藍芽低功耗之 Continua 血糖計實施案例研究

Case Study on the Bluetooth Low Energy Based Continua Glucose Monitor

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隨著健康觀念的提高，以及高齡人口的趨勢，醫療器材具有通訊功能成為重要的趨勢。舊有的醫療器材大多為封閉系統。該醫療器材僅能與可搭配之閘道器及後端伺服系統銜接。Continua 採用 ISO/IEEE 11073 做為個人化醫療器材通訊標準，使得醫療器材之間具有互通性，資訊亦能夠互相分享。目前符合國際通訊標準之醫療器材，多半為 USB PHDC，Bluetooth HDP，以及 ZigBee HC 等介面。藍芽協會提出新一代技術：藍芽低功耗，其耗電量比傳統藍芽更小，有機會用於傳送資料量不大的個人化照護設備。本研究所提之 Continua BLE 血糖計是基於 TI BLE CC2540/41 所設計，並且符合 Continua design guidelines 及 ISO/IEEE 11073 醫療器材標準規範。Continua BLE 血糖計感測使用者之血糖生理量測資訊，並且將此些資訊轉換成符合 Bluetooth GATT 為主之資訊格式。透過 Continua BLE 血糖計之藍芽低功耗介面，將此些標準化之生理資訊傳送到服務閘道器及後端伺服系統。根據實驗結果，使用者能成功地透過 Bluetooth 介面，傳送血糖生理量測值到任何 Continua 認證之應用伺服主機。

With the increase of health concept and the threat of aging population, medical device with communication ability becomes important functionality. Old healthcare facilities were private communication systems. These medical devices only connect to the specific gateway and server. The ISO/IEEE 11073 specifications adopted by the Continua Health Alliance are the international personal healthcare device communication standards. By these standards, the medical devices can intercommunication and exchange measurement data within a single system. The transport interfaces supported by international communication standards are USB PHDC, Bluetooth HDP, and ZigBee HC. Current the Bluetooth SIG proposes the Bluetooth LE technology with power consumption than traditional Bluetooth. The Bluetooth LE is possible used in medical devices with low data transmission. The design for the Continua BLE Glucose meter proposed in this paper is based on the TI BLE CC2540/41 chipset as well as the Continua Design Guidelines and ISO/IEEE 11073 Personal Health Device standard. The Continua BLE Glucose meter senses the glucose measurements from the users, and then transmits these data to the application hosting device and server in compliance with Bluetooth GATT-based data format and protocol standards via the Bluetooth Low Energy interface. Based on the testing results, users can transmit glucose measurement to any application hosting device certified by the Continua Health Alliance over the Bluetooth LE interface successfully.

一、前言

遠距照護系統之研究近年來不斷的被提出，具有通訊功能之醫療器材成為重要探討之議題。目前，醫療器材之通訊介面大多為 RS232、USB PHDC (personal healthcare device profile)[1][2]、Bluetooth SPP (serial port profile) 或是 Bluetooth HDP (health device profile)[3][4]、亦或是 ZigBee HC (health care)[5] 等。

Park 等人[6] 提出一個 ISO/IEEE 11073 標準之系統，包括 Universal PHD adapter，UPA interface board，以及 PHD manager。UPA interface board 透過 RS-232 介面與非標準 (Non-PHD) 的醫療設備連接，並且透過 ZigBee 介面使生理量測資訊經由 Universal PHD adapter 傳送到 PHD manager。Lee 等人[7] 提出一個革新的個人健康照護系統，包含服務閘道器、轉換器，以及非標準醫療設備。轉換器之功能類似橋接器一般，用以轉換來自非標準醫療設備之生理量測資訊，並且以 ISO/IEEE 11073 標準資料封包之格式，透過 Bluetooth HDP 介面傳送到服務閘道器。Wu 等人[8] 提出一個採用 ISO/IEEE 11073 標準之體重系統，包括以軟體實現之 ×73 adapter 及 ×73 gateway。非標準之體重機透過 RS-232 或藍芽將生理量測資訊傳送到 ×73 adapter，並經過 ×73 gateway 轉換資訊後，傳送到伺服主機系統。然而，這些系統皆非以藍芽低功耗介面為基礎之照護系統或是醫療器材設備。藍芽低功耗之特色：傳送少量資料以及耗電量少，有機會成為新一代醫療器材產品之通訊介面。

本研究提出一個具備互通性與生理資訊共享之 Continua BLE 血糖計，可連接支援國際醫療器材通訊標準之個人化健康照護系統。透過 Continua BLE 血糖計提供之互通性平台，Continua BLE 血糖計以符合國際醫療器材通訊標準 ISO/IEEE 11073 PHD 之資料格式與服務閘道器交換彼此訊息[9]。此外，服務閘道器與 Continua BLE 血糖計兩者之間交換訊息的傳輸層介面是透過 Bluetooth low energy 技術[10]，以及符合 Bluetooth GATT-based glucose profile/service 標準[11][12]。透過藍芽低功耗介面，服務閘道器和 Continua BLE 血糖計很容易地建立一個無線之連結。基於此互通性之平台，Continua BLE 血糖計將可以和不同之標準應用伺服主機彼此互通，並且在個人化之網域內彼此交換健康資訊。

二、醫療通訊標準介紹

為了達到 Continua BLE 血糖計之目標，本系統採用以下醫療器材通訊標準，並分述如下：

1. Continua Design Guidelines V4.0

Continua Health Alliance[13] 以現今個人化健康照護之生態系統架構為主軸，企圖統一不同廠商或領域之間的差異。其目標在於疾病管理，例如居家之慢性疾病照護，獨居老人之照護，例如利用現今之科技及服務，使獨居老人雖然在家裡仍可獲得妥善照護，以及健康生活之管理，使得個人能提升自我健康之管理。Continua Health Alliance 提出點對點 (end-to-end) 之參考架構[14]。此一分散式之系統架構依其功能可區分為五種照護設備類別以及五種網域之介面技術。其中五種照護設備類別分別為：個人網域設備 (PAN device)、區域網域設備 (LAN device)、應用主機設備 (application hosting device)，廣域網域設備 (WAN device) 與健康記錄網域設備 (health record device) 等。五種網域介面技術，分別為接觸網域介面技術 (touch area network, TAN-IF)、個人網域介面技術 (personal area network interface, PAN-IF)、區域網域介面技術 (local area network interface, LAN-IF)、廣域網路介面技術 (wide area network interface, WAN-IF)，以及健康記錄網域介面技術 (health record network interface, HRN-IF) 等。此五種介面技術亦為 Continua 能夠做好互通性目標之關鍵核心。

圖 1 顯示 Continua 採用之醫療器材介面堆疊架構圖，包含 TAN、PAN 以及 LAN。目前 Continua 明訂各個介面採用之通訊標準及其互通性之規範於 design guidelines version 2013 (又稱為 design guidelines V4.0)。其中 TAN 的介面選定 NFC 技術，PAN 的介面又分為 wire PAN、wireless PAN，以及 low power wireless PAN，分別

選定 UAB PHDC、Bluetooth HDP，以及 Bluetooth low energy 等技術，LAN 的介面則選定 ZigBee 技術。本研究之 Continua BLE 血糖計屬於 low power wireless PAN 之介面技術。

Continua design guidelines V4.0 中[14]，明確定義各個 TAN/PAN/LAN 之 communication capability、device information、quality of service、regulatory settings/information、user identification。對於不同種類之設備 (包括：血氧計、ECG、heart rate sensor、血壓計、體溫計、體重計、血糖計、INR meter、body composition analyzer、peak flow monitor、心血管運動器材、cardiovascular step counter、強度訓練、activity hub、fall sensor、motion sensor、enuresis sensor、contact closure sensor、switch sensor、dosage sensor、water sensor、smoke sensor、property exit sensor、temperature sensor、usage sensor、PERS sensor、CO sensor、gas sensor，以及 adherence monitor 等)，也明訂出對應之規範。

