

NAG Library Function Document

nag_complex_sparse_eigensystem_iter (f12apc)

Note: this function uses **optional parameters** to define choices in the problem specification. If you wish to use default settings for all of the optional parameters, then the option setting function `nag_complex_sparse_eigensystem_option (f12arc)` need not be called. If, however, you wish to reset some or all of the settings please refer to Section 11 in `nag_complex_sparse_eigensystem_option (f12arc)` for a detailed description of the specification of the optional parameters.

1 Purpose

`nag_complex_sparse_eigensystem_iter (f12apc)` is an iterative solver in a suite of functions consisting of `nag_complex_sparse_eigensystem_init (f12anc)`, `nag_complex_sparse_eigensystem_iter (f12apc)`, `nag_complex_sparse_eigensystem_sol (f12aqc)`, `nag_complex_sparse_eigensystem_option (f12arc)` and `nag_complex_sparse_eigensystem_monit (f12asc)`. It is used to find some of the eigenvalues (and optionally the corresponding eigenvectors) of a standard or generalized eigenvalue problem defined by complex nonsymmetric matrices.

2 Specification

```
#include <nag.h>
#include <nagf12.h>

void nag_complex_sparse_eigensystem_iter (Integer *irevcm, Complex resid[],
    Complex v[], Complex **x, Complex **y, Complex **mx, Integer *nshift,
    Complex comm[], Integer icomm[], NagError *fail)
```

3 Description

The suite of functions is designed to calculate some of the eigenvalues, λ , (and optionally the corresponding eigenvectors, x) of a standard eigenvalue problem $Ax = \lambda x$, or of a generalized eigenvalue problem $Ax = \lambda Bx$ of order n , where n is large and the coefficient matrices A and B are sparse, complex and nonsymmetric. The suite can also be used to find selected eigenvalues/eigenvectors of smaller scale dense, complex and nonsymmetric problems.

`nag_complex_sparse_eigensystem_iter (f12apc)` is a **reverse communication** function, based on the ARPACK routine **znaupd**, using the Implicitly Restarted Arnoldi iteration method. The method is described in Lehoucq and Sorensen (1996) and Lehoucq (2001) while its use within the ARPACK software is described in great detail in Lehoucq *et al.* (1998). An evaluation of software for computing eigenvalues of sparse nonsymmetric matrices is provided in Lehoucq and Scott (1996). This suite of functions offers the same functionality as the ARPACK software for complex nonsymmetric problems, but the interface design is quite different in order to make the option setting clearer and to simplify the interface of `nag_complex_sparse_eigensystem_iter (f12apc)`.

The setup function `nag_complex_sparse_eigensystem_init (f12anc)` must be called before `nag_complex_sparse_eigensystem_iter (f12apc)`, the reverse communication iterative solver. Options may be set for `nag_complex_sparse_eigensystem_iter (f12apc)` by prior calls to the option setting function `nag_complex_sparse_eigensystem_option (f12arc)` and a post-processing function `nag_complex_sparse_eigensystem_sol (f12aqc)` must be called following a successful final exit from `nag_complex_sparse_eigensystem_iter (f12apc)`. `nag_complex_sparse_eigensystem_monit (f12asc)` may be called following certain flagged intermediate exits from `nag_complex_sparse_eigensystem_iter (f12apc)` to provide additional monitoring information about the computation.

`nag_complex_sparse_eigensystem_iter (f12apc)` uses **reverse communication**, i.e., it returns repeatedly to the calling program with the argument **irevcm** (see Section 5) set to specified values which require the calling program to carry out one of the following tasks:

- compute the matrix-vector product $y = OPx$, where OP is defined by the computational mode;
- compute the matrix-vector product $y = Bx$;
- notify the completion of the computation;
- allow the calling program to monitor the solution.

The problem type to be solved (standard or generalized), the spectrum of eigenvalues of interest, the mode used (regular, regular inverse, shifted inverse, shifted real or shifted imaginary) and other options can all be set using the option setting function `nag_complex_sparse_eigensystem_option` (f12arc) (see Section 11.1 in `nag_complex_sparse_eigensystem_option` (f12arc) for details on setting options and of the default settings).

