International Journal of Management and Applied Science, ISSN: 2394-7926 Volume-6, Issue-5, May.-2020
http://iraj.in

AUTONOMOUS UAV$_S$ SUPPORTING ACCIDENT EVALUATION FOR SMART CITIES' RECOVERY AFTER PHYSICAL DISASTERS

[1]THEODOROS ANAGNOSTOPOULOS, [2]KLIMIS NTALIANIS, [3]IOANNIS SALMON, [4]NIKOS TSOTSOLAS, [5]FILOTHEOS NTALIANIS

[1,2,3,4]Department of Business Administration, University of West Attica, Athens, Greece
[5]Department of Business Administration, University of Piraeus, Athens, Greece
[1]Department of Infocommunication Technologies, ITMO University, St. Petersburg, Russia
E-mail: [1]thanag@uniwa.gr, [2]kntal@uniwa.gr, [3]isalmon@uniwa.gr, [4]ntsotsol@uniwa.gr, [5]filotheos@unipi.gr

Abstract - This paper presents an autonomous Unmanned Aerial Vehicle (UAV)-enabled control system to handle accident incidents occurred by physical disasters in Smart Cities (SCs). Specifically, after a physical disaster like an earthquake or a tsunami wave several areas in SC are damaged. In these areas citizens are trapped and most of the cases hurt thus not being able to rescue themselves. However, there is not need to serve each incident with the same priority since there are cases of low, medium or high significance. In addition, SC infrastructure has a limited amount of UAVs to handle such cases. Concretely, after a trigger, like a phone call,the nearest UAV reaches a certain incident where a doctor make a remote diagnosis based on the video and audio provided by the camera and the microphone embedded in the UAV. After evaluating a high significance incident an ambulance is invoked to collect the injured citizen and transport her/him to the nearest hospital. Certain use cases are presented, which are evaluated with proposed metrics incorporated in the control system to infer the optimum use case. Such a use case is proposed to adopt by a SC infrastructure to handle a real physical disaster scenarios.

Keywords - Smart City, Physical Disaster, Recovery, Autonomous UAV, Control System.

I. INTRODUCTION

Physical disasters are a climate parameter, which has high impact to citizens of Smart Cities (SCs). Due to climate change and global warming we witness several physical disasters the last decades. Such disasters affect citizens' wellbeing since they cause severe injuries to earth's population. In this paper we propose a control system to face the effects of physical disasters to human population living in SCs by incorporating autonomous Unmanned Aerial Vehicle (UAV) technology. Specifically, a fleet of autonomous UAVs is located in certain areas within the SC and is available to provide remote evidence of a critical injury to doctors. Concretely, doctors are able to diagnose a high significant injury and call an ambulance to transport the injured citizen to the nearest health center or hospital.

In this paper it is proposed a control system to treat significant incidents. Certain use cases are examined to infer which is optimal for SC adoption. Concretely, Use Case I (UC-I) is a centralized approach where UAVs are assumed to located in the center of the SC. Use Case II (UC-II) assumes a decentralized distributed infrastructure to test the propose control system. Certain evaluation metrics are incorporated to infer which use case is better for adoption by SCs.

The structure of the paper is as follows. In Section II we mention prior work in the research area. Section III presents the proposed control system. Section IV introduces the evaluation metrics, while Section V describes certain metrics used to assess the proposed system. In Section VI we define the examined use cases. In Section VII we perform the experiments. Section VIII discusses the results, while in conclusion we propose future work.

II. PRIOR WORK

Even though incident evaluation and management of ambulances according to incidents' severity is a very important research area, still it has not received very extensive attention. Of course there are some interesting related works that have been presented in the past. In particular, regarding remote assessment of clinical incidents: in [1] a five-stage model is proposed as a framework for planning a comprehensive telehealth research program for a new intervention or service system. The stages are: (1) Concept development, (2) Service design, (3) Pre-implementation, (4) Implementation, (5) Post-implementation, and at each stage a number of studies are considered. In [2] questions, requirements, and challenges are discussed for (a) understanding the first step in tele-physiotherapy, the remote injury assessment activity and (b) understanding the impact of the activity on 3D teleimmersion to be deployed and assist doctors/patients in remote injury assessment activity.