目前在 low power Wireless PAN 之介面技術，Continua design guidelines V4.0 也明確定義：certified device classes、device communication styles、PAN-IF security、device discovery、pairing、service discovery、user notification、authentication、OEM requirements、date and time requirements、certification and regulatory、以及 transcoding。另外，也針對在藍芽 BLE GATT-based profile/service 規範中已支援之血壓計、體溫計、heart rate monitor、以及 glucose meter 等，明訂其內必須支援之 service 及 characteristic。

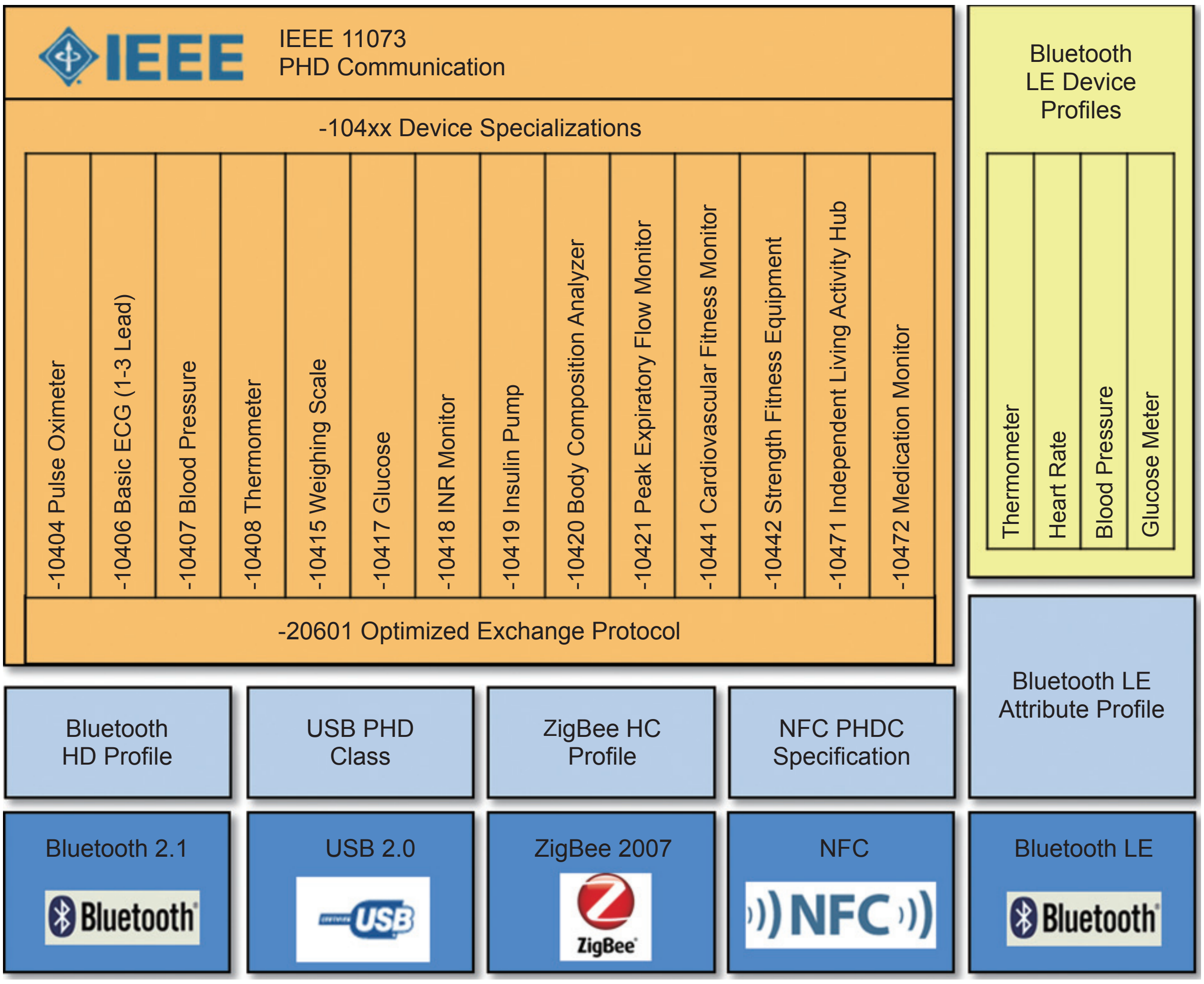


圖 1. Continua 採用之醫療器材介面堆疊架構圖。

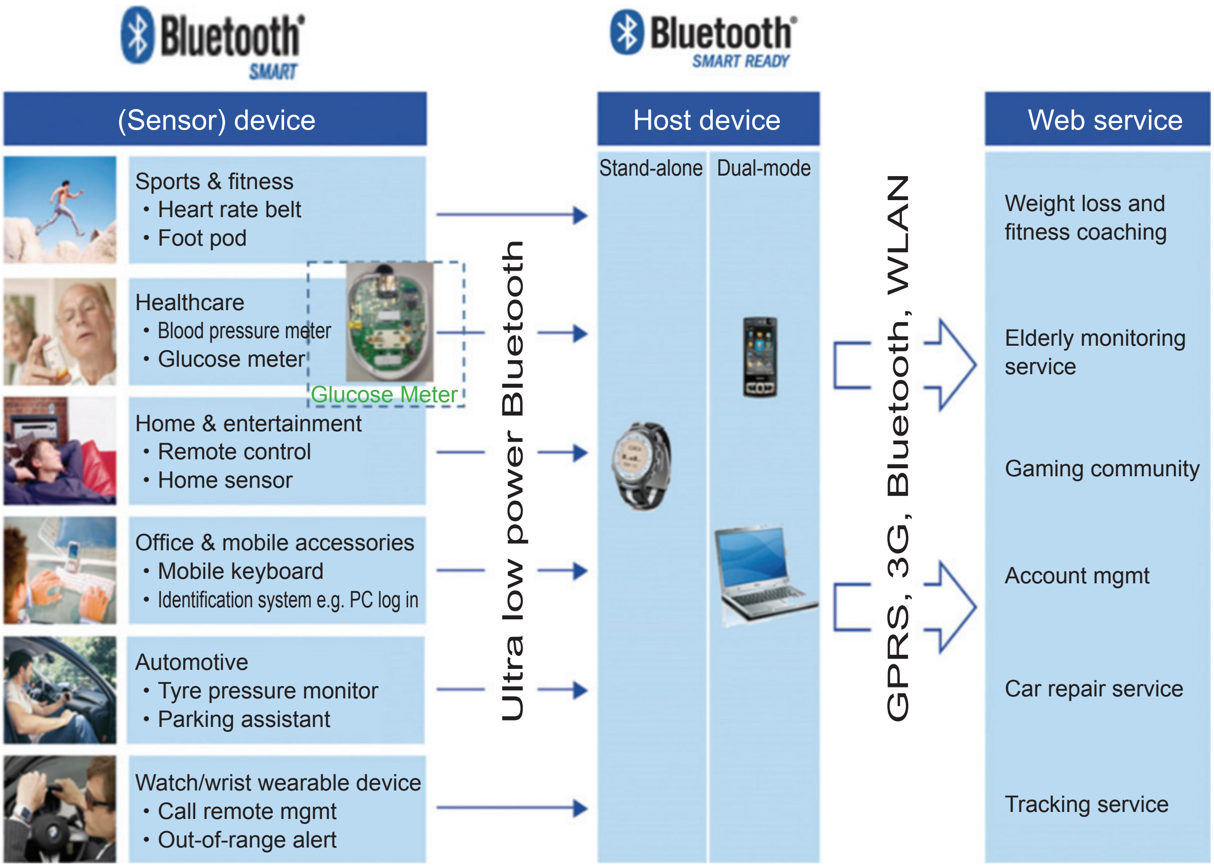


圖 2. 藍芽低功耗產品之使用情境。

2. BLE Glucose Profile and Service

舊有的醫療器材，例如血壓計或是血糖計，透過傳統 Bluetooth 傳送生理資訊至伺服端設備。之後，Bluetooth health device profile (HDP) 被 Bluetooth 協會訂出[3][4]，用以作為醫療器材與 Bluetooth 伺服端設備互相操作之標準概廓，並於此概廓中支援眾多種類的醫療器材與伺服端設備。然而，此些藍芽之標準皆未能夠支援低耗電流功能。目前藍芽規範 4.0 已經訂出藍芽低功耗之規範，並且制訂不同種類醫療器材之 profile/service 規範。

藍芽低功耗之產品區分為 Bluetooth Smart，Bluetooth Smart Ready，以及標準 Bluetooth。Smart Ready 適用於任何雙模藍牙 4.0 的電子產品，如 iPhone 4S 手機。而 Smart 則是應用在心率監控器或計步器等使用扭扣式電池並傳輸單一資訊的裝置。Smart Ready 的相容性會最高，可與 Smart 及標準藍牙相通。標準藍牙則無法與 Smart 或 Smart Ready 者相通。圖 2 顯示藍芽低功耗產品之使用情境。藍芽低功耗之技術將可滿足 sensor device (包括：sports & fitness、healthcare、home & entertainment、office & mobile accessories、automotive，以及 watch/wrist wearable device) 之需求。連接 sensor device 與 host device，並傳送資訊到後端伺服主機系統。

圖 3 顯示 BLE 架構圖。藍芽 BLE 之主要 stack 包括 physical layer (PHY)、link layer、host controller interface、logical link control and adaptation protocol、attribute protocol、generic attribute profile、generic access profile 等。其中，BLE 之 physical layer，如同 BR/EDR 一樣，仍採用 2.4 GH 的 industrial scientific medical (ISM) band，不同的是傳統 BT(BR/EDR) 分成 79 個 channels，而 BLE 拆成 40 個 channels (其中 3 個頻道專用於廣告封包；另外的 37 個頻道專用於資訊封包)，帶寬變寬 (2 MHz)。BLE 之 Tx power

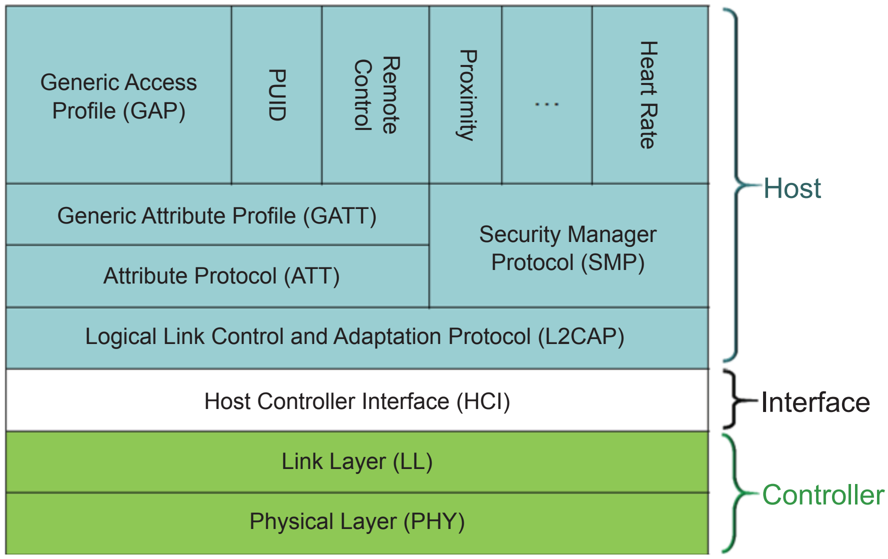


圖 3. BLE 架構圖。

output 一律最低為 –20 dbm，最高為 +10 dbm，傳送距離最遠可以到達 50 m，但會受限於藍芽對接端之能力。

