# A Proof-of-Concept of Light-weight Smart Cone for Explosive Ordnance Mitigation in Non-permissive Operating Environment


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## ABSTRACT

The prolonged armed conflict in Eastern Ukraine since 2014 has generated the increasing public safety concern about landmines, abandoned unexploded ordnance (UXO) and small-size explosive remnants of war, which are spreading around the region of a conflict. Such ordnance can be used for making the improvised explosive devices (IED) as well. The background studies have identified the following key obstacles which make UXO demining and cleaning in that region challenging: an absence of government-endorsed national technical standards against which demining activity can be measured in crowded areas and non-permissive operating environment (i.e. public transport hubs and metro), and not enough human and technical capacity. Demining is carried out often using different techniques and outdated equipment. During the applied research project, the available open source international best practices and the UXO risk assessment methods were reviewed and assessed, firstly. Secondly, a new demining methodology was developed for improving the existing standard operating procedures of the bomb disposal units of the State Emergency Service of Ukraine (SESU). Thirdly, a proof-of-concept was designed for field trials. A prototype of a light-weight smart steel cone was constructed and which can cover small-size UXO in critical infrastructures like metro without using heavy traditional commercial explosive ordinance disposal robots and causing a minimum impact to environment and ecology. Live field testing was conducted. Finally, based on the successful trials, the recommendations for the standard operating procedures (SOP) of the bomb disposal units of the SESU were produced. For example, this cone can be stored in metro station and easily transported by a security guard, who covers abandoned UXO. If an object goes off before the bomb squad arrives on site, then this device can efficiently protect the crowed area and environment from the bomb fragments. This new demining equipment has been granted a patent.



**Keywords:** Unexploded ordnance, explosive remnants of war, explosive ordnance disposal, non-permissive operating environment, public safety, threat and risk assessment, critical infrastructure protection


## 1. INTRODUCTION

The prolonged armed conflict in Eastern Ukraine since 2014 has generated the increasing public safety concern about landmines, abandoned UXO and small-size explosive remnants of war, which are spreading around the region of a conflict. Such ordnance can be used for making IEDs as well. One major public security concern is related to possible terrorist attacks to highly populated areas and critical infrastructures using UXO and IEDs. Due to reports[1,5], from 14 April 2014 to 31 March 2020, the number of conflict-related civilian deaths caused by UXO has reached at least 3,353. The number of injured civilians is estimated to exceed 7,000. During the last two decades a revolutionary digitalization of IP-based closed-circuit television (CCTV) surveillance technologies and intelligent (sometime called smart) video content analytics opened new opportunities for automatic threat detection for security operators (e.g. public law enforcement agencies and private security service providers). In the early 2000s, a number of applied R&D projects were carried out with regard to the development of intelligent digital CCTV surveillance systems. As reported by Samberg[23-25], one of the fields of applications is a public transport hub like metro, for instance. Today digital smart CCTV surveillance systems have a standard embedded function such as a detection of abandoned objects that have been left behind for a period of time.

Based on the analyses of available open source handbooks and guides for UXO/IED safety and disposal[8,10-16,21] the existing SOPs and methods for pyrotechnic teams are pretty much the same. Typically, there are nine steps of explosive's clearance: detection, location, accessibility, identification, hazard mitigation, threat evaluation, rendering safety area, recording and recovering, and final disposal. The simplified typical procedure is the following. A suspiciously abandoned object is detected either manually or by means of smart CCTV surveillance system. An adequate perimeter is secured by security guard or police. After a received notification of bomb threat call a bomb squad is alerted. Only the designated technician will approach within close proximity of a suspicious object. Whenever possible, devices are to be rendered safe in place. UXO and IED unable to be rendered safe in place will be placed in a bomb carrier and transported to the bomb range or emergency "cook off" area for dismantling and/or detonation. UXO and IED may, on rare occasion, be detonated in place if deemed necessary for the safety of the public. Due to the individual interviews of experts[22], in some public places the security personnel, who are not demining experts, are still instructed to remove an abandoned object by hands and place in a bomb carrier before the bomb squad arrives.

Our major task was to design a smart device for UXO and IED hazard mitigation in non-permissive operating environment like public transportation stations (e.g. metro) where the use of bomb disposal robots (BDR) is very difficult or impossible.

