A Distributed Search and Rescue System and Emergency Beacon: Applying Technological Factors to Distributed Systems

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Abstract

This dissertation aims to describe a graduated design project to design a distributed SAR(search and rescue) system for personal use in dangerous situations and to explain a practice-based approach to applying technological factors to distributed systems that emerged from this design project. This approach provides guidance for considering technological elements in the design of social innovation in three aspects: usability, openness and cost.

This design project investigated the possibility of using distributed solutions to improve efficiency, increase flexibility, and reduce costs of the search and rescue systems. It also considered opportunities for local people to engage in the search and rescue operations to generate social innovation. This project's critical issue was choosing the right technology to realize the design concept.

Keywords: design for social innovation, distributed system

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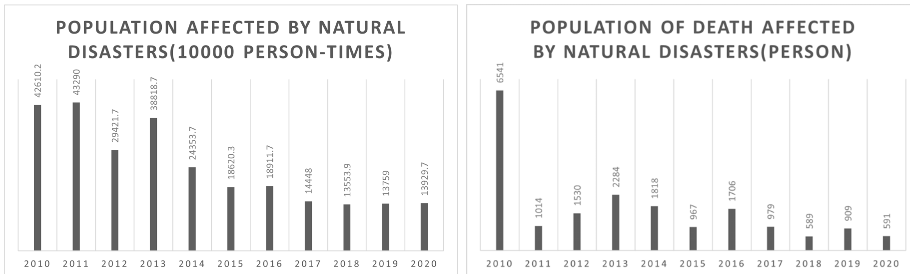

Figure 1: Population affected by natural disasters in China

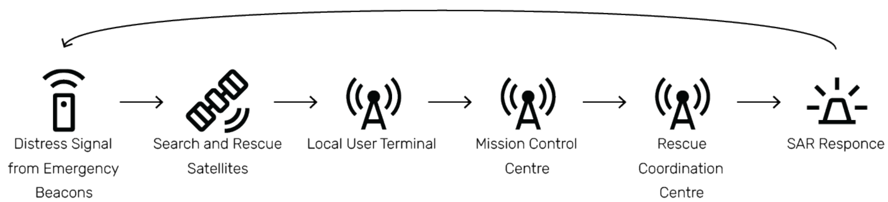

Figure 2: Workflow of centralized SAR system

1 Background to the Research

This design project started by looking at the safety of children on their way to school in remote areas and then expanded to general search and rescue systems. Search and rescue systems and Emergency locator beacons are widely used to locate airplanes, vessels, and persons in distress and in need of immediate rescue. In case of emergency, the beacons can transmit distress signals that used by professional search and rescue teams.

It is essential to establish a sound and efficient search and rescue system. In China, for example, a large number of people are affected by natural disasters every year. Natural disasters cause some of the population to go missing or die. The related statistics is shown in Figure 1. [7] And another important cause of people missing or encountering emergency is outdoor sports.

The workflow of currently used SAR systems such as Cospas-Sarsat is shown in Figure 2. Users can activate the emergency beacons and send distress signals when they encounter life-threatening emergencies. The satellites with SAR signal repeaters and SAR signal processors pick up the signals and then transfer them to ground stations called local user terminals. The local user terminal processes the signal and forwards the data to the mission control centre. Furthermore, the mission control centre distributes distress alert data to related rescue coordination centres. Finally, the rescue coordination centres send search and rescue teams to respond to distress situations. It is a traditional service controlled by a large centralized control system that relies on professional personnel and equipment. The emergency beacons are designed to transmit signals

