal path around the oven’s interior holes. Both plates are clamped together onto each end of the shroud by tightening nuts on four ¼” threaded rods inserted through holes in each corner of the plates. This arrangement effectively seals the oven and prevents any unwanted convective heat transfer. The top plate’s outer face has a curved surface machined to match the curvature of the copper pipe. It is attached to the copper tube via two ¼” bolts which in addition to a high temperature automotive sealant ensure that a proper seal is formed to prevent fume loss.



A – Nichrome lead holes
B – Ceramic rod holes
C – Aluminum shroud slot
D – Steel rod holes

Figure 12 – Bottom plate



A – Threaded rod holes
B – Vial openings
C – Top plate curvature
D – Copper pipe mounting
Screw holes

Figure 13 – Top plate

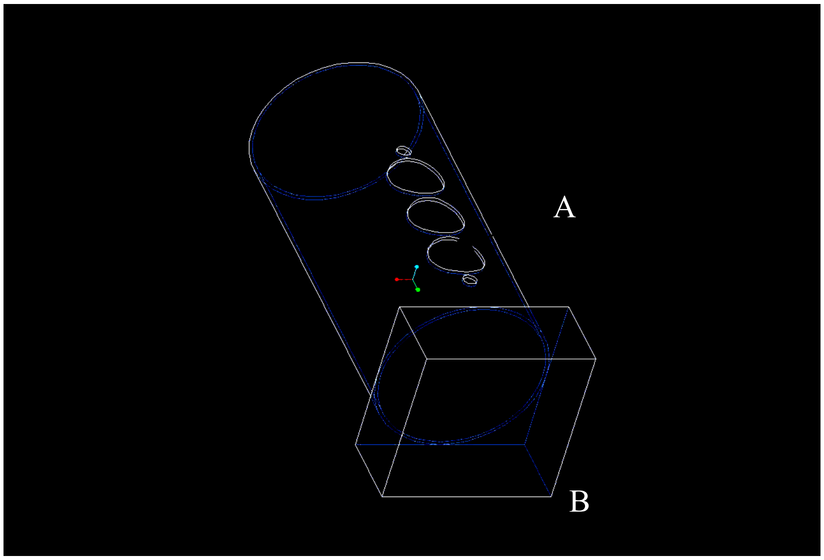
Glue Cartridge:
This component consists of a standard 1” Ø and 2” long laboratory vial lightly packed with coarse grade steel wool. The top ¼” of each vial is narrowed slightly to form a neck which a plastic stopper to allow easy sealing. It was found in earlier testing that fine steel wool has a tendency to auto-ignite under high temperature, whereas the coarser grades are not as susceptible to this problem. The vial is filled to about ½ full with super glue, and inserted through one of the 1” Ø holes in the bottom plate. The brass stopper is then screwed in after the vial to ensure proper placement. After each usage the vials are removed and disposed of.

If the vials are not used immediately an exothermic reaction that occurs between the steel wool and the CA will cause all the glue to crystallize in the vial within a few hours. One method of counteracting this is to add a polymerization retardant such as phosphoric acid. 10-25 drops of acid were found to be effective enough to allow storage of a glue cartridge at room temperature for several days. This would allow a bomb disposal officer to prepare the cartridges well in advance, thus saving valuable time in the field.

***Hexagonal Aluminium Shroud*:**
The shroud is a shell machined out of solid aluminium, and is 3/32” thick and 2 ¼” in height. It is shaped such that it easily fits inside the slot machined into the interior faces of the top and bottom plates. It serves to protect the interior components of the oven as well as to provide support for the insulation necessary to prevent unwanted heat transfer.

Pipe and Fan Assembly:
A 7” length of 3”Ø copper pipe was chosen to provide direction to the CA fumes because it withstands heating well and is readily available. The copper tube has three 1”Ø holes drilled through its underside in the configuration**.** This is done so that fumes from the vials may exit into the pipe. A 12V PC is attached to the end of the tube and provides the necessary airflow