In [3] a patent is proposed to control the movement of a remote aerial device in an incremental step manner during a close inspection of an object or other subject matter. At the inspection location, a control module "stabilizes" the remote aerial device in a maintained, consistent hover while maintaining a close distance to the desired object. The control module may retrieve proximal sensor data that indicates possible nearby obstructions to the remote aerial device and may transmit the data to a remote control client. The remote control module may determine and display the possible one or more non-obstructed directions that the remote aerial device is capable of moving by an incremental distance. In [4] an interactive mobile phone application is developed that enables transfer of both patient data and pictures of a wound from the point-of-care to a remote burns expert who, in turn, provides advice back. In [5] disaster relief operations are examined, where lives can depend on timely location and safe removal of trapped and often injured people within damaged infrastructure (collapsed buildings, etc.). An emerging class of rope-like continuous backbone “continuum” robots provides new capabilities to address these critical operational problems. Continuum robots, also known as “robot trunks and tentacles”, can bend continuously along their structure, and are highly compliant. These features allow continuum robots to gently penetrate into congested spaces, navigating within complex and a priori unknown obstacle fields. This allows them to safely deploy sensors into collapsed structures, such as within debris in collapsed buildings, to assess conditions and potentially identify survivors. The further ability of these robots to use their bodies to perform whole arm grasping, wrapping safely around environmental objects, offers the possibility of using them as “active ropes” to gently pull victims out of such environments, while avoiding generation of large forces which might further collapse already damaged structures. This paper develops a nine degree of freedom pneumatically actuated continuum robot, and deploys it to inspect within rubble piles and to gently grasp and retrieve human surrogates (dummies).

In [6] the perception and manipulation capabilities of the WALK-MAN robot for building assessment in areas affected by earthquakes is exploited. The presented work illustrates the hardware and software characteristics of the developed robotic platform, and results obtained with field testing in the real earthquake scenario of Amatrice, Italy. In [7] the successful implementation of video-enhanced telemedicine pilot project in a rural state is reported. Video-enhanced telemedicine using a store and forward process improved burn size estimation and facilitated management changes. Although not quantitatively assessed, the low cost of the system coupled with the changes in transportation and disposition strongly suggests a decrease in healthcare costs associated with the addition of video to a telephone-only transfer program. In [8] a systematic review of medical emergency triage and patient prioritization in a telemedicine environment is presented on the basis of two critical directions. Firstly, previous studies on patient triage and prioritization in such an environment are collected, analyzed and categorized. Secondly, many standards and guidelines of triage and different methods and techniques of prioritization are presented and reviewed in detail.

In [9] an integrated system, including personnel, hardware, communication protocols, portable power generation, medical kits, and Web-based tools, is developed and successfully tested in the Euro-Atlantic Disaster Response Coordination Centre's Exercises Ukraine 2015. In [10] a multimodal sensor system for wound assessment and pressure ulcer care is presented. Multiple imaging modalities including RGB, three- dimensional (3-D) depth, thermal, multispectral, and chemical sensing are integrated into a portable hand-held probe for real-time wound assessment. Analytic and quantitative algorithms for various assessments including tissue composition, wound measurement in 3-D, temperature profiling, spectral, and chemical vapor analysis are developed. In [11] Portable Healthcare Clinic (PHC) is adapted to fit post-disaster conditions. The PHC health assessment criteria are redesigned to deal with emergency cases and healthcare worker insufficiency. A new algorithm makes an initial assessment of age, symptoms, and whether the person is seeing a doctor. These changes will make the turn-around time shorter and will enable reaching the most affected patients better. The authors tested the operability and turn-around time of the adapted system at the debris flow disaster shelters in Hiroshima, Japan.