## 2. THE CONCEPT

When dealing with UXO and IED, we always must consider the most worth scenario. As shows the practice, nowadays, UXO and IED are often equipped with a radio-based detonator. (Fig. 1a) From the other side, a BDR is remotely controlled via a radio channel. This is a threat if UXO or IED is capable of intercepting the radio signal and goes off after that. UXO and IED can be equipped with a motion detector. Thus, if a BDR will try to remove UXO or IED, they can detonate. Additionally, UXO and IED can go off unexpectedly anytime when a bomb squad is still on the way to the scene. Thus, it is necessary to cover them during the waiting time. The price tag of BDRs is high range in price from approximately $30,000 to over $150,000 plus the annual maintenance cost[26-28]. In order to remotely operate a BDR a trained robot operator is needed. One of the main disadvantages of existing commercial BDRs is that they manipulate UXO and IED and transport them to a bomb carrier uncovered and unprotected.

Therefore, we need such device which is reusable, affordable, moderately priced, easy to operate (no robot operator training needed), radio free and can cover UXO or IED minimizing the possible damage to the people, environment and critical infrastructure's elements. (Fig. 1b)

a) b)

Figure 1. Examples of bomb disposal devices: a) a prototype of a smart cone device from the National University of Civil Defence of Ukraine, Ukraine (courtesy of Yevhen Stetsiuk), and b) remotely controlled bomb disposal robot Andros Wolverine 6X6 (source [27]).

## 3. METHDOLOGY

The finite element design of the device was carried out using the engineering simulation and 3D design software ANSYS. Modeling the structural behavior of environment under blast pressure was conducted applying the principle of the Euler–Lagrange equation[19]. The result of this design is presented in Fig. 2.

One key performance of the smart cone is the fatigue durability *N* which can be calculated by Eq. 1[19]:

$$N = 1 + \frac{1}{1 + 2 \cdot K} \cdot \frac{E^3 \cdot \sqrt{\partial}}{\left(\sigma \cdot Y \cdot \sqrt{n} \cdot d\right)^3} \cdot (L - d) \qquad (1)$$

where *K* - the percentage of estimated excess power, *E* - internal energy of explosion, $\sigma$ - Cauchy stress tensor, *Y* - geometric factor for the edge crack which is equal to 1.222 in our case), $\partial$ - Burgers vector of dislocations in steel, *n* - direction cosines of the outward normal to the boundary of the region, *L* – size of crack, and *d* – the current crack size.

Pseudo-fatigue damage analysis for structural durability analysis was conducted in laboratory before the field testing. We estimated that the fatigue durability *N* must be equal to minimum five full-scale successful explosions of maximum TNT equivalent of up to 200 grams.

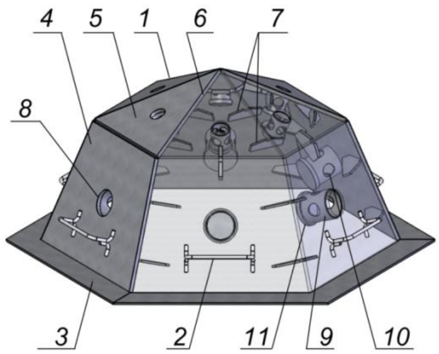


Figure 2. A view of designed smart cone for UXO and IED hazard mitigation and disposal in non-permissive operating environment (1 – the cover, 2 – handles for carrying the cone, 3 – ground stabilizer, 4 and 5 – protecting steel plates, 6 – high-strength welds, 7 - amplifiers, 8 – the exhausting wholes for partial relief of excess pressure of the shock air wave of the explosion, 9 – a protecting device from the impact of the shock wave from the fragments of the explosive, 10 – the radial holes on the side surface of protecting devices 9)

## 4. THE SMART CONE TESTBED

The testbed was designed for testing the concept of the smart cone for device for small-size UXO and IED hazard mitigation in non-permissive operating environment[19]. (Fig. 3)

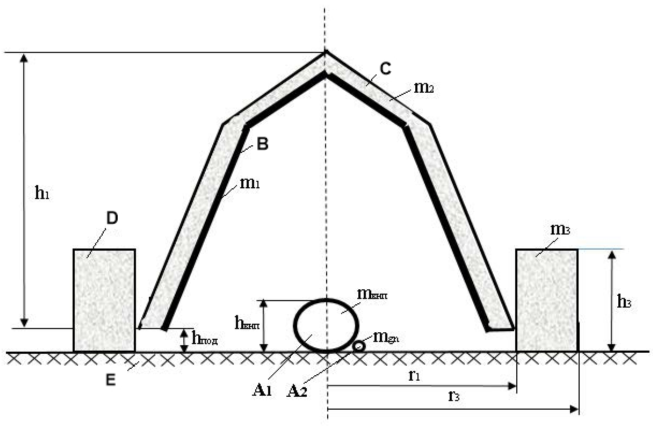


Figure 3. Design of smart cone testbed for UXO/IED hazard mitigation and disposal in non-permissive operating environment

where $A_1$ – IED of the weight $m_{BH}$, $A_2$ – detonator of the weight $m_{gn}$, B – fragment's absorber, C – additional load of the weight $m_2$, and D – the surface on which the cone testbed is placed

The shape of the cone was designed in such a way that the explosion energy is partly absorbed by the cone and partly safely uniformly exhausted up stream. The thickness of the cone has been calculated to stand the blast of up to TNT equivalent of 200 grams. UXO or IED is placed in the center of the steel cone.