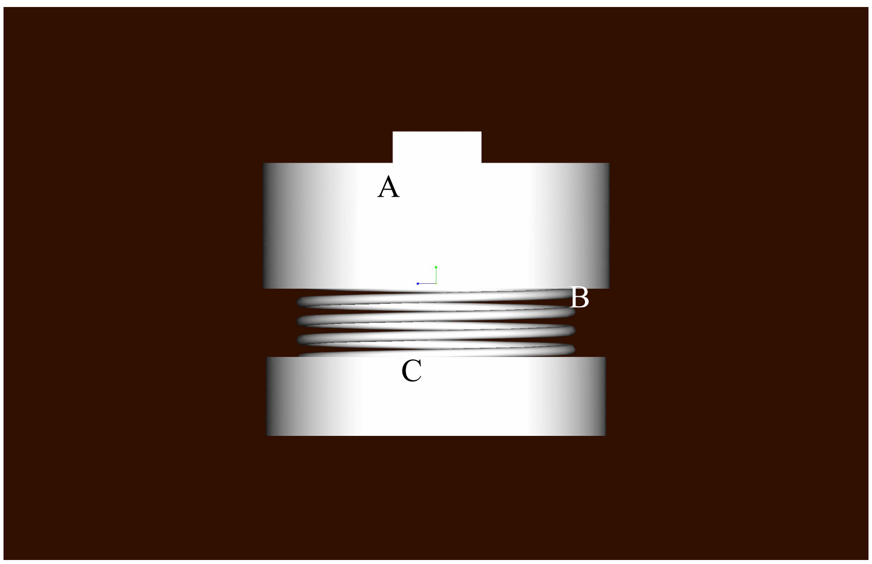
to move the fumes out of the pipe. A powerful fan is not required, as high velocity fumes will not develop latent prints as easily.



A – Three vial openings
B – Fan mount

Figure 14 – Pipe and fan assembly

Aluminium Stopper:
To hold the vials inside the oven, a brass stopper is screwed in against each vial through the 1”Ø vial holes in the bottom plate. The exterior face of each stopper is threaded so that it can be loosely twisted into the threading on the inside of the 1”Ø vial holes. The lower ¼” of the stopper protrudes from the bottom plate when fully inserted and has a knurled surface for easy handling. The top surface of the stopper is attached to a coiled spring, which is then mounted to a ceramic disc as shown in figure 15. The spring serves to maintain a constant force against the glue cartridge, thus keeping it in the same position during operation.



A – Aluminium threaded cap
B – Spring
C – Ceramic bottom

Figure 15 – Aluminium stopper

Insulation Panels:

The interior of the oven is insulated used a multi-layer concept. This is designed to both reflect radiant heat from the nichrome element as well as to insulate against unwanted heat transfer to the structural components of the oven. All insulation layers are applied to the interior of the oven so as to minimize the air volume that unnecessarily heated.

Our insulation scheme consists of an inner layer of aluminium foil (closest to the elements to reflect a large portion of the radiant heat), which is then surrounded by ceramic tape insulation (to prevent heat transfer). Another layer of foil is then added and surrounded by a final layer of ceramic tape. These layers are pre-cut so they will fit around all the interior components of the oven i.e. the ceramic rods. They are then glued together using a high temperature adhesive and then glued onto their respective interior oven surfaces. This adhesive need not be particularly strong it only needs to hold each insulation panel together during assembly and installation into the oven. After this point, the panel's geometry is sufficient to hold each panel in place. There are three insulation panels. Two are nearly identical and are attached to the interior surface of both aluminium plates within the hexagonal slot (which houses the shroud). The third panel lines the interior of the shroud and is prevented from touching the elements by the 1/8" steel rods and the ceramic rods.

The ceramic tape adhesive was chosen because of its excellent tolerance of high heats as well as its ability to slow heat transfer. It was also readily available, is easily cut and bent to any shape required.

Nichrome Heating Element and Ceramic Rods:

Preformed ceramic rods were chosen to secure the nichrome heating element, as they did not possess the same potential structural weaknesses seen in machinable ceramic. Each of the 14 rods are slightly less than 5/16" Ø and are cut using a tile saw to 2 ¼" in length. The rods are then inserted into the appropriate holes in the bottom plate (see figure 11) and glued into place. During assembly the holes on the inner face of the top plate fit precisely over the rods to further prevent any movement during operation. A 3Ω nichrome is then fed into the oven via two 1/8" Ø holes in the bottom plate and wound through the ceramic tubes around all three vials. This arrangement heats each vial in an even fashion because the element is not in direct contact with each vial. There are no significantly hotter or cooler regions, which could ignite the glue or cause condensation.