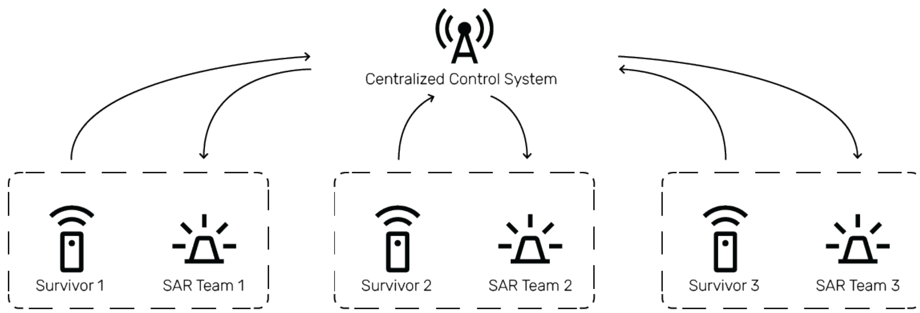

Figure 3: Traditional centralized SAR system

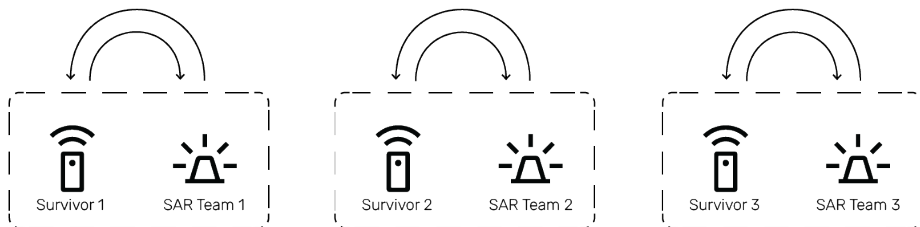

Figure 4: Ideal distributed SAR system

in frequencies 406MHz or 121.5MHz that can only be received by satellites or special equipment carried by search and rescue teams. Moreover, the data it transfers is usually encrypted and can only be processed by the centralized control system. Furthermore, some systems require that the beacons be registered to perform better.

The systems are effective but need to be more efficient. Firstly, in life-threatening emergencies, only the local people can help in time. It would be more efficient to send the distress signal to local search and rescue teams directly. Secondly, the systems are closed, and only professionals can participate in the rescue operation, preventing other local people who can help get involved. As a result, there are possibilities and necessities for replacing the current system with a distributed, localized and open solution, generating social innovation to improve efficiency, increase flexibility, and reduce costs. To achieve this goal, the distress beacons and receiving device must be re-designed.

Two key points can thus be identified within the research project: designing a distributed searching and rescue system and finding the right technologies to realize it.

2 Distributed System

Distributed system is a concept that corresponds to traditional centralized system. It can be defined as follows:

> The distributed model sees infrastructure and critical service systems (for water, food and energy etc.) positioned close to resources and points of demand. Individual systems may operate as separate, adaptive units but are also linked within ever-wider networks of exchange – at the local, regional or global level. Services traditionally provided by large centralised systems are instead delivered via the collective capacity of many smaller diverse systems. Each is tailored to the needs and opportunities of unique locations but has the capacity to transfer resources across a wider area.(Biggs, Ryan and Wiseman, 2010, p.10) [2]

Biggs, Ryan and Wiseman(2010) also indicate that the distributed system model has four key characteristics: localised, networked, modular and open. Moreover, case studies and related research have shown that distributed systems have advantages over traditional systems, such as increasing physical resilience, improving social and institutional flexibility and innovation, and reducing production and consumption's environmental footprint. [2] Those characteristics and advantages are considered and shown in this project.

The traditional centralised search and rescue system can be summarised in Figure 3. All distress signals are processed by a centralised control system and forwarded to nearby search and rescue teams. And the ideal distributed system is shown in Figure 4. The people in emergencies send distress signals directly to local search and rescue teams, making the system localised and reducing operating costs. Each small system can be scaled to meet local needs. For example, more professional search and rescue teams are needed in densely populated areas prone to natural disasters. On the contrary, This system may only be turned on in sparsely populated areas when there is a known accident.

To keep the system networked and open, the distress signals should be unencrypted and comprehensible. Thus not only the local professional search and rescue team can participate in the system, but also the local and foreign people who are willing to or able to help, generating social innovation.

Based on the concepts above, the distributed search and rescue system can be refined into Figure 5. When encountering life-threatening emergency, the user activates the emergency beacon. The beacon gets current location information and transmits open and comprehensible distress signals that can be received by nearby professional search and rescue team and local people with receiver equipment. In accident-prone areas, long-term operating surveillance towers can be set up to improve fault tolerance.

3 Applying Technological Factors

Social innovation can not exist in isolation from technology. Social change and technological progress influence each other and occur together. Innovation in sociotechnical systems does not only come from the technological side, but is also driven by society and culture.(Manzini, 2015) [6] In this design project, the

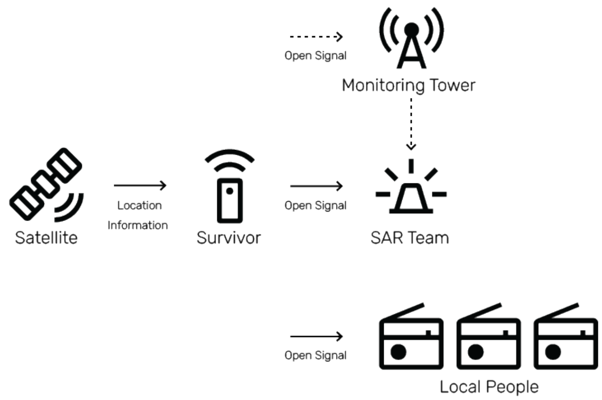

Figure 5: Detailed distributed SAR system

distributed system was set up before the technological part. Therefore, it can be considered as an innovation of sociotechnical system caused by social changes. It must be implemented by introducing a new way of using and integrating existing technologies in a social form.

