IDEA

Innovations Deserving Exploratory Analysis Programs

Transit IDEA Program

Detection of Explosives and Weapons in Transit Systems

Final Report for Transit IDEA Project 56A

Prepared by:
Dr. Kirill Mostov, Systems Micro Technology Inc.

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IDEA Programs Transportation
Research Board 500 Fifth Street,
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TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

Systems Micro Technology Inc. (SMT) has developed and tested a small-size, low-cost, extremely low-power prototype (KIED) enabled to detect explosives and weapons in transit systems. The system is totally safe for humans and animals. During this project, SMT demonstrated the feasibility of detecting various components of improvised explosives devices (IEDs) including explosive compounds, liquid, and strong reflectors (e.g., shrapnel and other metallic materials). SMT's system also has the capability to measure the psychophysical parameters (stress level) of the suspected terrorist remotely in order to increase the confidence of detection of potential threats.

During this project, SMT demonstrated the feasibility of detecting explosives and other dangerous objects and monitoring the cardiopulmonary state of human subjects using the KIED prototype in a non-revenue environment.

Four key activities were successfully completed during this project:

- The investigators developed a unique prototype, called KIED.
- In collaboration with Lawrence Livermore National Laboratory (LLNL), SMT's investigators successfully demonstrated that the KIED prototype can detect explosive compounds and strong reflectors in a laboratory setting.
- The KIED prototype was incorporated into a Bay Area Rapid Transit (BART) fare gate in a non-revenue environment.
- Field tests were successfully performed.

2. IDEA PRODUCT

The objective of this Transit IDEA project was to develop and test a prototype system based on unique and innovative technologies. The system operation relies on SMT's proprietary, breakthrough know-how of polarizing radiolocation and ion spectrometry analysis.

2.1. Proposed System

The proposed system, KIED, utilizes three remote detection mechanisms simultaneously to improve detection reliability and minimize false positives.

1. Polarization sub-system—The first sub-system is based on the newest, Frequency Modulation technology and the respective low-cost component base, which enables the affordable nature of the overall offering. This unit evaluates the polarization characteristics of typical shrapnel and other metallic materials. This unit can operate through opaque obstructions; for example, through clothing, bags, and walls.
2. Spectrometry sub-system—This sub-system utilizes ion mobility spectrometry technology. It samples, ionizes, and analyzes the ambient air to detect the presence of vapors from explosive materials. The system inspects the air surrounding the passenger while he or she is waiting for the payment to be processed. It can remotely sample objects and analyze the vapor emitted within 3–5 sec.
3. Psychophysical sub-system—This unit can remotely monitor vital parameters such as the heartbeat and respiratory rate of the suspected terrorist. The remote measurement of these parameters could aid in identifying high-risk threats during interrogation at checkpoints.

The first two sub-systems will be implemented directly inside the fare gate and analyze passengers while the payment is been processed. The last sub-system will be integrated into the attendant's booth (a drawing of the installation is found in Figure 2). Power consumption and weight-dimensional characteristics of the device are small enough to be integrated inside existing infrastructures (gates and station manager). Owing to the estimated low cost of the future production the device can be widely deployed to improve security in rapid rail transit systems.

2.2. Payment and Detection Process with KIED

The KIED system will scan every passenger while they are inserting their tickets into the fare gate. The scanning will last about 3 sec, which will not delay the payment process. While the console checks the ticket or smart card validity, the KIED system will scan for explosives. The new procedure will be very similar to the currently implemented procedures for dealing with bad or invalid tickets. Figure 1 shows the full process. If no explosive substance is detected, the process will be identical to the current procedure. If an explosive compound is detected during the scanning, the ticket would be rejected, the suspect asked to see the attendant ("See Agent"), and an alarm sent to attendant.

Once the suspected terrorist has been identified at the fare gate the secondary step, verification, can be implemented at the attendant's booth. The suspect will be asked to show his fare ticket to the attendant, where additional screening by our device will take place. The attendant will attempt to keep the terrorist suspect in front of the booth for as long as possible until the arrival of law enforcement staff. The additional device discretely located surrounding the suspect in front of the attendant's booth will scan the subject a second time to validate the results of the fare gate device. This device will also measure the psychophysical parameters (stress level) of the suspected terrorist remotely. The secondary validation and the measurement of psychophysical parameters will greatly increase the confidence of detection and consequently reduce the False Alarm Rate (FAR). This process will not be regarded as unusual, since the general public is already accustomed to having to deal with "bad" tickets once in a while.

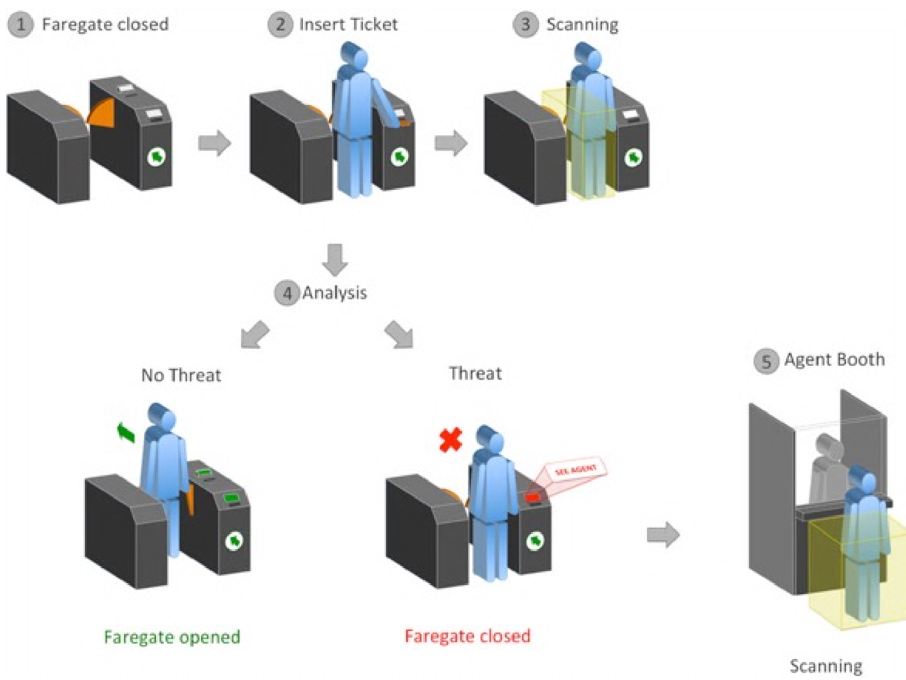

FIGURE 1 Detection process.

3. CONCEPT AND INNOVATION

Transportation systems are very vulnerable to terrorist threats. The tragic attacks in Madrid, London, Mumbai, and Moscow brought home the horror of this vulnerability. Transportation systems are not well prepared to resist terrorism on their own, which is why new technologies to screen people for potential threats need to be broadly deployed to ensure safe, timely, and undisrupted travel. Today's people-screening systems deliver unacceptable performance with high false alarm rates, slow throughput, high probability of human error due to dependence on security personnel, and high costs. Most importantly, non-metallic weapons, liquid, and plastic explosives are not detectable with traditional methods.

Furthermore, current methods require passengers to be singled out in order to be searched effectively, which is not practical in the a public transportation setting, where

- Passengers will not accept delays or inconveniences;
- Dedicated personnel for screening is not customary and comes at a too high a cost; and
- Large numbers of access points exist.

Systems Micro Technology Inc. (SMT) has invented a system, KIED, which solves the existing problems in a cost-effective way, which is ideally suited for the demanding public transportation setting. The KIED device detects dangerous objects, even those that cannot be detected with conventional metal detectors, such as suicide bomber vests. Potential threats can be detected even if hidden behind walls, garments, and inside luggage. KIED is safe, not harmful to people, reliable, and reduces the cost of screening.

The KIED device can be easily integrated into the existing infrastructure available in the public transportation setting and can be easily installed at existing security check points. It will provide accurate information about whether a person poses a credible threat or not.

4. INVESTIGATION

The work performed during this project included (1) defining project requirements, (2) developing and building the KIED prototype, (3) integrating the KIED prototype into a fare gate, and (4) performing in-lab and field tests.

4.1. Task 1: Define project requirements

The objective of this task was to specify which basic explosive components and compounds are most likely to be used in improvised explosives devices (IEDs). As described below, IEDs are complex explosives generally built using a wide range of commercial components, chemicals, and compounds that are readily available to civilians in most countries including in the United States.