4 References

Lehoucq R B (2001) Implicitly restarted Arnoldi methods and subspace iteration *SIAM Journal on Matrix Analysis and Applications* **23** 551–562

Lehoucq R B and Scott J A (1996) An evaluation of software for computing eigenvalues of sparse nonsymmetric matrices *Preprint MCS-P547-1195* Argonne National Laboratory

Lehoucq R B and Sorensen D C (1996) Deflation techniques for an implicitly restarted Arnoldi iteration *SIAM Journal on Matrix Analysis and Applications* **17** 789–821

Lehoucq R B, Sorensen D C and Yang C (1998) *ARPACK Users' Guide: Solution of Large-scale Eigenvalue Problems with Implicitly Restarted Arnoldi Methods* SIAM, Philadelphia

5 Arguments

Note: this function uses **reverse communication**. Its use involves an initial entry, intermediate exits and re-entries, and a final exit, as indicated by the argument **irevcn**. Between intermediate exits and re-entries, **all arguments other than x and y must remain unchanged**.

1: **irevcn** – Integer * *Input/Output*

On initial entry: **irevcn** = 0, otherwise an error condition will be raised.

On intermediate re-entry: must be unchanged from its previous exit value. Changing **irevcn** to any other value between calls will result in an error.

On intermediate exit: has the following meanings.

irevcn = -1

The calling program must compute the matrix-vector product $y = OPx$, where x is stored in **x** and the result y is placed in **y**.

irevcn = 1

The calling program must compute the matrix-vector product $y = OPx$. This is similar to the case **irevcn** = -1 except that the result of the matrix-vector product Bx (as required in some computational modes) has already been computed and is available in **mx**.

irevcn = 2

The calling program must compute the matrix-vector product $y = Bx$, where x is stored in **x** and y is placed in **y**.

irevcn = 3

Compute the **nshift** complex shifts to be placed in the first **nshift** locations of the array **y**. This value of **irevcn** will only arise if the optional parameter **Supplied Shifts** is set in a prior call to `nag_complex_sparse_eigensystem_option` (f12arc) which is intended for experienced users only; the default and recommended option is to use exact shifts (see Lehoucq *et al.* (1998) for details).

irevcn = 4

Monitoring step: a call to `nag_complex_sparse_eigensystem_monit` (f12asc) can now be made to return the number of Arnoldi iterations, the number of converged Ritz values, the array of converged values, and the corresponding Ritz estimates.

On final exit: **irevcn** = 5: `nag_complex_sparse_eigensystem_iter` (f12apc) has completed its tasks. The value of **fail.code** determines whether the iteration has been successfully completed, or whether errors have been detected. On successful completion `nag_complex_sparse_eigensystem_sol` (f12aqc) must be called to return the requested eigenvalues and eigenvectors (and/or Schur vectors).

Constraint: on initial entry, **irevcn** = 0; on re-entry **irevcn** must remain unchanged.

2: **resid**[*dim*] – Complex *Input/Output*

Note: the dimension, *dim*, of the array **resid** must be at least **n** (see `nag_complex_sparse_eigensystem_init` (f12anc)).

On initial entry: need not be set unless the option **Initial Residual** has been set in a prior call to `nag_complex_sparse_eigensystem_option` (f12arc) in which case **resid** should contain an initial residual vector, possibly from a previous run.

On intermediate re-entry: must be unchanged from its previous exit. Changing **resid** to any other value between calls may result in an error exit.

On intermediate exit: contains the current residual vector.

On final exit: contains the final residual vector.

3: **v**[**n** × **ncv**] – Complex *Input/Output*

The *i*th element of the *j*th basis vector is stored in location $\mathbf{v}[\mathbf{n} \times (i - 1) + j - 1]$, for $i = 1, 2, \dots, \mathbf{n}$ and $j = 1, 2, \dots, \mathbf{ncv}$.

On initial entry: need not be set.

On intermediate re-entry: must be unchanged from its previous exit.

On intermediate exit: contains the current set of Arnoldi basis vectors.

On final exit: contains the final set of Arnoldi basis vectors.