When applying technological factors, this distributed system that aims to generate social innovation was considered as an SLOC scenario, which means small, local, open and connected. The SLOC scenarios indicate two basic strategies: replicating and connecting. Through replicating, scaling out can be achieved. And through connecting, scaling up can be achieved. [5] This two strategies can also be applied on technological level.

The system includes two products: emergency beacons and distress signal receivers. The emergency beacon can receive location signals from satellites and send distress signals to receivers. The first part is proven and inexpensive technology, while there is no suitable solution for the second part. The VHF(Very high frequency) and UHF(Ultra high frequency) radio communication technologies used in traditional search and rescue systems are reliable but relatively expensive and not applicable to the replicating strategy. The technologies must be low-cost and easy to use to make the products small and connected.

After researching and consulting with telecommunications experts, HF(High frequency) radio communication, also known as short-wave radio, was chosen as the target communication method. Compared with VHF and UHF radio, HF radio have several advantages. Firstly, HF radio transmitter and receiver is cheaper and already widely used. Secondly, HF radio has better performance in areas with complex terrain. It is less susceptible to interference and travels farther.

The message that the beacon transfer should also be open, meaning it is short, clear, and easy to understand. Since HF radio is used in this design project, audio signal become a good option. To begin with, audio signal can be received by most ordinary shortwave radios and do not require specific receiver

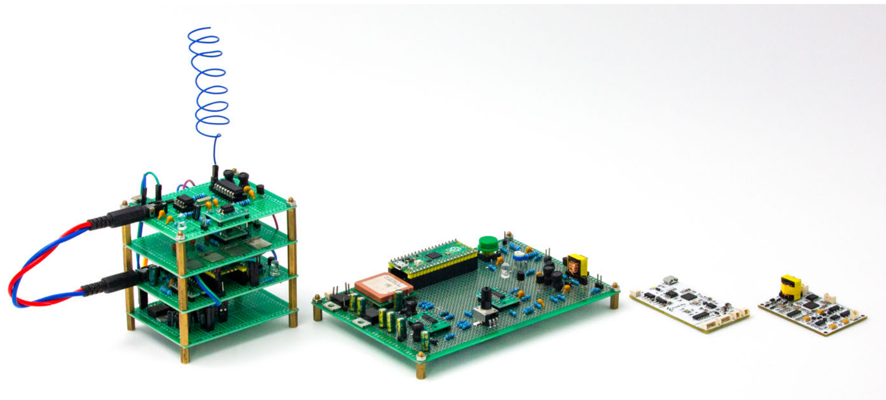

Figure 6: Functional prototypes

device. And it can be understood even in the case of poor signal quality. The message contains two parts: SOS distress signal in Morse code and coordinates of the current position obtained from the satellite.

Historically, shortwave emergency beacons were used, but were abandoned for a number of reasons. Because of the relationship between wavelength and frequency, the wavelength of HF radio is longer than VHF and UHF radio. And the longer the wavelength, the longer the antenna needed for transmission. If the antenna is not long enough, the transmission distance will be limited. This problem can be solved by using high-tech antennas like inverted-F antenna or microstrip antenna but it is not cost-effective. Since this design project is a distributed system, there is no need to consider long distance communication. Short antennas can also achieve acceptable results.

4 Design Development

The design process of this project was based on iterative design process that included a number of stages of prototyping and testing.(Rodgers and Milton, 2013) [8]

In the early stage of the design process, a rough functional model(the left in Figure 6) based on the concept design was made as a start point of the product design. The prototype was then split into different modules for function analysis. [10] The result is shown in Figure 7. The GPS/BDS module get location data from satellites and forward it to the MCU module. The MCU module processes the data and generates audio signals for HF radio transmitter. The power supply module is also straightforward, including batteries, charge port and power management circuit. The parts that need careful consideration are interaction part and the antenna.