link radio 負責傳送或接收在實體層 (physical channel) 之封包。link control 負責藍芽封包之加密及解密，並且負責執行 link layer protocol。link controller 負責從實體頻道，邏輯傳輸和邏輯鏈路相關的數據負載和參數中編碼和解碼藍牙封包。Link Controller 攜帶 link control 信號 (與 resource manager 的調度功能緊密結合)，用來實現流控，確認和傳輸請求的信號。link control 信號的解釋和控制與 baseband resource manager 的調度有關。link manager 負責邏輯鏈路 (也包括邏輯傳輸) 的創建，修改和釋放，以及設備間與實體鏈接相關之參數更新。link manager 通過與對端藍牙設備的 link manager 使用 LMP (link management protocol) 通信來實現這些功能。

HCI layer 制訂出一個標準界面用以介接 controller 與上層各 layer。類似於 BR/EDR，L2CAP 在 (BLE之) link layer 之上提供一 channel-based 之 abstraction 給應用或服務層，並實現應用層資訊之切割與重組，以及在一共享的邏輯連結上多個頻道之 multiplexing 及 de-multiplexing。attribute protocol 使一設備 (稱為 server) 揭示 attributes 或相關連之資訊給一對應之設備 (稱為 client)。而此些被 server 揭示之 attributes 可被 client 設備 discover，read 以及 write；或是由 server 端設備自行 indicate 或 notify。generic attribute profile (GATT) 定義了一個服務架構 (service framework)，以使用 attribute protocol。此架構並訂出程序 (procedures) 及格式 (service & characteristics)。其中，程序定義了包括 discovering、reading、writing、notifying & indicating characteristics 以及設定 (configuring) 廣告封包。GAP 提供幾個主要之功能：profile roles、discoverability modes and procedures、connection modes and procedures 以及 security modes and procedures。

基於此 BLE stack 之上，不同之 GATT-based profile/service 運行其上，以達成其預定之功能。本研究所提之 Continua BLE 血糖計，需要符合 BLE glucose profile 及 BLE glucose service 之規範[11][12]。其中，BLE glucose profile 明訂出不同設備 (glucose sensor 或 collector) 之角色定義與其行為，血糖機必需要包含之 service 種類，血糖設備連線建立之 procedures，取得血糖資訊或設備資訊之方法；BLE glucose service 則明訂血糖 service 內需要有哪些 characteristic 及各 characteristic 之行為。圖 4 顯示 BLE glucose profile 與 service 關係圖。

接下來，第三章節介紹 Continua BLE 血糖計

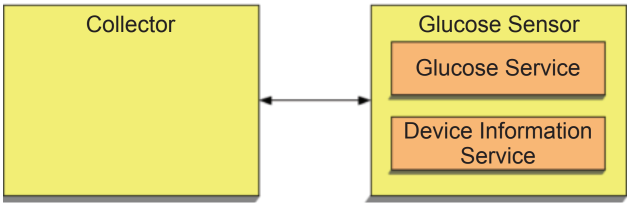


圖 4. BLE Glucose Profile/Service 關係圖。

之設計、第四章節介紹實作與測試，以及第五章節提出實作結果與討論。

三、Continua BLE 系統設計

本研究所提之 Continua BLE 血糖計包含兩個主要系統：Continua BLE 系統及 glucose sensor 系統。Continua BLE 系統透過 Bluetooth GATT 介面連接 Continua compliant-gateway (或稱為 Continua compliant AHD (application hosting device, 應用伺服主機))，以及透過 UART (universal asynchronous receiver/transmitter) 介面連接 glucose sensor 系統。量測所得之生理資訊，透過 Continua BLE 系統提供之互通性平台 (解析／轉換)，交換於 Continua compliant-gateway 與 glucose sensor 系統。