4: **x** – Complex ** *Input/Output*

On initial entry: need not be set, it is used as a convenient mechanism for accessing elements of **comm**.

On intermediate re-entry: is not normally changed.

On intermediate exit: contains the vector *x* when **irevcn** returns the value -1, +1 or 2.

On final exit: does not contain useful data.

5: **y** – Complex ** *Input/Output*

On initial entry: need not be set, it is used as a convenient mechanism for accessing elements of **comm**.

On intermediate re-entry: must contain the result of $y = OPx$ when **irevcn** returns the value -1 or +1. It must contain the computed shifts when **irevcn** returns the value 3.

On intermediate exit: does not contain useful data.

On final exit: does not contain useful data.

6: **mx** – Complex ** *Input/Output*

On initial entry: need not be set, it is used as a convenient mechanism for accessing elements of **comm**.

On intermediate re-entry: must contain the result of $y = Bx$ when **irevcn** returns the value 2.

On intermediate exit: contains the vector Bx when **irevcn** returns the value +1.

On final exit: does not contain any useful data.

- 7: **nshift** – Integer * *Output*
On intermediate exit: if the option **Supplied Shifts** is set and **irevcn** returns a value of 3, **nshift** returns the number of complex shifts required.
- 8: **comm**[*dim*] – Complex *Communication Array*
Note: the dimension, *dim*, of the array **comm** must be at least $\max(1, \mathbf{lcomm})$ (see `nag_complex_sparse_eigensystem_init` (f12anc)).
On initial entry: must remain unchanged following a call to the setup function `nag_complex_sparse_eigensystem_init` (f12anc).
On exit: contains data defining the current state of the iterative process.
- 9: **icomm**[*dim*] – Integer *Communication Array*
Note: the dimension, *dim*, of the array **icomm** must be at least $\max(1, \mathbf{licomm})$ (see `nag_complex_sparse_eigensystem_init` (f12anc)).
On initial entry: must remain unchanged following a call to the setup function `nag_complex_sparse_eigensystem_init` (f12anc).
On exit: contains data defining the current state of the iterative process.
- 10: **fail** – NagError * *Input/Output*
The NAG error argument (see Section 2.7 in How to Use the NAG Library and its Documentation).
Error details reported in **fail** are only valid on final exit. On intermediate exit, returned values of **fail** should be ignored.

6 Error Indicators and Warnings

NE_ALLOC_FAIL

Dynamic memory allocation failed.

See Section 2.3.1.2 in How to Use the NAG Library and its Documentation for further information.

NE_BAD_PARAM

On entry, argument *<value>* had an illegal value.

NE_INITIALIZATION

Either the initialization function has not been called prior to the first call of this function or a communication array has become corrupted.

NE_INT

The maximum number of iterations ≤ 0 , the option **Iteration Limit** has been set to *<value>*.

NE_INTERNAL_EIGVAL_FAIL

Error in internal call to compute eigenvalues and corresponding error bounds of the current upper Hessenberg matrix. Please contact NAG.

NE_INTERNAL_ERROR

An internal error has occurred in this function. Check the function call and any array sizes. If the call is correct then please contact NAG for assistance.

An unexpected error has been triggered by this function. Please contact NAG.
See Section 2.7.6 in How to Use the NAG Library and its Documentation for further information.

NE_MAX_ITER

The maximum number of iterations has been reached. The maximum number of iterations = $\langle value \rangle$. The number of converged eigenvalues = $\langle value \rangle$. The post-processing function `nag_complex_sparse_eigensystem_sol` (f12aqc) may be called to recover the converged eigenvalues at this point. Alternatively, the maximum number of iterations may be increased by a call to the option setting function `nag_complex_sparse_eigensystem_option` (f12arc) and the reverse communication loop restarted. A large number of iterations may indicate a poor choice for the values of `nev` and `ncv`; it is advisable to experiment with these values to reduce the number of iterations (see `nag_complex_sparse_eigensystem_init` (f12anc)).

NE_NO_ARNOLDI_FAC

Could not build an Arnoldi factorization. The size of the current Arnoldi factorization = $\langle value \rangle$.