In life-threatening emergencies, the user may have only a little time and space to activate the emergency beacon. Therefore, the input operation has to be

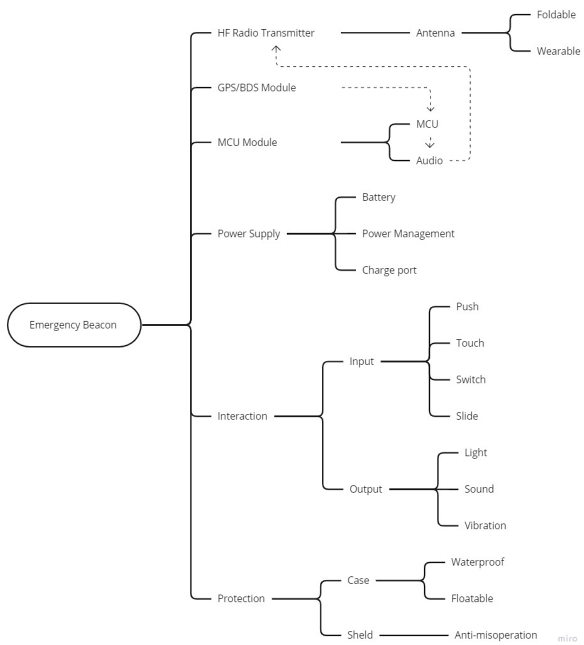

Figure 7: Function analysis of the emergency beacon

simple and easy like pushing down a big button or touching a capacitive button. On the other hand, misoperations may happen if the interaction was too easy. In that case, some protection designs is needed to avoid misoperations. The output interaction includes displaying the working condition of the emergency beacon and the feedback of the inputs. An indicator light would be fine.

As for the antenna, there are two directions: making it foldable so that the user only expands it before use the beacon, or combining it with other function to use it when the emergency beacon is not activated.

The first concept design of the emergency beacon, which is shown in Figure 8, is modular, including a core module, a battery module and a functional module. And a series of functional modules are designed to meet different needs in different situations. The antenna is designed to be hung around the neck as a way to carry the product. It use four capacitive buttons as input method. The user can slide on the surface once to activate the function module and slide it back and forth to activate the emergency beacon. A LED indicator shows the work condition. After analysis and test, this concept design has several problems that need to solve. Firstly, the slide operation is not reliable enough. User may need to try more than once to trigger it. Secondly, the capacitive buttons are invisible and lack physical feedback. They are hard to use in the dark. Thirdly, the antenna design is prone to loosen during strenuous activities. And the attempt to add other function on the emergency beacon is deviated

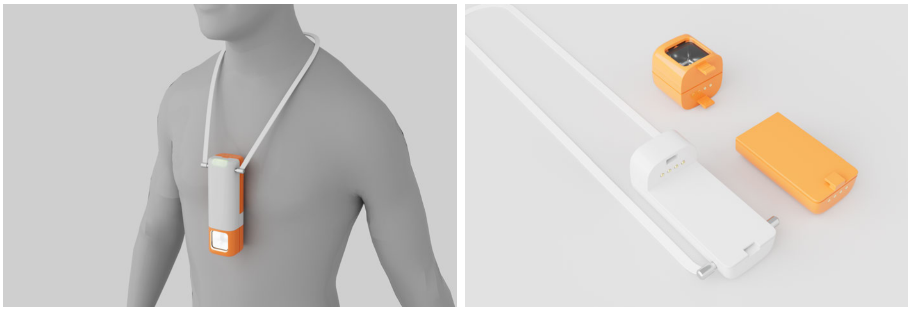

Figure 8: The first concept design

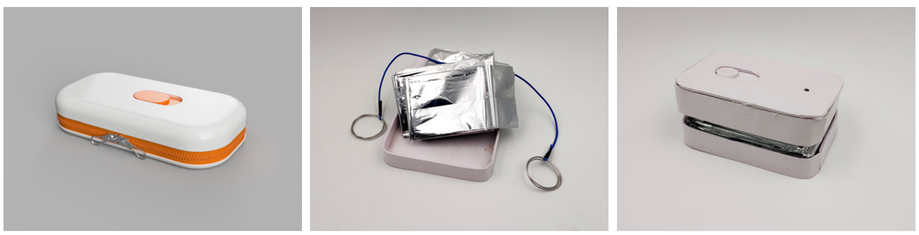

Figure 9: The second concept design

from the original design intention.