4.1.1. Identify basic explosive compounds

Identifying IEDs is far more difficult than detecting weapons, because explosives do not have defined and predictable forms and signatures. IEDs are often difficult to identify because they are constructed by terrorists entirely to their own designs. They can be liquid or solid and in any shape or size. As far as the technical aspects of constructing IEDs are concerned, terrorist devices have ranged from bombs made from normal everyday items, to highly sophisticated devices utilizing digital components. IEDs used in bomb attacks in train stations and other government buildings are often suicide bombs carried in a bag, box, or other object, or worn under the clothing of the bomber. These types of bombs have a higher quantity of explosives to create bigger detonation (*1*).

IEDs are comprised of a few basic components, which will vary in basic appearance, but generally always be present. The component parts of an IED are explosives, shrapnel, power supply, a detonator, a switch/timer, and wiring.

Most component parts of an IED are common commercial products that are difficult to detect in fare gate application. Our investigators decided to focus on the most critical and dangerous compounds and components; the explosive compounds and shrapnel.

- Explosive—The explosive charge in an IED can be military, commercial, or homemade explosives. Types of explosives that have been used by terrorists include RDX, C4, SEMTEX, PETN, TNT, dynamite, black powder, and also homemade improvised explosive mixtures based on common ammonium nitrate fertilizers and other readily available household ingredients such as wax, oil, paraffin, and sugar. Nitrate-based explosive compounds including PETN and TNT have been used in recent IEDs and suicide bombs. Lately, numerous bomb attacks and attempts were made using PETN including the 2001 shoe bomber (*2*), the 2009 Christmas Day bomb plot (*3*), the 2010 cargo plane bomb plot (*4*), and the 2012 Al-Qaida bomb plot (*5*). The 2009 Nevsky Express bombing in Russia (*6*) and 2011 Moscow airport bombing (*7*) were both made with TNT. The 2011 Mumbai bombings and the 2006 Mumbai train bombings were made with ammonium nitrate-based explosives (*8*). During this project, SMT's investigator collaborated with Lawrence Livermore National Laboratory (LLNL) to conduct experiments using a vast variety of real explosives such as TNT, RDX, and PETN.

- Shrapnel—Terrorists sometimes include shrapnel in their IEDs to cause greater injuries. Shrapnel is composed of metal fragments such as nails, nuts, and bolts, which are thrown out by an exploding bomb or shell. In an explosion, shrapnel can travel up to 6000 km per hour, inflicting horrific injuries. The detection of shrapnel was tested for during this project.

- Power supply—Power supplies, often using commercial batteries, are used to power IEDs. Power sources are difficult to detect at fare gates due to their similarity with commercial items carried by daily commuters. To avoid high false alert rates, power supplies were not used as an IED detection component during this project.

- Detonator—Most explosives use a detonator to trigger the explosion of the IED. Detonators are made from a copper, glass, or aluminum tube, closed at one end. Detonators are generally extremely delicate structures, about 6 mm in diameter and 25 to 150 mm in length. Owing to their small size and relative lack of density detonators can be difficult to detect and therefore were not tested in this project.

- Switch/Timer—A switch can either be a complex electronic component or something as simple as two intersecting loops of wire. Delay switches time the explosion by clockwork, digital, thermal, chemical, or electro-chemical mechanisms. Switches can also detonate a device by remote control. A switch can be just one tiny and common component, so it is really difficult to detect in fare gate applications and was not tested in this project.

- Wiring—Wiring is required to inter-connect the components of an IED. Terrorists will often use various lengths of wire. Wiring was not tested in this project.

Two categories of IEDs are used for building attacks, Type I—carried in bag and Type II—worn under clothing. Device sizes may range from 5 lbs. to 30 lbs. (*1*). In the 2011 Moscow airport bombing, the terrorist used an improvised explosive device packed with shrapnel and pieces of chopped wire with about 15 lbs. of TNT (*7*). Although the typical sizes of IEDs are bigger, during this project SMT's investigators performed experiments using only small amounts of explosives due to the availability.

The following compounds were tested during this project: TNT, SEMTEX 1H, RDX, PETN, C-4, Comp B, PBX, black powder, and shrapnel. The latest bomb attacks and attempted attacks demonstrate that the selected compounds cover all types of IEDs and Suicide Bombs.

4.1.2. Prototype integration

As described in section 4.2 of this document, KIED consists of three sub-systems which will work simultaneously to detect (i) explosives and (ii) shrapnel and other metallic objects and (iii) psychophysical parameters.

The sub-systems allowing the detection of explosives and shrapnel will be integrated into the fare gate. Based on the current design of the gates, to be able to scan the full body, two sub-systems will have to be placed on top of the console (processing part and upper antennas) as well as on the side (lower antennas). The potential location of two sub-systems inside the fare gate is shown on the left of Figure 2. The three sub-systems will also be integrated into the agent booth (manager station) as shown in the right of Figure 2. In this project, the investigators integrated the prototype in a non-revenue environment using a BART fare gate.

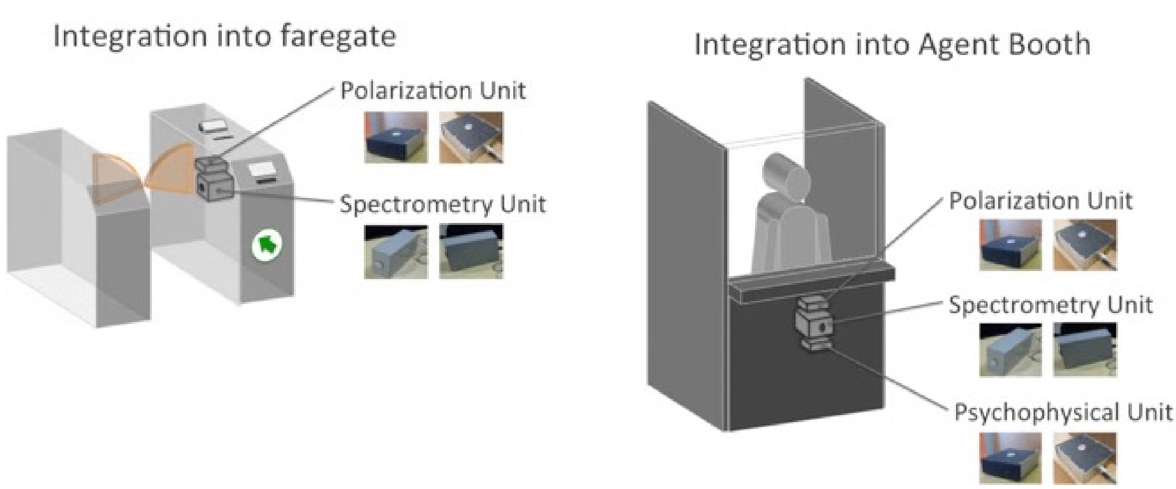

FIGURE 2 Integration into fare gates (*left*) and agent booth (*right*).

4.2. Task 2: Develop KIED prototype

During this project, the investigators developed and built a unique system, KIED, based on two innovative technologies (Figure 3). This prototype combined three remote detection mechanisms that detect explosives using ion spectrometry, strong reflectors (e.g., shrapnel and other threatening objects) using polarization, and cardiopulmonary (psychophysical) parameters using radar. Our polarization and our psychophysical units use frequency modulated radar, while our spectrometry unit is based on ion mobility spectrometry technology.

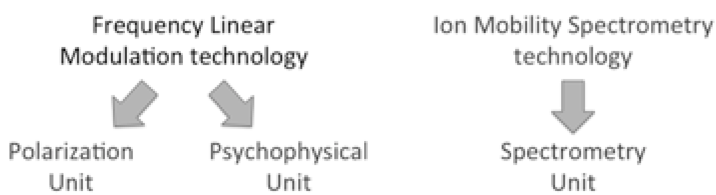

FIGURE 3 Technologies used for each sub-system.

The integration of multiple technologies dramatically improves the detection reliability of IEDs by relying not only on detecting explosives but also on detecting other commonly used IED components such as shrapnel and other threatening objects. While spectrometry has been proven efficient for detecting explosives, this technology is not able to detect shrapnel and other non-vaporous materials.

4.2.1. Sub-system #1: Polarization

SMT uses frequency modulation technology and the respective low-cost component base, which enables the affordable nature of the overall offering. The system operation relies on proprietary, breakthrough know-how of polarizing radiolocation of the effective surface of the observable object. If common radio-transparent materials are used to provide a disguise, the attempt would be thwarted by the ability of the KIED unit to "see-through" such camouflage. In the case of a suicide belt, the KIED system will be able to detect shrapnel in any possible shape or form and positively identify the threat. Even in the case of non-radio-transparent camouflage, the system will be trained to detect large "non-penetrable" areas and trigger a suspicion alarm.

The photograph of the polarization sub-system prototype is presented in Figure 4.

FIGURE 4 Polarization prototype.