概觀而言，Continua BLE 血糖計透過 Bluetooth 介面與應用伺服主機建立藍芽實體連線通道。Continua BLE 血糖計開始與應用伺服主機建立符合國際醫療器材標準 (ISO/IEEE 11073-20601) 之互通性平台。於此平台中，進行血糖生理資訊的交換。

1. Continua BLE 血糖計之系統需求分析

本研究所提出之 Continua BLE 血糖計，包含兩個部份：其一為 Continua BLE 系統，採用 TI BLE CC2540/41 為基礎之 iMCC2541 模組作為藍芽低功耗之解決方案；另一為 glucose sensor 系統，由欣生醫物聯網公司研發血糖感測功能。Continua BLE 血糖計是一台具有藍芽低功耗傳輸功能，並符合 Continua 規範之血糖機。依據系統各元件之關係，圖 6 顯示 Continua BLE 血糖計之系統需求分析圖。

圖 6 是以 UML (unified modeling language) 描述系統之使用案例，圖中顯示以 Continua BLE 系統為核心，具有 6 個主要功能：start system、stop system、send advertisement、get vital sign info.、establish BLE data channel，以及 send out BLE data 等。其中，start system 提供系統開始功能；stop system 提供系統結束功能；send advertisement 提供 Bluetooth LE 之廣播功能；get vital sign info. 提供向 glucose sensor 提取生理量測資訊；establish BLE data channel 提供藍芽 GATT 為基礎之資料通道建

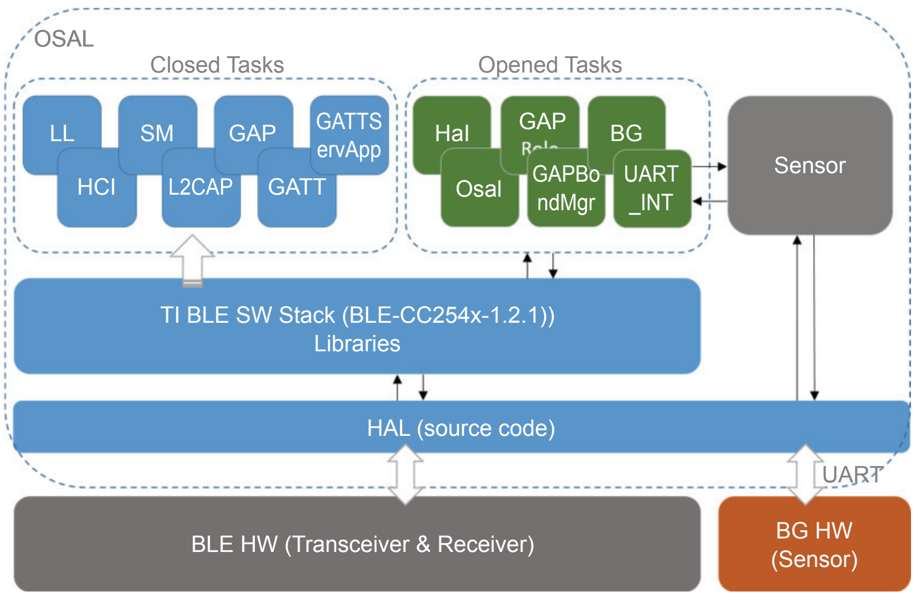


圖 5. 以 TI BLE CC2541 為基礎之 Continua BLE 血糖計系統架構圖。

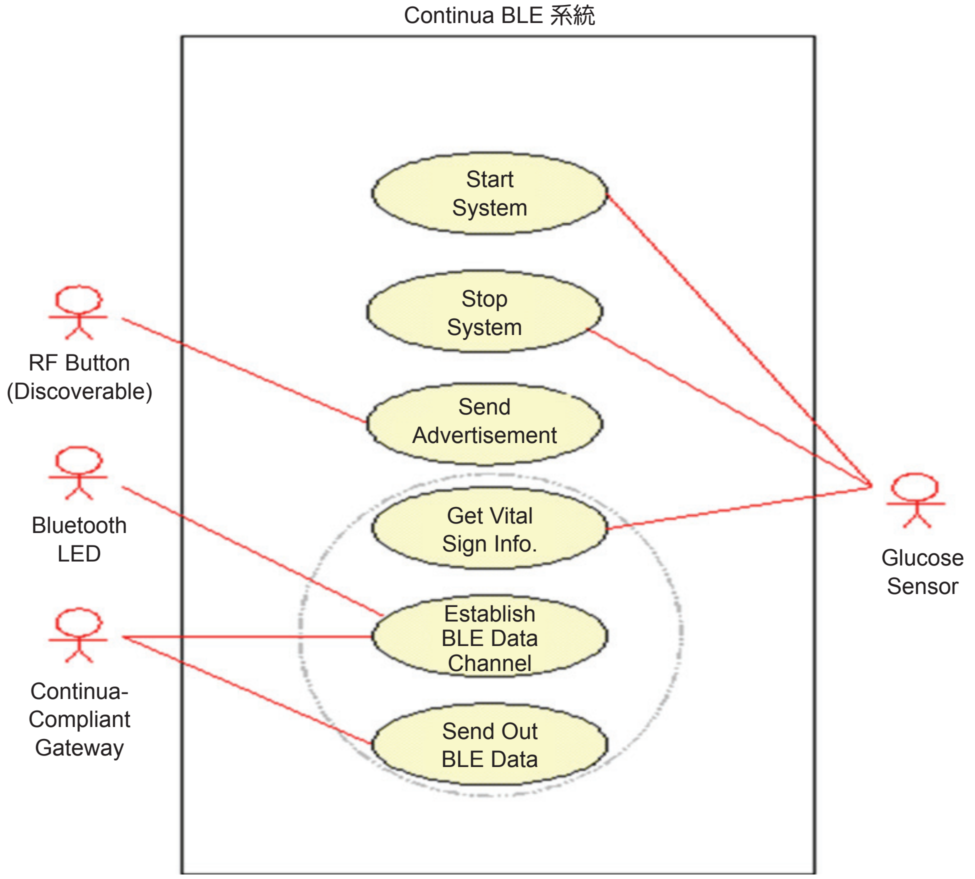


圖 6.
Continua BLE 血糖計之系統需求分析圖。

立；以及 send out BLE data 提供透過既有之資訊通到傳送生理量測資訊。

Continua BLE 系統藉由 glucose sensor 系統執行 start system 及 stop system 之功能，且 Continua BLE 系統可透過與 glucose sensor 系統雙方建立之通訊協定，提取血糖生理量測資訊。透過 RF button 功能鍵可以使 Continua BLE 系統送出藍芽廣播封包，使其成為可被連線之狀態。Bluetooth LED 用以顯示藍芽連線成功之結果。Continua BLE 系統與 Continua compliant-gateway 建立藍芽連線之資訊通道，並且透過此資訊通道用以傳送生理量測資訊。