In [12] a framework for 3D real-time communication is proposed that combines interaction via Virtual Reality and Augmented Reality. The capabilities of this framework are demonstrated on a prototype system consisting of a depth camera, projector and 3D display. The system is used to analyze the network performance and data transmission quality of the multimodal streaming in a remote scenario.On the other hand there are also some research papers focusing on ambulances’ fleet management and routing. In particular in [13] the authors evaluate the performance of different Response Time Thresholds (RTTs), by designing a location model which takes into consideration calls of high priority. Also the concept of patient survival is introduced in the overall model. In [14] a modified version of the p-envy model is presented, where the distance objective-function is replaced by a survival function. The scheme sets bounds to individuals’ survival rates and focuses on the overall survival rate. Additionally a hypercube model is introduced to handle the lack of ambulances.

In [15] the dynamic ambulance management problem is studied in case of rural regions, which poses a limited number of ambulances. The paper proposes a heuristic approach that tries to minimizing the penalty induced by the next emergency call. Different penalty functions are incorporated to measure the overall performance. Results for the rural province of Flevoland (Netherlands) show an improvement of up to 2 minutes in the average response time. In [16] an extended DSM is proposed, capable of dealing with multiple types of ambulances as well as various priority levels of emergency. To prove the overall concept, real data is incorporated coming from Chicago, USA. In [17] a multi-objective, multi-period, multi-commodity model is proposed to locate distribution centers, allocation of disaster areas and vehicles to distribution centers and to design routes from distribution centers to disaster areas. Aims of this research are (a) to minimize the fixed costs to create distribution centers, (b) to minimize the travel cost of vehicles, (c) to minimize the cost of repairing the damaged roads, (d) to minimize the maximum travel time in the route and (e) to maximize the reliability of route.

Even though interesting, the aforementioned studies do not solve the whole problem of ambulances' fleet management based on remote assessment of the injured. Towards this direction, in this paper an autonomous UAV-enabled control system is proposed to handle accident incidents. Incidents are prioritized as of low, medium or high significance based on a doctor's remote diagnosis. After evaluating a high significance incident an ambulance is invoked to collect the injured citizen and transport her/him to the nearest hospital. Certain use cases are evaluated to prove the efficiency of the proposed scheme.

III. CONTROL SYSTEM

Detection and service algorithms compose the proposed control system, respectively. Detection algorithm takes as input the status of the system, i.e., if there is an incident to serve, as well as the location of the incident. The output of the algorithm is the verification that the incident has been served. When an incident occurs it invokes service algorithm providing the location of the incident. Detection algorithm is presented in Table 1.

```
Detection algorithm
Input:status, $l_i$ //Status, incidence location
Output:status //Trigger status
Begin
status = 0 //Originally there is no trigger to handle
While(True) Do
If status = 1 Then //If a phone call trigger happens
        status ← service(status, $l_i$)
    //Invoke service algorithm to handle the event
End If
            return (status)
End While
End
```

Table.1 Detection algorithm

After service algorithm is invoked the system engages the nearest autonomous UAV to the incident location. If checks if the battery lifetime is greater than the estimated time to serve the incident, thus to verify that the selected UAV has enough energy to perform the task. If not, the system engages the next nearest autonomous UAV to incident location. When an available UAV has been selected it is navigated autonomously to the incident location by incorporating the shortest path algorithm. On arrival to the incident location embedded camera and microphone are activated to give the doctor a view of the patient's significance of treatment and provide remote diagnosis.

If the incident significance is judged high by the doctor the system calls an ambulance to transfer patient form current location to the nearest health care place or hospital. When the incident has been served the status of the system is updated to be ready to serve another incident. Service algorithm is presented in Table 2.

```
Service algorithm
Input:status, $l_i$ //Status, incidence location
Output:status //Trigger status
Begin
        engage UAV nearest to $l_i$
While(True) Do
If (battery lifetime > estimated time) Then
    //If UAV has enough energy to perform task
        navigate autonomous UAV to $l_i$
    //Incorporate shortest path to reach $l_i$
        enable remote diagnosis
    //Doctor provide remote diagnosis
If (incidence significance = high) Then
        call an ambulance to tranfer patient
    //Transfer patient from $l_i$ to hospital
End If
status ← 0//Indicate that incident has been served
return (status) //Exit service algorithm
  Else
        engage another UAV nearest to $l_i$
End If
End While
End
```