## 5. THE RESULTS

The theoretical work was backed up by a series of field trials. During the field exercises the same smart cone was placed covering the small-size IED. The cone was blown up for five different TNT equivalents (30/40/50/60/70 grams) (Fig. 5). The internal diameter of the smart cone was 90 cm. The outside diameter was 105 cm. The height was 45 cm in the center. The thickness of the protecting steel plates was calculated to stand a blast of explosive of TNT equivalent of 200 grams. In order to protect the environment and the personnel of the training bomb squad from possible IED fragments, the cone was entirely covered by the sand bags as shown in Fig. 4c. The whole preparation of trials is presented in Fig. 4.

a) b) c)

Figure 4. A setup of smart cone testbed: a) a preparation of testbed, b) smart cone is in place, and c) a testbed is ready-to-go.

a) b) c)

Figure 5. An explosion of IED and a behavior of smart cone: a) a detonation, b) an explosion, and c) flight direction.

a) b) c)

Figure 6. The results of the IED explosion covered by the smart cone: a) an explosion of IED, b) the view after the explosion, and c) the view inside the cone after the IED explosion (absolutely whole inside without cracks).

## 6. THE CONCLUSIONS

Our main goal was to design and build a smart device for UXO and IED hazard mitigation in non-permissive operating environment like public transport station (e.g. metro) where the use of BDRs is very difficult or impossible. Also, the environmental protection matter must be taken into account. Based on the conducted analyses of commercial BDR technologies[2,6,7] (table 2) we concluded that the existing solutions are not suitable for public transport station as it is (e.g. metro and railway station). Also, bomb storage boxes on stations, if exist at all, are typically fixed. Thus, a suspicious abandoned object must be carried to a such box by non-expert security personnel[22] which is not acceptable. Therefore, it is necessary to have an alternative solution which is proposed in this study.

During the field testing it was demonstrated that the developed smart cone is environment-friendly and dramatically reduces the negative impact which may be cause by an explosion of small-size UXO or IED and its fragments.

As shown in Fig. 6, the repeated explosion did not destroy (b) or caused any damage (c) to the smart cone, thanks to its design of the geometry. The cone survived several explosions and remained absolutely whole inside without cracks. The comparison table 1 consists of the estimated results and the real results. The archived results are very close to the estimated ones within the 99% confidence interval.

Table 1. Estimated vs. real field trial results depending on TNT equivalent of the IED explosive.

| Trial No. | TNT equivalent, grams | $h_{calc}$, m | $h$, m |
|---|---|---|---|
| 1 | 30 | 1,50 | 1,52 |
| 2 | 40 | 2,05 | 2,07 |
| 3 | 50 | 2,60 | 2,60 |
| 4 | 60 | 3,15 | 3,12 |
| 5 | 70 | 3,70 | 3,66 |

where $h_{calc}$ is the expected height of the jump up of the cone after the explosive has gone off, and $h$ is the real height of the jump up of the cone after the explosive has gone off.

The field testing proved our expectations in Section 3 that the prototype smart cone will survive, at least, five full-scale successful explosions of maximum TNT equivalent of up to 200 grams. No structural damages to the prototype smart cone were observed after five exercises. (Fig. 6c) (Table 1) As shown in Fig, 5c and Fig. 6b, the "flight" direction of the prototype smart cone was straight up in air. Landing was directly on the surface like the landing of the booster of SpaceX's Falcon 9 rocket in 2020. As shown in Table 1, the "flying" height logically increases if the TNT equivalent increases. In case of TNT equivalent of 70 grams, the "flying" height was measured 3.66 m. Somehow it is the limiting factor if the smart cone's application is considered to be indoor. However, a floor-to-ceiling height is high enough in large public transportation stations. Thus, the smart cone can be easily operated in large public transportation stations.