2. Gateway 與 Continua BLE 血糖計之訊息流程設計

如上節所述，Continua BLE 系統向 glucose sensor 系統提取設備及生理量測等資訊，並且透過其與 Continua compliant-gateway 建立之藍芽連線資訊通道傳送此些資訊。圖 7 顯示 gateway 與 Continua BLE 血糖計 (包含 Continua BLE 系統及 glucose sensor 系統) 之訊息流程圖。

Continua BLE 系統 (透過 glucose sensor 系統啟動) 完成初始化之後，首先展開藍芽之 advertisement 封包之廣播。接著，對 glucose sensor 系統送出 online test 訊息，藉以通知 glucose sensor 系統：後方連線已完成。Continua BLE 系統開始與 glucose sensor 系統交換訊息以了解預備傳送哪些生理量測資訊。以 Continua BLE 系統當作中繼，連線的雙方 (glucose sensor 系統與 Continua compliant-gateway) 開始進行雙方資訊之交換 (包含提取量測資訊及回覆傳送結果)。爾後，glucose sensor 系統主動提出連線中止，或是由 Gateway 端系統主動提出連線中止之命令。Continua BLE 系統收到藍芽底層回覆之連線中斷事件後，通知 glucose sensor 系統 link change (link down) 訊息。

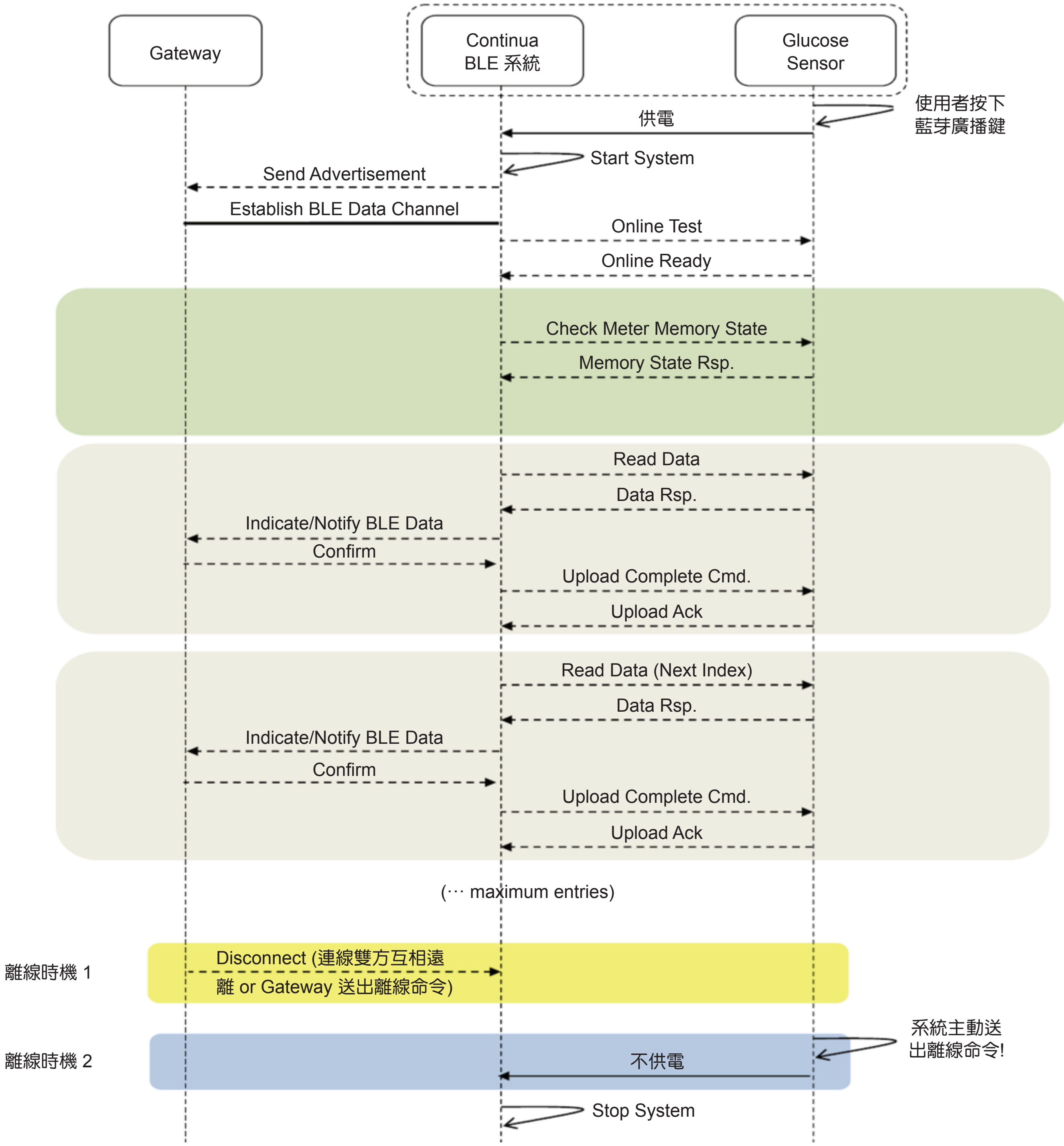


圖 7. Gateway 與 Continua BLE 血糖計之訊息流程圖。

3. Continua BLE 系統架構設計

圖 5 顯示以 TI BLE CC254/41 為基礎之 Continua BLE 血糖計系統架構圖。TI 提供 BLE-CC254X-X.X 作為其 BLE 開發工具之軟體開發套件 (SDK)。Continua BLE 系統架構在此平台之上，共包含若干模組與相關之 tasks。其中，有 7 個模組及其 tasks 內嵌於 libraries 中 (包含：LL 模組、HCI 模組、SM 模組、L2CAP 模組、GAP 模組、GATT 模組，以及 GATT ServApp 模組等都無法增／修)；其餘之模組及其 tasks 則可透過修改原始

ConHnd	Handle	Uuid	Uuid Description	Value
0x0000	0x0001	0x2800	GATT Primary Service Declaration	00:18
0x0000	0x0002	0x2803	GATT Characteristic Declaration	02:03:00:00:2A
0x0000	0x0003	0x2A00	Device Name	42:47:20:4D:65:74:65:72
0x0000	0x0004	0x2803	GATT Characteristic Declaration	02:05:00:01:2A
0x0000	0x0005	0x2A01	Appearance	00:00
0x0000	0x0006	0x2800	GATT Primary Service Declaration	08:18
0x0000	0x0007	0x2803	GATT Characteristic Declaration	10:08:00:18:2A
0x0000	0x0008	0x2A18	Glucose Measurement	
0x0000	0x0009	0x2902	Client Characteristic Configuration	
0x0000	0x000A	0x2803	GATT Characteristic Declaration	02:0B:00:51:2A
0x0000	0x000B	0x2A51	Glucose Feature	00:00
0x0000	0x000C	0x2803	GATT Characteristic Declaration	28:0D:00:52:2A
0x0000	0x000D	0x2A52	Record Access Control Point	
0x0000	0x000E	0x2902	Client Characteristic Configuration	
0x0000	0x000F	0x2803	GATT Characteristic Declaration	02:10:00:08:2A
0x0000	0x0010	0x2A08	Date Time	DD:07:0A:1F:0E:0C:00
0x0000	0x0011	0x2800	GATT Primary Service Declaration	0A:18
0x0000	0x0012	0x2803	GATT Characteristic Declaration	02:13:00:23:2A
0x0000	0x0013	0x2A23	System ID	00:00:00:00:00:00:00:00
0x0000	0x0014	0x2803	GATT Characteristic Declaration	02:15:00:24:A2
0x0000	0x0015	0x2A24	Model Number String	54:44:33:32:36:31:46
0x0000	0x0016	0x2803	GATT Characteristic Declaration	02:17:00:29:2A
0x0000	0x0017	0x2A29	Manufacturer Name String	57:2D:69:4F:54:20:43:6F:2E
0x0000	0x0018	0x2803	GATT Characteristic Declaration	02:19:00:26:2A
0x0000	0x0019	0x2A26	Firmware Revision String	31:2E:30:30:2D:42:30:31
0x0000	0x001A	0x2803	GATT Characteristic Declaration	02:1B:00:25:2A
0x0000	0x001B	0x2A25	Serial Number String	30:30:30:30:30:30:30:30:30:30
0x0000	0x001C	0x2803	GATT Characteristic Declaration	02:1D:00:2A:2A
0x0000	0x001D	0x2A2A	IEEE 11073-20601 Regulatory Certificati...	00:02:00:12:02:01:00:08:02:00:00:01:00:02:11:80:02:02:00:02:00:00