The second concept design of the emergency beacon is shown in Figure 9. It has a physical switch as the input device, balancing the convenience and reliability. And physical switch also provides good feedback that can be easily used in the dark. The antenna is combined with a rescue blanket and folded with a zipper. There are two metal rings in the end of the antenna used to unfold the antenna and rescue blanket quickly. After tests, the problems of this prototype are as follows: The biggest problem is that the use scenarios of antenna and rescue blanket do not completely overlap. The user has to unfold the rescue blanket, no matter if he or she needs it when using the emergency beacon. And the rescue blanket is hard to fold after using it since it is usually be considered disposable product. What is more, the only switch can not meet the need of adding a test function.

After several iteration, the final concept design of the emergency beacon is shown in Figure 10. In this concept, all unnecessary functions and structures are removed. The physical switch is replaced by a button. The emergency beacon function can be activated by pressing and holding the button. And the test function can be activated by holding it a longer time. A LED indicator shows the working condition. Thus the interaction part is easy, clear and reliable as the design goals. And different functions are controlled by a single input device. The antenna design was inspired by tape measures. When using the beacon, it can be pulled out directly. After using the beacon, the user can push

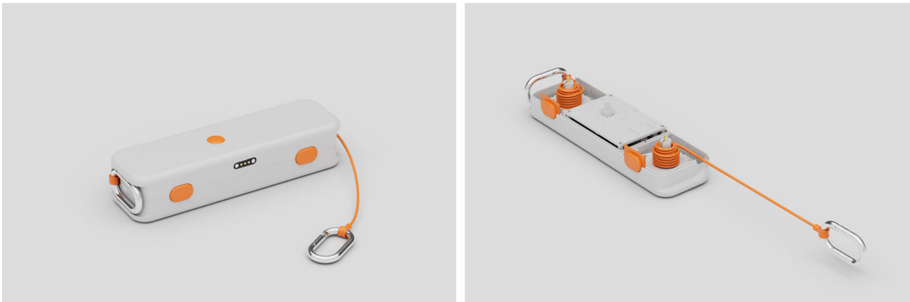

Figure 10: The final concept design

Figure 11: The final prototype

the buttons to roll it back. The rings in the end of the antenna are replaced by clasps to cope with a variety of use environments. When not in use, they can be placed in the slots on the side of the product. This concept uses a rechargeable lithium polymer battery and a magnetic charging port to reduce the size and keep waterproof performance. The case is made of engineering plastics like nylon, making sure is durable enough in wild environments. The shape is designed following the function, as simple and small as possible.

A high quality prototype containing 3D printed parts and functional PCB was made to test. It is shown in Figure 11. This prototype works as expected and the user experience is satisfactory.

This design project also includes a range of accessories. There is a web application that can run in most software platforms, like computers and mobile phones, used to display the received location coordinates on digital map and to provide navigation. And any other map application can use the data since it is open-sourced. In extreme conditions without internet connection, a paper map can be used instead.