Detection of the presence of an IED is based on the depolarization analysis of the signal reflected from the target. The depolarization effect makes it possible to detect the presence of the suicide belts that contain metal. A radiolocation signal contains two components: (1) diffusive hum, and (2) reflection from bright points.

Diffusive hum is conditioned by the target roughness having specific dimensions that are less than wavelength. Diffusive hum has no primary direction in the limits of the demi-sphere. Hum polarization is random and weakly depends on the polarization of the probing signal. Thus, diffusive hum brings a small contribution in reflected (scattered) signal.

Bright points (*glares*) on the target bring significant contribution in the scattered signal. The cause of this is that there are small mirrors on the target. These mirrors are oriented normally to sighting line. If their dimension is near half of the wavelength (half wave dipole), then contributions into scattered signal will be maximum. Polarization plane rotation for scattered radiation (*H*) relative to the probing one (*E*) depends on dipole orientation. Locator antenna emits linearly polarized wave with vertical polarization (*E*) (see Figure 5).

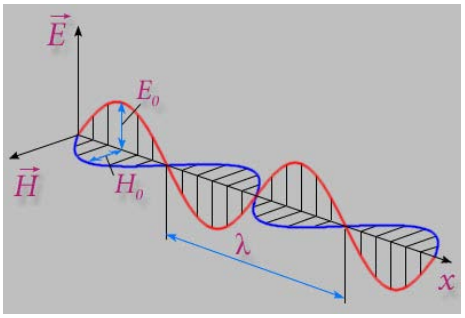

FIGURE 5 Vertically (*E*) and horizontally (*H*) polarized waves.

When a signal reflects from a shrapnel element, the polarization plane rotates and polarized waves with horizontal components (*H*) appear. As shown in Figure 6, if the probing radiation is polarized vertically (*E*) and the dipole is oriented under 450°, then the scattered signal will contain both vertical (G2,1) and horizontal (G3,1) polarizations.

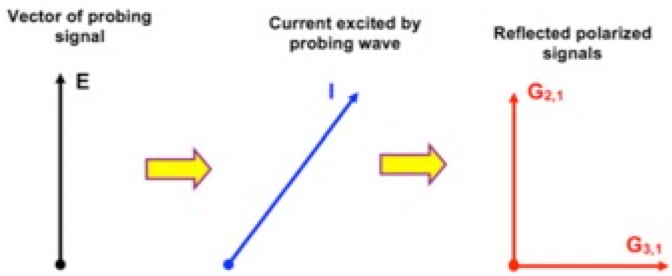

FIGURE 6 Forming scattered signals, polarized in horizontal ($G^*_{2,1}$) and vertical ($G^*_{3,1}$) planes, if probing signal scatters on a sloping string.

It is convenient to evaluate the effect of cross-polarization appearance using coefficient of depolarization:
B = (G2,1*- G3,1*)/(G2,1*+ G3,1*).

When the target is a half wave dipole turned 45^o toward the horizon, the proposed coefficient *B* will be equal to zero. Less corresponds to projection of the vector *B*, more to increasing probability that the given object is armed. As described in multiple experts' publications, suicide belts are often furnished with 1 cm nails or bolts that have accidental orientations in space. Such an object has significant depolarization and should be evaluated as:

$B < B_{shahid\_belt}$, where B_{shahid_belt} is the threshold value that is set a priori and defined by the class of searched suicide belts.

Small details of firearms and cold steel exposed in special fore-shortenings also have depolarizing properties. The depolarization coefficients for suicide belt and for firearms differ significantly:

$B_{\text{weapon}} > B_{shaxid\_belt}$, where B_{weapon} is the calculated coefficient of depolarization of firearms.

Figure 7 shows the block diagram of the polarization unit. This unit has five antennas, four emitting vertical polarization, and one emitting horizontal polarization.

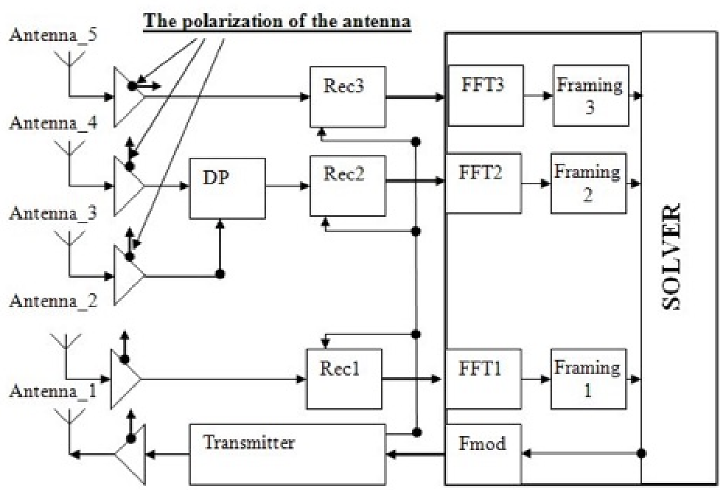

FIGURE 7 Block diagram of device prototype.

- Antennas 1 to 4—emitters with vertical polarization;
- Antenna 5—emitter with horizontal polarization;
- DP—difference diagram former;
- Fmod—transmission signal modulator,
- Rec1,2,3—SHF receivers providing selection of LF component of the input signal owing to multiplication of input and output (emitted) signals;
- FFT1,2,3—fast Fourier transform;
- Framing 1,2,3—framing units:
- Framing 1—array of input information for main channel: selection of dynamic targets;
- Framing 2—array of input information for azimuth calculation;
- Framing 1, Framing 3—arrays of input information for polarization analysis of weapon presence;
- SOLVER—computational device executing processing algorithm.

Table 1 shows the main characteristics of the prototype.

TABLE 1
FM RADAR CHARACTERISTICS

Frequency band	10.5–11.5GHz
Modulating frequency	120Hz
Radiating power	8 mW (uninterrupted)
Work distance up to objects	0,5-5 м
Work angle of sight	60° horizontally and 55° vertically
Dimensions	160 x 135 x 50 mm
Mass	1.900 kg

4.2.2. Sub-system #2: Spectrometry

Our prototype, KIED, utilizes ion mobility spectrometry technology. This sub-system samples, ionizes, and analyzes the ambient air to detect the presence of vapors of explosives. The system inspects the air surrounding the passenger while he or she is waiting for the payment to be processed. It can remotely sample objects and analyze the vapor emitted within 5 sec.

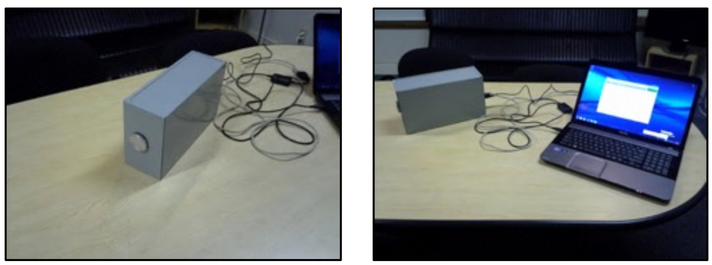

FIGURE 8 Spectrometry sub-system: Detection unit (*left*) and full sub-system (*right*).

Our spectrometry sub-system process includes four distinct phases as shown in Figure 9. In the first phase, air from the environment is vacuumed and sampled. This is accomplished by vacuuming the sample using a pump located in the front of the device, also called the nose. In the ionization phase, the air is electrically charged or ionized. This is accomplished using a small radioactive isotopic source. Under the influence of an electric field, the mixture of reactant and product ions reaches the gate grid that separates the ionization region and the drift tube. The grid is made of a set of mesh wires with a voltage bias between them. The ions are attracted to the grid and then transmitted to the drift tube. The chamber is equipped with an electric field that draws the ions to a detector. When the ions reach the end of the drift tube, they collide into the collector and generate electrical signals. The characteristic speed at which an ion moves through the drift region, called ion mobility, is a distinct fingerprint that identifies the original substance.

FIGURE 9 Block diagram of spectrometry sub-system.

The measured drift time (t) through an electric field gradient E (V/cm) is related to the mobility of the ions K

$\boldsymbol{v_d} = \boldsymbol{K.E}$, where $\boldsymbol{v_d}$ is the drift velocity (cm/s).

$\boldsymbol{K} = \dfrac{\boldsymbol{d}}{\boldsymbol{E.t}}$, where d is the length of the drift tube (cm).

The reduced mobility of ions (K_o) is: $$K_o = \left(\frac{d}{E.t}\right) \cdot \left(\frac{273}{T}\right) \cdot \left(\frac{P}{760}\right)$$

Where T is temperature (Kelvin) and P is atmospheric pressure (torr).