NE_NO_LICENCE

Your licence key may have expired or may not have been installed correctly.
See Section 2.7.5 in How to Use the NAG Library and its Documentation for further information.

NE_NO_SHIFTS_APPLIED

No shifts could be applied during a cycle of the implicitly restarted Arnoldi iteration.

NE_OPT_INCOMPAT

The options **Generalized** and **Regular** are incompatible.

NE_ZERO_INIT_RESID

The option **Initial Residual** was selected but the starting vector held in `resid` is zero.

7 Accuracy

The relative accuracy of a Ritz value, λ , is considered acceptable if its Ritz estimate $\leq \mathbf{Tolerance} \times |\lambda|$. The default **Tolerance** used is the *machine precision* given by `nag_machine_precision` (X02AJC).

8 Parallelism and Performance

`nag_complex_sparse_eigensystem_iter` (f12apc) is threaded by NAG for parallel execution in multithreaded implementations of the NAG Library.

`nag_complex_sparse_eigensystem_iter` (f12apc) makes calls to BLAS and/or LAPACK routines, which may be threaded within the vendor library used by this implementation. Consult the documentation for the vendor library for further information.

Please consult the x06 Chapter Introduction for information on how to control and interrogate the OpenMP environment used within this function. Please also consult the Users' Note for your implementation for any additional implementation-specific information.

9 Further Comments

None.

10 Example

This example solves $Ax = \lambda x$ in shift-invert mode, where A is obtained from the standard central difference discretization of the convection-diffusion operator $\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \rho \frac{\partial u}{\partial x}$ on the unit square, with zero Dirichlet boundary conditions. The shift used is a complex number.

10.1 Program Text

```

/* nag_complex_sparse_eigensystem_iter (f12apc) Example Program.
 *
 * NAGPRODCODE Version.
 *
 * Copyright 2016 Numerical Algorithms Group.
 *
 * Mark 26, 2016.
 */

#include <math.h>
#include <nag.h>
#include <nag_stdlib.h>
#include <nag_string.h>
#include <stdio.h>
#include <naga02.h>
#include <nagf12.h>
#include <nagf16.h>

static void my_zgtrrf(Integer, Complex *, Complex *, Complex *,
                    Complex *, Integer *, Integer *);
static void my_zgtrrs(Integer, Complex *, Complex *, Complex *,
                    Complex *, Integer *, Complex *, Complex *);

int main(void)
{
    /* Constants */
    Integer licomm = 140, imon = 0;

    /* Scalars */
    Complex rho, s1, s2, s3, sigma;
    double estnrm, hr1, hr2, sr;
    Integer exit_status, info, irevcn, j, lcomm, n, nconv;
    Integer ncv, nev, niter, nshift, nx;
    /* Nag types */
    NagError fail;
    /* Arrays */
    Complex *comm = 0, *eigv = 0, *eigest = 0, *dd = 0, *dl = 0, *du = 0;
    Complex *du2 = 0, *resid = 0, *v = 0;
    Integer *icomm = 0, *ipiv = 0;
    /* Pointers */
    Complex *mx = 0, *x = 0, *y = 0;

    exit_status = 0;
    INIT_FAIL(fail);

    printf("nag_complex_sparse_eigensystem_iter (f12apc) Example "
           "Program Results\n");
    /* Skip heading in data file */
#ifdef _WIN32
    scanf_s("%*[\n] ");
#else
    scanf("%*[\n] ");
#endif

#ifdef _WIN32
    scanf_s("%" NAG_IFMT "%" NAG_IFMT "%" NAG_IFMT "%*[\n] ", &nx, &nev, &ncv);
#else
    scanf("%" NAG_IFMT "%" NAG_IFMT "%" NAG_IFMT "%*[\n] ", &nx, &nev, &ncv);
#endif
    n = nx * nx;