Table.2 Service algorithm

Parameter	Description
i	Average total number of incidents
l	Average number of low significance incidents
m	Average number of medium significance incidents
h	Average number of high significance incidents
u	Average number of autonomous UAVs
b	Average number of battery recharges
t	Average amount of time required
d	Average distance covered

Table. 3 Evaluation parameters

IV. EVALUATION PARAMETERS

We introduce certain evaluation parameters to assess the efficiency of the proposed use cases. Specifically, average number of incidents occurred are decomposed to average number of incidentsi, which characterized by doctors either as of low, l, medium, m or high, h, significance. Average number of autonomous UAVs engaged, u, during average number of incidents is also considered. UAVs use battery which need recharge when drain. An indicator of the average number of battery recharges is also proposed for examination, b. Average amount of time required, t, as well as average distance covered, d, to serve an incident is also important. Evaluation parameters are presented in Table 3.

V. EVALUATION METRICS

To assess the performance of the proposed system per each use case we define certain metrics, which assess the evaluation parameter values. Specifically, let $r_1 = \frac{u}{i} \in [0,1]$ be the average number of UAVs per average incidence ratio, which measures average number of UAVs engaged per average number of incidents. Low value of r_1 indicates an optimum use case since less average number of UAVs are engaged. Assume, $r_2 = \frac{h}{l+m+h} \in [0,1]$ be the average number of high significance incidences per average number of low, medium or high incidents occurred. Low value of r_2 indicates an efficient use case since less average number of high significant incidents occurred and need treatment. Let $r_3 = \frac{b}{t} \in [0,1]$ be the ratio of average number of battery recharges per average amount of time required to serve an incident. Low value of r_3 indicates an effective way to serve average amount of incidents. Assume, $r_4 = \frac{d}{t} \in [0,1]$ be the ratio of average velocity (i.e., ratio of average distance covered per average timerequired) observed during average UAVs invocation. High value of r_4 indicates optimum service average velocity of the proposed system. Evaluation metrics are presented in Table 4.

Metric	Measures
$r_1 = \frac{u}{i} \in [0,1]$	Average number of UAVs engaged per average total number of incidents
$r_2 = \frac{h}{l+m+h} \in [0,1]$	Average number of high significance incidences per average number of low, medium or high incidents occurred
$r_3 = \frac{b}{t} \in [0,1]$	Average number of battery recharges per average amount of time required to serve an incident
$r_4 = \frac{d}{t} \in [0,1]$	Average velocity (i.e., ratio of average distance covered per average time required) observed during average UAVs invocation

Table. 4 Evaluation metrics

VI. USE CASES

The proposed control system is evaluated on certain categories of SC infrastructure. Specifically, UC-I describes a centralized infrastructure where certain number of autonomous UAVs is located in a base station at the center of the SC. Assume that we incorporate a number n of UAVs to serve a possible incident in the SC. When a phone call triggers the control system the nearest UAV is invoked to serve the incident. The process is continued until all the UAVs are invoked. Note that the SC terrain is not divided to certain sectors, which means that on a next system trigger a UAV is possible to engaged at any location within the SC. In such a case the system resources are not used efficiently and may be not sufficient to serve the citizens needs and provide recovery services. UC-I is presented in Figure 1.