4.2.3. Sub-system #3: Psychophysical

The psychophysical unit is based on the same technology as the polarization unit, frequency linear modulation. Detection of human breathing is based on the analysis of fluctuations of amplitudes of the received signal, which is caused by the change of the radar cross section (RCS) of a breathing person. Breathing patterns indicate whether the person is stressed or not. Breathing detection will utilize special filtering of the input signal. Average breathing frequency is on the order of 12 breaths per minute; therefore, the recording time should not be less than 2.5 sec (half-period). This condition is necessary for effectively distinguishing breathing people from motionless and inanimate objects. The amplitude of respiratory effect changes approximately 10% of the target RCS. The measurement of breathing frequency with an accuracy of 40%-60% requires an observation time of 5 sec.

The structure of an initial processing algorithm for input signal is represented in Figure 10.

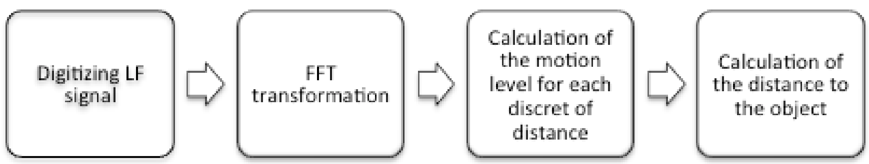

FIGURE 10 Initial input signal processing.

The algorithm consists of:

- LF signal passed mixing and digitization by an A/D converter to allow FFT transform analysis. Each harmonic corresponds to a concrete distance. In the current prototype, distance discretion equals 12 cm.
- Calculation of the motion level in the each distance discret. Harmonics having the maximum motion level is assigned to be the main one.
- To detect breathing rates, the harmonic, corresponding to object's distance, is passed through the filter cutting off all the frequencies above 30 ppm. Then the device performs a search of the local maximums and minimums to determine the breathing period and frequency (see Figure 11).
- To determine pulse frequency, the band-pass filter band is adjusted to a band from 40 to 240 ppm and the signal is processed with the corresponding distance discret. The motion of the human skin caused by tachycardia is measured by movement on the order of fractions of a millimeter. Amplitude of the pulse signal change is by one order less than amplitude of the thorax excursion during the breathing act. To ensure needed trustworthiness, we used an autocorrelation method allowing the selection of a periodic component and calculating its frequency even when the noise content of the signal is high (see Figure 12).

FIGURE 11 Calculating breathing frequency.

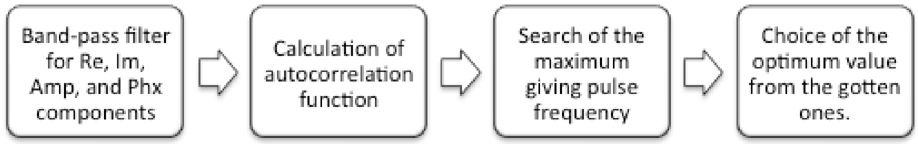

FIGURE 12 Calculation of the pulse frequency.

A typical signal caused by an actual breathing person is shown in Figure 13. Two components are clearly visible in the signal spectrum:

- The breathing component has a frequency at 0.2 Hz; and
- The heartbeat component has a frequency at 1 Hz.

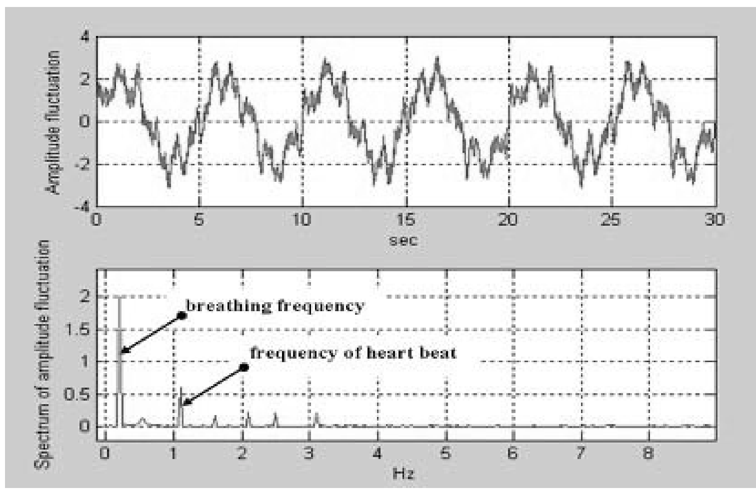

FIGURE 13 Typical signal of amplitude fluctuations caused by the person and its spectrum.

The principle of frequency linear modulation is described in detail in the Stage I report.

4.3. Task 3: Full-featured testing in the lab

Extensive experiments have been done to demonstrate the ability of the three sub-systems to detect IEDs as well as psycho-physical parameters. The experiments related to non-explosive compounds were performed at SMT's laboratory in Berkeley, California. The experiment with explosives was performed at LLNL's laboratory in Livermore, California.

4.3.1. Experiment with polarization unit

The experiment was performed on six subjects with strong reflectors (shrapnel belt and knife). The KIED polarization prototype was installed on a table as shown in Figure 14. The unit was connected to power outlet using a 12V power supply. The processing was performed using a laptop. The tested threatening objects are shown in Figure 15

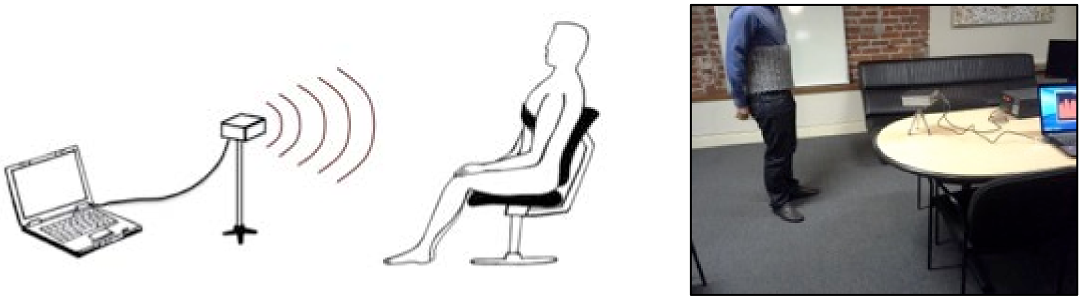

FIGURE 14 Experiment setting.

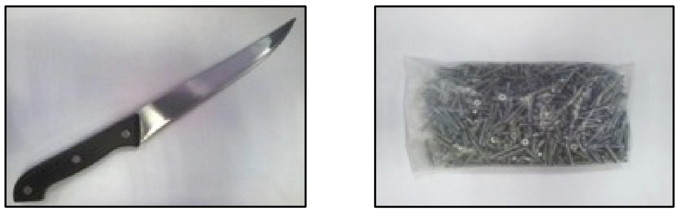

FIGURE 15 Objects tested—Knife (*left*) and shrapnel (*right*).

Figure 16 shows the channels of the input signal (*Y* axis), reflected from the object, at different distances from locator (*X* axis). The input channels have the following designations:

- Channel 1—Main channel. It is designated for selection of psychophysical parameters (breathing and pulse frequencies);
- Channel 2—Polarized channel. It receives polarized signal reflected from the object;
- Channel 3—Additional channel. It allows for determination of the object's azimuth.

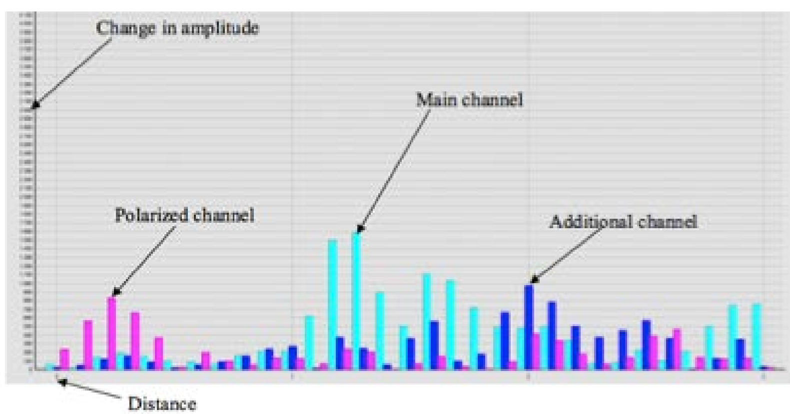

FIGURE 16 Explanation of radar output.

During the testing process, the following readings were recorded for each person: (1) without threatening objects, (2) with a knife, and (3) with a shrapnel belt. The results of the experiment are shown in Table 2. Figure 17 shows the graphs obtained for subject A with and without a shrapnel belt. While the main channels show similar amplitudes, the polarized channels are different. The amplitude of polarized channels with shrapnel belt (*right*) is drastically higher.