```

```

lcomm = 3 * n + 3 * ncv * ncv + 5 * ncv + 60;
/* Allocate memory */
if (!(comm = NAG_ALLOC(lcomm, Complex)) ||
    !(eigv = NAG_ALLOC(ncv, Complex)) ||
    !(eigest = NAG_ALLOC(ncv, Complex)) ||
    !(dd = NAG_ALLOC(n, Complex)) ||
    !(dl = NAG_ALLOC(n, Complex)) ||
    !(du = NAG_ALLOC(n, Complex)) ||
    !(du2 = NAG_ALLOC(n, Complex)) ||
    !(resid = NAG_ALLOC(n, Complex)) ||
    !(v = NAG_ALLOC(n * ncv, Complex)) ||
    !(icomm = NAG_ALLOC(lcomm, Integer)) ||
    !(ipiv = NAG_ALLOC(n, Integer)))
{
    printf("Allocation failure\n");
    exit_status = -1;
    goto END;
}
/* Initialize communication arrays for problem using
   nag_complex_sparse_eigensystem_init (f12anc). */
nag_complex_sparse_eigensystem_init(n, nev, ncv, icomm, lcomm,
                                     comm, lcomm, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_complex_sparse_eigensystem_init (f12anc).\n%s\n",
          fail.message);
    exit_status = 1;
    goto END;
}
/* Select the required mode using
   nag_complex_sparse_eigensystem_option (f12arc). */
nag_complex_sparse_eigensystem_option("SHIFTED INVERSE", icomm,
                                       comm, &fail);
/* Set values for sigma and rho */
/* Assign to Complex type using nag_complex (a02bac) */
sigma = nag_complex(0.0, 0.0);
rho = nag_complex(10.0, 0.0);
hr1 = (double) (n + 1); /* 1/h */
hr2 = hr1 * hr1; /* 1/(h*h) */
sr = 0.5 * hr1 * rho.re; /* s/h */
/* Assign to Complex type using nag_complex (a02bac) */
s1 = nag_complex(-hr2 - sr, 0.0); /* -1/(h*h) - s/h */
s3 = nag_complex(-hr2 + sr, 0.0); /* -1/(h*h) + s/h */
s2 = nag_complex(2.0 * hr2, 0.0);
/* Compute Complex subtraction using nag_complex_subtract
   (a02cbc). */
s2 = nag_complex_subtract(s2, sigma); /* two/(h*h) - sigma */

for (j = 0; j <= n - 2; ++j) {
    dl[j] = s1;
    dd[j] = s2;
    du[j] = s3;
}
dd[n - 1] = s2;

my_zgttrf(n, dl, dd, du, du2, ipiv, &info);
irevcm = 0;
REVCOMLOOP:
/* repeated calls to reverse communication routine
   nag_complex_sparse_eigensystem_iter (f12apc). */
nag_complex_sparse_eigensystem_iter(&irevcm, resid, v, &x, &y, &mx,
                                     &nshift, comm, icomm, &fail);
if (irevcm != 5) {
    if (irevcm == -1 || irevcm == 1) {
        /* Perform  $x \leftarrow OP*x = inv[A-\sigma I]*x$  */
        my_zgttrs(n, dl, dd, du, du2, ipiv, x, y);
    }
    else if (irevcm == 4 && imon == 1) {
        /* If imon=1, get monitoring information using
           nag_complex_sparse_eigensystem_monit (f12asc). */
        nag_complex_sparse_eigensystem_monit(&niter, &nconv, eigv,
                                             eigest, icomm, comm);
    }
}