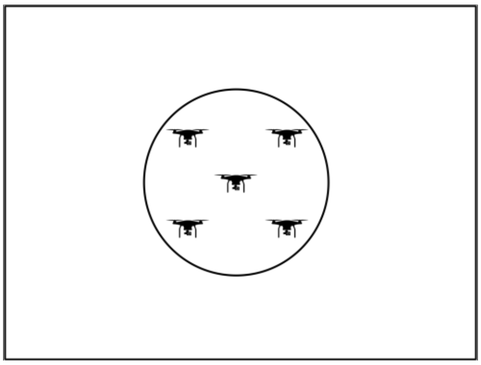

Figure 1: UC-I

UC-II describes a decentralized distributed infrastructure where the SC terrain is divided to certain number of p sectors equal to the number nof the available autonomous UAVs. This means that each sector has assigned a unique UAV. In this use case we have nnumber of base stations at the center of each sector. In case of a control system trigger it is invoked the UAV, which is assigned to the nearest sector. In this case as well the process is continued until all the UAVs are invoked. However, when a new trigger is occurred it is served by the nearest UAV, which actually is located in the nearest neighbor of the incident sector. UC-II is presented in Figure 2.

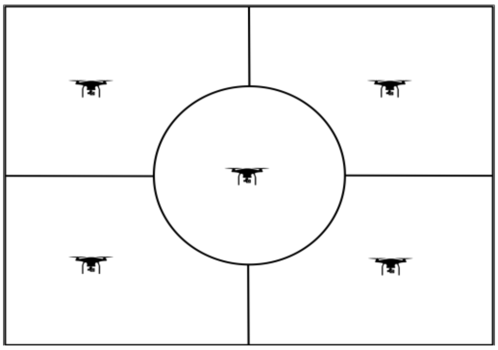

Figure 2: UC-II

VII. EXPERIMENTS

We perform certain experiments to assess the efficiency of each use case and define which is more effective in case of physical disasters in SCs. We assume that we have $n = 10$ autonomous UAVs in the SC. In case of UC-I autonomous UAVs are located at the city centre, while in case of UC-II UAVs are distributed evenly at $p = 10$ sectors of the SC. For UC-II it holds that for each sector is assigned a unique UAV. We run the experiments for a number of $it = 1000$ iterations. For certain iteration,the control system is invoked several times according to the incidents, ic, occurred, which are following a random distribution between the interval $ic \in (0,100]$ incidents. We used random distribution to avoid bias on the system's results. Experimental parameters are presented in Table. 5.

Experimental Parameter	Value
n	10
p	10
it	1000
ic	(0,100]

Table. 5 Experimental parameters

VIII. RESULTS AND DISCUSSION

Proposed control system is input with experimental parameters, which output the values of evaluation parameters. Based on the vales of the evaluation parameters the system results on certain metrics, which assess the effectiveness of each use case. Specifically, in Figure 3 are presented the results of r_1 metric for UC-I and UC-II, respectively. We observe that r_1 values for UC-II are less than that of UC-I, which indicates that UC-II is an optimum use case since less average number of UAVs are engaged.

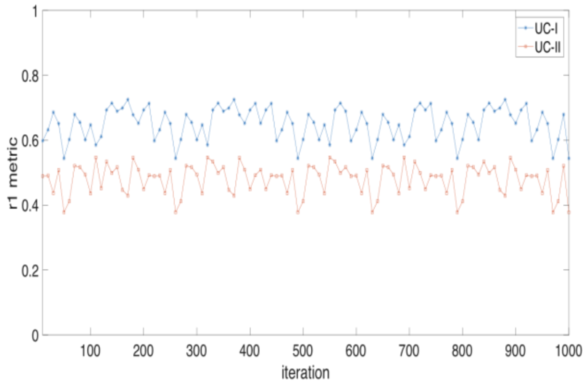

Figure 3:r_1 metric for UC-I and UC-II.

Concretely, results for r_2 metric are presented in Figure 4. Values of r_2 metric for UC-I are greater than that of UC-II, which indicates that UC-II is an efficient use case since less average number of high significant incidents occurred and need treatment.