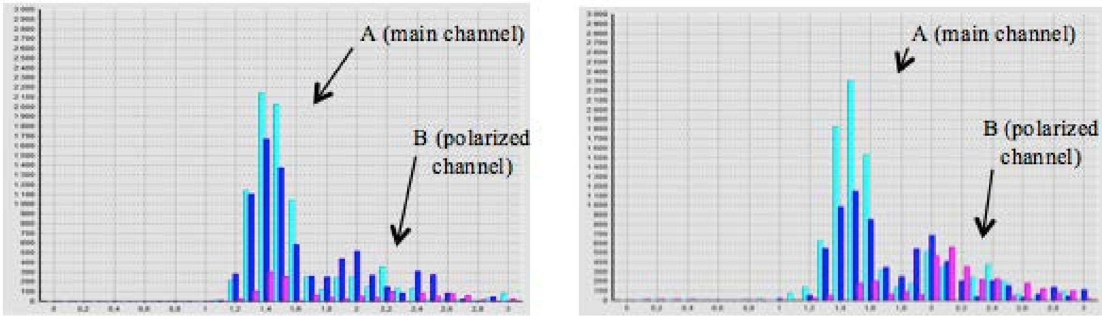

FIGURE 17 Radar output for subject A—Without dangerous object (*left*) and with shrapnel belt (*right*).

TABLE 2
TESTING RESULTS

Subject	Polarized channel	Subject	Polarized channel
Subject_A	300	Subject_D	300
Subject_A + knife	350	Subject_D + knife	750
Subject_A + belt	550	Subject_D + belt	400
Subject_B	400	Subject_E	700
Subject_B + knife	600	Subject_E + knife	400
Subject_B + belt	600	Subject_E + belt	1700
Subject_C	500	Subject_F	300
Subject_C + knife	450	Subject_F + knife	600
Subject_C+belt	650	Subject_F+ belt	800

4.3.2. Experiments with spectrometry unit

The experiment was performed to demonstrate the capability of detecting explosives. To gain access to military, commercial and homemade explosives, the investigators collaborated with LLNL. The investigators worked with Dr. Amy Walters, Program Leader at Lawrence Livermore National Laboratory. Dr. Walters' team is experts on explosive characterization and detection, and the protection of transportation infrastructure. LLNL's staff was responsible for handling explosives and performing the tests (Figure 18).

The spectrometry unit was installed on a table and connected to a laptop. The target objects were placed at 5 and 15 cm (2 and 6 in.) from the "nose" of the spectrometry unit. As shown in Table 3, the explosives used during this experiment were TNT, SEMTEX 1H, RDX, PETN, C-4, Comp B, and PBX, as well as black powder.

FIGURE 18 Experiment setting at LLNL lab—Test with C-4 at 15 cm (*left*) and test with Comp B at 15 cm (*right*).

TABLE 3
CHARACTERISTICS OF EXPLOSIVES

Explosive name composition	**Weight (g) Dimensions**	**Distance (cm)**	**Result**			
			Detected?	**Detection time?**	**Type of explosive**	**Value**
Background noise (for reference)						0.01
TNT, Pressed parts	101.8 g ¾'' x 1''	5 cm	Yes	4 sec	TNT	1.5
		15 cm	Yes	5 sec	TNT	1
SEMTEX 1H 60.5% RDX, 25.0% PETN, 11.6% semtexoil, 2.9% rubber (styrene/butadiene) Plastic explosive	150.5 g Log ~12 cm x 4 cm	5 cm	Yes	5 sec	RDX PETN	1.5 1.5
		15 cm	Yes	5 sec	RDX PETN	0.3 0.3
C4 , 91% RDX, 5.3% dioctyl sebacate, 2.1% polyisobutylene, 1.6% oil Plastic explosive	105.2 g Sphere of material	5 cm	Yes	4 sec	RDX	1.5
		15 cm	Yes	4 sec	RDX	1.2
PBXN-301 80% PETN, 20% silicone resin Extrudable	149.6 g clumps	5 cm	Yes	5 sec	PETN	2
		15 cm	Yes	5 sec	PETN	1.4
Comp B 59–65% RDX, 36–40% TNT, wax Pressed parts	138.0 g ¾'' x ¾ '' parts	5 cm	Yes	5 sec	RDX TNT	2 2
		15 cm	Yes	5 sec	RDX TNT	1.5 1.5
LX-10 95% HMX, 5% Viton-A Pressed parts	119.6 g 1''x1'' parts	5 cm	Yes	5 sec	RDX	3.5

Figure 19 illustrates the sample results for some of the explosives. The spectra “a” shows the baseline of the system after calibration. Due to the background contamination, the system needed to be calibrated to ensure the background noise did not disturb the measurements. The spectra “b” shows that the spectrometry unit was able to clearly detect TNT at a distance of 5 cm. Spectra “c” and ‘d” show that our spectrometry unit is able to detect multiple explosive compounds. For all explosives, the signal amplitudes at 15 cm were around 3 to 4 times lower than at 5 cm.

The room where the experiment was performed is used to stock explosives and therefore the air was contaminated with explosive vapor. To avoid false positive detection, SMT’s investigators had to adjust the detection baseline by calibrating the system. These calibrations drastically attenuated the strength of the signal and thus the signal amplitude was lower than expected, especially at 15 cm. In a real environment, the system does not require such calibration because the air is not contaminated.

The results of this experiment, shown in Table 3, demonstrated the excellent capability of our spectrometry unit to detect all explosives at 5 cm and 15 cm. The spectrometry unit was able to detect the presence of explosives and to define the composition. All the main compounds of commercialized and homemade explosives were detected.

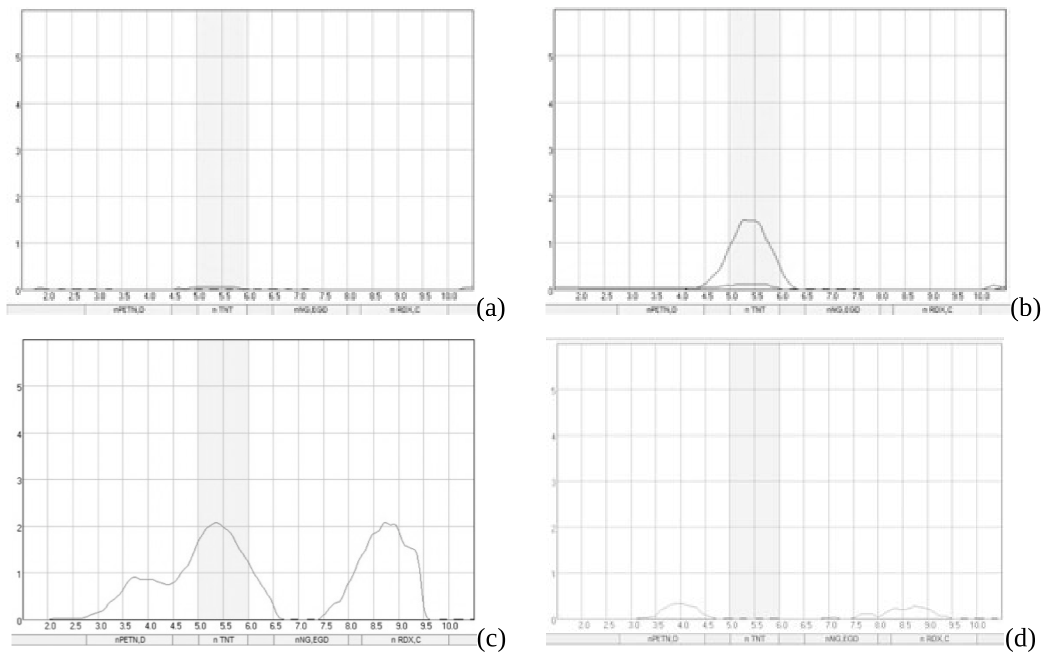

FIGURE 19 Ion mobility spectra observed for multiple explosives—(a) No explosive, (b) TNT at 5 cm, (c) Comp B (59–65% RDX, 36–40% TNT, 0–1% wax) at 5 cm, and (d) SEMTEX 1H [60.5% RDX, 25.0% PETN, 11.6% semtexoil, 2.9% rubber (styrene/butadiene)] at 5 cm. The spectra showed the amplitude is much lower at a distance of 15 cm.

4.3.3. Experiments with Psycho-physical unit

Fifteen human volunteer experiments were performed under normal conditions: constant heart rate (HR) and respiratory rhythm (RR) measured during a 60 sec test in a screening environment where a single subject was present in the field of view, with a radar beam pointed at the subject's chest.