```

```

    /* Compute 2-norm of Ritz estimates using
       nag_zge_norm (f16uac). */
    nag_zge_norm(Nag_ColMajor, Nag_FrobeniusNorm, nev, 1, eigest,
                nev, &estnrm, &fail);
    printf("Iteration %3" NAG_IFMT " ", niter);
    printf(" No. converged = %3" NAG_IFMT " ", nconv);
    printf(" norm of estimates = %17.8e\n\n", estnrm);
}
goto REVCOMLOOP;
}
if (fail.code == NE_NOERROR) {
    /* Post-Process using nag_complex_sparse_eigensystem_sol
       (f12aqc) to compute eigenvalues/vectors. */
    nag_complex_sparse_eigensystem_sol(&nconv, eigv, v, sigma,
                                       resid, v, comm, icomm, &fail);

    printf("\n");
    printf(" The %4" NAG_IFMT " Ritz values of smallest magnitude are:\n\n",
           nconv);
    for (j = 0; j <= nconv - 1; ++j) {
        printf("%8" NAG_IFMT "%5s( %12.4f , %12.4f )\n", j + 1, "",
               eigv[j].re, eigv[j].im);
    }
}
else {
    printf(" Error from nag_complex_sparse_eigensystem_iter (f12apc). "
           "\n%s\n", fail.message);
    exit_status = 1;
    goto END;
}
END:
    NAG_FREE(comm);
    NAG_FREE(eigv);
    NAG_FREE(eigest);
    NAG_FREE(dd);
    NAG_FREE(dl);
    NAG_FREE(du);
    NAG_FREE(du2);
    NAG_FREE(resid);
    NAG_FREE(v);
    NAG_FREE(icomm);
    NAG_FREE(ipiv);

    return exit_status;
}

static void my_zgttrf(Integer n, Complex dl[], Complex d[],
                     Complex du[], Complex du2[], Integer ipiv[],
                     Integer *info)
{
    /* A simple C version of the Lapack routine zgttrf with argument
       checking removed */
    /* Scalars */
    Complex temp, fact, z1;
    Integer i;
    /* Function Body */
    *info = 0;
    for (i = 0; i < n; ++i) {
        ipiv[i] = i;
    }
    for (i = 0; i < n - 2; ++i) {
        du2[i] = nag_complex(0.0, 0.0);
    }
    for (i = 0; i < n - 2; ++i) {
        if (fabs(d[i].re) + fabs(d[i].im) >= fabs(dl[i].re) + fabs(dl[i].im)) {
            /* No row interchange required, eliminate dl[i]. */
            if (fabs(d[i].re) + fabs(d[i].im) != 0.0) {
                /* Compute Complex division using nag_complex_divide
                   (a02cdc). */
                fact = nag_complex_divide(dl[i], d[i]);
                dl[i] = fact;
                /* Compute Complex multiply using nag_complex_multiply

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        (a02ccc). */
        fact = nag_complex_multiply(fact, du[i]);
        /* Compute Complex subtraction using
           nag_complex_subtract (a02cbc). */
        d[i + 1] = nag_complex_subtract(d[i + 1], fact);
    }
}
else {
    /* Interchange rows I and I+1, eliminate dl[I] */
    /* Compute Complex division using nag_complex_divide
       (a02cdc). */
    fact = nag_complex_divide(d[i], dl[i]);
    d[i] = dl[i];
    dl[i] = fact;
    temp = du[i];
    du[i] = d[i + 1];
    /* Compute Complex multiply using nag_complex_multiply
       (a02ccc). */
    z1 = nag_complex_multiply(fact, d[i + 1]);
    /* Compute Complex subtraction using nag_complex_subtract
       (a02cbc). */
    d[i + 1] = nag_complex_subtract(temp, z1);
    du2[i] = du[i + 1];
    /* Compute Complex multiply using nag_complex_multiply
       (a02ccc). */
    du[i + 1] = nag_complex_multiply(fact, du[i + 1]);
    /* Perform Complex negation using nag_complex_negate
       (a02cec). */
    du[i + 1] = nag_complex_negate(du[i + 1]);
    ipiv[i] = i + 1;
}
}
if (n > 1) {
    i = n - 2;
    if (fabs(d[i].re) + fabs(d[i].im) >= fabs(dl[i].re) + fabs(dl[i].im)) {
        if (fabs(d[i].re) + fabs(d[i].im) != 0.0) {
            /* Compute Complex division using nag_complex_divide
               (a02cdc). */
            fact = nag_complex_divide(dl[i], d[i]);
            dl[i] = fact;
            /* Compute Complex multiply using nag_complex_multiply
               (a02ccc). */
            fact = nag_complex_multiply(fact, du[i]);
            /* Compute Complex subtraction using
               nag_complex_subtract (a02cbc). */
            d[i + 1] = nag_complex_subtract(d[i + 1], fact);
        }
    }
    else {
        /* Compute Complex division using nag_complex_divide
           (a02cdc). */
        fact = nag_complex_divide(d[i], dl[i]);
        d[i] = dl[i];
        dl[i] = fact;
        temp = du[i];
        du[i] = d[i + 1];
        /* Compute Complex multiply using nag_complex_multiply
           (a02ccc). */
        z1 = nag_complex_multiply(fact, d[i + 1]);
        /* Compute Complex subtraction using nag_complex_subtract
           (a02cbc). */
        d[i + 1] = nag_complex_subtract(temp, z1);
        ipiv[i] = i + 1;
    }
}
/* Check for a zero on the diagonal of U. */
for (i = 0; i < n; ++i) {
    if (fabs(d[i].re) + fabs(d[i].im) == 0.0) {
        *info = i;
        goto END;
    }
}