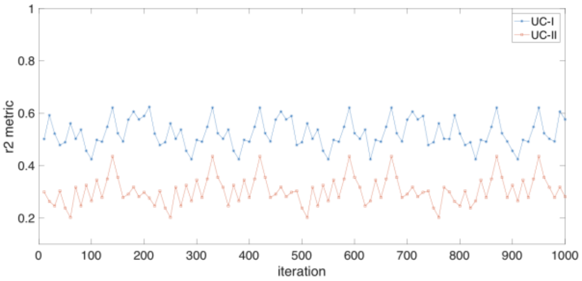

Figure 4:r_2 metric for UC-I and UC-II.

In addition, in Figure 5 are presented the r_3 metric results. Note that r_3 values for UC-II are less than that of UC-I, which indicates that UC-IIis a use case with an effective way to serve average amount of incidents

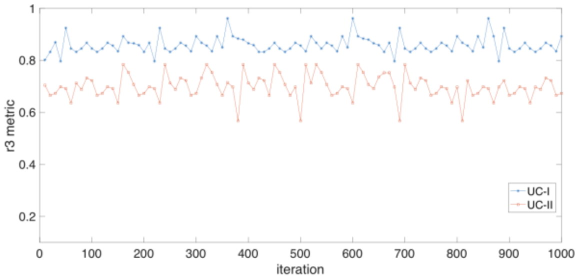

Figure 5:r_3 metric for UC-I and UC-II.

Consequently, r_4 metric results are presented in Figure 6. We can see that values of r_4 metric for UC-I are less than that of UC-II, which indicates that UC-II is a use case with optimum service of average velocity for the proposed system.

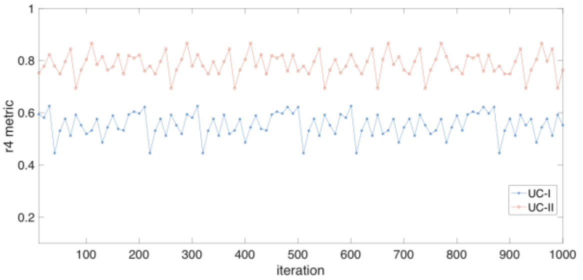

Figure 6:r_4 metric for UC-I and UC-II.

Comparing results obtained form the experiments we can infer that UC-II use case is optimum compared with the UC-I, since it has less r_1, r_2, and r_3 values than UC-I. In addition, UC-II has higher r_4 metric values than UC-I. For optimality of a certain use case, see Section V.

IX. CONCLUSION AND FUTURE WORK

Physical disasters affect citizens' wellbeing since they cause severe injuries to SCs' population. We propose a control system to face the effects of physical disasters to human population living in SCs by incorporating autonomous UAVs. Control system is based on detection and service algorithms to serve an emergency incident after a physical disaster in SCs. A fleet of autonomous UAVs is located in certain areas within the SC according to certain use cases. We used a centralized UC-I and a decentralized distributed UC-II to test the efficiency of the proposed control system.

Certain evaluation metrics and parameters are incorporated to infer which use case is better for adoption by SCs. After performing certain experiments we proved that UC-II is optimum compared with UC-I according to the proposed evaluation metrics. Future research direction is to provide advanced first aid to all of the citizens' injury incidents and not only to the considered as emergency incidents.

ACKNOWLEDGMENT

This research was financially supported by the Master's Programme "Health and Social Welfare Management" of the University of West Attica.