Table 2. A comparison of commercial BDRs (adopted from [6])

| Robot Name | Manufacturer | Weight (lbs) | Max Vertical Reach from Ground (in) | Max Horizontal Reach from base (in) | Max Lifting Capacity (lbs) | Gripper Pressure (lbs) | Max Gripper Opening (in) | Max Speed (mph) | Arm DOF |
|---|---|---|---|---|---|---|---|---|---|
| **Talon [27]** | QinetiQ | 115-156 | 52 | 52 | 20 | 30 | 6 | 5.2 | 3 |
| **Caliber [12]** | ICOR | 140-190 | 66 | 66 | 65 | | 10 | 5 | 3 |
| **Andros HD-1 [21]** | Remotec | 200 | 72 | 46 | 30 | | 6 | 4.3 | 3 |
| **MURV-100 [6]** | HDE | 66.1 | 96 | 86 | 50 | | | 1.4 | 3 |
| **Knight [29]** | WM Robotics | 550 | 103.5 | 76.5 | 260 | 79 | 12 | 2.5 | 4 |
| **RMI-9WT [22]** | Pedsco | 317-387 | 90 | 44 | 175 | 20-60 | 10.25 | 1.8 | 4 |
| **RMI-10F [22]** | Pedsco | 140 | 55 | 13 | 75 | 20-60 | 10.25 | 1.8 | 4 |
| **Scarab IIA [25]** | ROV Technology | 50 | 100 | 94 | 15 | 115 | 6.5 | 0.23 | 4 |
| **Packbot [15]** | iRobot | 53 | 90 | 82 | 30 | | | 5.8 | 5 |
| **Andros F6A [21]** | Remotec | 485 | 109 | 56 | 65 | 50 | 12 | 3.5 | 5 |
| **MK2-ROV [28]** | Vanguard | 123.5 | 69.5 | 38 | 40 | | | 2.8 | 5 |
| **Matilda [18]** | Mesa Robotics | 106 | 50 | 44 | 35 | | | 2 | 5 |
| **MR-5 [8]** | EOD Partner | 550 | 98 | 69 | 264 | 80 | 12 | 1.24 | 6 |

The designed prototype smart cone has been already granted the patent[9]. Future R&D work will be dedicated to making the smart cone lighter and capable to stand a bigger TNT equivalent. Furthermore, the authors will propose to take this new type of bomb disposal device into consideration and update the existing standard operating procedures of first responders using together with the benefits of intelligent CCTV surveillance system.

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## REFERENCES

[1] OSCE Special Monitoring Mission to Ukraine, “Thematic report: The impact of mines, unexploded ordnance and other explosive objects on civilians in the Donetsk and Luhansk regions of Eastern Ukraine, January 2018 – October 2019”, 29 p. (2019). https://www.osce.org/special-monitoring-mission-to-ukraine/441170

[2] Nguyen, H.G. and Bott, J.P., “Technical report 1839 - Robotics for Law Enforcement: Beyond explosive ordnance displosal,” SPAWAR Systems Center, San Diego, 64 p. (November 2000)

[3] MacDonald, J., Knopman, D., Lockwood, J.R., Cecchine, G. and Willis, H., [Unexploded ordnance: A critical review of risk assessment methods], RAND Corporation, 181 p. (2004).

[4] White, R. (ed.), “Long-Term risk management tools and protocols for residual explosive ordnance mitigation, Vietnam,” Geneva International Centre For Humanitarian Demining GICHD, Geneva, 96 p. (2019).

[5] UN High Commissioner for Human Rights (OHCHR), “Conflict-related civilian casualties in Ukraine,” March 2020, https://reliefweb.int/report/ukraine/conflict-related-civilian-casualties-ukraine-march-2020 (April 2020).

[6] Carey, M., Kurz, E., Matte, J., Perrault, T. and Padir, T., “Project report: Novel EOD robot design with dexterous gripper and intuitive teleoperation,” Worcester Polytechnic Institute, USA, 111 p. (22 April 2011)

[7] Hinton, M., Burck. J., Collins, K., Johannes, M., Tunstel, E. and Zeher, M., “Integration of advanced explosive ordnance disposal robotic systems within a modular open systems architecture,” Johns Hopkins APL Technical Digest, Volume 32, Number 3, 595-604 (2013).