圖 8. BLE 血糖計之 GATT Table 設計。

碼，使能夠增／修模組之功能。再者，系統各模組與硬體互動的部份是透過 HAL 模組與硬體界接，修改 HAL 模組使得以控制硬體及收送資訊。

系統完成初始化作業後，開始進入系統排程之程序，依序將 MCU 資源分配給各 task 使用。task scheduler 是以 TaskID 依序提取各 task 之 process event 函式，以進行各事件之處理。各 task 之處理程序如下：LL_ProcessEvent、Hal_ProcessEvent、osal_CbTimerProcessEvent (for OSAL 模組)、L2CAP_ProcessEvent、GAP_ProcessEvent、GATT_ProcessEvent、SM_ProcessEvent、GAPRole_ProcessEvent、GAPBondMgr_ProcessEvent、GATTServApp_ProcessEvent、Glucose_ProcessEvent，以及UART_INT_ProcessEvent。

4. GATT table 之設計

圖 8 顯示 BLE 血糖計之 GATT table 設計。GATT table 之目的在於使 GATT client 端 (亦即 gateway) 了解 GATT server 端 (亦即 Continua BLE 血糖計) 之設備相關設定資訊，使 GATT client 能夠以此 GATT table 解析 (由 GATT server 傳送之) 生理量測資訊。本研究之 Continua BLE 血糖

計其主要 GATT table 之組成包含：GAP service (0x1800)、glucose service (0x1808)，以及 device information service (0x180A) 等。

GATT table 內三個 service 之順序，依序為 GAP service、glucose service，以及 device information service。其中 GAP service 包含 device name 及 appearance；glucose service 包含 glucose measurement、client characteristic configuration、glucose feature、record access control point、及 date time；device information service 包含 system ID、model number string、manufacturer name string、firmware revision string、serial number string，以及 IEEE 11073-20601 regulatory certification data list。

GAP service 之 date time 及 device information service 之 IEEE 11073-20601 regulatory certification data list 皆是以符合 Continua design guidelines V4.0 之規範而加入之設計，使血糖計不僅符合藍芽低功耗 glucose profile/service 規格，並且符合 Continua design guidelines V4.0 之 low power (LP) Wireless PAN 之規範。

四、實作與測試

Continua BLE 血糖計之硬體由欣生醫物聯網公司協助開發，並選用 iMCC2541 模組作為其藍芽低功耗之解決方案。基於 TI BLE-CC254x SDK，Continua BLE 系統所有功能得以完成。閘道器方面，採用生醫所已完成研發之 BLE APP (Android-based)，以及架設 Continua 官方標準測試平台[15]，用以驗證本研究所提之 Continua BLE 血糖計。在研發與測試的過程中，採用 Frontline 藍芽低功耗分析儀 (Bluetooth low energy protocol analyzer) 用以輔助系統之開發與除錯。表 1 顯示實驗室設備一覽表。

Continua BLE 血糖計之測試包含 3 個主要項目：(1) BLE APP 與 Continua BLE 血糖計之測試；(2) Continua CESL manager 與 Continua BLE 血糖計之測試；(3) Continua test management lite 與 Continua BLE 血糖計之測試。其中 Continua CESL manager 與 Continua test management lite 皆是官方釋出用以研發或測試醫療器材通訊標準之平台，透過此標準平台得以驗證 Continua BLE 血糖計。以下就三個主要測試分別說明。

1. BLE APP 與 Continua BLE 血糖計之測試

本研究採用生醫所已經研發完成之 BLE APP，其支援 BLE 血糖計與 BLE 血壓計。將 BLE APP 安裝於 Google Nexus 4 手機，且其 Android 版本是 4.4.4。圖 9 顯示 gateway (以 Android 為基礎之手機) 與 Continua BLE 血糖計之測試架構圖。測試結果顯示，當 Continua BLE 血糖計按下 RF 功能鍵後，BLE APP 能夠找到 (scan) 此設備，且與之完成 GATT table 之訪問並建立連線，最後上傳生理量測資訊。

表 1. 實驗室設備。

Device Name	Personal Healthcare System	
	Item	Used in the test
Gateway	Hardware	Google Nexus 4 (Phone) *Support Bluetooth LE Feature (as Master)
Continua AHD	Hardware/ Software	Intel® Core 2 Duo CPU 2.40 GHz (Windows XP) CSR 8510 USB dongle (as Master) CESL Manager & Test Management Lite
BLE 血糖計	Hardware	iMCC2541 module (as Slave)
TI CC2540/41 BLE Evaluation Board	Hardware	TI SmartRF05 Evaluation Board CC2540 Evaluation Module (with BLE-CC254x-1.3.0)
Frontline BPA	Hardware	Bluetooth Protocol Analyzer

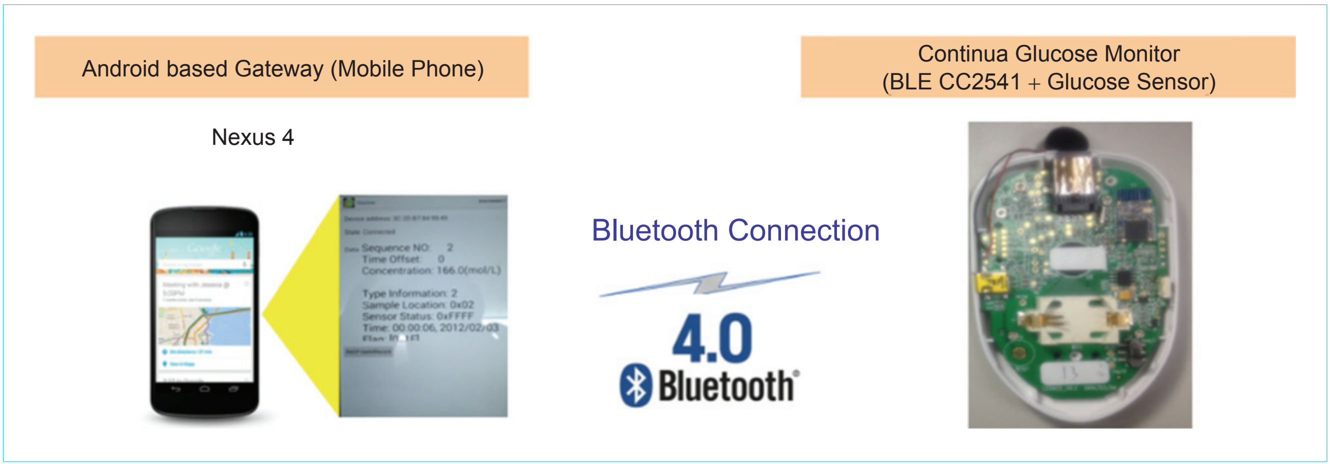


圖 9. Gateway (以 Android 為主之手機) 與 Continua BLE 血糖計之測試架構圖。

2. Continua CESL Manager 與 Continua BLE 血糖計之測試

以 PC 為硬體平台，架設 Continua CESL manager。Continua CESL manager 為標準之 Continua gateway，用以測試互通性 (interoperability)，其可以支援 USB PHDC，Bluetooth HDP，ZigBee HC，以及藍芽低功耗等介面。Continua CESL manager 採用 CSR 8510 USB dongle 作為藍芽 LE 之 transceiver/receiver。圖 10 顯示 Continua CESL manager 與 Continua BLE 血糖計之測試架構圖。測試結果顯示，當 Continua BLE 血糖計按下 RF 功能鍵後，Continua CESL manager 能夠找到 (scan) 此設備，且與之完成 GATT table 之訪問並建立連線，最後上傳生理量測資訊。