REFERENCES

[1] F.Fatehi, A. C. Smith, A. Maeder, V. Wade, and L. C. Gray, "How to formulate research questions and design studies for telehealth assessment and evaluation," J TelemedTelecare, vol. 23, no. 9, pp. 759-763, Oct. 2016.
[2] K. Nahrstedt, "3D tele-immersion for remote injury assessment," in Proc. of Int. Workshop on Socially-aware multimedia, 2012.
[3] N. L. Tofte, J. M. Freeman, and B. N. Harvey, "System and method for controlling a remote aerial device for up-close inspection," US Patent 9,085,363, 2015.
[4] L. A. Wallis, J. Fleming, M. Hasselberg, L. Laflamme,and J. Lundin, "A smartphone app and cloud-based consultation system for burn injury emergency care," PLoS ONE, vol. 11, no. 2, e0147253, 2016.
[5] M. B. Wooten,and I. D. Walker, "Robot ropes for disaster response operations,"in Proc. of IEEE global humanitarian technology conference (GHTC), pp. 1-1, 2017.
[6] F. Negrello, A. Settimi, D. Caporale, G. Lentini, M. Poggiani, D. Kanoulas, L. Muratore, E. Luberto, G. Santaera, L. Ciarleglio, L. Pallottino, D. Caldwell, N. Tsagarakis, A. Bicchi, M. Garabini, and M. Catalano, "WALKMAN humanoid robot: Field experiments in a post-earthquake scenario," IEEE Robot. Autom. Mag., vol.25, no.3, pp. 8-22, Sep. 2018.
[7] L. Wibbenmeyer, K. Kluesner, H. Wu, A. Eid, J. Heard, B. Mann, A. Pauley, and C. Peek-Asa, "Video-enhanced telemedicine improves the care of acutely injured burn patients in a rural state," Journal of Burn Care & Research, vol. 37, no. 6, pp. e531-e538, Nov.-Dec. 2016.
[8] N. M. Napi, A. A. Zaidan, B. B. Zaidan, O. S. Albahri, M. A. Alsalem, and A. S. Albahri, ''Medical emergency triage and patient prioritisation in a telemedicine environment: A systematic review,'' Health and Technology, Springer, pp. 1-22, 2019.
[9] C. R. Doarn, R. Latifi, R. K. Poropatich, N. Sokolovich, D. Kosiak, F. Hostiuc, C. Zoicas, A. Buciu, and R. Arafat, "Development and Validation of Telemedicine for Disaster Response: The North Atlantic Treaty Organization Multinational System," Telemedicine and e-Health, vol. 24, no. 9, 2018.
[10] M. C. Chang, T. Yu, J. Luo, K. Duan, P. Tu, Y. Zhao, N. Nagraj, V. Rajiv, M. Priebe, E. A. Wood, and M. Stachura, "Multimodal Sensor System for Pressure Ulcer Wound Assessment and Care," IEEE Transactions on Industrial Informatics, vol. 14, no. 3, Mar. 2018.
[11] M. Hu, M. Sugimoto, A. RebeiroHargrave, Y. Nohara, M. Moriyama, A. Ahmed, S. Shimizu, and N. Nakashima "Mobile Healthcare System for Health Checkups and Telemedicine in Post-Disaster Situations," MEDINFO 2015: eHealth-enabled Health, I.N. Sarkar et al. (Eds.), IMIA and IOS Press, doi:10.3233/978-1-61499-564-7-79, 2015.
[12] D. Anton, G. Kurillo, A. Y. Yang, and R. Bajcsy, "Augmented Telemedicine Platform for Real-Time Remote Medical Consultation," in Proc. of International Conference on Multimedia Modeling (MMM),pp. 77-89, 2017.
[13] L.A. McLay, and M.E. Mayorga, "Evaluating emergency medical service performance measures,".Health Care Management Science, vol. 13, no. 2, pp. 124-136, 2010.
[14] S. Chanta, M.E. Mayorga, and L.A. McLay, "The minimum p-envy location problem with requirement on minimum survival rate," Computers & Industrial Engineering, vol. 74, pp. 228-239, 2014.
[15] T.C. van Barneveld, S. Bhulai, and R.D. van der Mei, "A dynamic ambulance management model for rural areas," Health Care Management Science, vol. 20, pp. 165-186, 2017.
[16] Y. Liu, Z. Li, J. Lieu, and H. Patel, "A double standard model for allocating limited emergency medical service vehicle resources ensuring service reliability," Transportation Research Part C, vol. 69, pp. 120-133, 2016.
[17] B. Vahdani, D. Veysmoradi, N. Shekari, and S. M. Mousavi, "Multi-objective, multi-period location-routing model to distribute relief after earthquake by considering emergency roadway repair," Neural Computing and Applications, vol. 30, no. 3, pp. 835-854, Aug. 2018.

★★★