[8] Bevz, A., Tolkunov, I. and Stetsiuk, E., ”Problems of humanitarian demining of Bomb Squads of the State Emergency Service of Ukraine in the Donetsk and Luhansk regions,” In Proceedings of the All-Ukrainian Scientific and Practical Seminar “Law Enforcement in the region of the Joint Forces Operation,” Mariupol, Ukraine, 149-156 (2018) (available in Ukrainian only)

[9] Patent 132849/U201810411, “System for modeling blast waves propagation in air” (22 October 2018)

[10] Strilets, V., Stetsiuk, E. and Ivanov, E., “Scientifical and practical approaches in developing the Standard Operating Procedures for humanitarian demining,” In Proceedings of XVI International scientific conference “Life safety – education and hands-on practice”, Lviv, Ukraine, 82-84 (2018) (available in Ukrainian only)

[11] National Standard Operating Procedures of The State Emergency Service of Ukraine DSTU-P IMAS 09.12:2016 (IMAS 09.12:2012, IDT) "Explosive Device Response Operations Guide for Public Safety Authorities and Civil Defense Units for Demining of IED incident sites," (8 August 2018) https://zakon.rada.gov.ua/rada/show/v0461388-18/print (available in Ukrainian only)

[12] National Standard Operating Procedures of The State Emergency Service of Ukraine DSTU-P IMAS 07.11:2016 (IMAS 07.11:2016, IDT) “Demining for land release process” (2016) (available in Ukrainian only)

[13] National Standard Operating Procedures of The State Emergency Service of Ukraine DSTU-P IMAS 09.12:2016 (IMAS 09.12:2012, IDT) “Cleaning up after an explosion in ammunition storage areas” (08 August 2018) (available in Ukrainian only)

[14] United Nations, [United Nations Improvised Explosive Device Disposal Standards], 146 p. (May 2018)

[15] United Nations Mine Action Service (UNMAS), [United Nations Landmines, Explosive Remnants of War and Improvised Explosive Devices Safety Handbook], 3rd edition, 130 p. (2015)
[16] United Nations Mine Action Service (UNMAS), Demining standard IMAS 09.31 “Improvised Explosive Device Disposal”, 22 p. (February 2019)
[17] United Nations Development Programme, Protection Cluster Ukraine, Report “Mine actions in Ukraine”, 4 p. https://www.undp.org/content/dam/ukraine/docs/Donbas/RPP/2018_02%20Protection%20Cluster%20-%20Mine%20Action_v9.pdf (February 2018)
[18] Danish Refugee Council/Danish Demining Group, Twitter news, https://twitter.com/drcddgua (July 2020)
[19] Stetsiuk, E., Ph.D. thesis “Methodology for improving emergency management in case of small size improvised explosive devices” (19 December 2019) https://nuczu.edu.ua/images/topmenu/science/spetsializovani-vcheni-rady/aref_Stetsiuk.pdf (available in Ukrainian only)
[20] Evans, R. and Duncan, A. “Disposal of explosive ordnance and environmental risk mitigation,” The Journal of Conventional Weapons Destruction, Vol. 24: Iss. 1, Article 5 (July 2020). https://commons.lib.jmu.edu/cisr-journal/vol24/iss1/5
[21] Griffiths, R., Rickard, R. and Askham, L., "Detailed Unexploded Ordnance Threat and Risk Assessment – Meeting the requirements of CIRIA C681 “Unexploded Ordnance (UXO) – A guide for the Construction Industry” Risk Management Framework," Alpha Associates, 34 p. (2015). https://www.rbkc.gov.uk/idoxWAM/doc/Other-1635984.pdf?extension=.pdf&id=1635984&location=volume2&contentType=application/pdf&pageCount=1 (August 2018).
[22] Experts of The State Emergency Service of Ukraine, confidential interviews, 2018-2020
[23] Samberg A., “Abandoned object detection in underground critical infrastructure by means of smart digital video surveillance and a need to review the Standard Operating Procedures of first responders and LEAs”, Internal technical report, 23 p., EU-funded FP7 project VANAHEIM (https://cordis.europa.eu/project/id/248907) (2013)
[24] Samberg A., “Future research work in video analytics for real-time mobile security applications”, Final workshop of EU-funded FP7 project SAMURAI (https://cordis.europa.eu/project/id/217899) (2011)
[25] Samberg A., “The benefits of SAMURAI video content analytical solutions in public safety and a vision for their applications with cognitive wireless communications”, Technical report, 12p., EU-funded FP7 project SAMURAI (https://cordis.europa.eu/project/id/217899) (2011)
[26] U.S. Department of Justice, “Vanguard Robot Assessment” https://www.ncjrs.gov/pdffiles1/nij/204637.pdf (4 July 2020)
[27] U.S. Homeland Security, “Snapshot: U.S. – Israeli Robot Accessory Arm Provides Enhanced Capabilities and Precise Manipulation” https://www.dhs.gov/science-and-technology/news/2020/04/07/snapshot-us-israel-empower-bomb-squad-robots-second-arm (7 April 2020)
[28] The Cumberland Times-News, “New BDR ready for action” https://www.times-news.com/news/local_news/new-bomb-disposal-robot-ready-for-action/article_50cdad7a-24b7-5b04-bf90-5ac72fe24e1e.html (4 February 2020)