3. Continua Test Management Lite 與 Continua BLE 血糖計之測試

以 PC 作為硬體平台，架設 Continua test management lite，並採用 CSR 8510 USB dongle 作為藍芽 LE 之 transceiver/receiver。Continua test management lite 為標準之 Continua pretest 平台，用以測試通訊規格，且其除了可以支援 PAN (包括 USB，Bluetooth HDP，ZigBee，以及藍芽低功耗等) 介面測試外，還提供 WAN 及 HRN 之測試。圖 11 顯示 Continua test management lite 之測試架構圖。測試結果顯示，當 Continua BLE 血糖計按下 RF 功能鍵後，Continua test management lite 能夠找到 (scan) 此設備，且與之完成 GATT table 之訪問，並建立連線，且所有項目皆可通過測試。表

圖 10. Continua CESL Manager 與 Continua BLE 血糖計之測試架構圖。

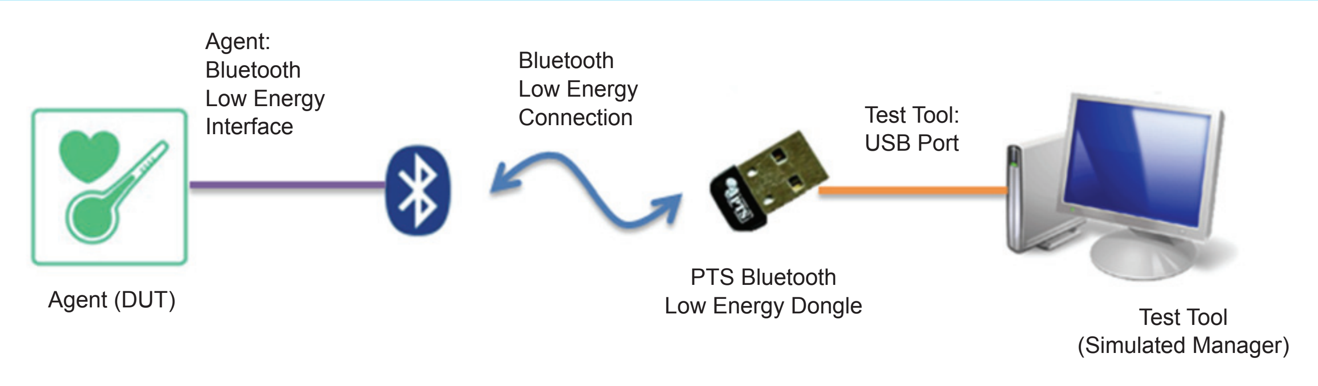
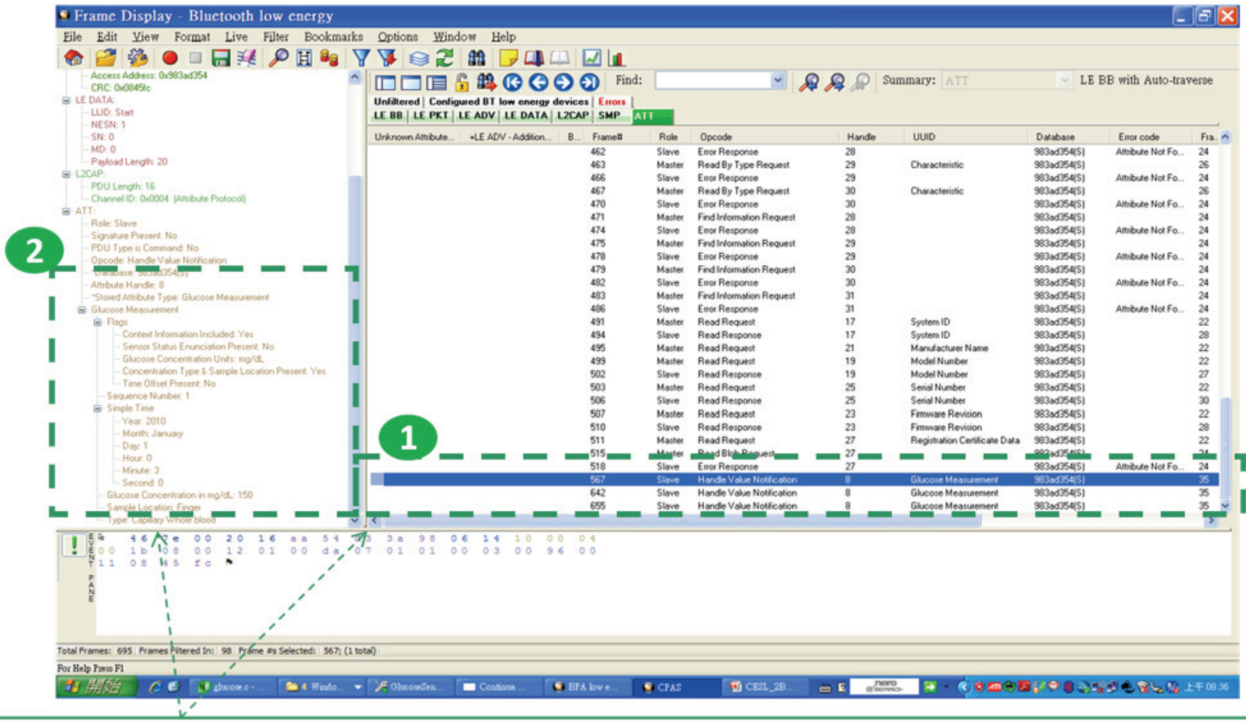