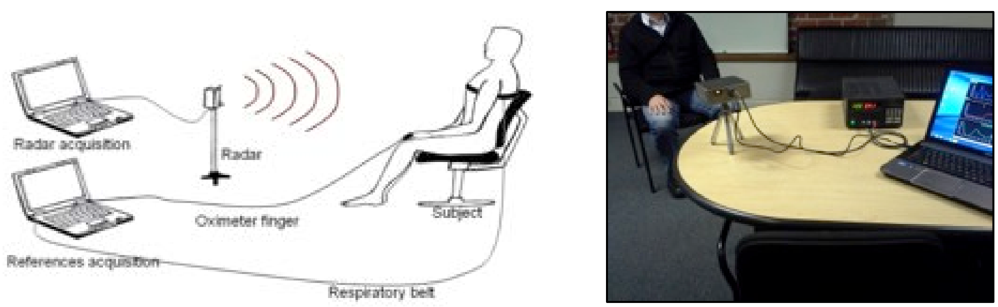

FIGURE 20 Experiment setting.

The objective of this experiment was to evaluate the KIED prototype data processing algorithm for simultaneous extraction of heart rate and respiratory parameters in humans. Reference methods were used to compare the heartbeat and respiration rates measured by the KIED prototype. The heart rate was measured using a standard pulse oximeter (Nonin oximetry module, 4100, Nonin Medical, Inc.). The breathing rate was verified by an air pressure respiratory belt (RMB, Vernier Software & Technology). The correlation between signals detected by KIED and reference systems was assessed using evaluation of correlations (using linear regression) and agreement (using Bland-Altman plots). The results of KIED measurements and references data were analyzed by SMT's investigators. SMT compared the results of both the scalar HR and RR values, and for 60-sec waveform epoch recordings. The investigators determined the optimal band filtering kernel and the optimal choice of main analysis variable (A or γ).

Respiration—The KIED prototype recordings were synchronized with the respiratory belt measurements. Figure 21 shows respiration patterns obtained by the KIED prototype and the respiratory belt. The results show that the breathing rhythm is easily detectable using KIED.

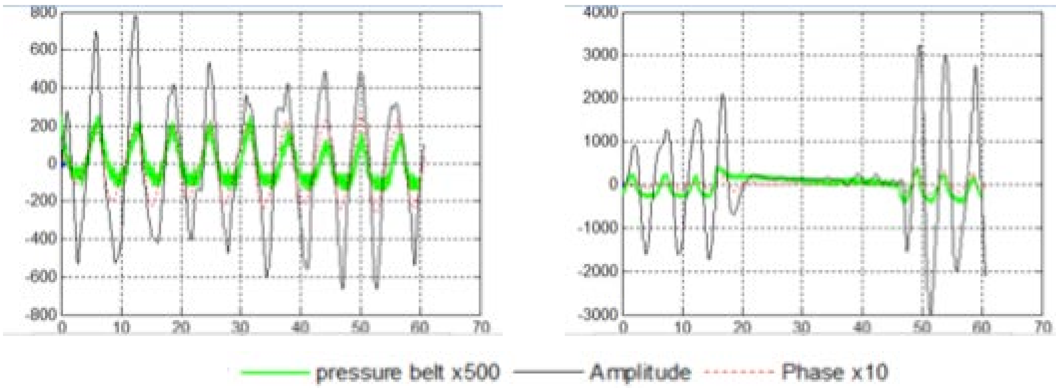

FIGURE 21 Respiration rate variability and changes obtained by KIED and respiratory belt—Plot of normal breathing of 10 breathes per minute (*left*), plot of holding breathing of 10 breathes per minute (*right*).

Figure 22 shows the excellent correlation (r = 0.99) between respiration rates determined by the KIED prototype and respiration rates obtained by the respiratory belt.

FIGURE 22 Respiration rate—Correlation of respiration rate values measured by KIED (*x* axis) and respiratory belt (*y* axis) (*left*); and agreement between respiratory belt and KIED using Bland-Altman plot. The plot shows differences between respiration rate from respiratory belt and KIED (*y* axis) vs. the corresponding average values of the two values (*x* axis) (*right*).

Heartbeat—The KIED data were synchronized with pulse oximeter measurements. Figure 23 shows heartbeat values obtained by the KIED prototype and the pulse oximeter. The KIED prototype does not display the first 20 sec of heart rate signal because the radar needs 20 sec to acquire enough data to start calculating the heartbeat value.

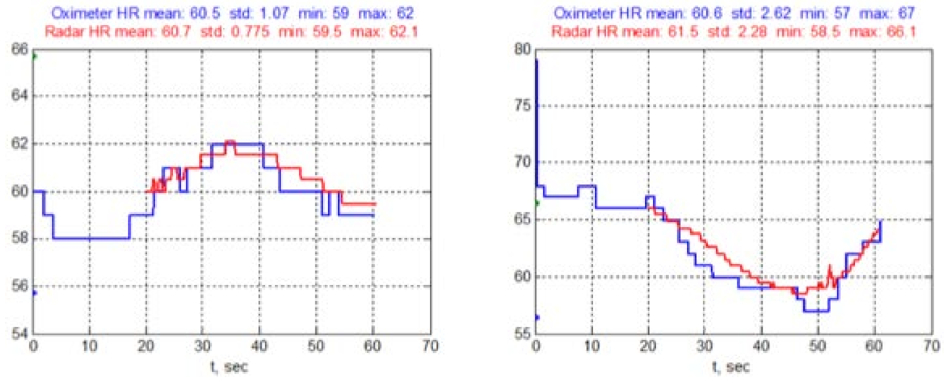

FIGURE 23 Two samples of heart rates obtained by KIED (red) and pulse oximeter (blue).

Figure 24 shows the correlation between heart rates determined by the KIED prototype and heart rates determined by the normal pulse oximeter (r = 0.90).

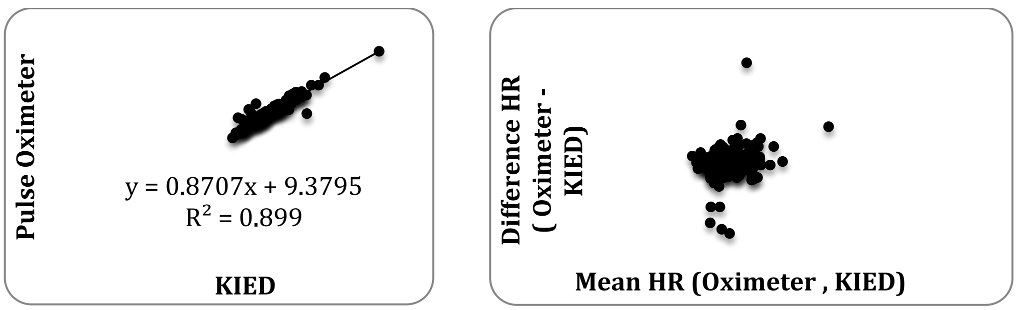

FIGURE 24 Heart rate measurements—Correlation of heart rate values measured by KIED (*x* axis) and pulse oximeter (*y* axis) (*left*); agreement between pulse oximeter and KIED using Bland-Altman plot. The plot shows differences between heart rate from pulse oximeter and MFMR (*y* axis) vs the corresponding average values of the two values (*x* axis) (*right*).

The agreement between the two methods is good. Except for a small number of measurements (mostly the measurement with really high heartbeat variability), the KIED correlates very well with the pulse oximeter for constant heartbeat.

4.3.4. Experiments summary

SMT's prototypes demonstrate excellent capabilities to detect any explosives using spectrometry, shrapnel, and other threatening objects using polarization and cardiopulmonary activities using radar reflections. Multiple refinements are required to improve the overall performance of the system. Some of the critical improvements were made during this project as described in the next tasks.

4.4. Task 4: Integrate KIED into fare gate

The KIED prototypes were installed into a BART fare gate in a non-revenue environment. As shown in Figure 25, two sub-systems, the polarization and spectrometry units, were installed inside the gate console. These two sub-systems allow for the detection of explosives and shrapnel.

The aim was to install the units inside the console without modifying the size and shape of the gate. This will ensure the easy and cost-effective implementation of the commercialized KIED product, which will be ideally suited for the demanding public transportation setting. The KIED sub-systems were mounted underneath the ticket mechanism.

The fare gates used during this project were old gates that were previously used in a revenue environment at BART. The consoles are about 39 inches high, 8 inches wide, and 80 inches long. A typical passageway consists of two adjacent consoles, each containing one half of a bi-parting leaf and a passageway, or aisle, between them. The width of the aisle, which is the distance between two adjacent consoles, is about 20 inches. The consoles are fully made out of metal and the bi-parting leaf is made out of plastic.