```

```

    }
END:
    return;
}

static void my_zgttrs(Integer n, Complex dl[], Complex d[],
                    Complex du[], Complex du2[], Integer ipiv[],
                    Complex b[], Complex y[])
{
    /* A simple C version of the Lapack routine zgttrs with argument
       checking removed, the number of right-hand-sides=1, Trans='N' */
    /* Scalars */
    Complex temp, z1;
    Integer i;
    /* Solve L*x = b. */
    for (i = 0; i < n; ++i) {
        y[i] = b[i];
    }
    for (i = 0; i < n - 1; ++i) {
        if (ipiv[i] == i) {
            /* y[i+1] = y[i+1] - dl[i]*y[i] */
            /* Compute Complex multiply using nag_complex_multiply
               (a02ccc). */
            temp = nag_complex_multiply(dl[i], y[i]);
            /* Compute Complex subtraction using nag_complex_subtract
               (a02cbc). */
            y[i + 1] = nag_complex_subtract(y[i + 1], temp);
        }
        else {
            temp = y[i];
            y[i] = y[i + 1];
            /* Compute Complex multiply using nag_complex_multiply
               (a02ccc). */
            z1 = nag_complex_multiply(dl[i], y[i]);
            /* Compute Complex subtraction using nag_complex_subtract
               (a02cbc). */
            y[i + 1] = nag_complex_subtract(temp, z1);
        }
    }
    /* Solve U*x = b. */
    /* Compute Complex division using nag_complex_divide (a02cdc). */
    y[n - 1] = nag_complex_divide(y[n - 1], d[n - 1]);
    if (n > 1) {
        /* Compute Complex multiply using nag_complex_multiply
           (a02ccc). */
        temp = nag_complex_multiply(du[n - 2], y[n - 1]);
        /* Compute Complex subtraction using nag_complex_subtract
           (a02cbc). */
        z1 = nag_complex_subtract(y[n - 2], temp);
        /* Compute Complex division using nag_complex_divide (a02cdc). */
        y[n - 2] = nag_complex_divide(z1, d[n - 2]);
    }
    for (i = n - 3; i >= 0; --i) {
        /* y[i] = (y[i]-du[i]*y[i+1]-du2[i]*y[i+2])/d[i]; */
        /* Compute Complex multiply using nag_complex_multiply
           (a02ccc). */
        temp = nag_complex_multiply(du[i], y[i + 1]);
        z1 = nag_complex_multiply(du2[i], y[i + 2]);
        /* Compute Complex addition using nag_complex_add
           (a02cac). */
        temp = nag_complex_add(temp, z1);
        /* Compute Complex subtraction using nag_complex_subtract
           (a02cbc). */
        z1 = nag_complex_subtract(y[i], temp);
        /* Compute Complex division using nag_complex_divide
           (a02cdc). */
        y[i] = nag_complex_divide(z1, d[i]);
    }
    return;
}

```

10.2 Program Data

```
nag_complex_sparse_eigensystem_iter (f12apc) Example Program Data
 10  4  20 : Vaues for nx, nev and ncv
```

10.3 Program Results

```
nag_complex_sparse_eigensystem_iter (f12apc) Example Program Results
```

The 4 Ritz values of smallest magnitude are:

1	(34.8720	,	-0.0000)
2	(64.4326	,	0.0000)
3	(113.6685	,	-0.0000)
4	(182.5320	,	0.0000)