圖 11. Continua Test Management Lite 測試架構圖。

表 2. 以 Continua Test Management Lite 測試 BLE 血糖計之結果。

Test Item	Description	Test Result	
1	TP_LP_PAN_AG_TR_BLEDG_BV_010	Measurement time stamp and Date time characteristic	PASS
2	TP_LP_PAN_AG_TR_BLEDG_BI_000	Abnormal cases management-Data exchange before pairing	PASS
3	TP_LP_PAN_AG_TR_BLEDG_BV_000	Discoverabilty mode service	PASS
4	TP_LP_PAN_AG_TR_BLEDG_BV_001	Maximum Discovery service duration	PASS
5	TP_LP_PAN_AG_TR_BLEDG_BV_002	Pairing service and delete pairing service	PASS
6	TP_LP_PAN_AG_TR_BLEDG_BV_003	Storage pairing service	PASS
7	TP_LP_PAN_AG_TR_BLEDG_BV_004	Supported service profiles	PASS
8	TP_LP_PAN_AG_TR_BLEDG_BV_005	Authentication support service	PASS
9	TP_LP_PAN_AG_TR_BLEDG_BV_006	Continua DG Bluetooth LE attribute requirements-System Model	PASS
10	TP_LP_PAN_AG_TR_BLEDG_BV_007	Continua DG Bluetooth LE attribute requirements-System ID	PASS
11	TP_LP_PAN_AG_TR_BLEDG_BV_008	Continua DG Bluetooth LE attribute requirements-Production Specification	PASS
12	TP_LP_PAN_AG_TR_BLEDG_BV_009	Continua DG Bluetooth LE attribute requirements-Reg-Cert-Data-List	PASS
13	TP_LP_PAN_AG_PHDTW_GEN_BV_000	Whitepaper. Date Time characteristic	PASS
14	TP_LP_PAN_AG_PHDTW_GL_BV_000	Whitepaper. Glucose Measurement, Glucose Concentration value	PASS
15	TP_LP_PAN_AG_PHDTW_GL_BV_001	Whitepaper. Glucose Measurement, Base Time and Time Offset values	PASS
16	TP_LP_PAN_AG_PHDTW_GL_BV_002	Whitepaper. Glucose Measurement, Type and Sample Location values	PASS
17	TP_LP_PAN_AG_PHDTW_GL_BV_003	Whitepaper. Glucose Measurement, Sensor Status Annunciation value	PASS
18	TP_LP_PAN_AG_PHDTW_GL_BV_004	Whitepaper. Glucose Measurement, Blood Glucose Concentration below the capabilities of the device sensor	PASS
19	TP_LP_PAN_AG_PHDTW_GL_BV_005	Whitepaper. Glucose Measurement, Blood Glucose Concentration above the capabilities of the device sensor	PASS
20	TP_LP_PAN_AG_PHDTW_GL_BV_006	Whitepaper. Glucose Measurement Context values	PASS



1.顯示經由BLE Glucose之Notify方式傳送的 Glucose Measurement, 共3筆!
2.顯示每筆Glucose Measurement之詳細資訊: Glucose concentration value, Sample time, Concentration type & Sample location.

圖 12. 以 Frontline BPA 監聽藍芽封包之顯示結果。

2 顯示以 Continua test management lite 測試 BLE 血糖計之結果一覽表。

五、實作結果與討論

本研究所提之 Continua BLE 血糖計除了通過上述 3 項測試外，圖 12 顯示以 Frontline BPA 監聽藍芽封包交換之結果。

當 Continua BLE 血糖機持續送出廣播封包時，gateway 端進行 scan request，並等待 Continua BLE 血糖機之回覆 scan response。gateway 送出藍芽連線 connect 之命令後，藍芽實體層通道完成建立。隨即，gateway 進入訪問 GATT table 的階段。依據 gateway 設計的不同，訪問 GATT table 之方式也不盡相同。大致上，先由 primary service (0x2800) 提問：包含哪些 service 且其範圍為何？接著，針對每一個 primary service 訪問其內之所有 characteristic (0x2803) 以及其相對之內容值。當所有的 characteristic 都訪查過後，gateway 端 (GATT client) 端將設定 client characteristic configuration 值 (true or false)，以此作為開啟或關閉生理量測資訊是否由 Continua BLE 血糖機 (GATT server) 開始傳送。

由於藍芽低功耗之產品，訴求的是耗電量少 (待機時間較長)，傳輸資料量不大。在系統設計上，由藍芽開啟到傳輸結束，大致上可分為三個階段：廣播 (advertisement)、訪查 GATT table，以及傳送生理資訊。以下分別討論之：

1. 廣播 (Advertisement)

依據藍芽之規範 (time profile)，GATT client 端之設備建議採用 30 秒內進行 fast connection (scan window 為 30 ms，scan interval 為 30 ms－60 ms)；在 30 秒以後建議採用 reduced power 方式 (scan window為 11.25 ms，scan interval 為 1.28 sec) 之 slow connection；又再經過 30 秒以後建議採用 reduced power 方式 (scan window 為 11.25ms，scan interval 為 2.56 sec)。目前本研究所提之 Continua

BLE 血糖機僅在 30 秒內進行廣播，30 秒後不再廣播且進入 stop system 階段。使用者可經過按壓 RF 功能鍵使 start system 後，再次進入藍芽廣播階段。此設計將有助於將系統在藍芽廣播階段之耗電量降到最低。

2. 訪查 GATT table

隨著不同之生理量測設備，以 Bluetooth GATT-based 之對應規範，對 GATT table 之內容要求有所不同；再者，跟隨系統之設計特色或使用者之需求，GATT table 之設計內容也會不同。可能需要更多的 service 加入 GATT table 內；亦或是，可能需要增加較多的 characteristic 或其他功能到對應之 service 內。然而，隨著 GATT table 之內容大小不同，GATT client 端訪查的時間也將不同，也因此將影響生理量測設備之耗電流狀況。目前，在 GATT client 端為了減少與設備端連線的時間，加入 cache 之機制用以記憶已連線過藍芽設備之 GATT table；換言之，連線的兩端，僅在第一次連線時需要交換 GATT table；爾後之連線，將可跳過此階段，而直接進入傳送資訊之階段，將可有效縮短雙方藍芽連線的時間，以及設備之耗電情形。在實作與測試的過程，發現：BLE APP 能夠支援上述之功能 (省略每次連線需要訪查 GATT table)；而 Continua CESL manager 或 Continua test management lite 則在每次藍芽連線時都需要訪查 GATT table，但這與其要檢測 BLE 設備端是否符合互通性與規範有關。

3. 傳送生理資訊

依據 Bluetooth GATT-based 之對應規範，生理量測值都有其固定之封包格式與長度，此階段將影響設備耗電的原因，可能和相同的生理量測記錄是否需要一再重複傳送有關。例如，生理量測設備之使用情境為：量測紀錄不刪除，且可重覆傳送，則總傳輸時間將提高，設備耗電情況也將增加。目前本研究所提之 Continua BLE 血糖機，其內儲存最大有限量測筆數，且生理量測資訊在傳送完成後會紀錄為已傳送，支援在生理資訊傳送完成後可刪除之機制，故使得 Continua BLE 血糖機之總傳輸生理量測資訊之時間最短，且耗電情況降至最低。

在研發的過程中，發現：Bluetooth GATT-based glucose profile/service 之規範已涵蓋系統之 GATT table 設計；而 Continua design guidelines V4.0 之要求，則是必須在 glucose service 內增加 date time 之 characteristic，且在 device information service 內需要有 IEEE 11073-20601 regulatory certification data list 的設計。增加兩個 characteristic (date time & IEEE 11073-20601 regulatory certification data list)，可以讓符合藍芽低功耗之產品，也能同樣滿足 Continua 在 LP Wireless PAN 之規範。

六、結論與未來方向

在此論文中，筆者提出以藍芽低功耗為基礎之 Continua 血糖機。此 Continua BLE 血糖機能夠與符合 BLE glucose APP 相連接並交換生理量測資訊；其也能夠與 Continua 標準閘道器相連接及上傳生理量測資訊。本架構基於 ISO/IEEE 11073 個人健康照護醫療器材之最佳交換通訊協定技術標準與 Continua design guidelines V4.0 規範，以及藍芽低功耗技術 (BLE glucose profile/service)，提供一個互通性之健康照護平台。經由這些標準之採用，此架構提供完整之個人化遠距健康照護生態系統。此研究之成果可助益於個人或醫療照護組織做好個人健康管理、家庭成員之健康管理、慢性疾病管理，乃至於照護獨居老人之生活起居。未來本研究之後續工作，將著眼於將藍芽低功耗技術應用於運動器材、行動照護閘道器之開發，以及增加與後端應用伺服主機互相操作之功能。

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