The KIED system does not work through metal; therefore, the investigators were required to cut two openings on one of the console panels. The opening for the spectrometry unit is a hole of 5 cm (2 inches), which allows the “nose of the spectrometry unit to collect air samples and detect vapors. The opening for the polarization unit is a rectangular window of 10 cm x 2.5 cm (4 x 1 in.). This window was required to ensure the RF antennas can detect objects. The window was covered by radio-transparent plastic. Figure 26 shows the locations of the two sub-systems. The spectrometry unit was placed below the polarization unit due the ticket mechanism.

The KIED units were connected to a laptop. The data processing and display were performed using SMT’s software as well as Matlab. During the next phase of the product development, SMT will integrate the data processing and display into the fare gate system.

FIGURE 25 KIED installation in a fare gate.

FIGURE 26 Locations of the two sub-systems inside the gate.

4.5. Task 5: Field testing and prototype update

Various experiments were performed to demonstrate the detection capabilities of the KIED prototype when installed into a non-revenue fare gate. Due to the difficulties of gaining access to explosives, we limited the field experiment to the detection of explosive vapor generators (e.g., TNT vapor generator) and black powder. A full set of commercialized and homemade explosives was successfully tested during Task 3.

The experiments were performed using a simple test protocol. The subject, with or without explosive, was standing in front of the gate for 4 to 5 sec. The subject was located at around 10 to 15 cm (4 to 6 inches) from the console. While the subject was waiting for the payment to be processed (simulated payment) the KIED prototype was collecting data, analyzing the sample and providing the result. Each test was repeated multiple times to define detection reliability. Figures 27 and 28 illustrate the test setting for shrapnel detection and explosive detection, respectively.

FIGURE 27 Shrapnel detection—test with the belt not covered (*left*) and test with the belt hidden underneath a jacket (*right*).

FIGURE 28 Explosive detection—test with the explosive compound located inside a backpack (*left*) and test with the explosive compound located on the subject's thorax underneath a jacket (*right*).

The investigators also tested the detection performance at various heights, as shown in Figure 29. The target (explosive or shrapnel) was located at 85 cm (34 inches) from the floor and then at 125 cm (49 inches).

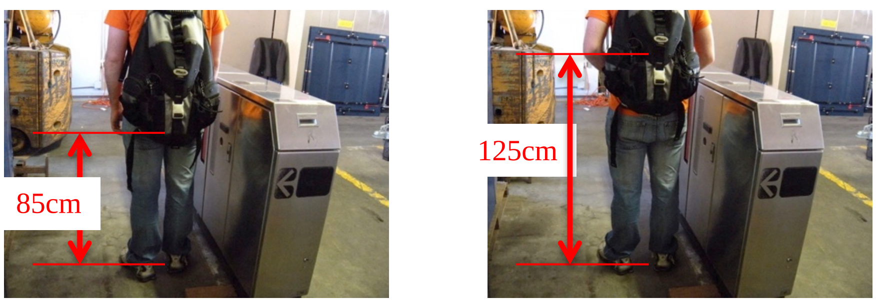

FIGURE 29 Experiments with targets located at different heights.

During this experiment, 440 measurements were collected and analyzed. Twenty measurements for each test were performed. The number of measurements is not sufficient to allow a full statistical analysis; however, it allows one to demonstrate the capabilities of the KIED system. Table 4 shows the results obtained after the KIED system was improved. The improvements made to the system are described here.

Each measurement lasted about 60 sec. The measurement included three phases:

- First phase "before subject" lasted 30 sec. During this phase the measurement was made without subject and without explosive. This allows for the checking of the system to detect any alert when there were no explosives.
- Second phase "Subject" lasted 5 sec. During these phase the subject walked to the gate. The subject acted like he was inserting a ticket inside the gate. The subject, with or without explosives, was standing in front of the gate for 5 sec.
- Third phase "after subject" lasted 25 sec. During this phase the measurement was made after the subject walked away from the gate. This phase allows for checking the system to detect any false positive alarm due to vapor residue.

The phase 1 “before subject” and the phase 3 “after subject” allow us to calculate false positives, while the phase 2 “Subject” allows us to calculate false negatives.

TABLE 4
FIELD TEST RESULTS

Compound	**Location**	**Height (cm)**	**Final Results**
TNT Vapor	Backpack	85	90%
	Backpack	125	75%
	Place in subject’s hand	85	100%
	Place in subject’s pocket (hidden)	85	100%
	Wrap on subject’s chest	125	80%
	Wrap on subject’s chest and covered with jacket	125	80%
RDX Vapor	Backpack	85	80%
	Backpack	125	70%
	Place in subject’s hand	85	100%
	Place in subject’s pocket (hidden)	85	100%
	Wrap on subject’s chest	125	75%
	Wrap on subject’s chest and covered with jacket	125	75%
Black Powder	Backpack	85	95%
	Backpack	125	85%
	Place in subject’s hand	85	100%
	Place in subject’s pocket (hidden)	85	100%
	Wrap on subject’s chest	125	80%
	Wrap on subject’s chest and covered with jacket	125	80%
Shrapnel Belt	Backpack	85	100%
	Backpack	125	95%
	Wrap on subject’s chest	125	95%
	Wrap on subject’s chest and covered with jacket	125	95%

The results demonstrated the ability of the KIED system to detect explosives and shrapnel in field environments. As described in previous sections, the polarization unit is used to detect shrapnel inside the suicide belt. A sample of the test results can be found in the Attachment A.

Of the 80 measurements performed with the shrapnel belt, the polarization unit was unable to detect the belt in only three measurements. The accuracy of the polarization unit was 100% while the belt was located 85 cm from the floor and 95% when the belt was located 125 cm from the floor. During this set of measurements, no false positives were detected, only false negatives.

Of the 360 measurements performed with the explosives, the spectrometry unit detected explosives in 87% of the measurements. In addition, the system had approximately 1% of false positive alerts. The results obtained with the spectrometry unit demonstrated that the location of the explosive affects the detection. The accuracy of the explosive detection is approximately 90% when the explosive compounds are located lower than 100 cm (40 inches) from the floor and around 80% when the explosive compounds are located above 100 cm. The three false positives were obtained during the Phase 3 “after subject.” These three alerts were due to vapor residue while the explosive was placed at 85 cm from the floor.

Multiples improvements were required to obtain the results shown in Table 4.

(1) Improvement of the spectrometry sensitivity

Problem—The detection performances of the spectrometry unit in real environment were lower than in the lab. The detection was greatly affected by the airflow created by the movements of the subject.

Solution—The investigators increased the sensitivity by modifying the drift tube and increasing the pump output. After improvement, the sensitivity level is around 1 part per million.

(2) Improvement of the polarization ratio signal/noise

Problem—The amplitude of the reflected signal when the suicide belt was placed higher than 60 inches was about 10 times lower than the amplitude of the reflected signal when the belt was located at the same level as the antenna.

Solution—The investigators improved the noise reception path by better filtering power and using hardware components with a lower level of intrinsic thermal noise, improved the stability of the power source, and the stability of VCO (voltage-controlled oscillator, used to generate a chirp signal).

(3) Improvement of the psycho-physical measurement for subjects with very fast respiratory rate

Problem—The fluctuations of chest and upper abdominal areas during respiration have an order of magnitude higher signal levels compared with heartbeats. In addition to the dominant harmonic corresponding to the respiratory rate, the spectra manifests integer multiples, also called overtones, which often coincide with the first pulse harmonic. The faster the breathing, the more disturbances are created for pulse measurements, which we observed in the pulse measurement tests with fast respiratory rate subjects.

Solution—The solution to the problem was achieved by using improved front end hardware and replacement of the spectral processing with a wavelet approach that significantly improved the reliable estimation system and allowed us to separate harmonics caused by respiration and pulse. The algorithmic methods to deal with the fast respiratory rate are based on high fidelity observers that are able to distinguish between the respiratory and pulse harmonics.

4.6. Task 6: Final demonstration and planning

The KIED prototype and test results were presented to all stakeholders. The final demonstration was performed on the non-revenue gate at SMT’s lab. The results obtained during this project satisfied the stakeholders and demonstrated the feasibility of using the KIED for detecting explosives and weapons in transit systems. This encouraging outcome motivates the investigators to move forward with the next phase of this project.

The next phase will be to finalize the KIED system and explore commercialization with partners. To achieve this ultimate goal, SMT will work on decreasing the detection time to around 2 sec, developing a mass producible device and integrating the KIED system into the fare gate operation process. This will include improving KIED hardware and manufacturing the KIED system, as well as modifying the payment process and integrating the KIED detection output with the current communication network system. Additional field experiments will need to be performed to improve the KIED performance and to verify the false alarm rate. SMT is discussing further collaboration with LLNL for potential further work. SMT is currently working to secure funds for this next phase.