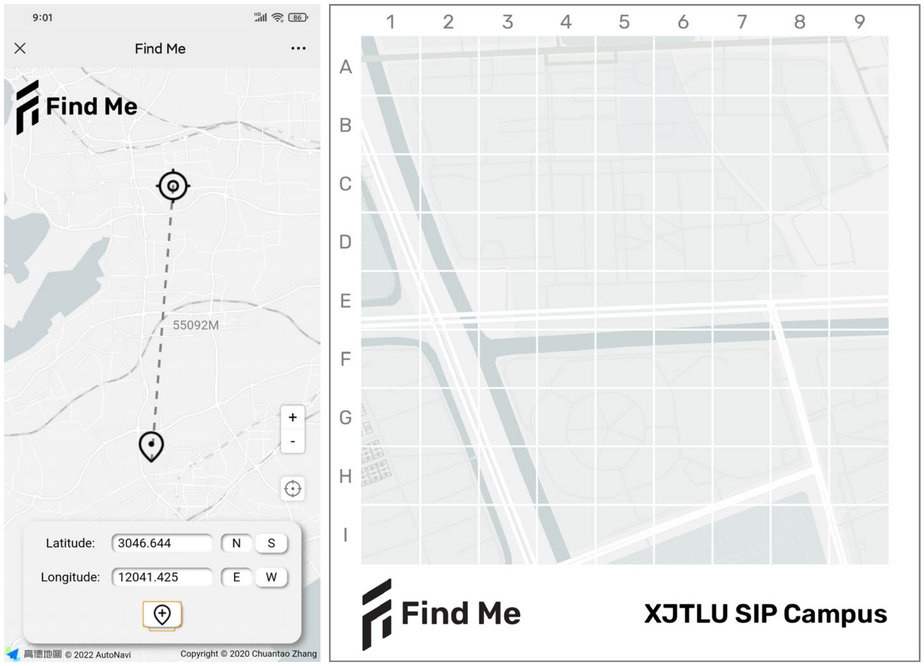

Figure 12: Web application and paper map

5 Outcomes and Findings

This design project produced a low-cost, efficient and flexible distributed search and rescue system. This system fits the definition of a SLOC scenario and has the potential to generate social innovation. It is a small system that can work totally localized. And it is open and connected, with the ability to scale out by getting local people involved, and to scale up by establishing monitoring tower in areas prone to natural disasters. The transmission and data is also open and can be used by other systems or services.

In terms of product design, this project produced a low-cost, durable and convenient emergency beacon. It is a HF radio beacon. But the common problem of excessively long antennas for HF radio transmitter was solve through a rotating antenna design with ratchet constructions. The product is durable and waterproof to adapt to a variety of complex environments. It has a small and light, making it easy to carry when not in use. This system do not require a special receiver since the signal is open to most ordinary HF radio receiver, while there is the flexibility to design a specific receiver to get better performance if it is needed in some areas prone to natural disasters.

6 Transferable Approach

The concept of research through design is applied on this design project. [9] Zimmerman, Stolterman and Forlizzi(2010) indicate that The projects using research through design concept will generate thoery on design and thoery for design, like new design methodologies or new design structures. [11]

The research and practice of this project shows that applying technological factor on designed distributed system concept is feasible. In this project, the system design at a macro level is finished based on the trends and need of social innovation without consideration of specific technological factors. And those technological factor was applied after the system design through a series of guidelines that generated from the system level. It can be summarised as a new methodology to be used in other similar scenarios.

The technological factors are applied according to the characteristics of the distributed system. The distributed systems are localized. It should be close to the resource and demands, reflecting the scale and context the system. This means that the products and technologies should be small and simple. In this design project, every single emergency beacon can work as small system within an area using mature and simple technologies. The distributed systems are networked and open. They are linked to each other, and have the capacity to exchange information and resources freely. This means that at the technological level, information and resources must be able to be disseminated in an open-sourced format. In this project, audio messages transmitted on short waves that can be received by most ordinary radio receivers ensure that the dissemination of information in the system is open both internally and externally. And the distributed systems are modular. it can operate independently and combine with other systems or networks to get better performance and enable even wider resource distribution. In this project, every emergency beacon and receiver can be considered as a module. They can work independently, and also work with other module like monitoring tower depending on the local demands. What is more, to generate higher social impact, more local people should get involved. The technology used in a distributed system should therefore be easy to use and inexpensive, adapted to mass production and use, like the emergency beacon in this project.

Therefore, a transferable approach can be summarised as follow: the technologies applied on the distributed systems should be economically efficient, open, and have high usability. Being economically efficient means the technologies have low production and usage costs, allowing for large scale distribution. Being open means the technologies are open in form and content and can be interfaced with other systems. High usability means that technology should be understandable and usable by most people.

7 Further Use

The Approach to applying technological factors to distributed system that generated from this design project can be apply on projects of design for social innovation. However, it does not apply to all design research projects. Manzini(2015) indicates that design for social innovation is all the activities that professional design can implement to activate, sustain, and guide society towards sustainable development. [6] Social innovation can be driven by technologies, and also can be driven by social change. And it can be designed too. This approach can be applied to those design projects driven by social change or professional designers in the case that a concept of distributed system has been established, but the detail of how to achieve it still needs to be defined. For example, it is a good tool in the projects that aims to replace traditional centralized system with distributed system.

8 Conclusion

In this design project, the current search and rescue system was researched. Based on the research, a new low-cost efficient distributed system was proposed. The project also explores the possibility of using easy and cheap technology to involve more people and make search and rescue operations more efficient. An emergency beacon was designed as the fundamental element of the distributed system, along with a series of accessories. The test result was satisfactory, preliminary proving that the distributed search and rescue system has higher efficiency than traditional centralized system and has the potential to generate social innovation. While further testing and iteration is needed.

The approach of applying technological generated from the design practice has produced good results in this project. The potential exists for this method to be applied to other similar projects, but more practice and research is needed to refine it and maximise its applicability.

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