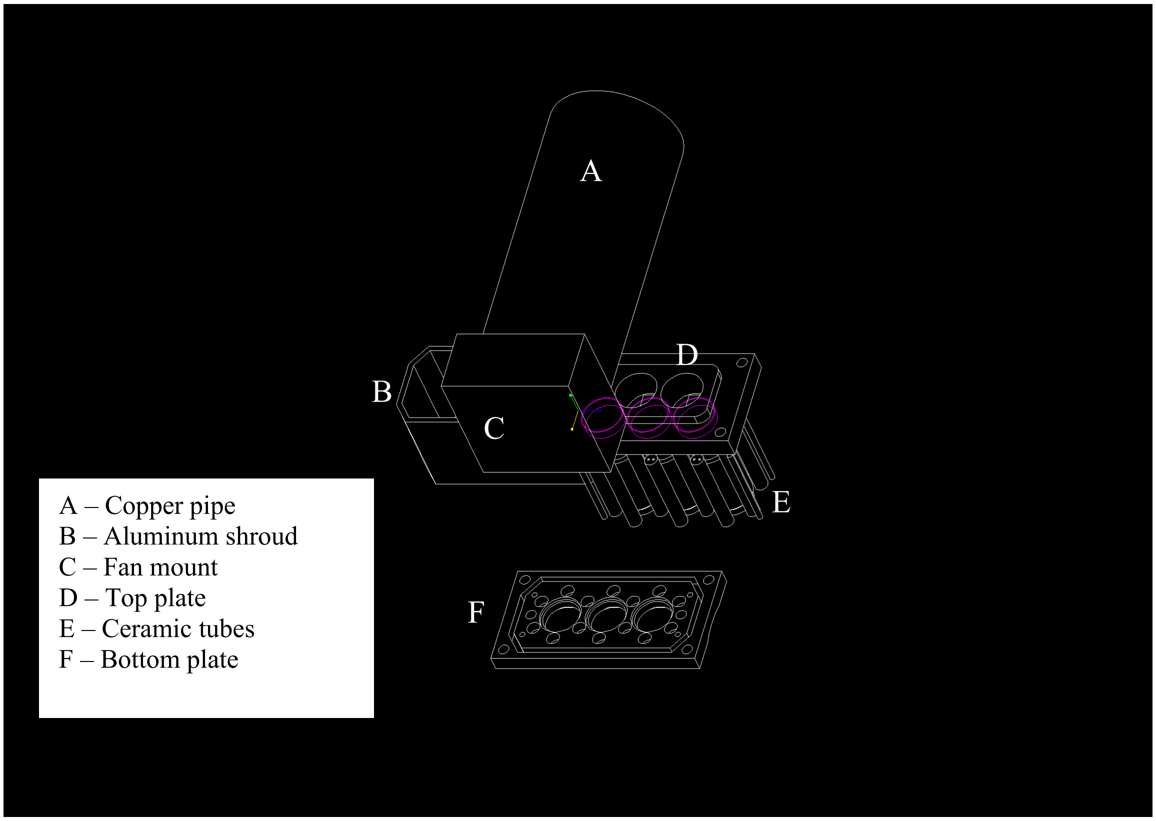


Figure 16 – RAFFE final opened assembly

7.2 Results and Discussion

The efficiency result for this design was 56.6% with 24 volts applied. Consistent fumes were visible throughout a 25 minute 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 Figure 17. The fingerprint became visible after five minutes. Note that these results were obtained in a fume hood and that conditions may be very different when the device is used in the field. The device has been delivered to the Calgary Police Service for field testing.

Figure 17 – Fingerprinted vial container

7.3 Conclusion

The results from the preliminary test of the RAFFE device are encouraging. Further testing is required to optimize factors such as voltage, glue level, and fan speed. Enhancements such as the use of steam to hydrate the print and a fuming shelter to control the fumes may improve its performance.

8. Conclusions

This project stemmed from a need expressed by the Calgary Police Service 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. Six design alternatives were created based on principles of conduction, convection, and maximizing the amount of glue surface area to heat. The most promising design alternative was developed into a working prototype, called RAFFE. It is recommended that future design enhancements consider the addition of a fuming shelter and a steam emitter.

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.

Appendix A

Table 1

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	367	77.75

Table 2(A)

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 wool 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

Table 2(B)

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 wool 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

Table 3

Heating tray experimental results							
Voltage (V)	Current (A)	Mass of glue (g)	Glue fumed (g)	Total fuming time (sec)	Visible fuming time (sec)	Steel wool 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

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