5. CONCLUSION

All the activities specified in the grant application were successfully completed:

- The investigators developed a unique prototype, called KIED.
- In collaboration with Lawrence Livermore National Laboratory (LLNL), Systems Micro Technology Inc. (SMT’s) investigators successfully demonstrated that the KIED prototype can detect explosive compounds, liquids, and strong reflectors in a laboratory setting.
- The KIED prototype was incorporated into a Bay Area Rapid Transit (BART) fare gate in a non-revenue environment.
- Field tests were successfully performed.

During this project, SMT demonstrated the feasibility of detecting explosives and other dangerous objects using the KIED prototype in a non-revenue environment. SMT has identified multiple improvements necessary to successfully deploy and commercialize the KIED system. SMT is currently starting the next phase of this project (Phase 2) in which all of these improvements will be addressed. During this second phase, we will improve and finalize the KIED system, validate detection performance, and explore commercialization with partners. We will also perform trials in real environment at the BART station.

One of the main challenges is the detection time. Our system scans every passenger while they are inserting their tickets into the fare gate. Our ultimate goal is to scan without delaying the current payment process. The current payment process from the time the user inserts the ticket until the time the gate opens lasts between 1 and 2 seconds. Based on our current estimation and additional improvements we are making, we believe we can reach this goal during phase 2.

Before commercialization, SMT will need to validate the reliability over the time of the KIED system in real environments. During this initial phase, performed during this grant, the amount of testing was limited by the project scope, resources and time. SMT is fully aware that the number of tests does not allow to define properly the accuracy and repeatability. However, the testing demonstrated the feasibility of the system. During the next phase, Phase 2, we will work on improving the system and performing a high volume of testing to define the performance of the system. During the second phase, SMT will also deploy multiple KIED systems for field trials.

The investigators are confident that all the technical challenges will be solved during the second development phase and the KIED will be ready for commercialization within 18 months.

6. INVESTIGATOR PROFILE

Principal Investigator

Kirill S. Mostov, Ph.D., President, Systems Micro Technology Inc.
2041 Bancroft Way, Suite 204, Berkeley, CA 94704
Email: kmostov@sysmicrotech.com, Phone: 510/517-5625, Fax: 510/540-5969

Key Investigator

Cyril Rastoll, Data Analyst, Systems Micro Technology Inc.
2041 Bancroft Way, Suite 204, Berkeley, CA 94704
Email: crastoll@sysmicrotech.com, Phone: 602-363/9238, Fax: 928/543-5383

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ATTACHEMENT A

Results obtained with TNT vapor

Test	Compound	Location	Height (cm)	Result			
				Phase 1 "before subject"?	Phase 2 "subject"	Phase 3 "after subject"	Final result
1	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
2	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
3	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
4	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
5	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
6	TNT Vapor	Backpack	85	Pass	No	Pass	No
7	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
8	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
9	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
10	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
11	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
12	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
13	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
14	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
15	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
16	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
17	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
18	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
19	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
20	TNT Vapor	Backpack	85	Pass	Pass	Pass	Pass
21	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
22	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
23	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
24	TNT Vapor	Backpack	125	Pass	No	Pass	No
25	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
26	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
27	TNT Vapor	Backpack	125	Pass	No	Pass	No
28	TNT Vapor	Backpack	125	Pass	Pass	No	No
29	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
30	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
31	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
32	TNT Vapor	Backpack	125	Pass	No	Pass	No
33	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
34	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
35	TNT Vapor	Backpack	125	Pass	No	Pass	No
36	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
37	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
38	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
39	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
40	TNT Vapor	Backpack	125	Pass	Pass	Pass	Pass
41	TNT Vapor	Place in subject's hand	85	Pass	Pass	Pass	Pass
42	TNT Vapor	Place in subject's hand	85	Pass	Pass	Pass	Pass
43	TNT Vapor	Place in subject's hand	85	Pass	Pass	Pass	Pass
44	TNT Vapor	Place in subject's hand	85	Pass	Pass	Pass	Pass
45	TNT Vapor	Place in subject's hand	85	Pass	Pass	Pass	Pass
46	TNT Vapor	Place in subject's hand	85	Pass	Pass	Pass	Pass
47	TNT Vapor	Place in subject's hand	85	Pass	Pass	Pass	Pass
48	TNT Vapor	Place in subject's hand	85	Pass	Pass	Pass	Pass
49	TNT Vapor	Place in subject's hand	85	Pass	Pass	Pass	Pass
50	TNT Vapor	Place in subject's hand	85	Pass	Pass	Pass	Pass
51	TNT Vapor	Place in subject's hand	85	Pass	Pass	Pass	Pass
52	TNT Vapor	Place in subject's hand	85	Pass	Pass	Pass	Pass

53	TNT Vapor	Place in subject’s hand	85	Pass	Pass	Pass	Pass	
54	TNT Vapor	Place in subject’s hand	85	Pass	Pass	Pass	Pass	
55	TNT Vapor	Place in subject’s hand	85	Pass	Pass	Pass	Pass	
56	TNT Vapor	Place in subject’s hand	85	Pass	Pass	Pass	Pass	
57	TNT Vapor	Place in subject’s hand	85	Pass	Pass	Pass	Pass	
58	TNT Vapor	Place in subject’s hand	85	Pass	Pass	Pass	Pass	
59	TNT Vapor	Place in subject’s hand	85	Pass	Pass	Pass	Pass	
60	TNT Vapor	Place in subject’s hand	85	Pass	Pass	Pass	Pass	
61	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
62	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
63	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
64	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
65	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
66	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
67	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
68	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
69	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
70	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
71	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
72	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
73	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
74	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
75	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
76	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
77	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
78	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
79	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
80	TNT Vapor	Place in subject’s pocket (hidden)	85	Pass	Pass	Pass	Pass	
81	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
82	TNT Vapor	Wrap on subject’s chest	125	Pass	No	Pass	No	
83	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
84	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
85	TNT Vapor	Wrap on subject’s chest	125	Pass	No	Pass	No	
86	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
87	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
88	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
89	TNT Vapor	Wrap on subject’s chest	125	Pass	No	Pass	No	
90	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
91	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
92	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
93	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
94	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
95	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
96	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
97	TNT Vapor	Wrap on subject’s chest	125	Pass	No	Pass	No	
98	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
99	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
100	TNT Vapor	Wrap on subject’s chest	125	Pass	Pass	Pass	Pass	
101	TNT Vapor	Wrap on subject’s chest and covered with jacket	125	Pass	Pass	Pass	Pass	
102	TNT Vapor	Wrap on subject’s chest and covered with jacket	125	Pass	Pass	Pass	Pass	
103	TNT Vapor	Wrap on subject’s chest and covered with jacket	125	Pass	No	Pass	No	
104	TNT Vapor	Wrap on subject’s chest and covered with jacket	125	Pass	Pass	Pass	Pass	
105	TNT Vapor	Wrap on subject’s chest and covered with jacket	125	Pass	Pass	Pass	Pass	
106	TNT Vapor	Wrap on subject’s chest and covered with jacket	125	Pass	No	Pass	No	
107	TNT Vapor	Wrap on subject’s chest and covered with jacket	125	Pass	Pass	Pass	Pass	
108	TNT Vapor	Wrap on subject’s chest and covered with jacket	125	Pass	Pass	Pass	Pass	
109	TNT Vapor	Wrap on subject’s chest and covered with jacket	125		Pass No	Pass	No	No

110	TNT Vapor	Wrap on subject's chest and covered with jacket	125	Pass	Pass	Pass	Pass
111	TNT Vapor	Wrap on subject's chest and covered with jacket	125	Pass	Pass	Pass	Pass
112	TNT Vapor	Wrap on subject's chest and covered with jacket	125	Pass	Pass	Pass	Pass
113	TNT Vapor	Wrap on subject's chest and covered with jacket	125	Pass	Pass	Pass	Pass
114	TNT Vapor	Wrap on subject's chest and covered with jacket	125	Pass	Pass	Pass	Pass
115	TNT Vapor	Wrap on subject's chest and covered with jacket	125	Pass	Pass	Pass	Pass
116	TNT Vapor	Wrap on subject's chest and covered with jacket	125	Pass	Pass	Pass	Pass
117	TNT Vapor	Wrap on subject's chest and covered with jacket	125	Pass	Pass	Pass	Pass
118	TNT Vapor	Wrap on subject's chest and covered with jacket	125	Pass	No	Pass	No
119	TNT Vapor	Wrap on subject's chest and covered with jacket	125	Pass	Pass	Pass	Pass
120	TNT Vapor	Wrap on subject's chest and covered with jacket	125	Pass	Pass	Pass	Pass